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A Summary

of

The Geology of Western Australia

By
A. Gibb Maitland.

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Geology of Western Australia.

By
A. Gibb Maitland.

CHAPTER I. A SUMMARY OF THE GEOLOGY OF WESTERN AUSTRALIA.

BY

A. Gibb Maitland, F.G.S.

(WITH A GEOLOGICAL SKETCH MAP, PLATE I.)

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INTRODUCTION.

The State of Western Australia is one, and the largest, of the divisions of the Commonwealth, though it does not constitute a natural geographical region. It occupies, as its name implies, the western portion of the Continent, and embraces an area of 975,920 square miles out of the 2,974,581 which make up the whole area of the Commonwealth (Fig. 1). Western Australia when viewed broadly does not present any great variety in its physical features.

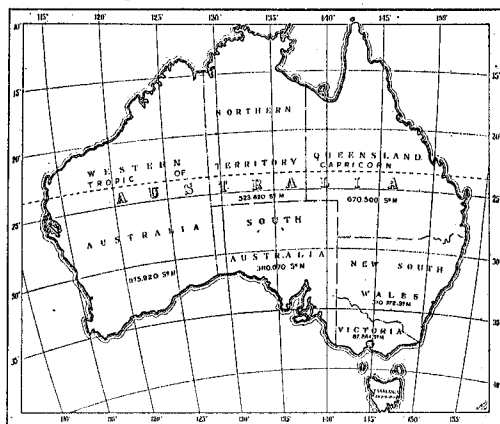


Fig. 1.—Outline Map of Australia showing position and area of Western Australia in relation to the other States.

The State extends over twenty-one degrees of latitude and lies between the 14th and 35th parallels of South latitude, "thus having its northern portion well within the tropics and its southern parts approaching the cooler regions of the temperate zone. There is, therefore, a considerable range of climate in the different parts of the State. There is a good rainfall along most of the west coast, averaging 30 to 40 inches annually, but it decreases going inland, and on about 57 per cent. of the area of the State the rainfall is under ten inches per annum, sub-arid conditions prevailing, and the provision of permanent supplies of fresh water being a first necessity of settlement. In the summer months the shade temperature often rises to over 100deg. F. and in the tropical parts of the country there is naturally a high average annual temperature, but south of the tropics the climate for the greater part of the year though warm is not by any means excessively hot, and in winter it is often fairly cold, frosts at night being not uncommon. The atmosphere being generally dry, higher temperatures are endurable without discomfort than in more humid regions. On the whole, the climate of sub-tropical Western Australia must be regarded as an exceptionally pleasant one, and even within the tropics Europeans can live and work with much comfort and excellent health." (Fig. 2).

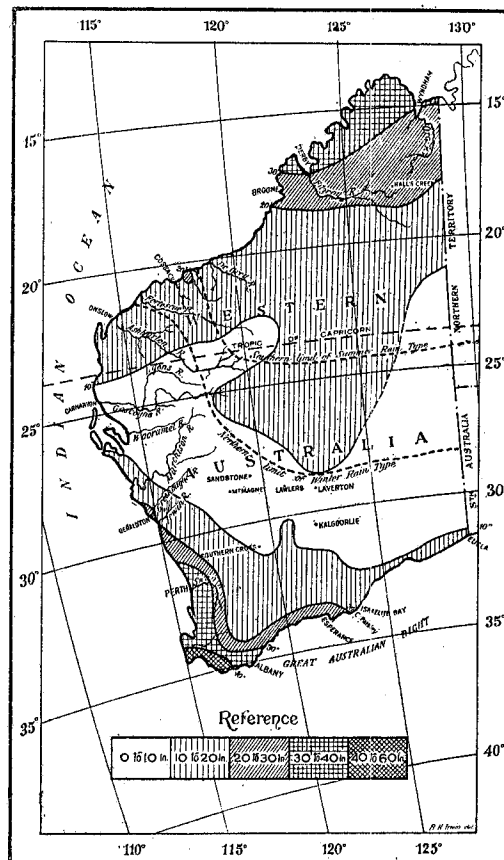


Fig. 2.—Rainfall Map of Western Australia showing Isohyets.

A scientific study of the mineral industry and resources of a country is of necessity based upon a knowledge of its geology, hence it is natural that any account thereof can only be properly dealt with after its geological features have been set out. The fact is, however, very often overlooked that a correct knowledge of the general stratigraphical geology of a country, such as reliable and detailed mapping alone can supply, is fundamental to any systematic development of its mineral wealth.

Considering its geographical extent, the numerical strength of the Geological Survey staff, and the paramount necessity for attention being concentrated upon examinations in and around mining and other districts of potentially economic value, geological investigation in the State has, up to the present, consisted chiefly of a series of more or less unconnected observations, for the co-ordination of which we must look to the future. Despite this circumstance, it has now been found possible to obtain a bird's-eye view of the salient geological features of Western Australia. The geological correlation adopted in this chapter is under the circumstances therefore only more or less provisional, and subject to modification with the advance of our knowledge.

In the broad area of the State pretty nearly all geological systems have representatives in the rocks. In general the Pre-Cambrian rocks, which occupy about one-third of the superficial extent of Western Australia, are found chiefly in the south-western portion of the State, and in scattered areas north of latitude 26deg. The Palaeozoic systems are best known in the northern and the eastern interior, though they are also met with in the Irwin River Valley to the north of Perth. The Mesozoic Rocks are exposed chiefly in the maritime districts of the State in the Kimberley, north-west, west, and south. The Tertiary and Recent Formations form a narrow fringe along the coast and have their widest distribution in the westernmost portion of the country.

HISTORY.

As this account is to a large extent based upon the work of the previous official geologists, it is not out of place to give a succinct account of their labours.

Dr. F. von Sommer was the first official geologist employed in Western Australia, and held office from 1844 to 1847. Neither the maps nor the reports of Dr. von Sommer have ever been published, although some articles from his pen appeared in the current literature during the years 1848 and 1849. The original drawings of Dr. von Sommer's maps were discovered some years ago, and are preserved in the historical collection of the Survey showing the progress of geological mapping in Western Australia.

After an interval of twenty-one years, during which much excellent geological work was accomplished by the Gregory Bros., Mr. H. Y. L. Brown was appointed to the post of Government Geologist. This gentleman during the years 1870 to 1873 prepared three geological maps and ten reports, dealing principally with the southern and maritime portions of the State. In 1882, Mr. E. T. Hardman, of the Geological Survey of Ireland, was appointed Government Geologist, and his labours were confined chiefly to the Kimberley Division, in which he was the pioneer geological observer; his field work, carried out during the years 1883-4, laid the foundations of our knowledge of the geology of the tropical portion of Western Australia, and played an important part in the opening up of the State's first goldfield. Very shortly after Mr. Hardman's term of service in Western Australia came to an end, a motion was brought forward in the Legislative Council in 1885 having for its object:—

... the establishment of a permanent geological department of the Colony

After a vigorous debate, however, the motion was defeated, principally on the question of ways and means. The late Rev. C. G.

Nicolay, Chaplain to the Fremantle Gaol, contributed in very many ways to the knowledge of the geology of the State, and was officer-in-charge of the Geological Museum at Fremantle, which was founded by Mr. Hardman, and which ultimately became merged into the Western Australian Museum. In 1887 the position of Government Geologist was conferred upon Mr. H. P. Woodward, who held the post from 1887 to 1895. With a very limited staff, and still more limited appropriation, and in spite of the difficulties presented by the vast area of the State, the survey under Mr. Woodward issued 21 reports and six geological maps. It was during this period that the paramount necessity for:—

“the publication of reliable geological knowledge relating to the nature and extent of useful mineral deposits, supplemented by geological maps and plans,”

was impressed upon the Government by its scientific advisers.

The work of organising a more or less systematic geological survey was entrusted to the writer in 1896, its object being the investigation of the geological structure, mineral resources, mining industries, and underground water supplies of the State. These objects, so far as the resources available will admit, are carried out by means of:—(a) Reconnaissance surveys of those portions of the State about the structure and resources of which little is known; (b) detailed geological surveys of mining centres under active development; (c) chemical and mineralogical examinations of soils, rocks, minerals, and natural waters collected by the field staff, and under certain specified conditions by prospectors and others; (d) palaeontological and petrological investigations; (e) the maintenance of a geological museum; and (f) the publication of the data acquired in this way.

When viewed broadly, it may be said that the time of the Geological Survey staff has been pretty well divided between work in connection with (a) mining, (b) agriculture, (c) underground water supply, (d) general geological surveys, (e) engineering questions, (f) chemical and physical research work relating to mineral products, and (g) petrological and palaeontological investigations. With regard to palaeontological investigations, the fact is often overlooked or at any rate not sufficiently recognised, that geology is more or less dependent upon such research, for without the specific determination of fossils reports involving a wide range of stratigraphy could not be written, nor geological maps of large areas properly completed. Fossils being of such importance in determining the relative age, succession and correlation of strata, that the investigation of the palaeontology of a formation becomes an important factor in the early attempts at the development of the mineral resources of regions in which the stratigraphy has been but imperfectly worked out.

The Geological Survey has been, *inter alia*, engaged upon the delimitation of the actual and potential mineral and artesian resources of the State, or, in other words, “taking stock” of its mineral and allied resources, and has been directing its energies to the investigation of those raw materials, the exploitation of which are of special importance under present conditions. Surveys and other investigations have been made of the tin, copper, lead, iron, coal, molybdenum, graphite, and gold deposits, as well as the phosphatic and lime deposits in the interests of the agricultural industry, and of the artesian water areas in the interest of the pastoralist. The work of the different field parties has been primarily planned with the view to the determination of (a) the areal distribution, (b) the mode of occurrence, (c) the geological relationships, and (d) the value of the mineral resources of the districts dealt with and the study of the structural features of the formations in which they are contained.

The results of these investigations have been made available to the general public in three distinct forms, viz., Annual Reports, Bulletins, and Maps.

The Annual Reports number 21, and, in addition to the necessary administrative details, they contain the following reports:—

Gold-bearing Deposits	90
Copper and Lead Deposits	10
Tinfields	8
Iron Ore	4
Coal and Oil	13
Phosphates	3
Limestone	5
Miscellaneous Mineral Occurrences	25
Mining Act	8
General Geology	22
Petrology	6
Mining Technology	2
Palaontology	2
Underground Water Supply	32

The Bulletins number 75 volumes which deal with a great variety of subjects, *e.g.*, one is a Bibliography of the Geology of the State; five deal with Palaontology; one a General Index to the reports issued since 1870; four contain reports on Artesian Water resources; four on such general questions as The Mineral Wealth of the State, The Distribution of the Base Metals, Minerals of Economic Value, A Statistical Account of the Mineral Production of the State; one is exclusively devoted to tabulated lists of Analyses of Rocks, Natural Water and Meteorites made in the Survey Laboratory since its inception in 1897; three refer solely to General Geology, whilst fifty-six of the bulletins give more or less detailed accounts of the Geological Structure, Ore Occurrences, and future Mining prospects of pretty well every field in Western Australia.

Of Maps, there have been issued:—

Geological Maps of Goldfields	102
" " Copper and Lead Mining Districts	16
" " Tinfields	9
" " Coalfields	7
General Geological Maps	43
Mining Maps and Plans	105
Mineral Distribution Maps	16
Topographical Maps	9
Horizontal and Vertical Sections	32
Total	339

PHYSICAL FEATURES.

Physiographically considered the State of Western Australia falls naturally into three fairly well-marked subdivisions, *viz.*:—The Coastal Plain, the Hill Ranges, and the Plateau and Plains of the Interior. Each of these subdivisions is comparatively well-defined, though the line of separation cannot always be very sharply

drawn, owing to the blending of one subdivision with another; hence the boundaries can only be spoken of as occurring within certain limits.

For purposes of description the State may also be divided into six geographical divisions, *viz.*:—The Northern or Kimberley, the North-West, the South-East or Eucla, the Central or Salt Lake, and the Eastern Divisions. The boundaries of these divisions are fairly well marked. (Fig. 3.).

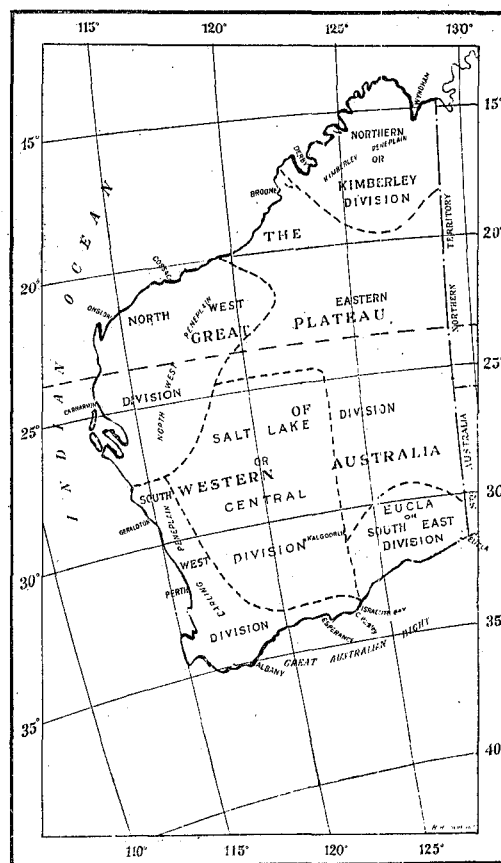


Fig. 3.—Outline Map of Western Australia, showing the Six Physiographical Divisions.

The Coastal Plain consists in reality of a fringe round the coast with a more or less gentle slope to the seaward. The plain has a width of 60 or 70 miles in places on the Western Coast, though in the country at the head of the Great Australian Bight it extends some 200 miles into the interior, and is absolutely devoid of rivers. The inner margin of the Coastal Plain reaches an altitude of 600 feet above sea level in certain localities. The line of demarcation of the Coastal Plain, and the hill ranges on the east, is marked by what is termed the Darling Fault Scarp, averaging about 1,000 feet in

height and traceable to the north and south of Perth for over 300 miles (Fig. 4). The southern half of Western Australia affords

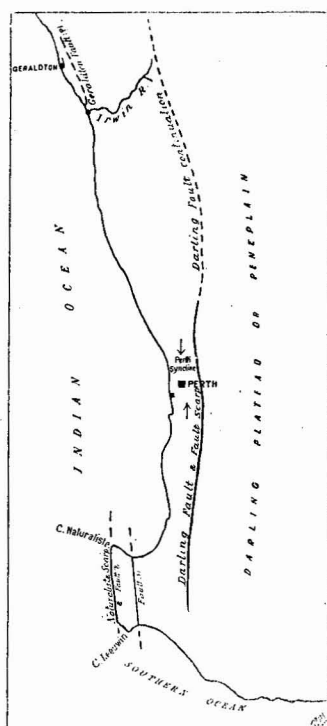


Fig. 4.—Plan of the Darling Range Fault Scarp.

perhaps no more striking feature than the scarp-like face of the Darling Range, which forms the western rim of the Plateau and Plains of the Interior (Fig. 5). The boundary between this plateau and the Coastal Plain (Fig. 6) is virtually constituted by a nearly straight, or at least a gently curving, line, and forms part of

a zone in which faulting is the most important structural feature. The western limit of the Coastal Plain is at the edge of the con-

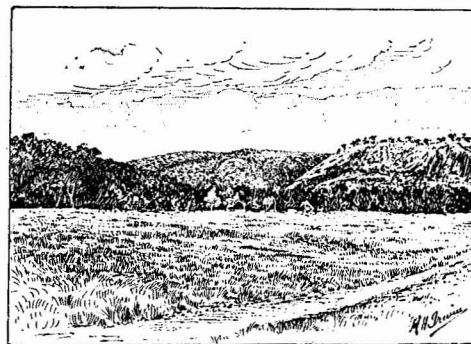


Fig. 5.—Scarp-like face of the Darling Range.

tinental shelf, which is located a great many miles off the shore at a depth of about 100 fathoms below the surface of the Indian Ocean. This is in reality the submerged border of the western portion of the Australian Continent, which extends seawards with a gradual slope to the 100 fathoms line.

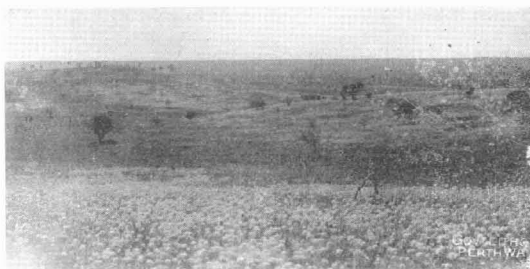


Fig. 6.—View of the Coastal Plain in the Valley of the Greenbrook, near Mount Seratch, South-West Division.

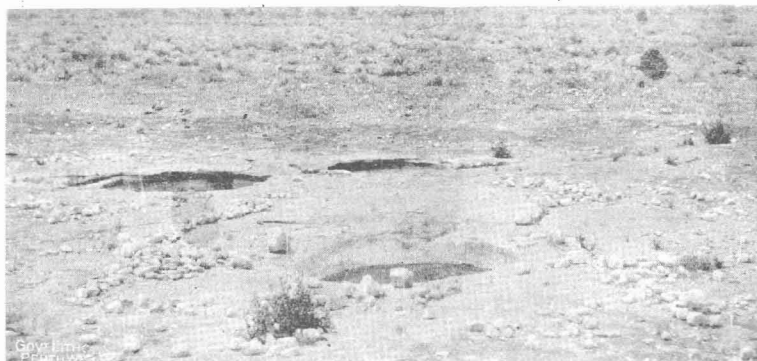


Fig. 7.—View of the Coastal Plain, near the 220 Mile-Peg, Trans-Continental Railway, Eucla Division.

The Coastal Plain may thus be divided into submarine and sub-aerial divisions, the line of demarcation between which is the sea-shore. The subaerial division is itself separable into the western and south-western portion, the latter comprising the Eucla Limestone Plateau or the Premier Downs, traversed by the Transcontinental Railway (Fig. 7). The average altitude of the northern or inland margin of this plain is about 1,000 feet above sea level. The rainfall is very slight, except near the coast, and no rivers enter the sea, anywhere, for 400 miles west of Eucla, on the South Australian border.

By far the greater portion of the State is in reality a very extensive plateau averaging about 1,400 feet in height, though isolated portions reach altitudes approaching 4,000 feet. The interior portion of the plateau has a very restricted and limited rainfall and is drained by intermittent watercourses, which debouch into shallow basins, generally known as "Salt" or "Dry" lakes (Fig. 8).

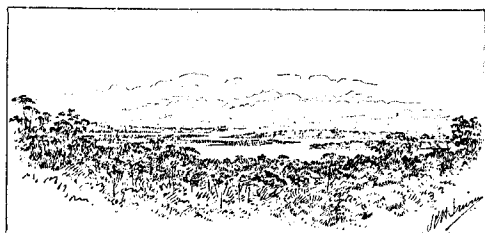


Fig. 8.—Lake Dundas, Norseman.

These salt lakes (clay pans) extend over a large stretch of country in the Central or Salt Lake Division (Fig. 9). They

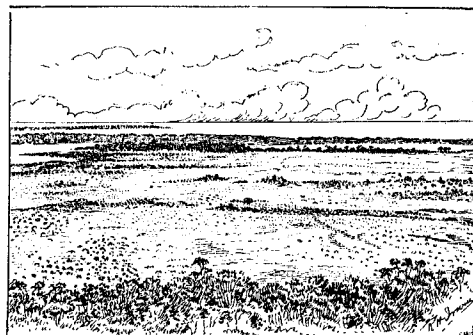


Fig. 9.—Lake Way, East Murchison Goldfield.

are very variable in their outline and are in some cases many miles wide. The clay pans are very often isolated, though at other times loosely strung together, being separated by narrow divisions; their resemblance to, and connection with, river channels may be noted in their elongated shape, of which Lake Raeside and Brockman Creek and Lake Carnegie are typical examples (Fig. 10). Wind erosion is the predominating agent in the formation of these salt and dry lakes, and also the chief denuding agent which tends to keep the plateau level. The potency of wind scour or sand blast may be noticed in the frosting of those heaps of discarded bottles which, in certain districts, are pretty well the sole relics of departed greatness. The plateau which forms the chief mineral region of the State is mantled by superficial deposits concealing the underlying rocks over very wide areas.

A large portion of the Kimberley and North-West Divisions consists of a dissected plateau built up of horizontal or gently inclined strata, and possesses in general all the familiar scenic features of such formations. This dissected plateau is drained by the principal rivers of the State, many of which extend for some hundreds



Fig. 10.—Brockman Creek and Lake Carnegie, Eastern Division.

of miles inland, and some of which flow through cañons of great extent and exceptional beauty.

There are no folded and few denuded mountain chains in Western Australia; such as do exist owe their origin either to block faulting or result from erosion.

The coast line is extensive and generally has a smooth irregular outline, though portions are broken and indented and fringed with numerous islands and archipelagoes. The very much indented coast line of the Kimberley Division is due to the drowning of the river valleys, of which the Prince Regent River (Fig. 11), falling into Brunswick Bay, is perhaps the most typical example.

STRATIGRAPHY OF WESTERN AUSTRALIA.

GENERAL.

One of the most marked features in the geology of Western Australia is the very great similarity in structure and constitution to that of India, South Africa, and Madagascar, and the divergence between the western and eastern portions of the Australian Continent. The resemblance to India and South Africa is parallel not only in the Pre-Cambrian, but also in the Palaeozoic, Mesozoic, and more Recent strata.

The geological formations so far recognised in Western Australia may be classified into the following divisions:—

ARCHÆOZOIC (ARCHÆAN).

Crystalline schists and allied rocks.

PROTEROZOIC (PRE-CAMBRIAN ALGONKIAN?).

Warrawoona Beds.
Mosquito Creek Beds.
Ashburton Beds.
Kalgoorlie Beds.
Stirling Range Beds.
Nullagine Formation.

PALÆOZOIC.

Cambrian.
Ordovician.
Devonian.
Carboniferous, and
Permo-Carboniferous.

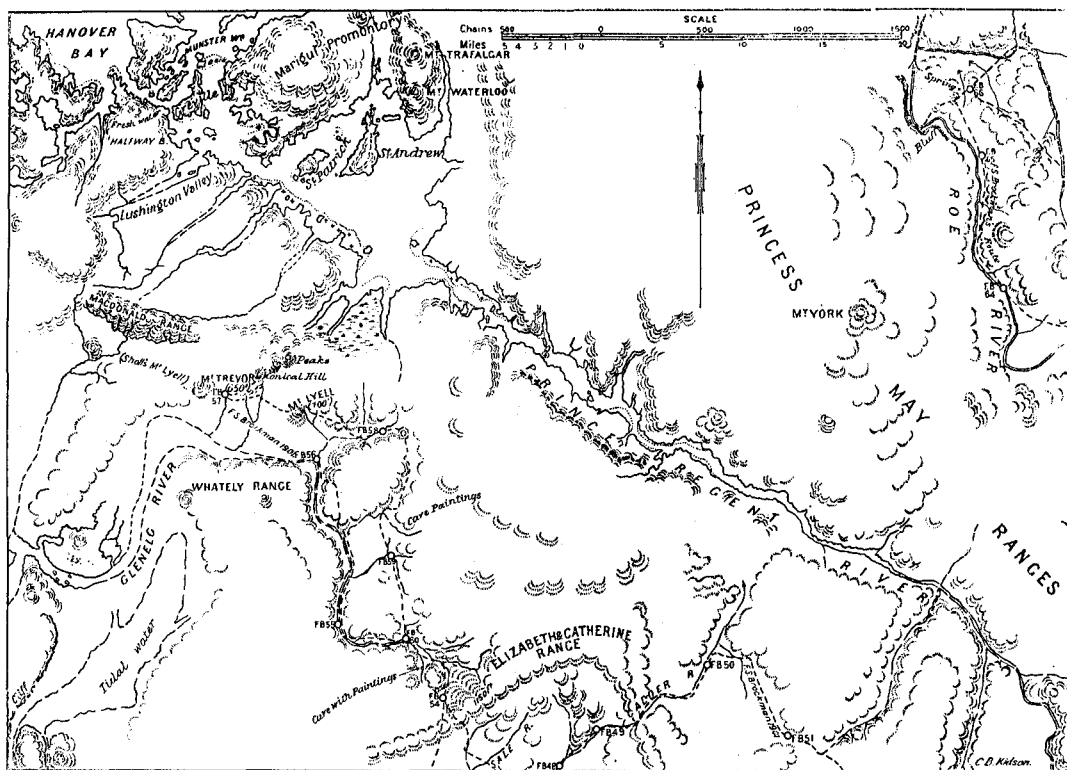


Fig. 11.—The Drowned Valley of the Prince Regent River, Kimberley Division.

MESOZOIC.

Jurassic, and
Cretaceous indifferently.

CAINOZOIC (TERTIARY).

Miocene.

POST-TERTIARY (QUATERNARY).

Coastal Limestone Series.
Pleistocene.

RECENT FORMATIONS.

Lacustrine and other Deposits.

ARCHAEOZOIC (ARCHAIC GROUP).

The oldest known rocks of Western Australia comprise a great group of crystalline rocks which almost everywhere constitute the foundation of the State. To the whole of these rocks, however, observers have invariably assigned an Archaean Age; but this is rather inferred than proved. There is only one instance on record at the present time upon which this classification may be considered to have been determined by palaeontological evidence. In the Kimberley Division certain limestones, sandstones, quartzites, etc., have yielded Lower Cambrian fossils, viz., *Salterella hardmani*, and *Olenellus forresti*; these fossiliferous beds are considered, and may probably be, newer than the schistose rocks in the vicinity. So far as geological observations have been carried, no actual junction has been noticed between the schists and the fossiliferous strata.

From such field work as has at present been carried out it appears that the most ancient rocks recognised in Western Australia is that group of crystalline schists to which as yet no distinctive name has been given.

The largest area over which the Archaeozoic (Pre-Cambrian) crystalline and metamorphic rocks are exposed is that which occupies the major portion of the Central Division of the State; it extends from about latitude 25 degrees south as far as the southern coast line, and is bounded on the west by a line drawn from the mouth of the Donnelly River, and on the east by the 124th meridian of longitude; thus embracing an area amounting to about 308,000 square miles.

Very much smaller areas occur (a) between the Gascoyne and the mouth of the Ashburton River, and (b) in the Pilbara and West Pilbara Goldfields. The major portion, also, of the Kimberley Division has a floor of crystalline rocks, whilst similar rocks cover a comparatively narrow strip on the southern slopes and foot hills of the King Leopold Plateau, extending from Collier Bay to the Mueller Range, and thence to the Carr Boyd Range, lying partly in the valleys of the Mada and Fitzroy Rivers in West Kimberley, and partly in the Ord River in East Kimberley.

Other areas of as yet unknown extent occur along the South Australian border, between latitudes 19 and 27 degrees south.

The base of the crystalline schists has not been unequivocally recognised anywhere for the reason that the actual contacts have been removed by the intrusion of the younger granites, gneisses, and allied rocks, in addition to having been more or less obscured by secondary processes. The intrusive granites have in very many

cases exercised a strong influence on the rocks into which they have been injected.

One of the most important of the original geological structures is the stratigraphical arrangement of the rocks, and perhaps the greatest and most important problem connected with the Archaeozoic (Pre-Cambrian) rocks is their division into series, which may be correlated from district to district. The stratigraphical arrangement, however, is in no way connected with or related to those secondary changes and metamorphic processes to which the Pre-Cambrian rocks have been subjected. Many points in regard to the true order of superposition as yet await solution which can only be brought about by detailed geological surveys carried out over fairly extensive areas, and the results carefully correlated. During the working out of the stratigraphical relationships the problem of a division into series is not nearly so hopeless as it appears at first sight. It is only by the application of stratigraphical methods (using this term in its widest scientific sense) to these ancient rocks that a classification quite as satisfactory as that applicable to the rocks much higher in the geological column can be arrived at.

There are probably few parts of the Australian Continent which can boast of a finer development of these older rocks than Western Australia, and perhaps no more promising field can be found for their investigation.

It is, however, proposed to retain the term Archaeozoic (Archæan) for that great complex of schists, gneisses and allied rocks, but, although that is done, it is not meant to imply that the rocks so designated in the Northern Hemisphere and elsewhere are exactly contemporaneous.

These Western Australian Archaeozoic (Archæan) rocks bear a close lithological and structural resemblance to the Keewatin Series of the Northern American Continent, the Dharwar System of Southern India, and the Swaziland System of South Africa.

The Archaeozoic (Archæan) rocks of the State present a bewildering variety of lithological types, which bid fair to make Western Australia a classic field for petrological research. Portions of the plateau in which they occur have been examined during many hasty traverses which individually yield somewhat limited information, although collectively they give a good general idea of the geological constitution; they have, however, been most closely investigated in those districts in which the probability of economic development has necessitated detailed geological surveys. These localities are very widely separated, and it is now becoming imperatively necessary to link up these districts by a study of the intervening areas, though many portions being masked by residual and other deposits the geological structure of these areas will, it is to be feared, remain more or less the subject of speculation and inference.

In the absence of any other evidence it has been found convenient to divide the Archaeozoic (Archæan) rocks into two great lithological groups, viz., (a) the gneissic and granitoid rocks, and (b) the crystalline schists. A much more satisfactory and logical classification, however, would be to divide these crystalline rocks and schists into three quite distinct groups, viz., (1) intrusive granite, (2) schistose rocks resulting from the intrusion of the granite into rocks which it has totally or partially assimilated, and (3) schists and rocks of an allied nature which are in an advanced state of metamorphism, and probably represent altered representatives of sedimentary beds together with their associated igneous rocks. The crystalline schists, of which there are at least two distinct groups, and which there is some reason to believe differ considerably in geological age are (a) phyllites, quartzites, arkoses, and conglomerates, and (b) an older mica-quartz schist and marble group associated with basic rocks which have in certain localities been converted into greenstone schists. These rocks have been more or less irregularly folded and compressed concertina fashion along highly inclined axial planes; the folding is meridional, the prevalent strike being generally north-west and south-east. The broad geological structure of

the western half of the State across some of these bands is shown in the section (Fig. 12), and will serve perhaps to make this clear.

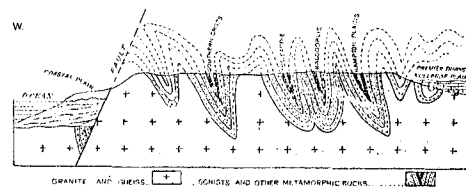


Fig. 12.—Generalised Section across Western Australia from the Coast to Premier Downs.

These narrow belts form merely the deeper portions of what was at one time a very thick continuous rock series and in reality they form the roots or base of denuded Pre-Cambrian mountain chains in which overthrusting and faulting have taken place.

In several cases the beds have been folded and faulted in a very remarkable manner.

The quartz reefs associated with these beds also afford evidence of this contortion, faulting, etc., and many of them present features which seem to indicate that they have been wrenched apart by movement along shear planes.

A feature of many of the reefs is the folding they have undergone, which is well exemplified in the case (Fig. 13) of the Horseshoe vein at the Bow Bells Mine at Warrawoona on the Pilbara Goldfield. The fold in the Horseshoe vein merely differs from the saddle reefs depicted in many geological text books in the fact that in this instance the legs are horizontal.

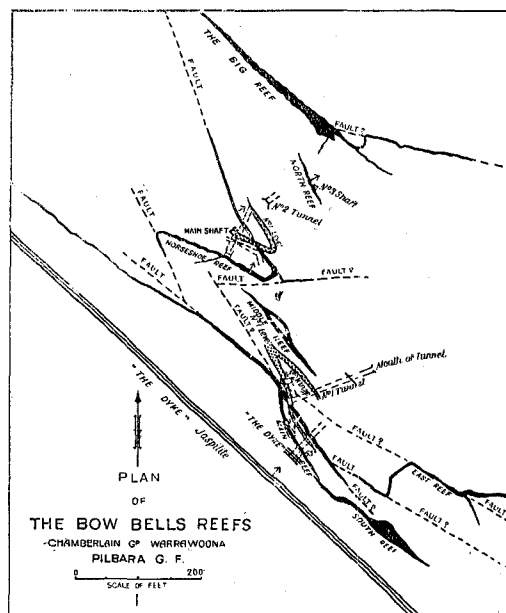


Fig. 13.—The Horseshoe Vein, Bow Bells Mine, Warrawoona, Pilbara Goldfield.

This folding of the reefs may also be noticed underground, a typical instance of which is seen in the Burbanks Main Lode at Coolgardie (Fig. 14).



Fig. 14.—The Burbanks Main Lode, Coolgardie Goldfield.

Folding and puckering of quartz veins may even be of microscopical dimensions and is well illustrated in the case of the quartz-schist [5789] on the Gauntlet East Mine, G.M.L. 560, at Warrawoona, Pilbara Goldfield. (Fig. 15.)

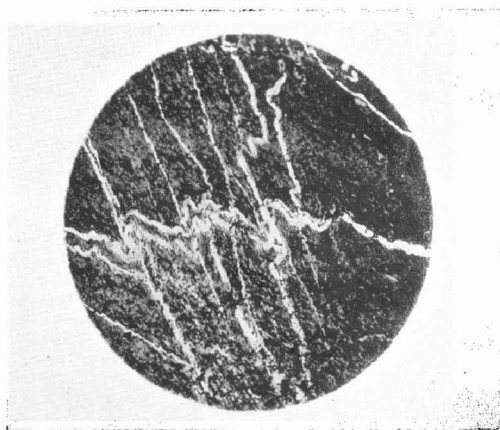


Fig. 15.—Contorted Quartz Laminae, East Gauntlet Mine, Warrawoona, Pilbara Goldfield.

Some, however, of the hornblende rocks associated with the schists may possibly represent original gritty beds made up of epidote and chlorite; in some instances quartzite in which original argillaceous impurities have recrystallised as felspar and mica rendering the rock easily mistaken for granite and its allies.

These ancient rocks consist of very different lithological types. Many of them are in a crystalline condition and form crystalline schist and gneiss which differ but little from granite and other rocks of like origin, as well as basic rocks which have been more or less crushed, foliated, and almost completely converted into crystalline schists. An important feature of the crystalline schists is the presence among them of unfoliated basic rocks which sometimes occur in the form of lenticular belts of (in certain places) considerable horizontal extent.

Several excellent sections in the Pilbara Goldfield show these basic rocks passing by almost imperceptible gradations into the greenstone schists. In one or two localities are belts of magnetite schist in the centre of some of which are uncrushed "eyes" (of large dimensions) of greenstone occurring in such a way as to indicate that the margins only of the mass have been ground down into schist. Many of these schists contain very large quantities of magnetite such as give a very distinctive character to the rock.

Some of the foliated greenstones on the Pilbara Field contain large brown crystals, a combination of cube and octahedron, of iron ore, viz., limonite pseudomorphs after pyrites. Many of these crystals are about an inch in length. In other portions of the same field the surface of the unfoliated greenstone is strewn with similar limonite crystals.

Some of these congeries of basic rocks have a very considerable lithological range, though linked together by ties of affinity; they comprise two main groups (a) comparatively fresh greenstones, which include dolerite, gabbro, norite, amphibolite, epidiorite, and serpentine, and (b) much altered chloritic, carbonated and talcose rocks, in which the individuality and geological identity have been almost entirely lost, due perhaps in part to the thermal metamorphism of the granitic rocks which almost everywhere invade them.

At Ora Banda, on the Broad Arrow Goldfield, the ancient crystalline schists and their allies, designated the Auriferous Igneous Complex, are represented by a series having a fairly wide range as regards acidity. They are divisible into a basic—mainly gabbro, dolerite, porphyrite, epidiorite, and serpentine, and their transmuted varieties—and an acidic series mainly granite and quartz-porphyr. It is possible that the various rock types are genetically related and may all owe their origin to some process of segregation from one parent magma.

Some of the greenstones and their derivatives contain fairly large quantities of calcite, dolomite, ankerite, etc.; in places this is so marked as to result in the production of rocks which are closely allied to some limestones of the ordinary aqueous type, which suggests that some limestones at any rate owe their present condition to changes in rocks of igneous origin.

Amphibolites everywhere play an important part in the Archeozoic rock series, and there seem some grounds for the belief that some at any rate owe their origin to alterations in and transmutations of (a) sedimentary and (b) igneous rocks. The recognition of the two types is not, however, an easy matter. Some of the quartz-amphibolites, which are fairly widely scattered in Western Australia, may prove on more detailed investigation to be of sedimentary origin.

Some of the older schists are of sedimentary origin and consist essentially of sericite, graphite, andalusite, and mica phyllites, with siliceous and ferruginous quartzites, and in a few places more or less deformed conglomerates (Fig. 16); some of the siliceous rocks are only distinguishable with difficulty from vein quartz. The sedimentary rocks of this type present all the phenomena resulting from contact metamorphism.

Andalusite schists have a fairly wide distribution in Western Australia and are almost invariably associated with the metamorphosed sediments. Of these there is a fairly large development in

the Yilgarn Goldfield where a relatively narrow belt has been mapped from Ennui to South Mount Ironcap, a distance of about 150 miles. Andalusite garnetiferous phyllites interbedded with sericite and graphite schists are of common occurrence in the belt. Andalusite slates have been found on the Yalgoo Goldfield in that belt of rugged country lying to the south of Ninghan (Mount



Fig. 16.—Deformed Quartz Conglomerate, Golden Valley, Yilgarn Goldfield.

Singleton) of which Yandanoo Hill forms the highest summit. The beds consist of metamorphic sediments interbedded with which are ferruginous jaspers. The andalusite slate in all probability owes its origin to the contact alteration induced by the underground mass of granite which does not reach the surface in the more immediate neighbourhood, but is represented by its offshoots, aplite and pegmatite veins; the main mass of the granite, however, outcrops about a mile to the south and covers a wide expanse of country. A quartz-rock containing from 20 to 30 per cent. of andalusite occurs at Mt. Leonora, on the Mount Margaret Goldfield; this is interbedded with those acid schists of sedimentary origin which extend northward as far as Mount George. Dark andalusite slates occur on a low hill two and a half miles to the eastward of the Child Harold Gold Mine, near Lake Carey. A quartz-sericite schist containing andalusite occurs at Warrawoona, on the Pilbara Goldfield, in association and interbedded with those metamorphic sediments which make such a prominent feature in this portion of the State. There seem, however, good reasons for believing this andalusite schist to have resulted from the metamor-

phism of a felspar-porphiry. Andalusite schists are known from the Phillips River Field, and the field relations indicate that they are evidently alteration products of the soda granite which covers such a wide area in this part of the State.

Sillimanite gneisses occur in many widely separated localities in Western Australia. They possess such a mineral and chemical composition as point to their originating from the metamorphism of varying degrees of intensity of argillaceous sediments. Garnetiferous-sillimanite schist or gneiss, resulting, however, from the dynamic metamorphism of a granitic rock, occurs at Westonia, in the Yilgarn Goldfield. The sillimanite is in the form of small sheaves of minute fibres chiefly in the quartz. A somewhat similar sillimanite gneiss has been noticed occurring along the foliation planes of the garnetiferous gneiss which is exposed on the sea shore at Ellensbrook in the extreme south-west of the State, between Capes Naturaliste and Leewards. A biotite-sillimanite gneiss has been met with near the Granite Hills on the Margaret River, in the Kimberley Division, but little is as yet known of its field relations.

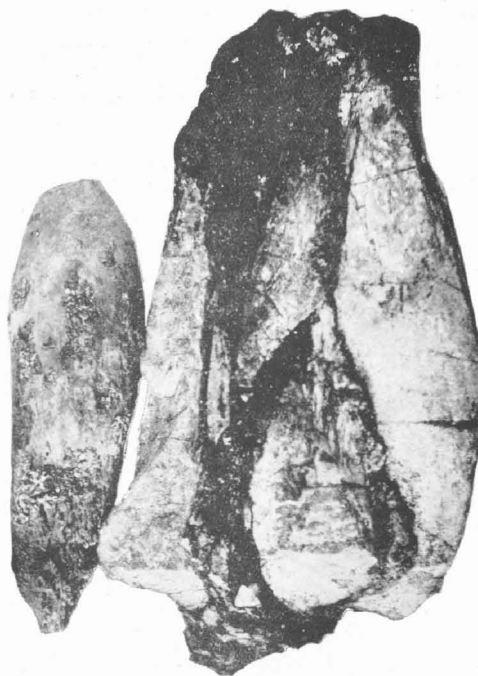


Fig. 17.—Elongated Quartz Pebbles from Quartz Conglomerate, Golden Valley, Yilgarn Goldfield.

Owing to the profound changes which the bulk of the Archaean rocks have undergone, the occurrence of distinctly recognisable clastic material can only be exceptional, and it is probable that such may in most cases be represented by rocks in which a holocrystalline dense or coarsely crystalline development is the most marked characteristic. Breccias and conglomerates possessing as they do greater resistance to metamorphic and allied agencies are better able to escape complete destruction than the finer-grained sediments, and have been detected in widely separated localities in Western Australia. These probably occur at different geological horizons and are easily recognisable as true conglomerates.

A very large and important development of these old sediments occurs in the Yilgarn Goldfield, the most important being that rela-

tively narrow band which extends with but few interruptions from Ennui to South Mount Ironcap, a distance of about 150 miles. The sedimentary rocks constituting this important belt consist essentially of sericite, graphite, andalusite, mica and garnetiferous phyllites, with siliceous and ferruginous quartzites and occasionally more or less deformed conglomerates. The pebbles of which the conglomerates are made up vary in size from that of a pea to others of from eight to 10 inches or more in length. In some instances, as a result of intense and profound dynamical alteration, the component pebbles have been elongated or drawn out into lenticular masses (Fig. 17). Some of the very highly siliceous rocks are only distinguishable with considerable difficulty from vein quartz.

There are also belts and masses of limestone associated with the rocks. The limestones are often dolomitic and pass by almost imperceptible gradations into pure dolomite. Some of the basic rocks and their derivatives are often found to contain fairly large quantities of calcite, dolomite, ankerite, etc. At times this association is sufficiently well marked to result in the formation of rocks which are closely allied to some of those limestones belonging to undoubted aqueous types. Many of these ancient calcareous rocks occur along what are obviously lines of weakness, suggesting that some at any rate owe their origin to profound changes in igneous rocks. The calc-schists of the Kalgoorlie Field, which are very closely allied to the fine-grained amphibolites, appear to be of this type. A dedolomitised limestone, now a white crystalline marble,

containing serpentine and chondrodite and associated with quartz and mica schists, occurs on the Gascoyne River, near Trig. Sta. K. 31. The schists with which the marble is interstratified are pierced by veins of pegmatite of which there are very many in the district. The mica-schists and phyllites of the Yannerie River are also associated with a dolomitic limestone and coarse calcareous grit which have been subjected to a considerable amount of crushing. Some of the dolomites and marbles are rich in silica which has, in all probability, been derived from permeating waters. Almost every gradation is to be found between siliceous dolomites and practically pure siliceous rocks, from which latter there is also a gradual change to ferruginous cherts or quartzites from which carbonates are absent. This association suggests that some at any rate of those highly ferruginous cherts or jaspers may have originated from the alteration of limestones of varying degrees of purity.

A most noticeable feature in these crystalline schists is constituted by these bands of cherts and brilliantly coloured jaspers (which often contain oxide of iron to such an extent as to warrant their being classed as iron ores). The brilliant appearance of these jaspilites is due to the interlamination of red, white, and dark-coloured bands with intermediate varieties, the difference in colour being due to the occurrence of iron in the form of either limonite, haematite, or magnetite. These extend as roughly parallel bands which, owing to their serrated ridges, stand out in bold relief (Fig. 18) and are very much in evidence in certain districts. These

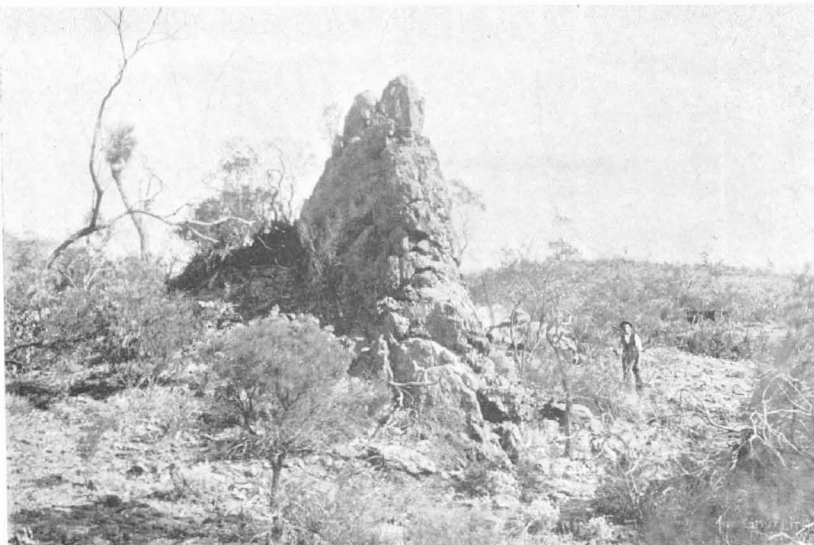


Fig. 18.—Haematite Quartzite, Mount Hunt, East Coolgardie Goldfield.

bands do not always occur in straight lines, but as they have also been subject to earth movement since their formation they are often thrown into a series of gentle curves which vary locally in general direction.

These bands are often intersected with faults which in some districts are of considerable economic importance, for it is along these fault lines, generally at right angles to the strike of the jaspilites, that rich shoots of gold often occur. In some cases these iron-bearing jaspilites attain a very great thickness and have been very much plicated and contorted, whilst in certain places they have been faulted (? overthrust) in a direction parallel to the strike, the fault fissure being filled with a breccia of jasper recemented by chalcedonic silica. In nearly all cases these jaspilites are vertical or at any rate inclined at high angles. The jaspilites in many

localities contain magnetite in such quantities as to render the use of a compass in the vicinity almost impossible.

These bands of jaspilite often present a ribbon-like structure, and in certain localities the geological associations suggest that they owe their origin to compression and intense shearing and a subsequent metasomatic replacement of the original rock through the action of carbonated waters. In some districts, notably at Sandstone, on the East Murchison Goldfield, the jaspilites when seen below ground in the mine workings are found to pass by almost imperceptible gradations into graphitic schists, which when examined microscopically exhibit evidence of having been subject to intense shearing, and being represented in places by chlorite-schists. Up to the present time, owing to the conditions of mining, no opportunity of studying these jaspilites at depths any greater than 500 or 600

feet has presented itself. On the other hand, the magnetite-hematite-quartz schists may perhaps have originally been ferruginous grits of sedimentary origin. Some of these jaspilites are found in

intimate association with the greenstone and allied schists, which suggests that the former may in some cases have originated as a replacement of basic lava flows or sills.

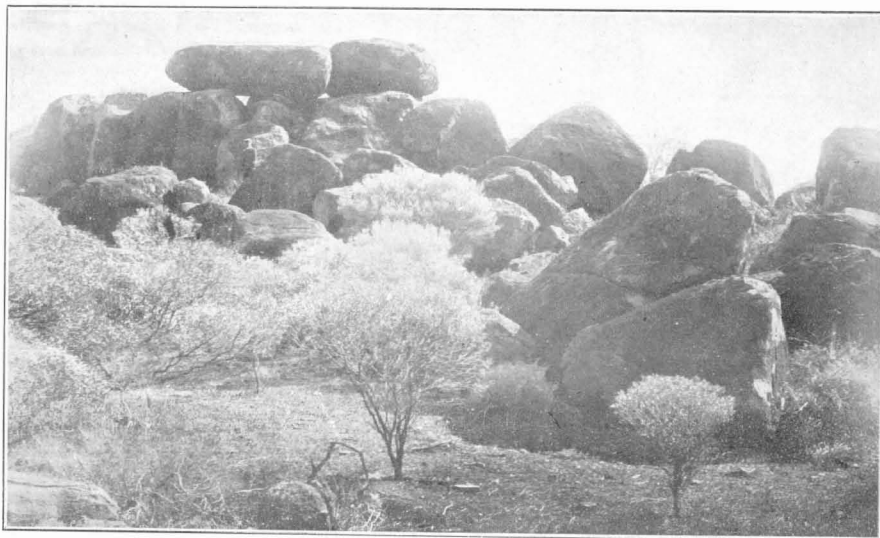


Fig. 19.—Granite Rocks, near Luke's Trig. Station, Meekatharra, Murchison Goldfield.

The crystalline schists have been invaded by huge masses and veins of granite which occupy some hundreds of square miles in parts of the State. The major portion of the surface of the plateau occupied by these rocks forms broad expanses of flat or rolling country above which protrude rounded bosses or domes of bare granite and upon which occasionally huge agglomerates of immense boulders are situated, taking the form of fantastic-shaped "tors." The intrusion of the granite is perhaps, from the economic point of view, the most important geological event at this period inasmuch as most of the gold deposits, which place Western Australia in the front rank of mining countries in the British Empire, bear some genetic relation thereto.

Granite and massive gneiss cover a large area of country in the vicinity of the Porongorup Range, near Albany, in the South-West Division. The range trends north-west and south-east—a strike which is practically coincident with the foliation which has resulted from the stresses and strains to which the rock has been subjected. A gradual passage from granitic gneiss to granite may be noted in many parts of the Porongorup Range, and what is significant is that the trend of the foliation has determined that of the longer axes of the large felspar crystals which these granitic rocks contain.

Granitic and gneissic rocks of the Porongorup type bulk very largely in the South-West Division of the State and have been more or less carefully investigated in the Champion Bay District in the more immediate vicinity of Northampton. In this locality the granitic gneisses are found to vary greatly in character and to be associated with various schistose rocks between which it has been found, up to the present, impracticable to draw any very distinct line of demarcation. There are in the Northampton neighbourhood several sheeted zones of micaceous and garnetiferous granulites traversed by very much puckered and contorted veins of quartz.

Sections are to be seen near the tin mining centre of Wodgina, in the Pilbara Goldfield, showing an ancient intrusive granite which has been invaded by a newer (though still old) tin-bearing granite.

The mining centre of Tambourah, in the Pilbara Goldfield, is one in which the intrusive nature of the granite may be readily studied (Fig. 20); here the country is very nearly destitute of

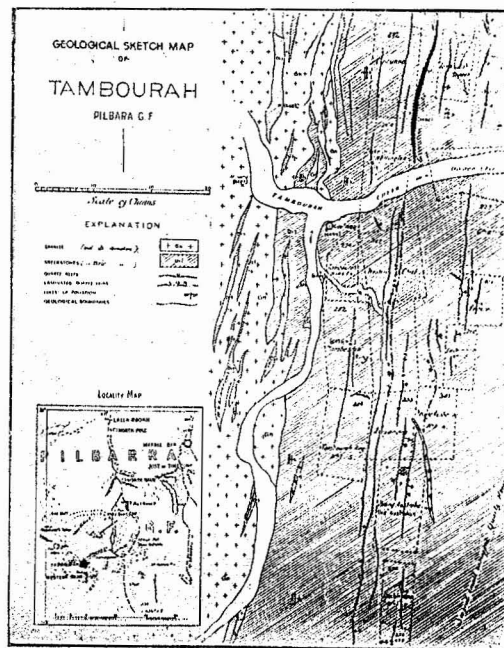


Fig. 20.—Geological Sketch Map of Tambourah, Pilbara Goldfield.

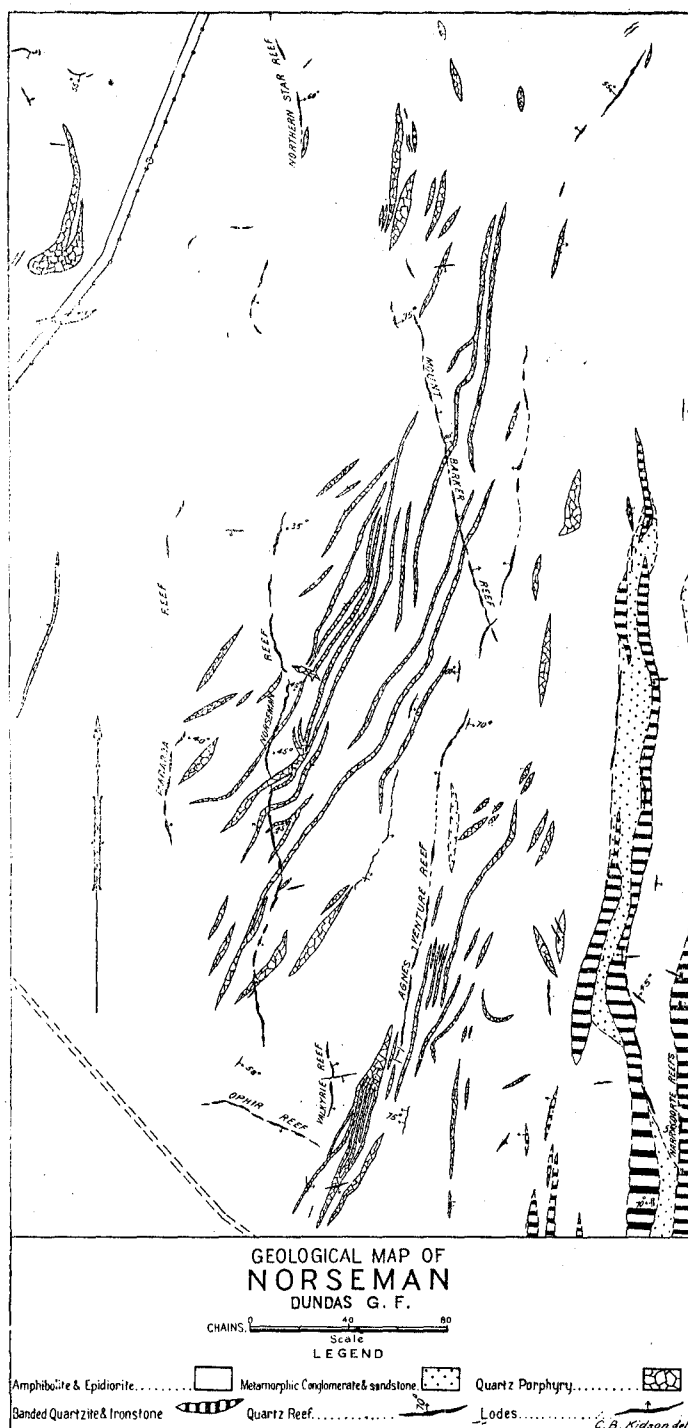


Fig. 21.—Geological Map of Norseman, Dundas Goldfield.

soil and the rocks lie ready for inspection anywhere. At this locality the granite may be seen to have wandered through the schists in addition to having engulfed and floated off extensive masses along its margin. From these large granite batholiths numerous dykes of pegmatite and acid porphyries emanate.

The intrusive granites have in nearly all cases exercised a markedly strong influence on the rocks they invaded. A selvage of greater or less width of dense fine-grained metamorphic rocks is often to be found in association with the granites; the boundaries between the two rock series can only be defined within certain more or less arbitrary limits. The network of acidic dykes of different ages affords evidence of the mutual relationships of the granite and its associates.

Extensive areas of porphyries also occur. Many of these pass into granite. In the neighbourhood of Mount Squires, in the Barrow Range, near the South Australian border, in south latitude 26 degrees, there is a considerable development of acid porphyries which gradually merge into granite. Tongue-like dykes of fine-grained quartz-porphyry, which form a fringe to the granite of the Yalgoo Field, are seen in the vicinity of the Highland Chief Mine near Warriedar, to gradually merge into granite. One of these acid porphyry dykes occurring in the vicinity of Mount Kenneth to the north of Lake Moore, on the Yalgoo Field, has a maximum width of 20 chains with a horizontal extent of at least six miles.

At Norseman, in the Dundas Goldfield, there is a large development of quartz-porphyry dykes which intersect all the formations developed in that centre other than the metamorphic sedimentary rocks and the large east and west norite dyke (Fig. 21). These porphyries are intimately associated with the quartz veins and appear to follow the same lines of fissure as some of the gold-bearing quartz reefs. In all probability the dykes are the apophyses of the large granite mass (batholith) which lies eastward of and adjacent to Norseman itself.

These granitic rocks constitute composite batholiths occupying hundreds of square miles, and there seem some geological reasons for believing them to have digested and replaced very large masses of sediments and possibly other adjacent rocks. These great intrusive granite masses, when considered in the light of their metamorphic effects, constitute one great significant and outstanding feature of the Western Australian goldfields geology.

Owing to the physiographic features of the Central Plateau, the erosion has not penetrated to any depth; hence it cannot be said that the "anatomy" of these masses has yet been thoroughly understood.

These granites are traversed by many ice-like quartz reefs which can be traced across country for miles (Fig. 22); the mode of occurrence, etc., of these large quartz masses point to their

being of igneous origin, representing the final product of the differentiation of a granite magma, its ultra acid portion.



Fig. 22.—Quartz Reef, Erlistoun, Mount Margaret Goldfield.

Veins or dykes of pure silica may be seen in some of the underground workings on the goldfields areas; in the case of one of the mines on the Peak Hill Goldfield a vein of this character is seen to cut across an auriferous quartz reef. An analogous instance occurs at the Nellie May Mine at Norseman (Fig. 23). Certain quartz

present been carried, cover any very large area; they consist of garnetiferous hypersthene granulites which bear some resemblance to the acid representatives of the Charnockite Series as developed in India and Africa. Somewhat similar rocks are known to occur in the Eastern Agricultural Districts in the vicinity of Greenhills, though up to the present time these occurrences have not been critically investigated in the field.

The Archeozoic (Archean) rocks of the State have been traversed by numerous basic dykes, chiefly dolerites, which wherever examined are remarkable for their freshness (Fig. 24). In

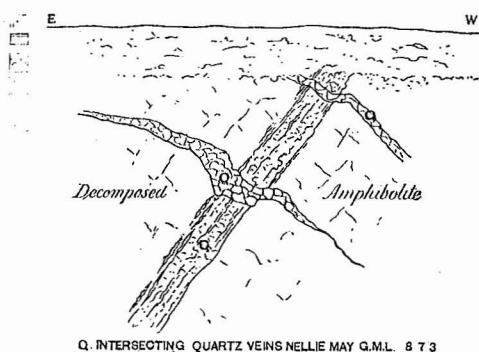


Fig. 23.—Intersecting Quartz Veins, Nellie May Mine, Norseman, Dundas Goldfield.

reefs occurring in the Coolgardie Goldfield are intimately associated with acid dykes, and in some instances the latter gradually pass into pure quartz at their extremities. These acid dykes can be seen to pass by almost imperceptible gradations into the main mass of the granite at Coolgardie.

In the vicinity of Cohn Hill and Mount Aloysius, not far from the South Australian border, in latitude 26 degrees south, there occur in the Archean plutonic complex rocks, in which hypersthene predominates. These rocks do not, so far as observations have at

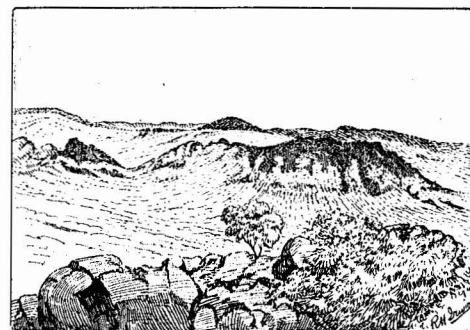


Fig. 24.—Gabbro Dyke between the George and Sherlock Rivers, West Pilbara Goldfield.

other areas the rocks have been traversed by a remarkably persistent series of north-west and south-east basic dykes. Such dykes are well typified at Warrawoona, in the Pilbara Goldfield, in the North-West Division of the State, where the dykes traverse the centre of the gold-bearing portions of the field approximately at right angles to the general trend of

what may be called the auriferous zone (Fig. 25). Besides these relatively newer greenstone dykes there are others which are intimately associated with the older rocks of the district. These older dyke rocks are often rudely cleaved and foliated and seem to occur in intimate connection with or parallel to the principal structural lines of the district. These older cleaved or foliated dykes

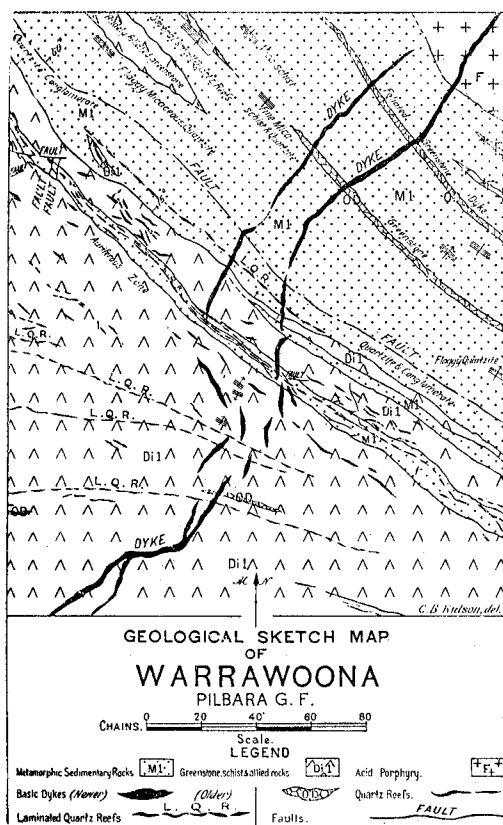


Fig. 25.—Geological Sketch Map of Warrawoona, Pilbara Goldfield.

may be seen in many places to be pierced almost at right angles to their general trend by the newer uncleaved series. The regular continuity of the newer system of the basic dykes of Warrawoona has been interrupted in the vicinity of their intersection with the auriferous series, indicating that they have undergone considerable movement since their injection. The somewhat curved and distorted fragments or isolated patches all point to a series of later movements along lines parallel to that of the main trend of the auriferous belt of Warrawoona.

PROTEROZOIC (PRE-CAMBRIAN GROUP).

Upon the fundamental crystalline rocks of the Interior Plateau of Western Australia there occurs a great series of sedimentary beds which up to the present time have yielded no fossils. These beds, which are very widely distributed in the State, constitute in many respects a very important feature in its geology. There are sound scientific reasons for believing these ancient sedimentary rocks to be of different geological ages, and, so far as all lines of available evidence go, they appear to justify the conclusion that these are at any rate Pre-Cambrian.

The Pilbara district, on the north side of the lofty Hamersley Tableland, affords better and more continuous sections than are generally to be met with in any of the other districts of the State which have, so far, been examined, and thus reveals structures which are not to be found in the more southerly districts.

These Pre-Cambrian rocks may be classified and grouped into discordant series, for which the following local names have been given:—

Warrawoona Beds.
Mosquito Creek Beds.
Ashburton Beds.
Kalgoorlie Series.
Stirling Range Beds.
Nullagine Formation.

Warrawoona Beds.

The Warrawoona Beds are named from the mining centre in the Pilbara Goldfield, where they form a continuous belt about 80 miles in length and where they have been chiefly studied. The district, of which Warrawoona is the centre, is formed of a lofty serrated razor-backed ridge, trending generally north-west and south-east; the general trend of these ridges has been determined by the outcrop of the siliceous rocks of which they are chiefly made up.

The Warrawoona Beds can be separated into two distinct lithological units which are sharply differentiated from each other, viz., an acidie and a basic series. The acidie series is made up of highly siliceous beds dipping at varying angles to the north-east, and trending generally north-west and south-east.

These beds, which are of sedimentary origin, consist of fine-grained flaggy quartzites, sheared conglomerates, which still retain traces of their original character, mica-sericite-quartz schists, together with certain fine-grained siliceous rocks which seem to have lost all trace of their original character. Some of the conglomerates, however, still retain traces of their original character, though in others most of the pebbles have been flattened out and stretched almost beyond recognition. Interbedded with the quartzites and quartz schists is a very calcareous rock of a pale salmon colour, which seems to be a limestone. In the Marble Bar district these rocks are interbedded with brilliantly coloured jaspilites which are of sedimentary origin (Fig. 26). The jaspilites present a brilliant appearance, due to the interlamination of red, white, and dark-coloured bands, with intermediate varieties, the differences in colour being due to the occurrence of iron in the form of either limonite, hematite, or magnetite.

Amongst the quartz schists which form the summit of the main Warrawoona ridge is a bed which contains what appears to be fossil wood; microscopic examination, however, failed to detect any trace of organic structure. It is, however, quite possible that the dynamic metamorphism which these rocks have undergone may have entirely obliterated all traces of organic structure, and that some form of plant life existed at the time these beds were deposited.

The basic series, which at Warrawoona occupies a large area of country, may, in part, represent lava flows or sills. The basic rocks have been in places completely converted into greenstone schists, and are in places represented by hornblende, magnetite, talc, and serpentinous schists. An important feature of these basic schists is the presence amongst them of unfoliated rocks, which in some places occur in the form of lenticular belts of considerable extent. The basic rocks may be seen passing by almost imperceptible gradations into hornblende schists, whilst in other localities are bands of magnetite schists, in the centre of which are large placoidal-shaped masses of the parent greenstone occurring in such a way as to indicate that the margins only have been ground down. These, which vary very much in grain, all contain more or less hornblende and its numerous alteration products, and some of the constituent minerals are largely replaced by carbonates.

The Warrawoona Beds are intruded by the large granite mass which occurs in the form of a huge batholith, covering some hundreds of square miles. From the granite there emanate dykes of aplite, pegmatite, and felspar-porphry. The granite presents a rude foliation or banding which is parallel to the general strike of the beds of the Warrawoona Series. In no case has the granite been

noticed rising to the level of and penetrating the beds of the newer Nullagine Formation. If the banding in the granite is not an original feature, then it is quite clear that both it and the Warrawoona Beds were subject to the same set of stresses and strains which were set up in the interval separating the strata of the Nullagine Formation from the older series.

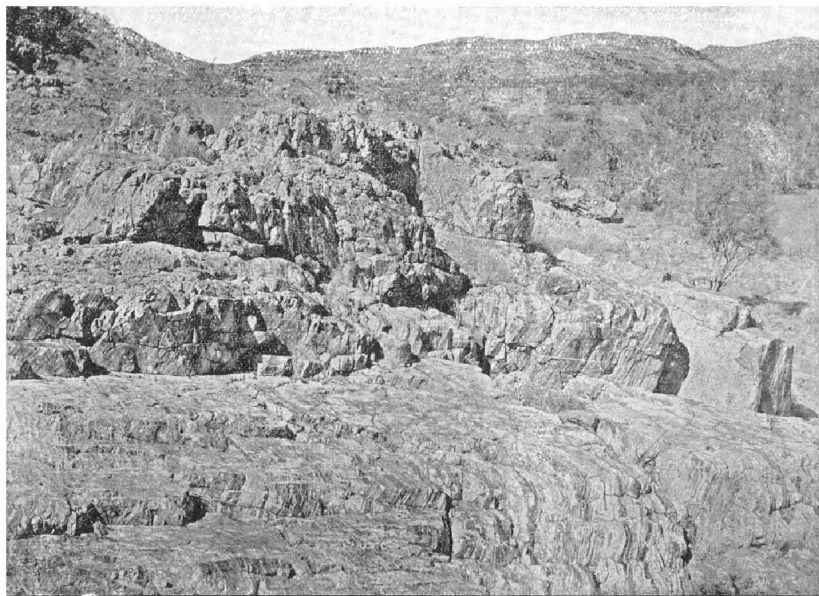


Fig. 26.—Banded Jaspilite near Marble Bar, Coongun River, Pilbara Goldfield.

The Warrawoona Beds are intersected by acidic dykes, now in part represented by quartz-sericite schists which may originally have been porphyries; some contain "eyes" of what were potash-felspar, around which the fine foliation of the matrix sweeps in graceful curves. These, when microscopically examined, present that peripheral granulation characteristic of crystals and fragments which have been subject to intense crushing.

Future detailed and comprehensive field work may show a very intimate and close relationship between the Warrawoona and Mosquito Creek Beds.

Economic Products.—The Warrawoona Beds are of considerable economic importance by reason of the fact that they carry all the auriferous reefs of Marble Bar, Salgash, Warrawoona, and Yandi-coogina.

Mosquito Creek Beds.

The name Mosquito Creek Beds has been given to a well marked series of sedimentary rocks consisting of grits, shales, and fine conglomerates, and takes its name from the district of Mosquito Creek, one of the tributaries of the Nullagine River, in the Pilbara Goldfield.

What seems to be the base of the series is exposed a little to the east of Nullagine in what is known as the North and South Dromedaries. The range in which the beds are exposed is made up of vertical beds of conglomerate of considerable thickness.

The conglomerate contains numerous pebbles of laminated quartz (chert) and jaspilite which form part of the Warrawoona Beds. The conglomerate is very much cleaved, and the cleavage planes are seen to cut through many of the quartz and other pebbles in it. The old 40-mile road from Mosquito Creek to Nullagine

follows an open longitudinal valley occupying the summit of a very broad anticlinal fold, which forms one of the most important structural features in the district. It is upon the northern and southern flanks of this arch that all the auriferous quartz reefs of the Nullagine, Mosquito and Middle Creek zones occur.

No estimate of even the approximate thickness of the Mosquito Creek Series can at present be made, though the apparent enormous thickness of the series may, in all probability, be due to the repetition of the beds by folding and overthrusting.

No trace of organic life has been met with anywhere in the Series, so no definite data as to the age of the beds are available. Field observations have shown that the Mosquito Creek Beds lie with a violent unconformity beneath the Nullagine Formation, hence a considerable interval of geological time must have elapsed between the deposition of the two series. Like the Warrawoona Beds the Mosquito Creek Series has been intruded by granitic rocks and its allies. An important feature at the township of Mosquito is an intrusive boss of grano-diorite a little over a mile in length and about half-a-mile in width, which rises to a considerable height above the general level of the surrounding country and makes a prominent feature in the landscape. This grano-diorite intersects the sedimentary rocks but does not appear to have produced any marked metamorphic effects.

Economic Products.—The Mosquito Creek Beds are of economic importance by reason of the fact that they form the matrices of the numerous gold-bearing quartz reefs, which have been more or less perfunctorily worked.

What have been described as the **Ashburton Beds** are at present believed to be the equivalent of the Mosquito Creek Beds and are found occurring in great force at Uaroo, situated 80 miles from

Onslow, upon Rous Creek, which forms one of the numerous branches of the Ashburton River. They also occupy the valley of the Ashburton River between Mount Hubert and the Top Camp, flanked by the lofty Tableland made up of the almost horizontal beds of the Nullagine (and Bagemall) Formation. The district, of which Uaroo is the centre, is formed of a series of lofty precipitous and serrated ridges which trend generally north-west and south-east. The locality is made up of one continuous series of sedimentary rocks, some bands of which have undergone more or less mechanical deformation. The strata consist of quartzites, micaceous slates, and conglomerates which have an average strike of north-west and south-east and a steep dip to the north-east; the beds are arranged in a series of steep anticlinal folds. The micaceous beds are represented by phyllites, some of which are garnetiferous and others haematite-bearing. The quartzites are occasionally flaggy and micaceous. Many of the conglomerates are traversed by both vertical and horizontal joints which cut clean through the component pebbles; some of the conglomerates are made up of quartz pebbles set in a matrix which resembles a phyllite.

The beds in the valley of the Ashburton consist of a series of highly inclined micaceous sandstones, ferruginous grits, quartzites, massive conglomerates, and thin shales, arranged in a series of sharp anticlinal folds. Some of the micaceous quartzites contain large lenticular masses of haematite, of which Mount Edith is a conspicuous example. The mountain is made up of a bed of haematite quartzite trending north-west and south-east and dipping south-east at an angle of about 25 degrees; an analysis of it showed it to be a high-grade haematite containing 96.75 per cent. of ferrie oxide, equivalent to 68.42 of metallic iron.

Associated with the Ashburton Beds in the valley of the Hardey River, there is a well-defined horizon of dolomitic limestone, which can be traced across country for at least 70 miles south-east from Coorara. At Coorara itself the dolomite is of exceptional purity and is seamed in places with quartz veins, some of which are ferruginous. The dolomite dips at angles varying from 40 to 60 degrees to the southward. The very great thickness of the limestone, as may

be inferred from the width of its outcrop, is probably deceptive, and due to repetition of the beds by folding.

Between Glen Florrie and Coorara micaceous seldists of sedimentary origin, and crystalline limestone belonging to the Ashburton Beds, are invaded by masses of granite and granodiorite. At Weston's, between the Yannarie and the Henry Rivers, and almost due west of the junction of the Hardey with the Henry, the Ashburton Beds are represented by quartzites, conglomerates, phyllites, and dolomitic limestone, dipping at high angles to the eastward.

Economic Products.—The sedimentary rocks of the Ashburton valley are of importance on account of the gold-bearing quartz reefs which occur parallel to the strike of the enclosing beds. The quartz reefs are found on the flanks of the arches into which the beds have been thrown and may possibly represent the legs of saddle reefs modified by denudation. The Uaroo sediments carry the lead and copper lodes, which have been more or less perfunctorily worked in that locality.

Kalgoorlie Series.

There is a considerable development of ancient sediments in the vicinity of Kalgoorlie and Boulder, where they form three main more or less parallel belts. The strata constituting this group, which has been designated the Kalgoorlie Series, consists of shales and soft sandstones together with conglomerates and boulder beds; its thickness is said to be about 10,000 feet. These sedimentary rocks have a general north-north-west trend and a high dip to the west; they cover a wide extent of country and have been found near Coolgardie on the west and Kurnalpi on the east, whilst a similar series of metamorphic sediments has been found to the southwards at Norseman on the Dundas Goldfield.

The sedimentary rocks of Kalgoorlie are traversed by banded jasperoid and haematite-quartz of that type which forms such a conspicuous feature in the geology of the sedimentary area of Uaroo in the watershed of the Ashburton River.

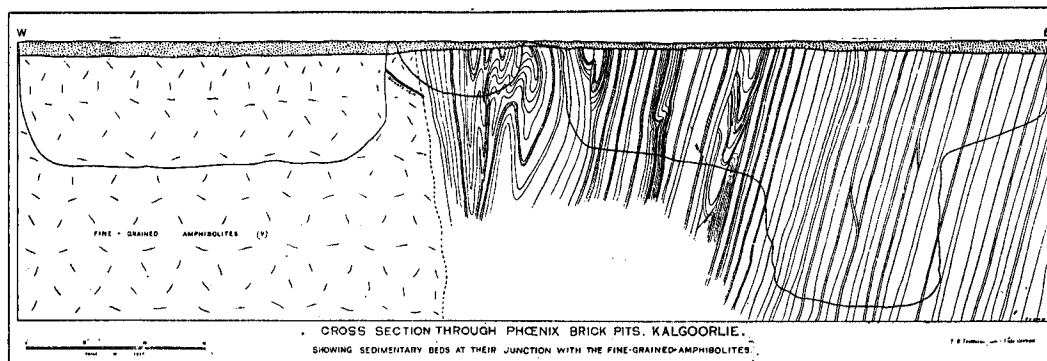


Fig. 27.—Section in the Phoenix Brick Pits, Kalgoorlie, East Coolgardie Goldfield.

The whole series of sediments appears to have been invaded by basic and acidic intrusives. (Fig. 27.) According to observations which have up to the present been made it appears possible to divide the Kalgoorlie Series into two groups differing somewhat in geological age and distinctly newer than the igneous complex which forms the axis of the Boulder auriferous belt; these have been designated the Kurrawang and Kurramia beds.

Coarse and fine grained conglomerates (Fig. 28) with occasional bands of grit and slate are of frequent occurrence in the

series. There are two main belts of conglomerate, one between Binduli and Kurrawang and the other about half way between Kalgoorlie and Kanowna. The individual beds of conglomerate have been traced for considerable distances along the strike.

The Kurrawang conglomerates are arranged in a broad synclinal fold, the axis of which trends generally west-north-west. One of the most easterly of the bands of conglomerate is about 66 feet wide on the surface; it contains pebbles of from one to 12 inches in length, and about eight times as long as wide. Another

bed of conglomerate about 15 feet thick lies stratigraphically about 200 feet above the one previously mentioned; it contains pebbles of a uniform size averaging about four inches in length.

Some of the conglomerates contain pebbles of quartz, iron-bearing jasper, quartzites, porphyry, granite and gneiss set in a matrix which is in some places siliceous and contains much mica.

The conglomerates are interbedded with fine grained micaceous and quartzitic sandstones.

The conglomerate in places appear to have undergone some dynamical alteration and many of the component pebbles show signs of having been sheared in a direction parallel to the trend of their longer axes.

The thickness of the sedimentary series is estimated at about 10,000 feet.

The Kurrawang beds are exposed on the eastern side of the Boorara Ridge and are continuous for a good many miles easterly.



Fig. 28.—Conglomerate $7\frac{1}{2}$ miles south-west of Boulder, East Coolgardie Goldfield.

The beds have a considerable extent in a general north-north-west direction and have a total length of well over 20 miles. The strata consist of soft sandstones and grits associated with which are several conglomerates, one of which is exposed in a cutting on the Kurramia Wood Line, and proves to be about 100 feet in thickness.

The sediments of the Kalgoorlie Series are associated with and rest upon a group of basic rocks and their derivatives forming that important igneous complex of which the Boulder Auriferous Belt is made up. The quartz-diabase (dolerite) is the most important of all the rocks of the complex, as it is within this and its alteration



Fig. 29.—Kurrawang Conglomerate, showing vertical cleavage, East Coolgardie Goldfield.

products that the principal gold-bearing deposits at present known occur. The quartz-diorite is, as a rule, massive, though owing to the dynamical and concomitant chemical alteration which it has undergone the rock occasionally assumes a more or less schistose phase.

Of a somewhat later origin than the quartz-diorite are dykes of a highly acidic rock, rich in soda—a quartz-keratophyre—which

field evidence indicates bears an intimate relation to some of the ore-bodies on the field.

There is a considerable development of old sedimentary rocks northwards from Kalgoorlie now represented at Kanowna by a thick series of elastic rocks, in intimate association with which are some more or less altered breccias and conglomerates. (Fig. 30.) The



Fig. 30.—Unaltered Sedimentary Beds near the Government Dam, two miles south of Kanowna, East Coolgardie Goldfield.

conglomeratic portion of the series has been subject to extreme chemical and dynamical metamorphism. The beds are practically

vertical with a general dip to the east. The conglomerates have been invaded by epidiorites and amphibolites and subsequently by a series

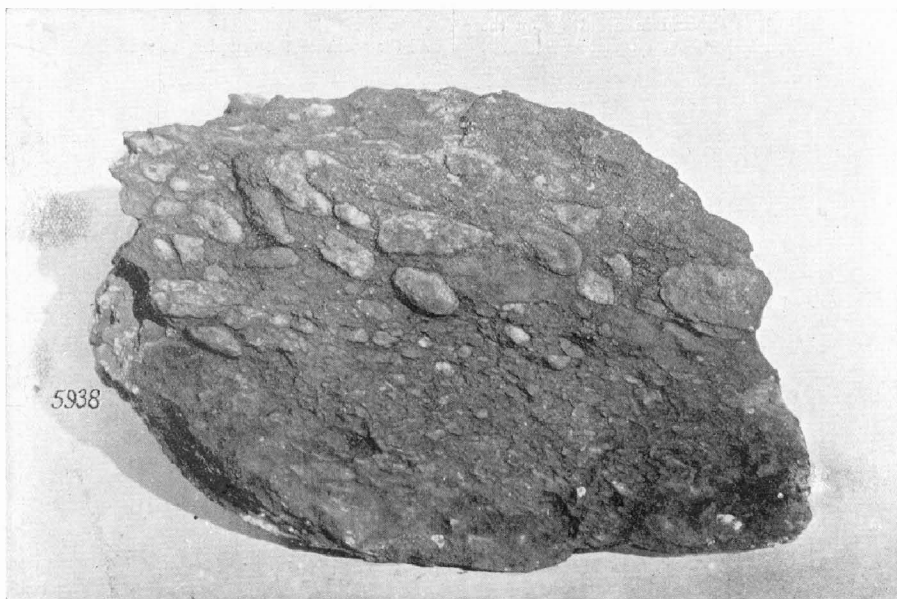


Fig. 31.—Metamorphic Conglomerate, Belmont Mine, G.M.L. 789, Norseman, Dundas Goldfield.

of quartz-porphyry dykes which seem to bear some genetic relationship to the main auriferous quartz reef which lies wholly in the conglomerate and has a longitudinal extent of over a mile. The reef has yielded over 200,000 ounces of fine gold. The conglomerates have been proved by mining operations to extend to 1,000 feet below the surface without showing any sign of thinning out.

The beds as developed at Kanowna belong to the same group as constitutes the staple formation at Kalgoorlie, which lies about twelve miles to the south-west; and that widespread series, developed in the vicinity of Lake Yindarigooda near Bulong, and Lake Lapage west of Kurnalpi and as far south as the northern end of Lake Lefroy.

The same series is in all probability continued southwards to Norseman, which in this locality consists of highly inclined more or less metamorphic sedimentary rocks estimated to reach a thickness, making due allowance for repetition by folding, of about 800 feet.

No argillaceous slates have been found in the Norseman district, but associated with the metamorphic sedimentary rocks is a coarse conglomerate. (Fig. 31.) Some of the sediments are inter-

bedded with jaspilites and allied rocks. A series of bedded amygdaloidal igneous rocks is associated with the Norseman sediments, but although most of their original characters have been almost entirely obliterated, they probably represent lava flows which were poured out at the same geological period as the associated sediments.

What probably represent the ancient sediments of Kalgoorlie and its vicinity are to be found in the neighbourhood of Yilgangi, on the North Coolgardie Goldfield, where there is a continuous belt of highly inclined sedimentary rocks about two or three miles in width and with a horizontal extent of about 25 miles in a general north-west and south-east direction. These beds are in all probability continuous with that series which occurs to the south-eastwards in the vicinity of Gilgarna, near Kurnalpi. The sediments consist of conglomerates, fine-grained grits and phyllites intersected by dykes of porphyry; no estimate, however, can be made of their thickness, but it would appear to be considerable. (Fig. 32.) To the east of Yilgangi there is a belt of ferruginous cherts and jaspilites, extending from Pingin to Lake Carey, west of Yundamindera, ar-



Fig. 32.—Metamorphic Conglomerate, Yilgangi, North Coolgardie Goldfield.

rauged in a series of steeply inclined anticlinal folds the axes of which are parallel in strike to the Yilgangi strata. Some greenstones associated with these appear to be basic lava flows and there is associated with them a graphitic rock which owes its origin to the contact metamorphism of an aluminous carbonaceous shale. Bands of serpentine and dolomite occur in parallel belts which coincide in strike with the jaspilites and their associates and may owe their origin to the alteration of dolomitic limestones associated with the other metamorphic rocks.

The series contains quartz reefs which lie parallel to the bedding planes of the sediments. The Pingin belt of jaspilites contains some haematite deposits; these ferruginous rocks are characterised by a high percentage of silica and a relatively low iron content; they could, however, be readily concentrated to high-grade iron ores.

Stirling Range Beds.

An important rock series has been designated the Stirling Range Beds from the name of the range in which they are so well developed. The beds form a grand chain of mountains which lie

not very far from the coast about 30 miles to the northward of Albany, and constitute one of the most conspicuous scenic features in the south-eastern portion of the State. The series is exposed over a length of about 50 miles, extending as a continuous belt from Warriup Hill, about 12 miles west of Cranbrook, to some distance to the east of Ellen's Peak, near the Pallinup River.

The strata constituting the series consist of ripple-marked quartzites, interbedded with fine-grained purple and blue-black slaty shales; it has been found that quartzites predominate in the lower portion of the series, and slates in the higher. According to Mr. H. Y. Lyell Brown, who investigated these beds during the years 1871-72, it appears that he recognised a difference in the lithological character and structural features between the upper and lower members of the Stirling Range Beds, and suggested that the upper "may prove by the future possible discovery of fossils to be of later date than the former."

In some parts of the Stirling Range the strata, as a result of earth stresses, have undergone more or less pronounced alteration, and are represented by phyllites and rocks closely approaching mica-schist.

In the Hamersley River the country on the south-east and to the west of Hopetoun, a series of beds consisting of quartzite, with bands of crystalline limestone, associated with oxide of manganese, is exposed in several sections. The cherty crystalline limestone as seen in the Hamersley Gorge is dolomite, the surface of which is covered in places with magnesite, occurring in the usual characteristic shapes.

Of the precise geological age of the Stirling Range Beds there is as yet no clear evidence, for no fossils have been found in them. The beds have been claimed as Silurian; this, however, is more inferred than proved, for the evidence upon which this determination was based has not been given. The strata, however, bear a very marked lithological and structural resemblance to the Table Mountain Sandstone Series, as developed in South Africa, and which has

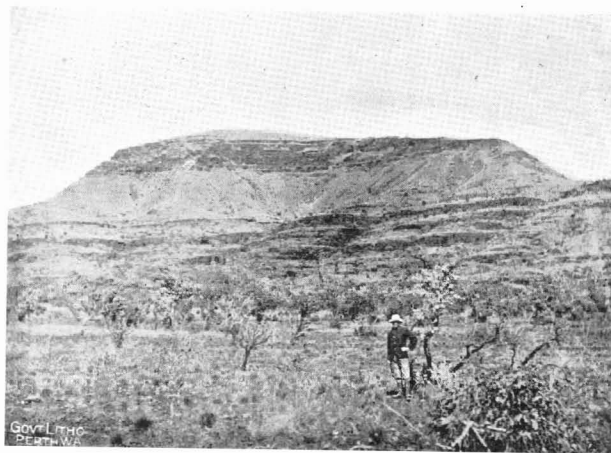


Fig. 35.—Nullagine Formation, Mount Margaret, looking east, Hamersley Range, North-West Division.

been claimed as Devonian. It may be, however, that the Stirling Range Beds are of late Pre-Cambrian Age, and represent the Upper Huronian Series, as developed in North America.

Economic Products.

Apart from the quartz veins previously referred to and some small veins of barytes near Cranbrook, no ore deposits have been found in the Stirling Range Beds. Some of the beds, however,

occurring near the western end of the Range have been quarried for slates; these, which have a reddish-purple colour, are fairly hard and finely laminated. The slates are mineralogically of good quality, though the lack of certain physical and structural properties preclude the possibility of those of the highest grade being obtained.

NULLAGINE FORMATION.

Resting with what appears to be a violent unconformity upon the older rocks previously mentioned, is a great thickness of strata, which has been designated the Nullagine Formation.

The Nullagine Formation is perhaps the most widely spread of any of the rock systems exposed in Western Australia, and in some respects one of the most important.

In its lithological characters, its behaviour and general aspect, the Nullagine Formation bears a very striking resemblance to those beds which constitute one continuous series in that tableland extending from Wyndham to Mount Hart, a prominent summit near the southern face of the King Leopold Plateau, in the Kimberley Division. The Nullagine Formation makes a very prominent feature in the landscape in those regions in which it is developed, presenting as it does a plateau-like appearance, owing to certain of the harder beds standing out in bold relief, and forming mural faces at different levels. (Fig. 35.) This formation is made up in very large part of material derived from the denudation of the earlier continental land surface.

The subdivisions recognisable in the Nullagine Formation are:—

- (a) Quartzites, sandstones, grits, and shales.
- (b) Carawine Dolomite Series.
- (c) Volcanic Series.

Lithologically the strata consist of a group of sedimentary rocks, sandstones, quartzites, conglomerates, and dolomitic limestones. Associated with these beds, igneous rocks are specially abundant, and according to their mode of origin they are readily divisible into two classes; some were formed from congealed molten matter, crystallising as dolerite, which forced its way either along the planes of bedding or across the strata in the form of intrusive sheets, sills or dykes, whilst the others were contemporaneous with the deposition of the associated sedimentaries and include outpourings of lavas, ashes, and other volcanic ejectamenta.

The violent unconformity separating the series from the underlying beds is to be seen in the neighbourhood of Nullagine (Fig. 36), and also at the Top Camp on the Ashburton River from which

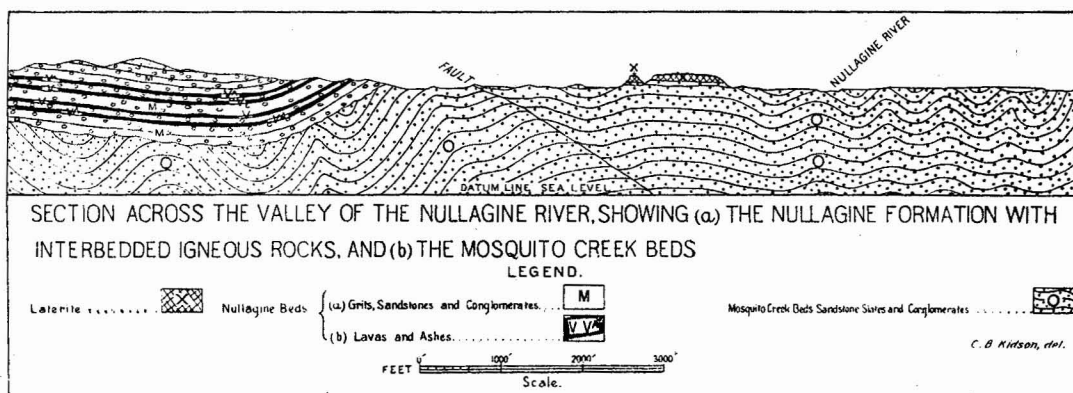
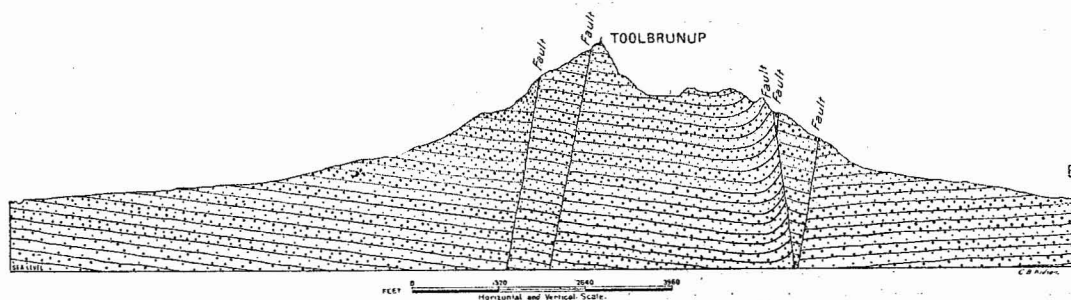


Fig. 36.—Geological Section across the Nullagine River, near Nullagine, Pilbara Goldfield.

The rocks, which have an average strike of north 30 to 40 degrees east (Fig. 33) are disposed in a series of anticlines and synclines, generally of low amplitude, though in places they are highly folded, contorted, and overthrust with the local production

of crush conglomerates and breccias. The beds at the western edge of the range, near Moondinup, have been thrown into three sharp anticlinal and synclinal folds in a distance north and south of about 10 miles by a lateral compression from the south. The strata are



PROJECTION OF GEOLOGICAL SECTION OF TRAVERSE BY H.W.B. TALBOT ACROSS TOOLBRUNUP, STIRLING RANGE.

Fig. 33.—Geological Section across the Stirling Range, South-West Division.

everywhere bounded by the ancient gneissic granite which is intersected by numerous basic dykes, and the base of the series has not yet been seen. The strata near Tenterden are, according to the researches of Prof. Woolnough, invaded by granite, and at the contact altered to somewhat jasperoid rocks and hornstones. Near the main and central summits of Toolbrunup, 3,341 feet above sea level, the sediments are stated to be traversed by a basic dyke. (Fig. 34.) The Stirling Range Beds seem to owe their position to

trough faulting. The thickness of the strata cannot, of course, be determined, but it is certainly well over 3,000 feet. The rocks are traversed by several sets of joint planes of which, however, two only are prominent; one has a strike of east 12 degrees south, with an inclination of about 48 degrees in a direction of south 12 degrees west, whilst the second set has an average strike of north 15 degrees west, and is practically vertical. The joint planes make an angle of about 34 degrees with the bedding planes.



Fig. 34.—Toolbrunup, Stirling Range, from the north-west. South-West Division.

The quasi-vitreous sandstones forming the high ground of which Yangermore, near the eastern extremity of the Range, constitutes the most prominent summit, are seamed with white quartz, some of the veins of which attain a thickness of about 12 inches: these veins may in all probability owe their origin to a differentiation of the invading granite, and represent its ultra-acid portion.

A portion of the mountainous maritime district on the south coast lying between the Gardiner and the Phillips Rivers, from West Mount Barren to East Mount Barren, is occupied by a series of highly inclined and folded metamorphic sedimentary rocks, dipping to the southward, which there seem to be reasons for believing are

of the same geological age as those of Stirling Range. The highest portions of the ranges are occupied by bluish white jointed quartzite, associated with more or less foliated, micaceous, clayey and sandy shales and other slaty rocks. These beds are invaded by sills of amphibolised quartz-dolerite, which in places out-number the sediments, and may possibly account for the greater degree of metamorphism than obtains in the Stirling Range, where basic sills are not in evidence.

The Mount Barren Range Beds are associated with quartz veins, which vary in thickness from that of a sheet of paper up to several feet and occur in and along the planes of bedding.

the formation takes its name. (Fig. 37.) The basal member of the formation is a massive layer of coarse conglomerate made up of rounded ellipsoidal, or sub-angular fragments of the underlying

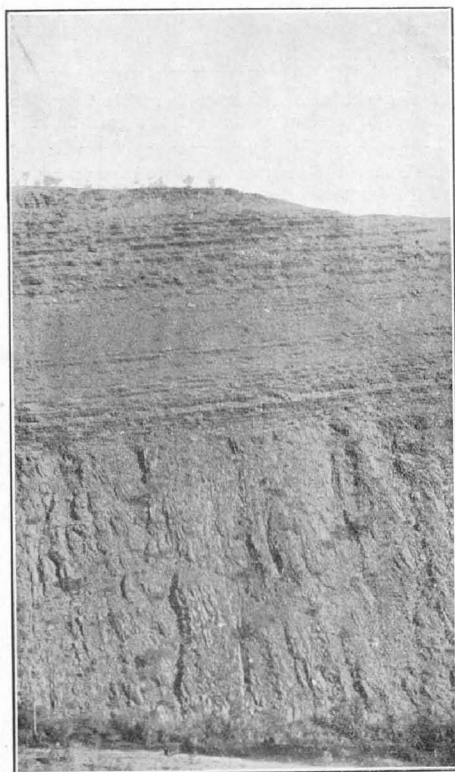


Fig. 37.—Unconformity between the Nullagine Formation and Auriferous Series, Top Camp, Ashburton River, North-West Division.

beds. The conglomerate often includes boulders which reach lengths of four to five feet, though the bands containing the large fragments are merely local. (Fig. 38.)

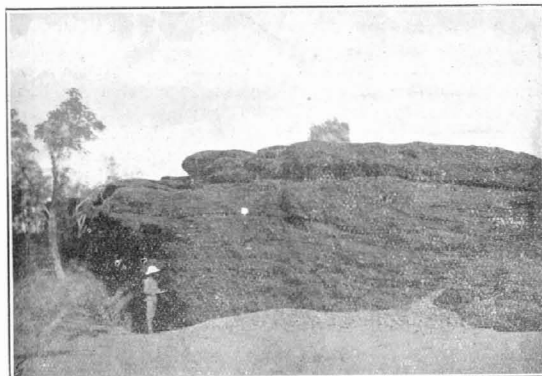


Fig. 38.—Basal Conglomerate, Nullagine Formation, Sherlock River, West Pilbara Goldfield.

The basal conglomerate at Nullagine is about 300 feet in thickness, though in some localities it is missing, whilst at Just-in-Time, eight miles from Marble Bar, where it had been mined for its gold contents, the bed varied from one inch to five feet six inches in thickness.

In other localities, as at Rooney's Patch, at the head of the Oakover River (lat. 23deg. S., long. 120deg. 35min. E. approx.) the basal beds of the Nullagine Formation are very angular, the rock being rather a breccia than a conglomerate. From the angularity of many of the pebbles in the conglomerate it may be reasonably inferred that the coastline which furnished them was not far distant, and in all probability the present boundaries of the formation approximately mark the original shore line.

What is believed to be an outlying patch of the Nullagine Formation occurs at Mount Yagahong, near Meekatharra; here the beds which are practically horizontal rest upon a granite floor. (Fig. 39.) The basal bed is a thin conglomerate, in part arkositic, in part tuffaceous made up of pebbles of granite, above which, as may be

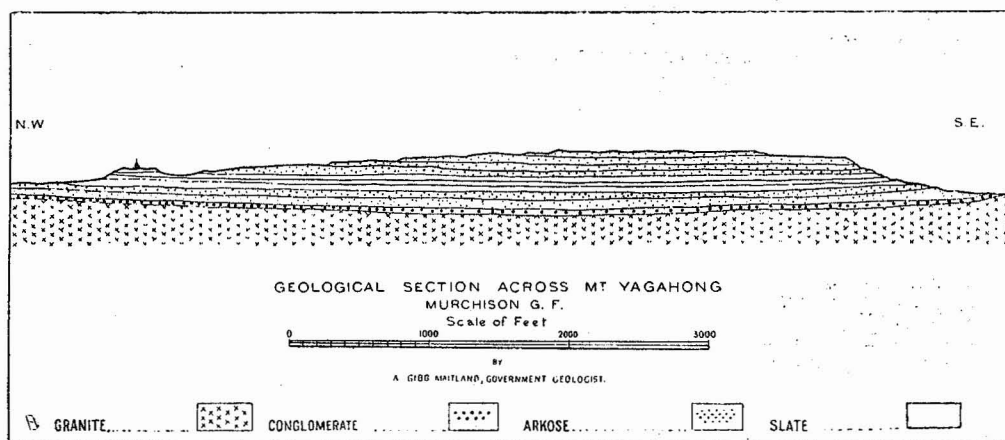


Fig. 39.—Geological Section across Mt. Yagahong, Murchison Goldfield.

seen in the cliff sections are a series of dark fine-grained sedimentary rocks. Possibly a small outlier of the tuffaceous facies occurs at Meekatharra, while Table Hill, in the same district, is probably a circum-detached outlier of the non-volcanic facies of the sediments. (Fig. 40.)

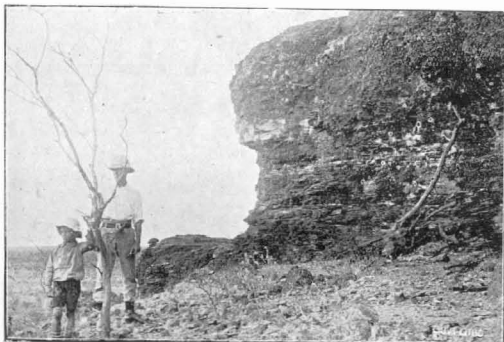


Fig. 40.—Sedimentary Rocks, Nullagine Formation, Table Hill, near Meekatharra, Murchison Goldfield.

The beds of the King Leopold Plateau, in the Kimberley Division, exhibit a remarkably uniform sandstone facies, indicating but little change in sedimentation in this portion of the State, at this period.

In the vicinity of Mount Singleton, between Lakes Moore and Monger, on the Yalgoo Goldfield, there is exposed a great group of ancient sediments and associated igneous rocks which bear a very close lithological and stratigraphical resemblance to the Nullagine Series. A special feature in this locality is the remarkable freshness of the rocks, which do not appear to have been much affected by secular decay.

Before the close of the period represented by the conglomerate and boulder beds, volcanic activity commenced in that portion of Western Australia now occupied by the Nullagine Formation. Lavas and ashes were thrown out from numerous and widely separated centres of eruption, of which the remains at present exist, submerging fairly large areas of country.

The occurrence of sandstones, quartzites, and other sediments interbedded with lava flows, etc., points to the fact that some of these volcanic eruptions took place under water, and must have been followed by intervals during which sedimentation was carried on.

These volcanic beds occur in great force in the King Leopold Plateau and form the highest parts of the country, whilst in certain localities they reach a very considerable thickness, often over 500 feet.

As a rule, these lavas have the composition of basalts or dolerites, though in certain places, such as Mount Anketell, West Pilbara, they are closely allied to augite-andesites; while at Bamboo, on one of the tributaries of the Coongan River, acidic lavas, quartz felsite, or rhyolite, occur near the base of the formation.

The Nullagine Volcanic Series lies very near the base of the formation, and the lavas from which it is made up vary in composition.

An important group of carbonate rocks occupies a distinctive and well-marked stratigraphical horizon in the Nullagine Formation and covers a very considerable area of country in the Barlee and Hamersley Ranges, as well as in the valleys of the Ashburton and Oakover Rivers. The group, as developed in these districts, normally consists of magnesian limestones which vary somewhat not only in chemical composition but in general appearance.

This lithological and stratigraphical unit has been designated the Carawine Dolomite Series, from the name of that locality on the Oakover River, where the dolomite is so well developed. (Fig. 41.)

The thickness of the series in the Carawine Pool section is, as measured, not less than 300 feet. The limestone contains bands of chert and jasper, which have not, up to the present, yielded any recognisable fossils, though in all probability their origin may be

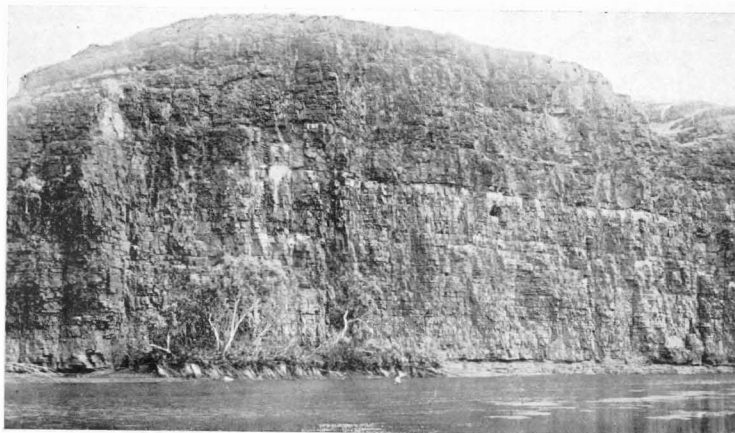


Fig. 41.—Dolomitic Limestone, Nullagine Formation, Carawine Pool, Oakover River, Pilbara Goldfield.

ascribed to the accumulation of siliceous skeletons of sponges or diatoms. In certain localities springs of water, highly charged with carbonate of lime, issue from the cliffs at the rate of many thousands of gallons per day.

Mount Russell, a hill on the boundary between the Murchison, Peak Hill, and East Murchison Goldfields, distant about 25 miles north-west from Lake Way, which rises to about a height of 250 feet above the general level of the surrounding country, is built up

of very thin beds of dolomitic limestone nowhere exceeding three or four feet in thickness, alternating with siliceous shales or slates. The beds are almost uniformly horizontal and the general succession indicates a condition such as is often found in proceeding from a shore-line to deeper areas of deposition. The limestones are clearly of marine origin, and as the siliceous beds are found to alternate with them, it may be inferred that they were also laid down in the sea, of which the southern margin is defined by the beds of Mount Yagahong, in lat. 27deg. south. (Fig. 42.)

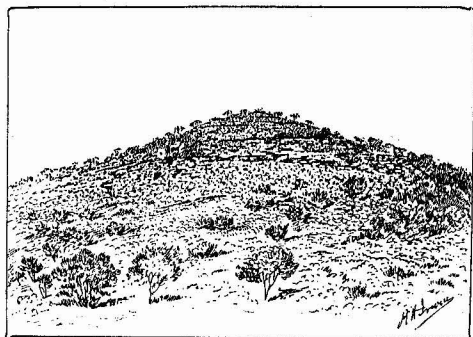


Fig. 42.—Plaggy Dolomitic Limestone and Shale, Nullagine Formation, Mount Russell, East Murchison Goldfield.

Lying conformably above the Carawine Dolomite Series is a considerable thickness of arenaceous sediments, quartzites, ferruginous sandstones, grits with subordinate sandy shales. At Mount Margaret, in the Hamersley Range, these are represented by very fine-grained ferruginous flaggy sandstones with some very siliceous bands, and also some banded ironstones, the beds being practically horizontal. The ferruginous beds contain magnetite and haematite, the percentage of iron being as much as from 28 to 37 per cent. The ferruginous quartzites, jaspers, and cherts, are sometimes cal-

careous; these banded ores bear a very remarkable resemblance to those banded ores, jaspilites, etc., which make such conspicuous features in the strata previously described, and suggest a common origin for the two.

A very important feature in the plateau region occupied by the Nullagine Formation is the abundance of dolerite intrusions which take the form either of nearly horizontal sills or steeply inclined dykes. (Fig. 43.)

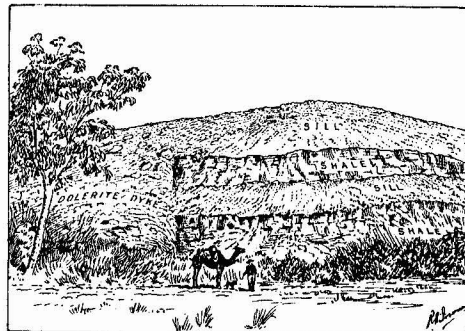


Fig. 43.—Dolerite Sills, Kunningina Hill, Tongololo Creek, five miles above Peelbeginja, Pilbara Goldfield.

These dolerites have a remarkably uniform composition, and wherever they have been examined the rocks exhibit little or no trace of recrystallisation or other signs of metamorphism. The dolerites seem to be in practically the condition in which they originally congealed, and no great terrestrial disturbance appears, when the Nullagine Formation is viewed broadly, to have affected the region since the time of their injection. The dykes extend across country in more or less straight lines for many miles, and give rise to fairly conspicuous features standing out as they do boldly on the banks of the ridges of which the Black Range, in Pilbara, is a typical example. (Fig. 44.)



Fig. 44.—Dolerite Dyke, Black Range, Hill Side Station, Pilbara Goldfield.

It appears that there must have been a huge reservoir of molten matter lying beneath the surface to the north of latitude 26, which merely awaited a suitable opportunity for rising to the surface.

The geological age of these dolerite intrusions cannot in the light of our present knowledge, be fixed with any degree of certainty; they may have some intimate connection with the disrup-

tion, towards the end of the Cretaceous Period, of the old Continent of Gondwanaland, which extended from Australia to India, South Africa, and South America.

Since their deposition the Nullagine beds have been uplifted and are now disposed in a series of broad anticlinal folds, trending in a general east and west direction, having participated in orographic movements during a period which appears to have preceded the formation of the Permian-Carboniferous strata. The beds were everywhere uplifted by mountain building processes accompanied by folding, some faulting, and occasional plication.

In post-Nullagine times erosion of the series was excessive, and possibly long continued. The strata were cut down until in some cases they were represented by mere isolated outliers; the horizontal or gently inclined beds have in other places been deeply incised and narrow trenches cut into them forming magnificent saucers, often some miles in length, down which the waters find their way seawards. (Fig. 45.)

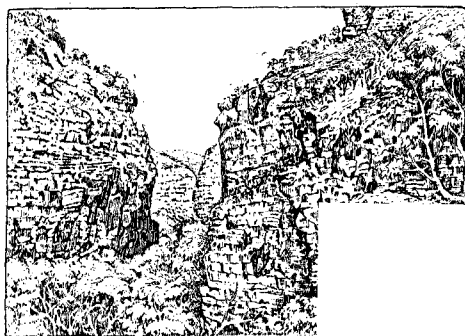


Fig. 45.—Canyon, Prince Regent River, Kimberley Division.

The volcanic rocks of the King Leopold Plateau are traversed by almost vertical dykes of epidiorite which are traceable across the country for long distances; whilst both the sedimentary and igneous rocks are intersected by numerous veins of quartz often of considerable size and horizontal extent, which may perhaps represent a highly acidic phase of pegmatite and allied dykes.

None of the beds of the Nullagine Formation, despite the fact that the dolomites are of marine origin, have as yet yielded any fossils, hence any correlation of the strata can be little else than tentative. The earliest observer, Mr. H. P. Woodward, assigned a Devonian Age to the formation, though the evidence does not seem to be conclusive. The next observer, the late Mr. Becher, writes that "of the age and origin of these interesting Nullagine beds nothing definite is known." Prof. David infers that the beds are "probably of older Palaeozoic age (? Pre-Cambrian)."

There is some reason to regard the Nullagine Formation as contemporaneous with the Townsend Range Series occurring in the Warburton Range country near the South Australian border. The Townsend Range Series is in turn pretty certainly to be correlated with that rock series yielding Ordovician fossils which occurs in the Macdonnell Ranges in the Northern Territory, forming the parting which divides the waters of the Finke River from those of the Sandover, the Hanson, etc.

In its lithological characters, its structural relationships, and its igneous phenomena, the Nullagine Formation bears a very marked resemblance to the beds in South Africa known as the Potchefstroom or Transvaal System, of the age of which all that is possible to say is that it is Pre-Devonian. The Nullagine beds also bear a very close relationship to the Bijawar or Cuddapah Series of Peninsular India, constituting a part of the Purana Group, which is assumed to be the equivalent of the Algonkian as the term was originally understood in American stratigraphical nomenclature.

Economic Products.

The Nullagine Formation is of some economic value by reason of the fact that the basal conglomerates have proved to be auriferous in two localities several miles apart, viz., Nullagine and Just-in-Time. These bear a very close resemblance to the auriferous conglomerates of the Rand (South Africa), better known as the Banket Deposits. At Rooney's Patch, near the head of Brown's Creek in the watershed of the Davis River, and at Sanday Hill on Coondoon Creek, also a tributary of the same river, alluvial gold has been obtained. Everything points to the fact that the gold was derived from the conglomerates of the Nullagine Formation, which occupy considerable areas in the vicinity. There are also a large number of quartz reefs containing more or less copper traversing the beds of the formation, but they have only been found to occur in those localities which have undergone more or less earth movement.

CAMBRIAN SYSTEM.

Strata of undoubted Cambrian Age are known to occur in the Kimberley Division and were discovered by Mr. E. T. Hardman in 1883-4. In the course of his explorations this observer gathered a suite of fossils which were critically examined by Mr. E. Etheridge, Mr. W. H. Foord, and Dr. Hy. Woodward. Amongst the *dissecta membra* were the head and spine of a trilobite belonging to the characteristic Cambrian family *Olenellus*; *O. forresti*, *Salterella hardmani*, and numerous pteropods. The strata with which these fossils were associated consist of limestones, sandstones, quartzites, clay slates, and sandy flags.

The fossils were found in the bed of the Elvire River to the south of Survey Station Z.27 (11B.27) near the base line WB-EB. Cambrian fossils were also obtained by Mr. Hardman in the bed of the Ord River, five miles below its junction with the Elvire, opposite hill J38 (11B.48) and at Mount Pantan in the Northern Territory in south latitude 17deg. 15min. (*Circe*) and not far from the Western Australian border.

In 1909 Mr. H. W. B. Talbot, during the course of a reconnaissance survey between Wiluna and Hall's Creek, visited the Ord River, and from the upper stratum of limestone in a cliff consisting of limestones and shales collected *Salterella hardmani*. (Fig. 46 N.G., 1701.) Similar strata have been found to extend from the Hardman Range to the Osmond Range on the north.

The limestones in the Ord River are for the most part hard and flaggy and generally of a greyish colour; in some places they are interbedded with red shales, marbles, and sandstones. Many of the Cambrian limestones have been highly silicified and in certain localities every gradation from pure agate and chalcedony into pure hard limestone may be noticed. Moss agates and opaline quartz occur in abundance. These limestones cover a wide area and have been estimated as being at least 600 feet thick and form fairly high tablelands.

What are believed to be the basal beds of the Cambrian Formation appear in the Albert Edward Range, which forms the western bank of the headwaters of the Elvire River. The beds are made up of indurated grits, sandstones, shales, and limestones which dip to the south-south-west at angles varying from 20 to 45 degrees. The sandstones are frequently indurated by the solution and redeposition of their silica and are virtually quartzites.

A complete section of the members of the Cambrian Formation is exposed in the gorge where the Elvire River cuts through the Albert Edward Range across the strike of the strata. The beds rest unconformably upon the older series of slates and schists, and dip to the south-west at an angle of about 45 degrees. The strata have been tilted in such a way that the principal axis of folding is north-west and south-east. The lowest beds consist of hard quartzose grits at least 1,000 feet thick, succeeded by about 1,400 feet of limestones, which in turn are overlaid by a series of hard grits, interbedded with red and green schistose slates followed by a considerable thickness of limestones and indurated shales.

What are believed on lithological and stratigraphical grounds to be Cambrian Rocks occur in the Gardiner Range about eight miles south of the 19th parallel of south latitude close to the border of the Northern Territory and Western Australia, where they consist of conglomerates, grits, sandstones, and quartzites.

According to the estimates of Mr. Hardman from measurements made near Mount Kinahan, the thickness of the Cambrian Beds must be at least 10,944 feet, though at a point 15 miles to the south they appear to have dwindled to from 5,000 to 6,000 feet.

The superficial area of the Cambrian Rocks would, in the light of such evidence as is available, appear to be extensive. The discovery of *Olenellus* and *Salterella* in the limestones of the Daly River, in the Northern Territory, is of considerable geological im-

portance, indicating as it does a somewhat wide distribution of Cambrian strata in the northern portion of Australia.

Economic Products.

The decomposition of the limestones produces an excellent soil which gives the district considerable value from the point of view of pasture.

ORDOVICIAN SYSTEM.

TOWNSEND RANGE BEDS.—A series of rocks covering about 275 square miles, which are so well developed in the Townsend Range in South lat. 26deg., near the South Australian border, has been designated the Townsend Range Series.

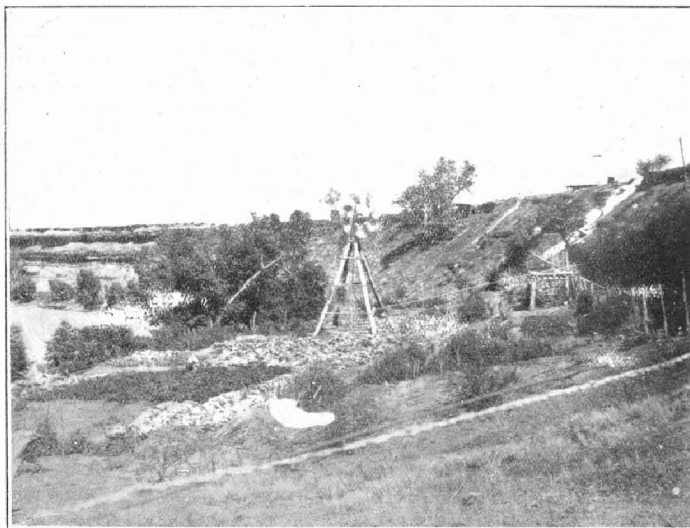


Fig. 46.—Cambrian Limestone, Ord River Station, Kimberley Division.

The beds have a general east and west strike and a prevailing dip to the south of about 20deg., they are seen resting on the older rocks at an altitude of about 1,750 feet above sea level. Lithologically, the rocks consist of conglomerates, calcareous grits and quartzites associated with interbedded vesicular basaltic and doleritic

has not yielded any fossils, hence it has been found impracticable to definitely fix its geological age, though, as mentioned in dealing with the Nullagine Series, it is probably Ordovician.

DEVONIAN SYSTEM.

The occurrence of strata of Devonian Age, formerly more or less a matter of conjecture, has as yet been definitely proved only in one district of the State, the Kimberley Division, where the formation appears to be largely developed. The strata consist of hard grits, conglomerates, indurated limestones, which are fossiliferous, and shales. The beds are seen to rest unconformably upon a much older series of schists and slates in the Elvire River. (Fig. 48.)

The Devonian Rocks are very well developed in the Napier Range, which forms a long narrow tableland trending west of north, and several miles in length. The range, which rises to an elevation of about 400 feet above the level of the surrounding country, is intersected by deep gorges from two to four miles long in which excellent sections of the strata are exposed. (Fig. 49.)

The Napier Range is made up of solid crystalline limestone, with a calcareous breccia and conglomerate at the base of the formation; the basement conglomerate contains boulders and pebbles of schist, granite, and quartz, derived directly from the crystalline schists, granites, greenstones, and allied rocks upon which they rest. Some parts of the Napier Range limestone are made up almost entirely of erinoid stems. The bore at the 67 miles peg, on the Derby-

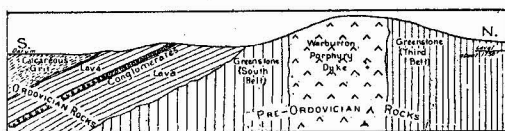


Fig. 47.—The Ordovician Strata of Mount Herbert in their relation to the older rocks, Eastern Division.

lavas and in some places conglomerates. None of these beds have been subject to dynamic metamorphism, though in places they have undergone a certain amount of carbonation, chloritisation, and epidotisation. (Fig. 46.) The volcanic rocks lie not far from the base of the series. In the Townsend Range itself the most prominent member of the series, which forms the uppermost portion, is a buff-coloured quartzite about 400 feet in thickness; the total thickness of the whole of the series cannot yet be ascertained. So far as observations have at present been carried the Townsend Range Series

Lennard road, about 25 miles south-west from the Napier Range, met with the limestone at a depth of 1,020 feet. The strata pierced by the bore-hole consisted in descending order of: shales and sandstones, 1,020 feet; crystalline and semi-crystalline limestone, 1,472 feet; beneath these at a depth of 2,492 feet, undifferentiated crys-

talline rocks were encountered and continued to the bottom of the bore-hole 3,012 feet below the ground level.

The Devonian Rocks are seen in the Barker River Gorge to pass beneath a series of sandstones and shales of what are believed to be of Carboniferous Age, and it may be that some at any rate of

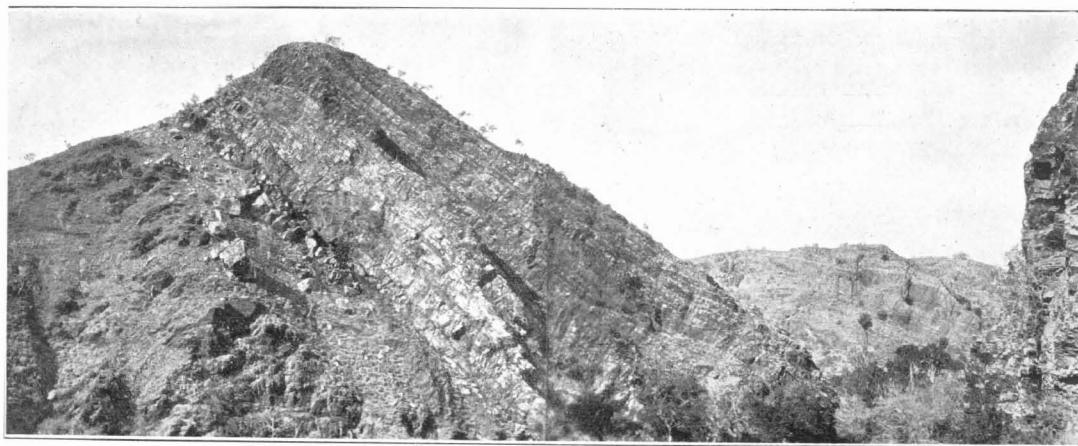


Fig. 48.—The junction of the Devonian and Metamorphic Rocks, Elvire River, Kimberley Division.

the strata overlying the limestone in the bore-hole previously mentioned are of the same age also.

Mr. H. P. Woodward visited the Napier Range in 1906 and obtained the following fossils from the limestones: a *Coccostean*

fish; a new species of *Proetus*; remains of *Loxonema*, sp.; *Euomphalus*, sp.; *Rhynchonella*, allied to *R. timorensis*; *Pachypora*, sp.; *Phillipsastrea*, sp.; and *Gonialites*, sp., which clearly indicate a Devonian age for the strata.

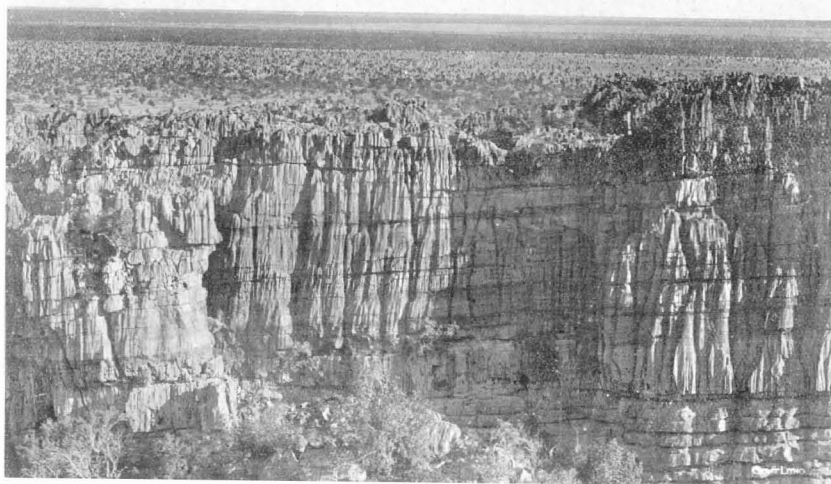


Fig. 49.—Devonian Rocks, Napier Range, Kimberley Division.

The same district was visited in 1915 by Dr. Herbert Basedow who obtained a suite of fossils from the Napier Range beds, which were submitted to Mr. R. Etheridge of the Australian Museum, and determined as follows: *Actinostroma subclathratum*, sp. nov.; *Stromatoporella kimberleyensis*, sp. nov.; and *Stachyodes dendroides*, sp. nov.

The following fossils have also been found occurring in the Devonian Rocks of the Kimberley Division:—

HYDROZOA. *Actinostroma clathratum* (Nich.); *Stromatoporella eifeliensis* (Nich.). ANTHOZOA. *Cyathophyllum depressum* (Hinde); *Cyathophyllum virgatum* (Hinde); *Phillipsastrea (smithia)* sp.; *Autopora repens* (Knorr and Walch); *Pavosites*

goldfussi (Ed. W. and Haime); *Pachypora tumida* (Hinde); *Pachypora*, sp. CRINOIDEA. Stems and arms of Crinoids. BRACHIOPODA. *Productus*, sp.; *Atrypa reticularis* (Linne); *Rhynchonella cuboides* (J. de C. Lowery); *Rhynchonella (hypothyris) pugnus* (Martin); *Rhynchonella (Uncinulus) cf. Timorensis* (Beyr); *Spirifera musakheylensis*, var. *australii* (Foord); *Spirifera cf. (vernemii)* (Murch); *Spirifera*, sp. GASTROPODA. *Puomphalus*, sp.; *Laxonema*, sp. CEPHALOPODA. *Goniatites (Brancoceras) cf. rotatorius* De Kon.; *Arthoceras*, spp. CRUSTACEA. *Proetus*, sp. nov.

Economic Products.

The limestones contain fine clear crystals of calcite, which also occurs in large veins, gypsum and carbonate of iron in addition to thin strings of copper ore. The lead deposits of Narlarla, in the Napier Range, which are associated with a little copper and zinc, occur along the bedding planes of the Devonian Limestone, and are fully described at a later page (Chapter 2, Section 2).

PERMO-CARBONIFEROUS SYSTEM.

The occurrence of rocks of Carboniferous Age in Western Australia would seem to have first been made known through Sir George (then Lieut.) Grey in the year 1841, in his journals of the two expeditions of discovery in North-Western and Western Australia during the years 1837-9.

It has in the past been usual to class certain formations occurring in Western Australia as (a) Carboniferous, and (b) Permo-Carboniferous, but it is now considered more than likely that the whole are really Permo-Carboniferous and that a mingling of the faunas has taken place.

There are three widely separated geographical regions in which fossiliferous Permo-Carboniferous Rocks are known, viz., the Kimberley, the North-West (Wooramel, Gascoyne, Lyons, Minilyn, and Lyndon Rivers), and the South-West Divisions (Irwin River and Collic River).

It will be convenient, therefore, to deal with each of the areas separately.

Kimberley.—There is in the Kimberley Division a very large development of fossiliferous Permo-Carboniferous strata which cover a very wide extent of country (lat. 16deg.—18deg. south). The formation is believed, from such evidence as is at present available, to underlie nearly the whole of the so-called Great Sandy Desert, which extends from the Ninety-Mile Beach eastward to the Northern Territory boundary.

The extensive tracts of plain country to the west and south-west of the rugged area of which the Napier, Oscar, and other ranges form the foot-hills, in a measure represent the partially eroded surface of the Permo-Carboniferous Rocks; and it is more than likely that the formation covered a much larger area than that which it now occupies. The monotony of the scenery of these plains is the

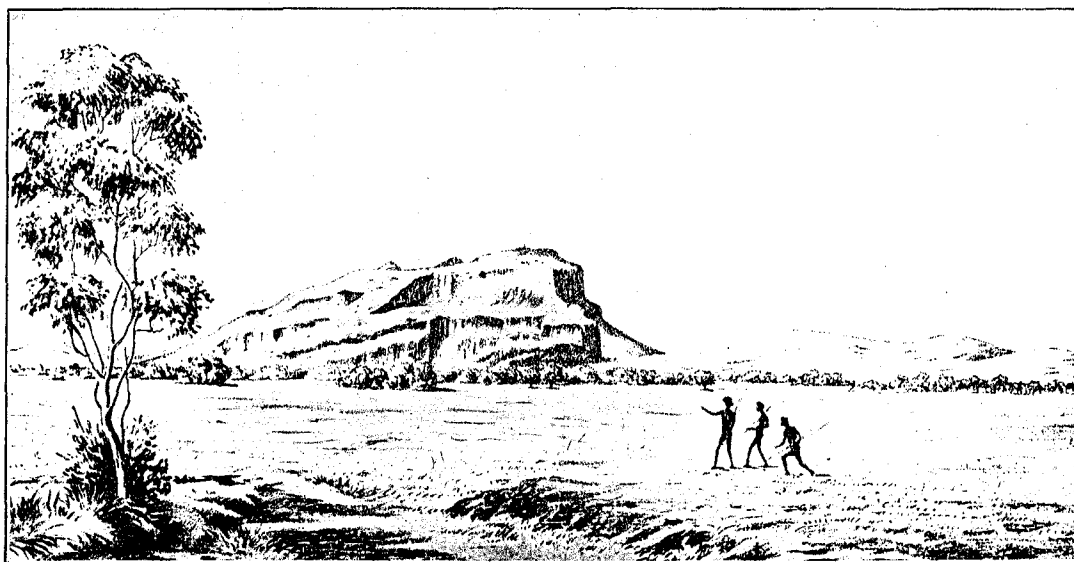


Fig. 50.—Carboniferous Sandstone, Mount Anderson, from the south-east, Kimberley Division.

direct result of a sameness of composition throughout the whole series of rocks.

The Permo-Carboniferous strata as developed in the Kimberley area are divisible into (1) a Lower Limestone or Marine Group, in which limestones predominate though associated with thick layers of shale and thin arenaceous bands, and (2) an Upper or Sandstone Group, made up largely of sandstones, usually reddish-yellow free-stones, and other sedimentary beds.

The two groups are seen to succeed each other conformably in the Haughton Range to the south of the head-waters of the Margaret River, S. lat. 19deg. and E. long. 127deg.; both groups have yielded a rich assemblage of fossils.

The Upper or Sandstone Group covers an immense area principally in the valleys of the Meda, Lennard, and Fitzroy Rivers, but is hidden, in great part, by the Pindan Sands and Gravels, as well as possibly Mesozoic Rocks. Individual beds of the group are often seen to emerge from beneath the Pindan Sands, which merely represent the decomposition products, *in situ*, of underlying sandy and gravelly rocks. The group is estimated to be considerably over 1,000 feet in thickness.

In the year 1888 Mr. Robert Etheridge, jr., examined and described a series of Permo-Carboniferous fossils from a sandy ferruginous rock, occurring on an ironstone ridge rising from beneath the Pindan Sands at a spot 25 miles south-east of Yeeda Station

on the Fitzroy River. The ridge from which the fossils came is about seven miles in length, from 30 to 40 feet above the level of the plains, and is made up of practically horizontally bedded ferruginous sandstone (ironstone). The sandy ironstone proved to be so crowded with organic remains as to render it difficult to determine individual fossils, but the following were recognised:—

BRACHIOPODA. *Productus bachythaerus*, G. B. Sowerby. PELECYPODA. *Aviculopecten tenuicollis*, Dana, sp.; *Pterinea macroptera*, Morris; *Parallelodon subarguta*, De Koninck; *Edmondia*, De Koninck. GASTROPODA. *Mourlonia humilis*, De Koninck; *Euphemus orbignii*, Portlock, var.

The Ironstone Ridge is probably co-terminous with the group of hills of which Mount Anderson (Fig. 50) and the Great Range to the south-east are part and which are also made up of red and white sandstones "with flaggy ironstone on the summit." From a yellowish ferruginous sandstone at Upper Liveringa Pool, near the eastern end of the Great Range, Mr. Hardman collected a suite of fossils of which Mr. A. H. Poord determined the following:—

PELECYPODA. *Aviculopecten tenuicollis*, Dana. CEPHALOPODA. *Goniolites micromphalus*, Morris.

Mr. Hardman in his report gives the following list of fossils from the same locality as determined by himself:—

PELECYPODA. *Curtonotus elegans*; *Pecten*, sp. (very plentiful); *Mytilus*, sp. GASTROPODA. *Natica*, sp.; *Bellerophon urei*; *Bellerophon* sp.; *Goniolites* (species undeterminable).

Further to the east of Upper Liveringa Pool is Mount Wynne made up of Carboniferous Sandstones which have a prevailing dip of about five degrees to the south. Low hills of thin flaggy grit with ironstone extend at intervals about four miles westward to Lake Josceline. This lake is a fine sheet of water half a mile in diameter, along the northern edge of which the ferruginous sandstones (ironstone) form a low east and west ridge. Mr. Hardman collected the following fossils from this locality:—

ECHINODERMATA. *Pentremites*, sp.; *Poteriocrinus crassus*; *Actinocrinus*, sp.; *Platycrinus*, sp. POLYZOA. *Ceripora*, sp. BRACHIOPODA. *Productus giganteus*; *Productus longispinus*; *Productus semireticulatus*; *Spirifera striata*; *Streptorhynchus crenistria* (frequent); *Chonetes hardensis*. GASTROPODA. *Loxonema*, small, sp. CEPHALOPODA. *Orthoceras* (undeterminable fragments).

The group of hills to the south of Mount Wynne, on the northern bank of the Fitzroy River, of which Mount Abbot, Macell Pyramid, and Mount Hardman form part, are also made up of beds of the sandstone series some of which are highly ferruginous. The beds dip northerly, though at Mount Abbot they have an inclination of 30 degrees and show considerable signs of disturbance. The beds near Mount Abbot have yielded the following fossils:—

BRACHIOPODA. *Productus giganteus*; *Productus longispinus*; *Productus semireticulatus*; *Productus*, sp.; *Strophalosia clarkei*; *Orthis resupinata*; *Orthis*, sp.; *Spirifera striata*; *Spirifera*, sp.; *Streptorhynchus crenistria* (frequent); *Chonetes hardensis*.

At Mount Marmion, of which the native name is Balmaningarra, an isolated flat-topped hill rising to a height of about 150 feet above the plains on the south bank of the junction of the Lennard and the Meda Rivers, the beds consist of hard sandstone, ironstone, and grits, at the base of which is a calcareous sandstone containing a marine fauna of which Mr. Froggart obtained a collection duly submitted to, and determined by Mr. Etheridge:—

ACTINOZOA. *Stenopora*, Lonsdale, sp.; *Evactinopora crucialis*, Huddleston, sp. BRACHIOPODA. *Spirifera*, Sowerby, sp.; *Athyris macleayana*, Eth. Fil.; *Cyrtina carbonaria*, McCoy, var. *australasica*, Eth. Fil.; *Productus subquadratus*, Morris (*P. scabriculus*). PELECYPODA. *Pachydons*, Morris, sp.

The lowermost strata dip at an angle of 20 degrees to the east, and strike generally north and south; while the uppermost present a bold escarpment to the north.

In the year 1906, during a visit to the Napier Range, Mr. H. P. Woodward made a further collection of fossils from Mount Marmion, of which Mr. R. Etheridge determined the following:—

THALLOPHYTA. *Palaeachyla gigas*, sp. nov. PORIFERA. *Calceolispongia hindei*, sp. nov. ACTINOZOA. *Pleurophyllum australe*, Hinde; *Favosites marmionensis*, sp. nov.; *Monilopora nicholsoni*, sp. nov.; *Evactinopora crucialis*, Huddleston; *Stenopora*, sp. A. B. C. BRACHIOPODA. *Cleiothyris macleayana*, Eth. Fil.; *Spirifera musakheylensis*, Davidson; *Spirifera marcoui*, Waagen; *Spirifera byroensis*, Glauert; *Spiriferella* (?) *australasica*, Eth. Fil.; *Reticularia*, sp.; *Strophalosia*, sp.; *Derbyia*, sp.; *Orthotetes crenistria*, Dav.; *Chonetes pratti*, Dav.; *Productus*, sp.

The Mount Marmion district was visited in 1915 by Dr. H. Basedow who described the section from the base upwards to be:—

- (a) grey fossiliferous shales;
- (b) soft, friable, brown and yellow, fossiliferous sandstones containing nodules of limonite;
- (c) micaceous shales with curved laminated planes;
- (d) ferruginous grits with mammillary and rosette-like concretions of manganiferous iron ore, and
- (e) slabby ferruginous sandstones.

From the lower horizon at Mount Marmion Dr. Basedow obtained a suit of fossils amongst which Mr. R. Etheridge recognised the following:—

THALLOPHYTA. *Palaeachyla gigas*, Eth. fil. PORIFERA. *Calceolispongia hindei*, Eth. fil. ACTINOZOA. *Pleurophyllum australe*, Hinde; *Stenopora*, sp. A. C.; *Favosites marmionensis*, Eth. fil.; *Monilopora nicholsoni*, Eth. fil.; *Evactinopora*, sps.

BRACHIOPODA. *Cleiothyris macleayana*, Eth. fil.; *Spirifera musakheylensis*, Dav.; *Spirifera marcoui*, Waagen; *Spirifera byroensis*, Glauert; *Spiriferella* (?) *australasica*, Eth. fil.; *Aulosteges baracodensis*, Eth. fil.; *Strophalosia*, sp.; *Strophalosia completeus*, sp. nov.; *Orthotetes crenistria*, Phillips; *Productus*, sp.; *Productus bellus*, sp. nov.; *Chonetes pratti*, Dav.; *Rhynchopora*, King; *Rhynchopora basedowi*, Eth. fil.; *Dellopecten subguineolimeatus*, McCoy.

It is by no means improbable that the lower beds at Mount Marmion mark the upper limits of the Second or Limestone Group into which the Permo-Carboniferous Beds are divisible.

The upper or sandy beds of Kimberley have also yielded the following plant-remains:—*Calamites*, sp.; *Cyperites*, sp.; *Lepidodendron*, sp.; *Lepidodendron* (knorria condition) sp.; *Lepidodendron* (*sagenaria*), sp.; *Lepidophyllum* (?) sp.; *Lepidostrobus*, sp.; *Sigillaria*, sp.; *Stigmara*, sp.; and *Lagenaria*, sp. Most of these have been obtained from the neighbourhood of Yarralla Hill, near the mouth of the Lennard River, from a thin bed of hard flaggy argillaceous sandstone. Many of these beds are crowded with impressions of reed-like plants. Plant remains also occur at the neighbourhood of Mount Wynne and to the south of the Fitzroy River in ferruginous flagstones, which contain quantities of *Calamites* and are in places a mass of interlaced leaves of this genus.

The plant-bearing beds are on a higher horizon than those which have yielded the marine fauna to which reference has already been made.

The Second or Limestone Group is made up in great part of massively bedded more or less magnesian limestone of a light grey and sometimes a pink colour, with which are interbedded thin flaggy earthy and sometimes sandy limestones in addition to dark grey sandy shales interstratified with nodular bands of limestone. The greater part of the limestones are highly fossiliferous; some of these are associated with and are apparently unconformable to those of Devonian Age, occurring in the Margaret River, near Mount Pierre. Mr. F. T. Hardman, the pioneer geological observer in Kimberley, noticed in 1883-4 and made direct reference to the association of fossils of carboniferous affinities with those characteristic of the Devonian Rocks of that area. A similar association of a Carboniferous and Devonian fauna was noticed in 1906 by Dr.

Jack; this observer in his report makes mention of the Carboniferous Limestone region at Minnie Pool, near Mount Pierre, on the Margaret River, containing limestones of an older date. At the head of Minnie Pool a well-bedded Carboniferous limestone dips west at 25 degrees; between this point and a hill a quarter of a mile to the south are vertical beds of micaceous schist upon which a limestone in beds almost entirely made up of corals rest. (Fig. 51.) These

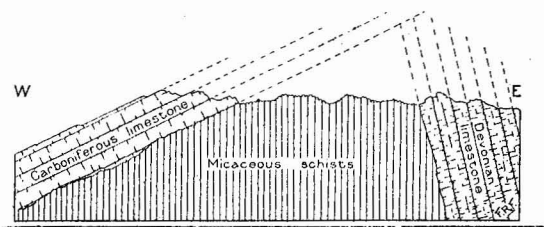


Fig. 51.—Sketch Section near Minnie Pool, Margaret River, Kimberley Division.

beds dip south-east at 80 degrees and contain the stromatoporeid corals *Actinostroma subclathratum*, sp. nov., and *Stachyodes dendroides*, sp. nov. From these observations it appears that either there are in the Mount Pierre region separable Carboniferous and Devonian strata, or that the same strata contain a Carboniferous-Devonian fauna, just as certain formations elsewhere have an intermingling of Permian and Carboniferous forms. It is possible, however, that this apparent admixture of Devonian and Carboniferous fauna may have been brought about by those earth movements which resulted in the break-up of the old Gondwanaland continent of which there is abundant evidence in different portions of the State.

The beds of the Second or Limestone Group are exposed about 17 miles north-east of Mount Campbell on the northern side of the Fitzroy River, in the Oscar Ranges, and rest unconformably upon slates and schists. The limestones are very hard, the bedding well marked, and the beds in this locality dip at angles of from 25 to 35 degrees to the south-east. This relatively high dip decreases to the south-west of the range to from 10 to 15 degrees, and the limestone passes beneath the sandstones of the Upper Group which outcrop to the south-west of the telegraph line. Some of the limestones are highly fossiliferous though owing to their hard splintery nature it was found almost impossible to obtain specimens; despite this inherent drawback, Mr. Hardman noticed the following:—*ACTINOZOA*, *Lithodendron*, and a small finely branching coral which was indeterminate; *CRINOIDEA*, *Poteroicrinus* (*Perassus*); *BRACHIOPODA*, *Terebratula*, sp., and *Athyris*; *CEPHALOPODA*, *Orthoceras*.

The Carboniferous Limestone occurs in the Geikie Range (Fig. 52), which is situated in the angle between the Fitzroy and the Margaret Rivers, and the outcrop is several miles in width. The beds, which are disposed in a series of antinodal and synclinal folds, trending generally north-west and south-east, are associated with flaggy and shaley limestones and dark shales. These beds contained the following:—*BRACHIOPODA*, *Rhynchonella pleurodon*; *Spirifera striata*, and *Productus*, sp.

What appear to be the basal beds of the Limestone Group have a fairly large development in the Hull Range; they consist of very hard light grey thinly bedded limestones dipping to the north-east at angles of from 15 to 20 degrees; they apparently rest upon the older metamorphic rocks which occupy the country northwards to the Leopold Range. The limestones are fossiliferous and contain the following:—*BRACHIOPODA*, *Chonetes*, sp.; *Eumyphalus* (?), sp.; *Streptorhynchus crenistria*; and *GASTEROPODA*, *Pleurotomaria*, sp.

Mr. Hardman records the following fossils as occurring in the limestone of Mount Krauss, J.61, near the south-eastern extremity



Fig. 52.—Carboniferous Limestone, Geikie Cañon, Fitzroy River, Kimberley Division.

of the Hull Range, not far from the northern bank of the Margaret River:—*POLYZOA*, *Stromatopora concentrica*?; *Stromatopora placenta*; *ANTHIZOA*, *Chaetetes tumidus*, Phill.; *Stenopora tasmaniensis*, Lonsdale; *Cyathophyllum*, sp.; *Lithostrotion* (*Lithodendron*) *affine*, Flem.; *Syringopora*, sp.; *Zaphrentis*, sp.; *BRYOZOA*, *Fenestella plebeia*, McCoy; *BRACHIOPODA*, *Productus giganteus*, Martin; *Spirifera striata*, Martin; *PELECYPODA*, *Pleurothynchus*, sp.; *GASTEROPODA*, *Pleurotomaria*, sp.; *Bellerophon*, sp.

The limestones of Mount Pierre, a table-topped hill on the south side of the Margaret River and almost due west of Mount Krauss, contain quantities of fossils, amongst which Mr. Hardman collected the following:—*BRACHIOPODA*, *Orthis resupinata*, Martin; *Streptorhynchus crenistria*; *Terebratula sacculus* (?); *Rhynchonella pleurodon*, Phill.; *Rhynchonella cuboides*, J. de C. Sowerby; *PELECYPODA*, *Curtonotus elegans*, Salter; *CEPHALOPODA*, *Orthoceras*, sp.; *Goniolites sphaericus*.

The Rough Range, which is situated about eight to ten miles to the south of Mount Pierre, extends over a considerable area of country and the greater part of it is made up of beds of the Limestone Group, the lateral extent of which has as yet not been defined. It is, however, known to be continuous in a south-easterly direction about 30 miles towards the Haughton Range. The beds in all probability pass beneath the sandy desert, for the limestones have not yet been met with anywhere along the Canning Stock Route, unless their place has been taken by the sandstones which occupy the country between No. 26 Well and Sturt Creek. The limestones of the Rough Range have yielded, according to Mr. Hardman's report, the following fossils:—*ANTHIZOA*, *Chaetetes tumidus* (Phill.); *Stenopora tasmaniensis*, Lonsd.; *Cyathophyllum*, sp.; *Lithostrotion* (*lithodendron*) *affine*, Flem.; *Syringopora*, sp.; *Zaphrentis*, sp.; *BRACHIOPODA*, *Rhynchonella pleurodon*, Phill.; *Rhynchonella cuboides*, J. de C. Sowerby; *Rhynchonella pugnus*, Martin; *Orthis*

resupinata, Martin; *Crania*, sp.; *Discina*, sp.; PELECYPODA, *Aviculopecten granosus*, J. de C. Sowerby.

North-West Division.—The Perno-Carboniferous Rocks of the North-West Division cover a very wide extent of country and bid fair to become of considerable economic importance. The formation has been traced with a few minor interruptions across the valleys of the Wooramel and the Murchison Rivers, and to the northwards across the Gaseoyne, Lyons, Minilya, and Lyndon Rivers, where many excellent sections of them are to be seen. The rocks of which the formation has been made up consist of sandstones, shales, limestones, and conglomerates. Near the base of the formation is a well-marked boulder bed showing undoubted evidences of a glacial origin, and forms a very valuable stratigraphical horizon, traceable for a distance of about 200 miles. It having been found convenient to have a name by which to designate this important horizon, the term "Lyons Conglomerate" has been adopted from the official designation of the Land District in which it was first discovered and where it is so well developed. The Perno-Carboniferous Rocks of the North-West, though arranged in a series of gentle folds, have a prevailing dip to the west and are highly fossiliferous.

The valley of the Gaseoyne River from its mouth to a point a few miles below its junction with Dalgely Brook is occupied by strata of Palaeozoic, Mesozoic, Tertiary, and Post-Tertiary Age. These strata have been pierced in the pioneer bore at Pelican Hill, near Carnarvon, which has been carried down to a depth of 3,011 feet. The last 1,650 feet penetrated beds of Perno-Carboniferous Age, as indicated by the fossils. The Perno-Carboniferous rocks are represented by calcareous shales and limestones, the cores of which have yielded specimens of *Spirifer*, *Aviculopecten*, *Anthrocoptera*, and *Favosites*. The bore-hole, however, did not pierce the whole thickness of the Perno-Carboniferous Formation, but the basal beds

may be seen some 130 miles higher up the Gaseoyne River. Like its representatives in Kimberley, the Perno-Carboniferous Formation of the Gaseoyne and the North-West Division is divisible into an Upper or Sandstone and a Lower or Limestone Group.

The Upper or Sandstone Group, which is seen resting conformably upon the Limestone Group, is well exposed in the Carandibby, Kennedy, and Moogooloo Ranges, making a more or less continuous bold escarpment about 200 miles in length, which rises to a height of about 350 feet above the general level of the surrounding country. The beds cross the Gaseoyne River in the vicinity of the Shipka Pass. The basal beds of the Lower or Limestone Group are exposed in the valley of the Gaseoyne River, between the Shipka and Kyber Passes, and near Trigonometrical Survey Station K33, south-west of Noondilyie Fish Pool, close to where Dalgely Brook falls into the Gaseoyne River. In this locality a complete section is obtainable of the strata which underlie the sandy beds of which the Kennedy Range is made up.

In the valley of an important tributary of the Lyons River, which in the lower portion of its course flows at the foot of the Kennedy Range escarpment, there are also many sections which show the nature of the beds below the Sandstone Group. These consist of a thickness of fossiliferous limestone which dips at gentle angles of from five to eight degrees to the westward. This limestone, which can be followed across country for a great many miles, is the equivalent of that met with in the deep bore at Pelican Hill, near Carnarvon. Many excellent exposures of the limestone and its associates are to be seen in the range through which the Wyndham and Arthur Rivers flow. A fine section of this limestone is exposed in the gorge cut by the Wyndham River, near Survey Traverse Station No. 56. The sections in the Arthur River above the range also give a fairly complete section of the basal members of the Perno-Carboniferous Formation (Fig. 53).

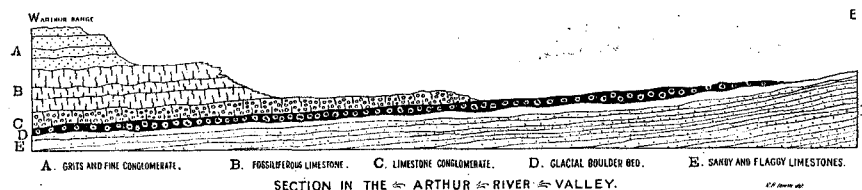


Fig. 53.—Section in the Arthur River Valley, North-West Division.

The base of the whole formation is seen in a low isolated hill about three miles to the west of Trig. Station K32, where a medium-grained quartz conglomerate rests upon the upturned edges of the older metamorphic rocks. Sections in the neighbourhood indicate that the basal conglomerate rests upon a very uneven surface.

Further to the north, in the water-shed of the Lyndon River at the cairn erected in the low table-topped hills to the south of Round Hill, the base of the formation is visible. In this locality the beds which consist of hard sandstone with a considerable development of

secondary silica, lie almost horizontally and are associated with a fine-grained ferruginous conglomerate which rests directly upon granite.

The Kennedy Range exposes, at Trig. Station K37, a complete section of the strata from base to summit; the rocks consist of sandstone, grits, and fine conglomerates containing many ferruginous concretions of all shapes and sizes. The beds are practically horizontal or with so low a dip as to be scarcely perceptible in a single section. (Fig. 54.) One of the ferruginous bands is crowded

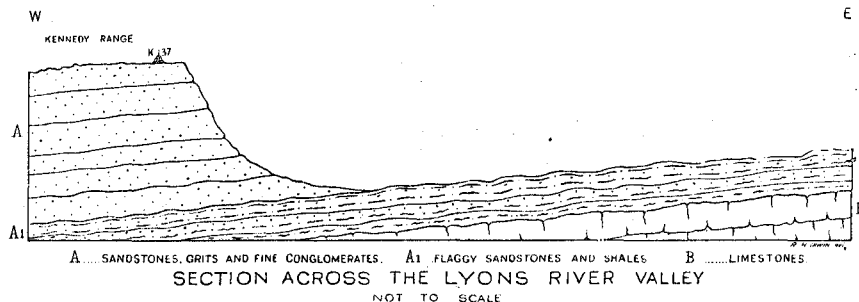


Fig. 54.—Section across the Lyons River Valley, North-West Division.

with fossils, the weathered surfaces of which are covered with an ironstone glaze, and yielded *Spirifera*, *Athyris* (?), *Productus*, and *Strophalosia*.

The beds more immediately beneath those of the Kennedy Range, as exposed in the Lyons River, consist of flaggy sandstones which are sometimes white and siliceous, sandy shales, grits, fine conglomerates, and limestone dipping north-west at from five to eight degrees.

A well-marked range of flat-topped hills, which for convenience of description has been designated the Arthur Range, forms a conspicuous feature on the eastern side of the Lyons River, and has been breached by the Wyndham and the Arthur Rivers.

In the gap formed in the range by the Arthur River to the south of Trig. Station K35 the cliffs give excellent sections of the strata. The beds consist of highly fossiliferous flaggy and somewhat sandy limestones dipping to the south-west at angles of between three and five degrees. The limestone, which forms the high bold cliffs on the northern front of the Arthur Range at K35, continues without interruption southwards to the Gascoyne River, in the neighbourhood of Minginoo Homestead. A fine section of the limestone is visible where the Arthur Range is breached by the Wyndham River near Traverse Station No. 56. The sections exposed in the valley of the Arthur above the range give a fairly complete series of the basal members of the Permo-Carboniferous Formation.

Between the Arthur Gap and Barragooda Pool there are one or two exposures of a boulder bed of undoubted glacial origin, forming a valuable stratigraphical horizon which has been traced across country for about 200 miles. The boulder bed, to which the term "Lyons Conglomerate" has been applied, from the official designation of the Land District in which it is so well developed and where it was first discovered, lies beneath the fossiliferous limestone. The thick bed of limestone above the boulder bed in the Arthur River has yielded such a series of fossils as clearly indicates its geological horizon, viz.:—*ANTIZOZA*, *Heragonella* (*Eoactinopora*) *crucialis*, Hindl.; *BRZOZA*, *Rhombopora tenuis*, Hindl.; *BRACHIO-*

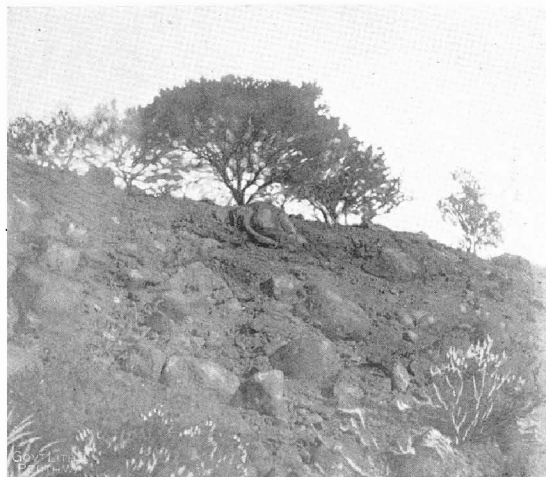


Fig. 55.—The Lyons Conglomerate in the southern bank of the Arthur River, North-West Division.

PODA, *Athyris macleayana*, Eth. fil., var.; *Productus semi-reticulatus*, Martin; *Aulosteges baracoodensis*, Eth. fil.; and *Dielasma*, sp. ind.

Figure 53 *supra* gives a section of the strata in the valley of the Arthur River and indicates the geological relationship of the Lyons Conglomerate. A section of it on the southern bank of the Arthur

River shows large striated boulders embedded in a very clayey calcareous matrix. The bed is not very thick and it is very seldom that it is actually seen *in situ*, though its presence is always indicated by the heterogeneous collection of boulders resulting from its weathering, which occupy a width in places of about a mile (Fig. 55). The boulders and fragments are of all sizes from an inch to several feet in diameter, and a very large proportion have smooth, polished, and striated faces (Fig. 56). The various rocks forming the boulders in the Lyons Conglomerate consist of quartzite,

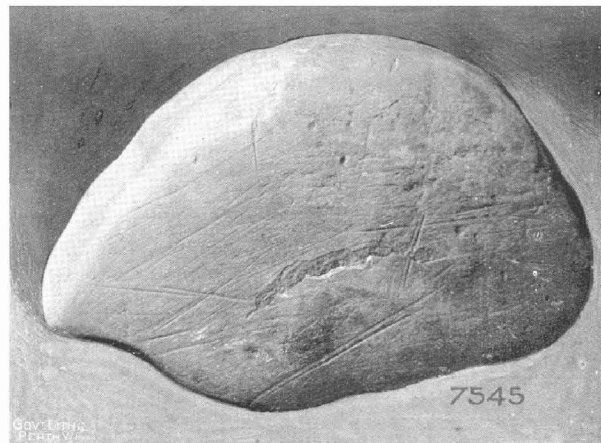


Fig. 56.—Ice-scratched Boulder, Arthur River, North-West Division.

granite, and basic and other rocks of the type which characterises the older formations immediately underlying the Permo-Carboniferous rocks to the eastward.

At a point in the Wyndham River just to the north of the range through which it has cut a channel is another section in which the boulder bed may be seen (Fig. 57). The deposit, which does not



Fig. 57.—The Boulder Bed in the Wyndham River, North-West Division.

attain any greater thickness than three feet, is crowded with glacially striated pebbles and boulders of granite, and crystalline and other rocks, embedded in a calcareous fossiliferous matrix. The flats

in the neighbourhood are covered with boulders and blocks, derived from the weathering *in situ* of the boulder bed, which in this locality has a dip of about three degrees to the south-west. The calcareous matrix in which the pebbles and boulders are embedded contains fragments of *Spirifera*, *Productus* and *Bryozoa*, in addition to *Aviculpecten tenticollis*, Dana. (Fig. 58.)

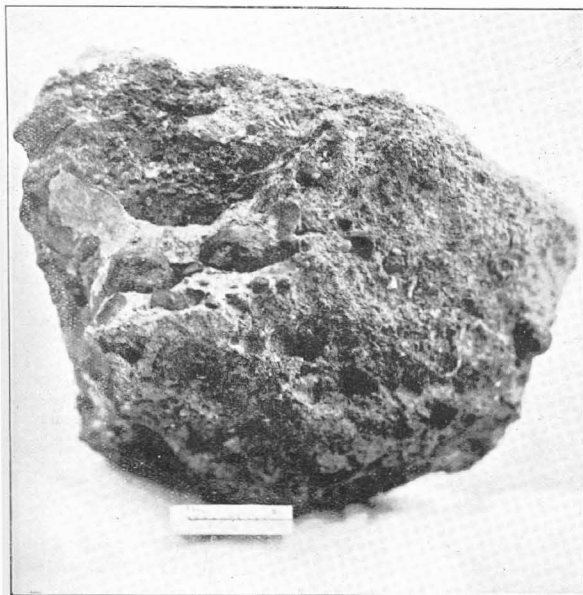


Fig. 58.—Fossiliferous Glacial Conglomerate, Wyndham River, North-West Division.

Beds of flaggy limestone are seen passing beneath the boulder conglomerate in the bed of the Wyndham River. Associated with the boulder bed are the following fossils:—*ANTHOZOA*, *Hexagonella dendroidea*, Hudleston; *Pleurophyllum australe*, Hinde; *BRACHIOPODA*, *Spirifera muskheyleensis*, Davison; *Spirifera hardmani*, Foord; *Spirifera lata*, McCoy; *Reticularia lineata*, Martin; *Cleiothyris (Althyris) macleayana*, Eth. Fil.; *Chronetes prattii*, Davidson; *Productus* (cf. *P. longistriatus*), Foord; in addition to fragments of *crinoid* stems and *bryozoa*.

The debris of the boulder bed makes its appearance in great force northwards from the Wyndham River, whilst the flaggy sand-

stones immediately underlying it are covered with large boulders of crystalline rocks. The actual base of the Permo-Carboniferous Formation—a quartz conglomerate—is seen in a low isolated hill about three miles west of Trigonometrical Survey Station K. 32, resting directly upon the upturned edges of the older metamorphic rocks which form the platform upon which the newer strata were built up. The section in the water-shed of the Wyndham River shows conclusively that the Lyons Conglomerate does not lie quite at the base of the Permo-Carboniferous Formation.

No glaciated surfaces have been noticed in this locality amongst the older rocks or amid the beds directly underlying the boulder bed. This, however, is not at all surprising, as the constant daily alternations in temperature to which the rocks in this latitude are subject, naturally tend to the very rapid destruction of brittle rocks. Under these conditions any glaciated pavement would tend to break up rapidly on exposure and could only be expected in the more immediate vicinity of the glacial conglomerate where the beds beneath have been exposed in comparatively recent geological times.

A fairly complete section of the Permo-Carboniferous Formation is exposed in the valley of the Minilya River which lies about 80 miles north of the Gascoyne River. The upper reaches of the Minilya River, which only extends some 150 miles inland, drain country made up of the ancient crystalline schists and other metamorphic associates. In no section in the Minilya water-shed has the actual base of the formation been seen. Near Trig. Survey Station K. 34 the Permo-Carboniferous rocks are seen to be faulted against the older crystalline rocks; a similar junction has also been noticed in the two main branches which form the head of the Minilya River to the northward. The beds of limestone adjacent to the fault which marks the boundary between the granite and the Permo-Carboniferous Formation are vertical and trend generally north and south. The limestones are covered conformably by gritty sandstone, which at some little distance to the west of the junction resume the normal low dip of the formation. This disruption would seem to indicate a former much more extended distribution of the beds to the eastward. Some distance to the westward of the junction of the two formations in the south branch of the river there is a very pronounced ridge of limestone overlaid by shaley beds; the whole series trends generally north and south and dips to the west. The glacial boulder bed (Lyons Conglomerate) appears in great force between Traverse Stations L. 64 and 65 on the south branch of the river, and its debris strews the surface for a considerable distance. In the neighbourhood of Williambery Pool, on the main branch of the Minilya River, there are several sections which show the general relationships of the different beds of the formation. Close to the Pool are beds of limestone, dipping west at angles of from 30 to 40 degrees, which form a very conspicuous ridge trending generally north and south. Sandstones and pebbly conglomerate are seen to rise from beneath the limestones in the hill upon which Trig. Station K. 51 has been erected (Fig. 59).

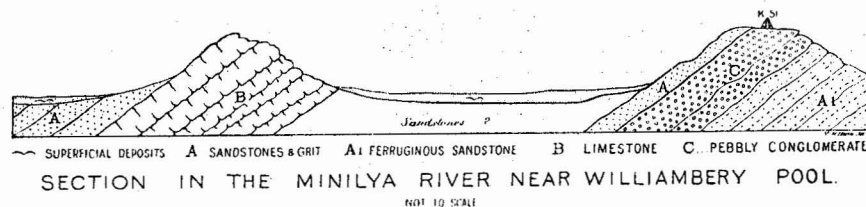


Fig. 59.—Section in the Minilya River near Williambery Pool, North-West Division.

The limestones of Williambery have yielded the following:—*ANTHOZOA*, *Amplexus pustulosus*, Hudleston; *Pleurophyllum australe*, Hinde; *BRACHIOPODA*, *Productus semi-reticulatus*, Martin; together with numerous *Crinoid* stems.

The limestones are covered by sandstones and grits. Some distance below the junction of the south branch with the main river, fossiliferous limestones dipping at low angles to the westward are exposed near Traverse Station L. 66. This limestone, which has

yielded the Brachiopod *Athyris* (*Cleiothyris*) *macleayana*, Eth. fil., may possibly represent the south-eastern extension of those occurring in the watershed at the Lyndon to the north of Moogooloo Range. Dark sandy shales overlaid by conglomerate are exposed in the bed of the Minilya River just below Middalya Station, whilst some miles further down, in the vicinity of Wandagee Station, the cliffs expose clear-cut sections of dark shaley micaceous sandstone with numerous ironstone concretions. Above these beds are some buff-coloured fossiliferous micaceous sandstones from which the following have been obtained:—PLANTÆ. *Chondrites* (?); BRACHIOPODA, *Chonetes pratti*, Dav.; *Aviculopecten tenuicollis*, Dana; and GASTROPODA, *Ptychomphalina maitlandi*, Eth. fil. Several of these shaley beds are coated with films of gypsum, sometimes as much as two inches thick. The sandy micaceous shales are exposed at intervals for about four miles below Wandagee in the form of syndinal troughs somewhat modified by faulting, where they give place to flaggy sandstones which at Cookkilya Pool dip eastward at from 10 to 15 degrees, and contain *Strophalosia*, sp. ind.

The Permo-Carboniferous Rocks of the Minilya are overlaid unconformably by a newer series of sedimentary beds made up of fine conglomerate and quasi-vitreous sandstone (Fig. 60). There

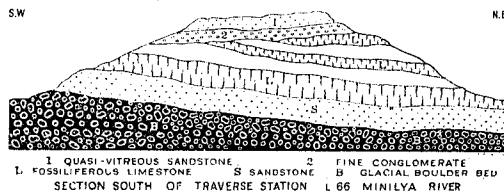


Fig. 60.—Section south of Traverse Station L. 66, Minilya River, North-West Division.

is as yet no direct evidence as to the geological age of these newer strata, which may represent the basal beds of the Mesozoic or Tertiary Systems fringing the coast-line in this portion of the State.

The basal beds of what is believed to be the Permo-Carboniferous formation is to be seen some distance to the southward of Tower House at Warria Well on the Yannerie River, which flows northwards into the Exmouth Gulf, near North-West Cape. The basement bed consists of a quasi-vitreous conglomerate lying practically horizontally on granite.

The formation is overlaid by Mesozoic Rocks, for fossiliferous green (glauconitic?) shales associated with casts of *Ammonites* were met with in a well put down to a depth of 162 feet at a point about 10 miles west of Wogoola Station, which is situated at the junction of Ema Creek with the Yannerie River. Further to the south in the valley of the Lyndon, near Traverse Station A. 31, the base of the Permo-Carboniferous formation is made up of a limestone conglomerate which rests directly upon the metamorphic and allied crystalline rocks; the conglomerate is overlaid by shales. Westward and in the bed of the river near Windalia Pool fine-grained argillaceous sandstone or sandy shale on a higher horizon than the shales previously referred to is to be seen. The glacial (Lyons) conglomerate, associated with limestone, is visible to the south of this on an important branch of the Lyndon River, near Traverse Station A. 49. This boulder bed and its debris covers a fairly wide expanse of country and its component boulders consist of a great variety of rocks many of them being covered with glacial striae. This section marks the most northerly extension of the glacial conglomerate yet proved in Western Australia. Westward from the boulder bed is a well-marked limestone ridge which contains Permo-Carboniferous fossils; this limestone occupies a considerable area of country in a north-west and south-east direction, and dips to the south-westward.

Overlying this limestone area is a series of sandstones and shales which form the range of hills upon which Moogooloo Peak stands; the uppermost beds are sandstone or quartzite varying from 20 to 70 feet in thickness. The beds dip at an angle of about 25 degrees to the westward, and are coterminal with those occurring near Middalya Station on the Minilya River.

The beds in the lower portion of the Lyndon valley have been pierced to a depth of 2,359 feet in the Government bore put down at a spot between Winning Pool and Maud's Landing, about 13 miles from the jetty. There is, however, no evidence to show whether the whole or any of the beds belong to the Permo-Carboniferous Formation, or are of Mesozoic or younger age.

The Wooramel River lies to the south of the Gascoyne, and in it at about 130 miles from the coast the lowermost beds of the Permo-Carboniferous formation are exposed. The valley of the Wooramel, however, has not been very closely examined, though from a geological point of view there is a much better series of natural rock sections exposed in its cliffs than in any other river in this portion of Western Australia.

The upper reaches of the Wooramel, between the Carandibby Range and Bilung Pool, are made up of sandy shales, clay shales, sandstones, and limestones. The limestones have yielded the following fossils:—

ANTHOZOA. *Alveolites obscurus*, de Kon.; *Hexagonella* (*Eucrinopora*) *crucialis*, Hudl.; *Hexagonella dendroidea*, Hudl.; CRINOIDEA. *Crinoid stems*; BRACHIOPODA. *Fenestella*, spp.; *Protoretepora ampla*, Lonsd.; BRACHIOPODA, *Anosteges baracandensis*, Eth. fil.; *Orthis*, cf. *Michelini*, Martin; *Productus subquadratus*, Morris; *Cleiothyris* (*Athyris*) *macleayana*, Eth. fil.; *Cleiothyris* (*Athyris*) *royssii*, Lev.; *Dielasma*, sp.; *Spirifera convoluta*, Phill.; *Spirifera lata*, McCoy; *Spirifera musakheyensis*, var. *australas*, Foord; *Spirifera trigonalis*, Martin; *Aviculopecten*, spp.; *Dellopecten* (*Aviculopecten*) *illawarrensis*, Morris; *Myalina* (?) spp.; *Pleurophorus* (*Pachydomus*) *carinatus*, Morris.

Bilung Pool, at the head of the Wooramel, is a fine sheet of water formed by the stream falling over an almost horizontal bed of sandstone; below the pool the watercourse is hemmed in by low cliffs of a shaley conglomerate which occasionally recede from the river to such an extent as to form large wide flats. Some of these are covered with large boulders derived from the disintegration of the glacial conglomerate; wherever the beds beneath the conglomerate are to be seen in the flats they are everywhere found to be composed of grey shales.

About half way between Bilung Pool and the junction of the Wooramel River the creek branches a whitish felspathic sandstone which forms cliffs about 30 feet in height; beneath this lies the conglomerate (Fig. 61) to the disintegration of which *in situ* the "boulder flats" are in all probability due.

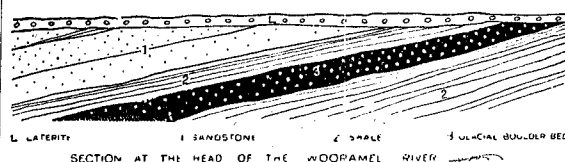


Fig. 61.—Section at the Head of the Wooramel River, North-West Division.

Some of the boulders are of very large size and made up of rocks identical with the older formations to the eastward.

The stony tableland shown on all the maps as the Byro Plains, at the foot of the Carandibby Range, and which is strewn with rounded boulders of quartz and crystalline rocks, probably owes its origin to the disintegration of the glacial boulder bed. Permo-

Carboniferous fossils have been met with in the course of putting down a bore for water on Byro Plains. The fossils include the following:—BRACHIOPODA. *Spirifera convoluta*, Phill.; *Spirifera muskheylensis*, var. *australis*, Foord; *Spirifera byroensis*, Foord; *Chonetes pratti*, Davidson; *Dellopecten subquiquelineatus*, McCoy; *Aviculopecten sprengi*, Johnston; GASTROPODA, *Conularia*, sp. nov. (?). The *Conularia* shows a much closer affinity to the Indian forms than to the two Eastern Australian Permo-Carboniferous species to which it is allied.

The sections in the headwaters of the Wooramel show that the glacial horizon lies below the *Productus* Limestone in the same stratigraphical position as that on the Gascoyne and the other rivers further to the north. The Wooramel Permo-Carboniferous beds pass beneath what are at present believed to be strata of Jurassic Age, somewhere in the vicinity of the Erabiddy Hills in the watershed of the Murchison River. Near the mouth of the Wooramel, at Hamelin Pool in Sharks Bay, there are in addition to the Coastal Limestone fossiliferous Tertiary strata and the Mesozoic beds from beneath which the Permo-Carboniferous strata emerge and occupy the surface of the upper portion of its course. The whole thickness of the Permo-Carboniferous rocks has not been penetrated in any of the bores put down in the watershed of the Wooramel.

Irwin River.

The Permo-Carboniferous formation does not make its appearance again until the Irwin River valley is reached, about 180 miles to the south of the Wooramel. The beds occupy a fairly large area in the valleys of the Lockier and the Irwin Rivers and the upper portion of Kockatea Creek, but the northern extension of the beds has not as yet been accurately defined. The strata present an uninterrupted series of shales, clay, sandstone, with occasional limestones, arranged in a very broad anticlinal fold, the axis of which trends generally north and south.

As is the case in Kimberley and the North-West, the formation is divisible into two distinct parts, viz., the lower, the Limestone, and the upper, the Sandstone Group. The Sandstone Group is well developed in the vicinity of Mingenew, where close to the railway line are a series of fossiliferous ferruginous sandstones which remind one very forcibly of the sandstones of the Kennedy Range on the Lyons River, to which reference has already been made. The beds of Mingenew have yielded casts and impressions of fossils; amongst the more important are *Productus undatus*, De France, and *Spirifera avicula*, G. B. Sby., together with numerous impressions of *Fenestella* or *Protoretopora*, and a large *Aviculopecten*. The casts are converted into limonite, which is often concretionary, and the former being frequently ill-preserved, specific determination of many of the forms is difficult; the following, however, have been recognised:—BRACHIOPODA. *Dielasma nobilis*, Eth. Fil.; *Spirifera*, sp. ind.; *Cyrtina carbonaria*, var. *australasica*, Eth. Fil.; *Cleiothyris* (*Athyris*) *macleayana*, Eth. Fil.; *Productus subquadratus*, Morris; *Chonetes*, sp. ind.; PALLASPODA. *Dellopecten subquiquelineatus*, McCoy; *Modiola*, sp. ind.; *Myalina* (?) *mingenewensis*, Eth. Fil. When viewed as a whole the aspect of the fossils from Mingenew is that of the Permo-Carboniferous as developed in Eastern Australia.

Beneath the Mingenew Beds, about the middle of the Limestone Group, a zone of clay shale and argillaceous limestones containing a glacial boulder bed in which occur very many boulders with smooth surfaces well defined grooves and cross hatchings. (Fig. 62.) The debris of this conglomerate strew the surface for a considerable distance. The boulders consist of granite, gneiss, amygdaloidal lava, sandstone and limestone identifiable with the rocks forming the plateau to the eastward of the main granite range. The boulder bed occurs more or less regularly along a general north-west and south-east direction over the whole area of the Irwin River Coalfield, and marks a very important stratigraphical horizon. It does not, however, lie exactly at the base of the Permo-Carboniferous Formation, and is in all probability the southern extension of that occurring in the valleys of the Lyndon, Lyons, Gascoyne, and Wooramel Rivers.

The most extensive outcrop of this boulder bed is near Nangatty Homestead, on the western side of the Irwin River; this same bed is also seen in Location 1902 where there is a very large quartz-



Fig. 62.—Ice-scratched Granite Boulders embedded in blue clay, Irwin River, South-West Division.

ite boulder of which the portion visible above the ground measures seven feet high, 18 feet long, and 13 feet wide, and is locally known as the "White Horse" (Fig. 63). The section (Fig. 64) showing



Fig. 63.—Glaciated Quartzite Boulder, "White Horse," Irwin River, South-West Division.

the stratigraphical position of this boulder bed clearly indicates that this horizon is interbedded with marine strata.

The following is a list of the fossils from the beds above this glacial horizon:—FORAMINIFERA. *Nubecularia lucifuga*, var. *stephensi*, Howchin; ACTINOZOA. *Pleurophyllum australe*, Hinde;

BRACHIOPODA. *Productus semi-reticulatus*, Matin; *Productus subquadratus*, Morris; *Productus tenuistriatus*, var. *foordi*, Eth. Fil.; *Productus undatus*, De France; *Reticularia lineata*, Matin; *Semimula subtilita*, Hall; *Chonetes prattii*, Dav.; *Dielasma*, sp.; POLYZOA. *Fenestella fossula*, Lonsdale; PELECYPODA. *Aviculopecten*

sprenti, Johnston; *Conocardium*, sp; *Stutchburia*, cf. S. (*pleurophorus*) *randsii*, Eth. Fil.; GASTEROPODA. *Bellerophon costatus*, J. de C. Sowerby; *Gasterioceras jacksoni*, Eth. Fil. From the fossil remains, Mr. R. Etheridge, jr., is of opinion that these beds are rather Carboniferous than the higher Permo-Carboniferous.

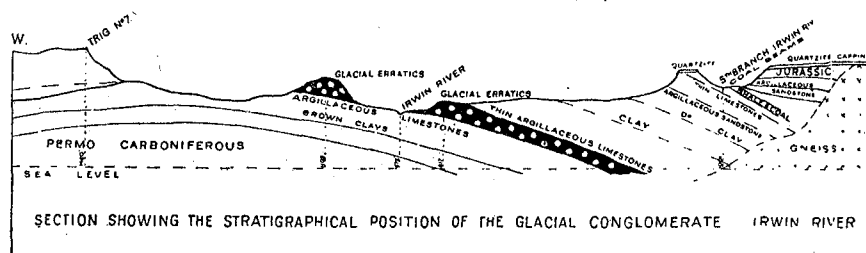


Fig. 64.—Section showing the Stratigraphical Position of the Glacial Conglomerate, Irwin River, South-West Division.

The major portion of the upper Irwin is covered by Mesozoic (and Tertiary) rocks which have been in part removed by denudation and the Permo-Carboniferous Rocks beneath exposed; the unconformity of the two formations being visible in the natural sections seen along the northern and southern branches of the river, which have eroded deep channels. The Permo-Carboniferous beds contain coal, the outcrops of seams of coal visible in several places being probably on the same horizon. Two seams of coal in the upper part of the formation, which outcrop just above the coal seam Reserve No. 900, are approximately 50 feet apart; the uppermost one being about five feet in thickness and the lower two feet. Beneath the sandstones and shales underlying the coal seams are beds containing the marine fossils of which a list has been given previously.

The coal seams are contained in a belt of shaley and sandy rocks estimated to be about 150 feet in thickness, which with few exceptions dip at gentle angles to the eastward. The precise relation to the underlying marine beds is not quite clear, though the discordance in strike between the marine beds and the coal-bearing series makes it possible that an unconformity separates the two; this, if substantiated by further field work, would coincide with the palaeontological evidence already alluded to that there are not only beds of Permo-Carboniferous, but also Carboniferous Age in the Irwin River Valley.

Collie River.

The Collie River Beds lie in a depression to the east of Bunbury, near the north-western edge of the tableland which succeeds the Coastal Plain, about 100 miles south of the Metropolis, and cover an area of about 500 square miles. The strata consist of alternations of micaceous shales, cross-bedded sandstones, and grits, which attain a thickness of over 2,000 feet and contain coal seams to a total thickness of about 137 feet. The strata owe their preservation to being faulted down into the Pre-Cambrian Rocks; the dip of the beds is fairly uniform in a general southerly direction, at angles nowhere exceeding 12 degrees.

The coals appear to be mainly of drift origin, and to have been deposited by current action in an extensive basin or river valley which corresponds very closely with that of the Collie River, under the influence of marine or estuarine conditions. Owing to the conditions of deposition the coals naturally vary in character, and in places pass insensibly through forms containing a large proportion of earthy matter into carbonaceous shales, which contain plant remains.

The question of the precise geological age of the Collie River Beds is one about which there has been considerable difference of opinion, some authorities assigning an Early Mesozoic and others

a Permo-Carboniferous Age to the series. The beds have yielded plant remains consisting of *Glossopteris* leaves and stem fragments contained in carbonaceous shales, together with tests of *Foraminifera* of depauperated variety, in some of the whitish sandstones.

The beds have yielded the following fossils:—PLANTÆ: *Glossopteris browniana*, Brong.; *Glossopteris indica*, Brong.; *Glossopteris angustifolia*, Brong.; *Glossopteris gangamopteroides*, Ferst.; FORAMINIFERA: *Endothyra*, sp.; *Valvulina plicata*, *Truncatulina haidingeri*, D'Orbigny; *Pulvulina*, cf. *exigua*, Brady. The *Valvulina* occurs in the Upper Carboniferous Limestone of England; *Bulimina* and *Truncatulina* in the Permo-Carboniferous formation of New South Wales; and the *Valvulina*, though very much dwarfed, is essentially a Carboniferous form. The other species above-mentioned point in a general way to the Palaeozoic Age of the Collie River Beds; whilst in 1893 Mr. Howchin in his "Census of the Fossil Foraminifera of Australia" pointed out that the Australian Palaeozoic foraminifera show a closer affinity with the Permian Fauna of the Northern Hemisphere than the older Palaeozoic. In view of all the evidence to be deduced from the plant remains and the marine organisms occurring in the Collie River beds, despite the nature of the coal and the physical characteristics of the basin, a Permo-Carboniferous Age for the series presents the strongest claims to acceptance.

Correlation.

The Permo-Carboniferous Rocks of Western Australia have yielded a rich assemblage of fossils, of which lists have been given above, and the fauna very closely resembles that of India.

According to recent researches into the palaeontology of the Salt Range Beds of India, it appears that *Spiriferina lata*, McCoy, of Western Australia is hardly to be distinguished from *Spiriferina infer*, Waag, occurring in the Lower Productus Limestone. *Spirifer hardmani* is merely a variety of *Spirifer marcoui* occurring at Amb; *Athyris macleaniana* is identical with *Athyris capillata*; *Aulosteges baracoodensis*, likewise, can hardly be distinguished from *Aulosteges medicottianus* and is closely allied to *A. dalhousi*, Davidson; *Productus tenuistriatus*, var. *foordi*, Eth., from the group *Productus tumidus*. *Productus bellus*, Eth. Fil., from Mount Marion, in Kimberley, is a small shell quite distinct from anything occurring in the Permo-Carboniferous strata of Eastern Australia, which has a very strong affinity with the small Indian species *Productus asperulus*, Waagen. The *Conularia* from the Byro Plains, though allied to the two species *C. levigata*, Morris, and *C. inornata*, Dana, occurring in the Permo-Carboniferous beds of Eastern Australia, shows a much closer affinity to the Indian form *C. worthi*, Waag, occurring in the basal Speckled Sandstone beneath the Productus Limestones in the Salt Range beds. The fossils from the Irwin River beds also show an intimate relationship to those of the

Salt Range, viz.:—*Productus subquadratus* belongs to the series of *Productus abichi*; *Productus undatus* is like *P. opunta*, and *Productus tenuistriatus* resembles *P. tumidus*.

More detailed palaeontological research may, of course, reveal further connecting links, but so far as the evidence at present goes it seems quite clear that the strata containing the glacial boulder beds of India are homotaxial with those of Western Australia, and appear to have been deposited in the same great marine area with more or less free communication between its different parts.

Economic Products.

The Permo-Carboniferous Formation is of economic importance by reason of the coal seams it contains, there having been produced from the beds of the Collie Coalfield 4,207,946 tons of coal, valued at £2,053,656.

The basal beds of the Permo-Carboniferous Formation in the North-West Division carry a considerable quantity of more or less potable artesian water from which 4,672,773,800 gallons per annum are being discharged from the 26 bores put down in that area.

Many clay shales, etc., occurring in the Collie River Valley are of such a nature as readily lend themselves to the manufacture of bricks, stoneware, etc.

The felspathic sandstones of Donnybrook have been utilised in several of the public buildings in the Metropolis and other places where they have been found suitable for rock-faced, dressed, and all varieties of toolled and carved work.

The limestones and their decomposition products produce an excellent soil which gives the districts where they occur considerable value from the point of view of pasture.

JURASSIC SYSTEM.

The Jurassic System of Western Australia has a fairly wide distribution, especially in the Champion Bay district near Geraldton. Strata of this age have been recorded from Sharks Bay, from the North-West, from Kimberley, and also from Cape Riche to the east of Albany. From this latter locality *Ammonites* (*Perisphinctes*) *championensis* has been recorded, but there is some doubt as to whether or not this specimen has been correctly localised or that it really did not come from Champion Bay.

The Jurassic Rocks of the State have not as yet been investigated in any detail by the Survey, hence our information in regard to them is not as comprehensive as is desirable or the importance of the system warrants.

The Jurassic beds of the State are represented by oolitic limestones, clays, sandstones (which are often ferruginous), grits, conglomerates, and lignites. Some of the ferruginous sandstones contain abundant plant remains. As a rule the strata are horizontal or but gently undulating, and have probably been deposited along the then coastline during a long period of depression.

No estimate can as yet be made of the thickness of the Jurassic strata; they have, however, been pierced by four bore-holes in the Champion Bay district, which have proved the thickness to be not less than 2,000 feet.

The most southerly area in which rocks of undoubted Jurassic age have been definitely recognised is in the basin of the Moore River, where there is a large area about 20 miles in width made up of ferruginous grits, sandstones, shales, and thin seams of lignite, which seem to owe their position to faulting in a rift valley (Fig. 65). These beds, which are horizontal or nearly so, have been

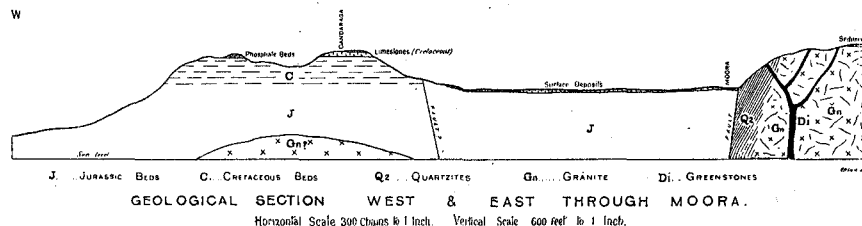


Fig. 65.—Geological section west and east through Moora, South-West Division.

pierced to a depth of 1,147 feet in the bore put down at Moora in the search for artesian water.

The cores from the Moora bore from 800 to 900 feet consisted of shales which contained impressions of a fern leaflet (*Taeniopteris*) and a portion of a cycad frond, which appears to possess the characters of the genus *Otozamites*, and others too indefinite to be

certain about. They clearly indicate a Jurassic age for the series and serve to connect them with the fossiliferous beds from Mingenew to the northward.

The Jurassic Rocks cover a large extent of country to the northward, and cross the Irwin River as a belt about 20 miles in width between Mingenew and Yardinaro. (Fig. 66.) From the Irwin

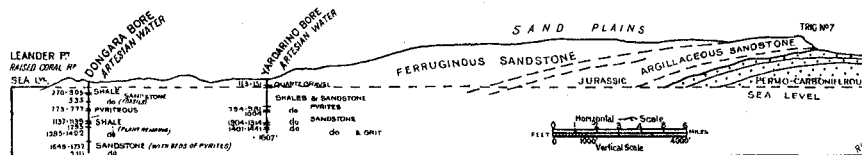


Fig. 66.—Geological section from Dougara to the Irwin River, South-West Division.

River the Jurassic Rocks extend without a break to the Greenough River, in the valley of which they cover a wide extent of country, where they appear to have been first examined and described by Mr. H. Y. Lyell Brown in the year 1873, although as far back as 1861 Mesozoic Rocks had been noticed by Mr. F. J. Gregory, who, however, on the evidence then available, believed them to be of Cretaceous Age.

The thickness of the Jurassic strata in this locality must be at least 3,000 feet, for the base of the series has not been reached in the bore at the Geraldton Racecourse, which has been put down to a depth of 1,531 feet; they also form the hills of which Wizard Peak, eight miles east from the bore, forms a prominent summit and which rises to an altitude of 1,180 feet above the level of the surrounding country.

The surface of the formation is generally covered with a variable thickness of sand, constituting the sand plains, which in the main owes its origin to the weathering *in situ* of the underlying sandstones.

Extensive denudation has gone on since the date of the formation of the Jurassic System in this portion of the State, and has removed a very large portion of the rocks, leaving the relics in the form of undulating plateaux and flat-topped mesas from beneath which the older rocks outcrop at the base of the hills. As a general rule these strata are practically horizontal, although in some cases a slightly undulating dip may be detected. Some of the sandstones are ripple-marked, and others contain patches of lignite.

The cliffs forming the eastern escarpment of the Jurassic Rocks in the vicinity of Mingenew consist of white sandstones in one band of which, three and a half miles due north of the town at an altitude of 880 feet, are a fine series of plant remains. These sandstones have yielded fronds of the Cyad *Otozamites feistmanteli*, Zigno, which serve to indicate that the beds are on the same horizon as those of Talgai on the Condamine River in Queensland.

The broad high-level plateau which extends from the head of the Irwin River terminates in a bold escarpment of sandstone about eight miles from the coast. Mount Hill, which forms an outlier of this plateau, consists of a succession of sandstones and grits associated with which is a band of fossiliferous limestones outcropping at about 100 feet below the summit (Fig. 67).

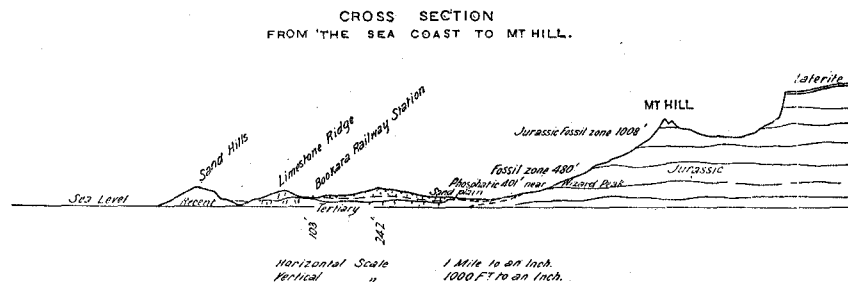


Fig. 67.—Geological section from The Sea Coast to Mount Hill, South-West Division.

The Mount Hill Beds have yielded the following fossils:—

PLANTÆ: *Otozamites feistmanteli* (Zigno).

BRACHIOPODA: *Rhynchonella variabilis* (Schl.).

PELECYPODA: *Alectryonia* (*Ostrea*) *marshii* (Sowerby); *Cucullaea*, spp.; *Lima*, spp.; *Modiola maitlandi* (Eth. Fil.); *Ostrea tholiformis* (Eth. Fil.); *Ostrea*, cf. *tholiformis* (Eth. Fil.); *Ostrea*, spp.; *Pecten cinctus* (Sowerby); *Pecten greenoughiensis* (Moore); *Radula* (*Lima*) *duplicata* (Sowerby); *Radula* (*Lima*), sp.; *Trigonia moorei* (Lycett); *Myacites saundersii* (Moore); *Astarte clifforti* (Moore); *Astarte*, spp.

CEPHALOPODA: *Ammonites* (*Dorsetensia*) *clarkei* (Crick); *Ammonites* (*Perisphinctes*) *championensis* (Crick); *Ammonites* (*Stephanoceras*) *australis* (Crick); *Ammonites* (*Normannites*) *australis* (Crick) *vide* Chapman; *Belemnites canaliculatus* (Schl.); *Belemnites canhami* and *Belemnites*, sp.

The limestone hills which extend over an area about 10 miles to the north and north-west of Mount Hill and which form the walls of the Greenough River Valley are highly fossiliferous, the fossils being identical with those occurring at Mount Hill itself.

Other fossiliferous localities in the Greenough River watershed are Sand Spring near Mount Kenneth, Woolanooka, Tibbraddon, Moonyoonooka, and Snake Farm. The Jurassic beds have been pierced by several bore-holes on the Geraldton-Cue Railway Line, the deepest being 1,418 feet, the lower portion of the bore being, it is believed, in Carboniferous Rocks. Another bore, Musk's, put down on the bank of the Greenough River, reached a depth of 1,008 feet, and the Jurassic coal-bearing horizon was passed through to a depth of 675 feet.

The Jurassic beds extend northwards to the Murchison River as more or less isolated tablelands, of which the Moresby flat-topped Range forms one of the most conspicuous.

The junction between these beds and the ancient crystalline schists and gneisses on the Murchison River is marked by a fault dipping to the west. At this point the river enters a narrow gorge which is flanked by vertical walls of sandstone and grit.

Northwards from the Murchison River the Jurassic Rocks occupy, so far as is at present known, a fairly wide extent of country, and seem to be fairly well developed in the neighbourhood of Shark Bay, where the beds are highly fossiliferous.

The following is a list of fossils from Shark Bay:—

BRACHIOPODA: *Rhynchonella variabilis* (Schl.).

PELECYPODA: *Alectryonia* (*Ostrea*) *marshii* (Sowerby); *Cucullaea oblonga* (Sowerby); *Cucullaea*, spp.; *Lima proboscidea* (Sowerby); *Lima punctata* (Sowerby); *Pecten calvus* (Goldfuss); *Pecten cinctus* (Sowerby); *Trigonia moorei* (Lycett); *Gresslyia donaciformis* (Phill.); *Myacites liassianus* (Queest); *Myacites*, spp.; *Pholadomya orbium* (Agassiz); *Cypriocardia*, sp.; *Isocardia*, sp.; *Teredo* (*Pholas*) *australis* (Moore).

GASTROPODA: *Phasianella*, sp.; *Turbo australis* (Moore); *Cerithium greenoughiensis* (Moore); *Rissoia australis* (Moore); *Actæon depressus* (Moore).

CEPHALOPODA: *Nautilus perornatus* (Crick); *Nautilus*, spp.; *Ammonites walcottii* (Sowerby); *Ammonites* (*Dorsetensia*) *clarkei* (Crick); *Ammonites* (*Dumortieria*) *moorei* (Lycett); *Ammonites* (*Macrocephalites*) *macrocephalus* (Schlot); *Ammonites* (*Normannites*), sp.; *Ammonites*, spp.; *Belemnites canaliculatus* (Schl.).

Mesozoic Rocks were met with in the pioneer bore at Pelican Hill, near Carnarvon at the mouth of the Gascoyne River, between the depths of 1,238 and 1,361 feet. In the year 1861 Mr. F. T. Gregory gives a generalised section across a part of Western Australia in lat. 25deg. 15min. south, in which Mesozoic Rocks (? Cretaceous) are shown as constituting the Kennedy Range on the Lyons River, to which reference has already been made (p. 33). According to this observer's description the range is made up of "a white chalk-like (but non-calcareous) rock and ferruginous sandstones in which occur *Ammonites*, *Trigonia*, and *Pecten*." The bulk, however, of the Kennedy Range beds are made up of fossiliferous rocks of Permo-Carboniferous Age; it is possible that Mesozoic rocks may occur on the eastern slopes, but this observation has not been confirmed.

Mr. H. P. Woodward, writing in the year 1894,* states: "Mesozoic Rocks also occur on the Gascoyne River forming the Kennedy Range and stretch away up north to Cape North-West, but do not seem to extend any farther North."

What are at present believed to be Jurassic Rocks are known on the Yarnarie River, near North-West Cape, south latitude 22 degrees. Fossiliferous Mesozoic Rocks, consisting of green (glauconitic?) shales associated with casts of *Ammonites*, have been met with in a well put down to a depth of 162 feet at a point about 10 miles west of Wogoola Station, which is situated at the junction of Enn Creek with the Yarnarie River.

Nothing is known as to the precise thickness of these beds in this locality, for there are few if any natural sections. Lignites are met with at Point Cloates, but whether these occur in the Mesozoic or Tertiary Rocks is not as yet definitely known.

The Kimberley Division is known to contain fossiliferous rocks of Jurassic Age, such having been found in one of the bores put down in the search for artesian water at Broome.

In Broome Bore No. 2 there occurred at a depth of 1,300 feet what the bore journal describes as "very hard fossilised country" interbedded with shales. This band, which is 5 feet thick, contains small *Belemmites*, too fragmental, however, for specific determination. The total depth of the bore, however, is 1,775 feet, but the base of the formation has not been reached. It is, however, by no means improbable that some of the beds which underlie the country to the east of the Ninety-Mile Bench are of Jurassic and Cretaceous age, and they may extend for some distance into the interior; owing, however, to the absence of any geological examination of this portion of the State, definite particulars upon this point are lacking.

Dr. H. Basedow obtained in 1916 several impressions of Mesozoic ferns in a yellowish argillaceous sandstone or grit met with in a well at Madinganarra, near Point Torment, to the north of Derby in King Sound in the Kimberley Division. The specimens have been determined by the late Mr. R. Etheridge, jun., as *Otozamites*, together with stem impressions of either *Phyllothea*, *Equisetites*, or *Schizoneura*. The evidence of these plant remains would seem to indicate a Jurassic age for the beds and a horizon equivalent to that of the beds in the vicinity of Mingnew.

Jurassic fossils have been recorded by Neumayer in 1885 from the Glenelg River in Kimberley, between South latitudes 15 and 16 degrees. It is stated that the species show a close affinity with those collected by Mr. Gregory in the southern districts, to which allusion has already been made. The lower reaches of the Glenelg River has not been visited by any member of the Geological staff, though the upper portion of the area which has been examined is made up of rocks bearing a strong resemblance to the beds of the Nullagine Formation.

Suess makes mention of the fact that:—

True Jurassic fossils are not obtained until we reach the Glenelg River, between Lat. 15°-16° South; this was the locality assigned to the specimens sent to Europe, which Neumayer described. They show a striking correspondence with the species collected by Gregory and his successors in the more southerly parts of the west coast.

Neumayer's paper shows quite clearly that he was in some doubt about the locality from which the specimens came, as may be seen from the context:—

Some Jurassic Fossils from Western Australia.

The Geological Institute of the University of this city (Vienna) contains a small suite of Jurassic forms, which according to the accompanying labels were obtained from the Glenelg River in Western Australia. I was unable to find a river of this name on the maps at my disposal, but on the other hand a Glenelg District, which is situated in the interior north-east of Perth approximately between lat. 30° and 31° South, and perhaps that portion which rises in this locality—or the Moore River of the maps—is intended by the above name. The locality has apparently not been mentioned in the literature up to the

present; the chief source of the specimens described by Moore (Ref. to Moore, Q. J. G. S., xxvi.) is situated on the Greenough River and is at least three degrees farther north; as the two localities show a close relationship and possess a number of species in common, the Jurassic Formation may also extend over the intervening country.

The rock in which the specimens occur is a friable somewhat sandy limestone, yellowish-brown, with large purple coloured patches (?).

The species submitted, most kindly supplied by Prof. Suess, are as follows:—

Stephanoceras blagdeni, Sow.
Stephanoceras leichardti (sic) n.f.
Perisphinctes (?)
Trigonia moorei, Lye.
Myacites indet.

Lima (Clenostreum) proboscidea, Sow.

Of these forms *Trigonia moorei* has been described by Lycett from Western Australia. *Lima proboscidea* which Moore mentions from Australia (ref. to Moore, loc. cit.) cannot be distinguished from the European forms; the same applies to the fragments (Plate 1, Fig. 3) determined by him as *Stephanoceras blagdeni*. The specimen determined as *Perisphinctes* (?) is very badly preserved and might also be a worn immature specimen of a form of the *Stephanoceras humphreianum* group. Finally there is a new form of which the following is a description. (Description of *Stephanoceras leichardti*, n.sp. Plate 1, Fig. 4, pp. 140-141.)*

The lower reaches of the Glenelg River were visited by Sir Geo. (then Lieut.) Grey, and described in his Journals published in the year 1841, and no mention whatever was made by him of any fossils or beds of the lithological character of those of the Jurassic System.

In the year 1901, during six months spent in geological exploration in the King Leopold Plateau in company with my colleague Mr. C. G. Gibson, the upper portion of the Glenelg River Valley was visited and found to be made up of quartzites, sandstones, conglomerates, and shales, associated with interbedded and intrusive igneous rocks disposed in a series of broad antiformal folds of an age at the very least of early Palaeozoic, though probably very much older. These beds are identical with those described by Grey, making it quite clear that they are continuous to the coast in this portion of the State.

From all the evidence available it appears that the Glenelg District from which the fossils described by Neumayer came is that between Lat. 30°-31° South in the Glenelg Land Division or County (now non-existent) on the Moore River shown on Petermann's map of Australia which bears the date 1876. This view is rendered more probable from the fact that this Division or County, which includes Mount Yule, Wongan Hills, and Cowwong Lake, is adjacent to the area from which the fossils described by Moore in 1869 were obtained and where our later collections have been made.

The Jurassic Rocks occurring in Western Australia contain a rich marine fauna, differing in this respect from beds of the same age in Eastern and Central Australia; the system also contains plant-bearing members and some inferior coal seams.

The list of fossils occurring in the system includes the following:—

CRINOIDEA. *Pentacrinus*, sp.
 TUBICOLA. *Serpula conformis*, Goldf.
 BRYOZOA. *Bryozoa*, sp.
 BRACHIOPODA. *Rhynchonella variabilis*, Sehl.; *Rhynchonella solitaria*, Moore.

PELLECYPODA. *Arca*, sp.; *Alectryonia (Ostrea) marshi*, Sow.; *Avicula aequalis*, Moore; *Avicula (MacCoyella) barklyi*, Moore; *Avicula echinata*, Sow.; *Avicula inaequalis*, Sow.; *Avicula munsteri*, Bronn.; *Clenostreum (Lima) pecteniformis*, Sehl.; *Cucullaea inflata*, Moore; *Cucullaea oblonga*, Sow.; *Cucullaea semistriata*; *Cucullaea tibraddonensis*, Eth. fils; *Gryphaea*, sp.; *Himmites*, sp.; *Lima gordonii*, Moore; *Lima proboscidea*, Sow.; *Lima punctata*,

* Mining Handbook to the Colony of Western Australia, H. P. Woodward, Government Geologist, 2nd Edition, 1895, p. 31.

* M. Neumayer. Die geographische Verbreitung der Jura Formation. Deutscher K. Akad. Wiss., Wien. 1885. I. p. 117.

Sow.; *Modiolola maitlandi*, Eth. filis; *Mytilus*, cf. *gygerensis*, d'Orb; *Nucula*, sp.; *Ostrea tholiformis*, Eth. filis; *Pecten calvus*, Goldf.; *Pecten cinctus*, Sow.; *Pecten*, cf. *frontalis*, Dum.; *Pecten greenoughiensis*, Moore; *Pecten valoniensis*, Defr.; *Pecten*, cf. *vesicularis*; *Perna*, sp.; *Plicatula*, sp.; *Radula (Lima) duplicata*, Sow.; *Trigonia moorei*, Lycett; *Trigonia costata*, Clarke; *Gresslya donaciformis*, Phill.; *Myacites liassianus*, Gueust; *Myacites sanfordii*, Moore; *Pholadomya ovulum*, Agassz; *Pleuromya*, sp.; *Astarte apicalis*, Moore; *Astarte Cliftoni*, Moore; *Cardium*, sp.; *Cypricardia*, sp.; *Isocardia*, sp.; *Lucina* sp.; *Opis* sp.; *Panopaea (Glycimeris) rugosa*, Moore; *Tancredia plana* (?), Moore; *Teredo (Pholas) Australis*, Moore; *Unicardium*, sp.; *Dentalium*, sp.; *Amberleya*, sp.; *Phasianella*, sp.; *Pleurotomaria greenoughiensis*, Eth. filis; *Trochus*; *Turbo australis*, Moore; *Turbo laevigatus*, Sow.; *Cerithium greenoughiensis*, Moore; *Chemnitzia*, sp.; *Nerinea*, sp.; *Rissoina australis*, Moore; *Actaeon depressus*, Moore.

CERIALOPODA. *Nautilus perornatus*, Crick; *Nautilus sinuatus*, Sow.; *Ammonites lautus*; *Ammonites walcottii*, Sow.; *Ammonites (Dorsetensis) clarkei*, Crick; *Ammonites (Dumortieria) moorei*, Lycett; *Ammonites (Macrocephalites) macrocephalus* Schl.; *Ammonites (Perisphinctes) championensis*, Crick; *Ammonites (Perisphinctes) robinosus*, Crick; *Ammonites (Sphaeroceras) semiornatus*, Crick; *Ammonites (Sphaeroceras) woodwardi*, Crick; *Ammonites (Stephanoceras) australis*, Crick; *Ammonites (Stephanoceras) blagdeni*, Sow.; *Ammonites (Stephanoceras) leichardti*, Neumayer; *Ammonites (Normanites) australis*, Crick; *Belemnites canaliculatus*, Schl.; *Belemnites canhami*, Tate.

ARTHOPODA. *Cythere corrossa*, var. *grossepunctata*, Chap.; *Cythere drupacea*, var. *fortior*, Chap.; *Cythere lobatula*, Chap.; *Cytheropterion australiense*, Chap.; *Lotocconcha elongata*, Chap.; *Lotocconcha jurassica*, Chap.; *Paradotorhyncha foveolata*, Chap.

PLANTÆ. Cf. *Araucaria peregrina*, Kurr; *Cunninghamites australis*, Ten-Woods; cf. *Pagiophyllum*, sp.; *Otozamites feistmanteli*, Zigno; cf. *Williamsonia pecten*, Phill. Fern fronds and seed-vessels.

Economic Products.

Some of the sandstones in the Irwin River district are in places so ferruginous and so thick as to almost constitute ores of iron, whilst others of the ironstone bands frequently afford a rough building material. A quarry at Mount Hill has been opened on a good flaggy sandstone which has been used for building purposes at Allanooka.

Some of the ferruginous sandstones are more or less phosphatic and contain varying proportions of the green hydrous iron phosphate, Dufrenite. The phosphatic rocks seem to have a wide distribution between the Greenough River and Moonyoonooka.

Beds of lignite occur in the Jurassic Rocks, but so far none of any economic importance have been met with.

The Jurassic sandstones are of considerable importance when viewed from the hydro-geological standpoint; their permeability lends itself to the absorption and transmission of large quantities of water, whilst the thickness gives the sandy members of the series a large storage capacity.

CRETACEOUS SYSTEM.

The presence of Cretaceous Strata in Western Australia appears to have been known for pretty well half a century, having been first recorded by Mr. F. T. Gregory in the year 1860, as occurring near Gingin and Yatheroo. This same observer stated that the Cretaceous Strata were the most extensively developed of the sedimentary formations of Western Australia and that the beds were closely connected with the Jurassic rocks of the Greenough River: the boundary between the two systems, however, has not as yet been satisfactorily traced.

The Cretaceous System as developed in Western Australia forms the landward border of the Coastal Plain and covers a very large surface area, and in very many places its outcrop is concealed beneath a cover of later deposits.

Fossiliferous Cretaceous rocks have been proved in three districts; viz. Eucla, the Metropolitan Area, and Gingin, and there are good grounds for believing that beds of this age occur in the valleys of the Gascoyne, Lyndon, and the Minilya Rivers.

The Cretaceous Strata are represented only by the lower members of the upper series, for no deposits of earlier age than the Albanian-cum-Cenomanian have as yet been definitely recognised in Western Australia.

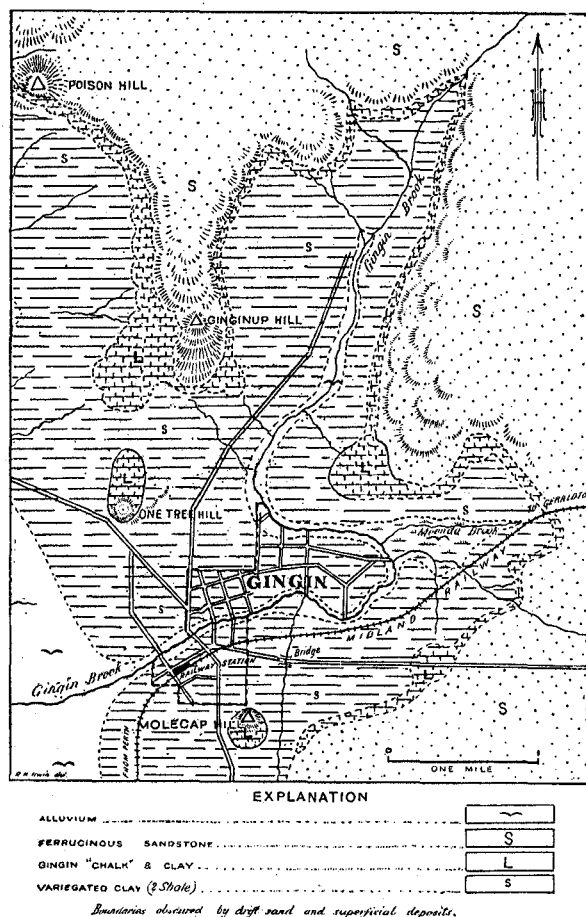


Fig. 68.—Geological Map of Gingin, South-West Division.

The Cretaceous Rocks of Gingin were first described by Mr. F. T. Gregory in the year 1861, who wrote: "The Cretaceous (?) are the most extensively developed of the sedimentary rocks of Western Australia and are almost exclusively siliceous in character, containing only a few beds of chalk of very inferior character. . . They abound, however, more in fossils than the Carboniferous do, and with the exception of the recent coast limestones, more so than any other formation. Flints are rarely found in them. . . The bed of the Greenough River is the best spot for procuring speci-

mens, although a few are found in the chalk hills near Gingin (Echinoderm spines, etc.).⁷⁸

In 1873 Mr. H. Y. L. Brown wrote: "The white chalky limestone of Gingin, Yatheroo, and Dandarragan, which outcrops from beneath the sandy soil of these localities in patches, most likely is also of Mesozoic Age." In the year 1903 Mr. E. S. Simpson collected a suite of fossils from the Chalk Pit on One Tree Hill at Gingin which were duly submitted to and examined by Mr. R. Etheridge of the Australian Museum, who pointed out their condition was not such as lent itself to accurate determination, but that "The fossils from One Tree Hill Chalk Pit are certainly not older than Tertiary . . ." In the same year Mr. Howchin of the Adelaide University described a series of thirty-eight Foraminifera from the Gingin beds; of these eight have been described as entirely confined to rocks of Cretaceous age elsewhere; four are peculiar to the Upper Tertiaries; whilst twenty-seven are known to have existed in Cretaceous times. The evidence of the foraminifera makes it quite clear that the beds are of Cretaceous age (Fig. 68).

The Cretaceous rocks of Gingin consist of a white chalky limestone without flints, which passes downwards into a greenish glauconitic marl, and below that into a clay shale. The Gingin "Chalk," which serves as a most important stratigraphical datum plane, appears to have a very wide extension to the northward. The lithological character of these beds is not uniformly constant, varying from clayey deposits on the east to more calcareous deposits on the west. The presence of these beds is invariably indicated by the rich black clayey soil which results from the weathering and disintegration of the component rocks; the black soil itself is frequently studded with fragments of limestone.

There are not very many natural sections of the Cretaceous rocks to be seen anywhere near Gingin. The chalky limestone forms the escarpment of a tableland which presents a more or less bold front to the west overlooking the Coastal Plain. (Fig. 69.) The face of the escarpment in the vicinity of Gingin is dissected by a series of valleys rising rapidly to a sandy plateau, which extends for variable distances inland. Heavy springs of water break out in some of these valleys at the base of the sandstone, which forms the upper portion of the plateau.

The escarpment extends from a point to the east of Molecap Hill and crosses the railway line at the head of Moonda Brook; it also forms the two walls of the valley of Gingin Brook, and is continuous as far as Poison Hill about four miles to the north of Gingin, from which point it presents a bold, unbroken face of sandstone with a laterite covering as far as the Moore River near Regan's Ford. The chalky limestone which forms the escarpment is overlaid by a variable thickness of ferruginous sandstone.

There are several outliers of the chalky limestone at One Tree Hill and Molecap Hill.

The section at One Tree Hill consists in descending order of: soil and subsoil, 12 inches; white limestone without fossils, 18 inches; chalk-like limestone becoming richer in alumina and silica as it is followed downwards; and at 15 feet below the summit greenish glauconitic clay of an unknown thickness.

Another somewhat similar section is seen at Molecap Hill, which lies about half a mile south-east of the railway station at Gingin, where a considerable amount of mining work has been carried out on the limestone and associated deposits.

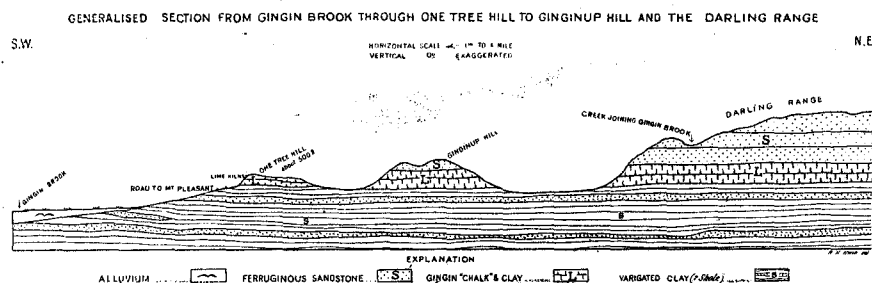


Fig. 69.—Generalised section from Gingin Brook, through One Tree Hill to Ginginup Hill and the Darling Range, South-West Division.

Several analyses of the chalky limestone have been made but they do not indicate any abnormal variation in the chemical composition, as may be seen by the table below:—

Analyses of Gingin Chalk.

Geological Survey No. ...	4,670.	11k.	11j.	11i.	11h.	11g.
Silica, SiO ₂ ...	15.09	15.25	25.56	27.04	20.28	16.72
Alumina, Al ₂ O ₃ ...	3.15	2.30	3.54	4.36	3.40	1.95
Iron peroxide, Fe ₂ O ₃ ...	1.29	2.33	3.32	3.29	2.53	1.90
Magnesia, MgO ...	1.32	.09	1.14	1.16	1.27	1.52
Lime, CaO ...	42.41	42.95	35.21	34.09	39.50	42.46
Water combined, H ₂ O ...	1.99	...	...	...	...	...
Water hygroscopic, H ₂ O + Carbonic Acid, CO ₂ ...	1.18	...	...	...	...	...
Sulphuric Anhydride, SO ₂ ...	33.02	34.76	28.84	28.46	32.34	35.03
	.13	...	...	...	...	...
	99.58	98.58	97.61	99.00	99.32	99.58

* On the Geology of a Part of Western Australia. Quart. Journ. Geol. Soc. (London), 1861, Vol. xvi., p. 475-483.

These limestones contained foraminifera, fragments of mollusca, quartz, flint, glauconite, and kaolin.

The uppermost portion of Molecap Hill is surmounted by a horizontal bed of white chalky limestone about 12 feet in thickness, beneath which is a somewhat irregular layer about 6 to 12 feet thick made up of phosphatic nodules. These phosphatic nodules, or coprolites, which represent the fossil faeces of fish and reptiles, show some variation in quantity, colour, and chemical composition, in different places, and are being used for commercial purposes. The coprolites are somewhat hard nodules containing about 50 per cent, of tricalcium phosphate, the balance being made up of calcium carbonate, quartz, etc. Partial analyses of three clean-picked coprolites, made in the Geological Survey Laboratory, gave the following in parts per hundred:—

	A.	B.	C.
Phosphoric Oxide, P ₂ O ₅ ...	21.84	23.54	24.03
Calcium Phosphate, Ca ₃ P ₂ O ₈ ...	51.69	55.72	56.88

Beneath the coprolite bed is a limestone about an inch or two in thickness, which rests conformably upon a green sand, over 30 feet thick, and made up of an admixture of olive-green glauconite and quartz. Analyses made in the Geological Survey Laboratory of this green sand, which consisted of an admixture of quartz and glauconite together with a little calcite, gave the following in parts per hundred:—

Geol. Survey Lab. No. ...	492R.	493R.
Potash ...	2.94	1.99
Soda ...	.14	.23
Lime ...	1.54	15.07
Magnesia ...	1.69	1.49
Phosphoric Oxide ...	.32	.20
Silica and Insoluble ...	66.70	48.56

Nothing is known of the thickness of the green sand (glauconite sand) in the neighbourhood of Gingin for neither boring nor deep shaft sinking has as yet been carried out.

The Gingin Cretaceous Rocks have been met with beneath the Swan Coastal Plain in the Metropolitan Area, as is proved not only by their lithological character but also their fossil contents.

In the bores put down in the Royal Agricultural Show Ground, the Hospital for the Insane at Claremont, and Rottnest Island, a considerable thickness of solid crystalline limestone, associated with glauconitic shales and sandstones, has been encountered.

A sample of the rock from the Royal Agricultural Society's bore, 1,500 feet deep, was found to contain the following minerals in the order of frequency: bitternspar (dolomite), calcite (partly present as marine organisms), quartz, pyrites, glauconite, microcline, kaolin, apatite, and rutile: the rock when analysed in the Geological Survey Laboratory showed its composition to be:—

	per cent.
SiO ₂ ...	20.86
TiO ₂ ...	.07
Al ₂ O ₃ ...	1.30
MnO ...	.39
Na ₂ O ...	1.02
K ₂ O ...	.54
CaO ...	23.00
MgO ...	10.55
FeO ...	6.00
FeS ₂ ...	3.44
P ₂ O ₅ ...	.15
CO ₂ ...	30.56
Organic matter ...	.28
H ₂ O + ...	.90
H ₂ O — ...	1.27
Total ...	100.33

The bore at the Hospital for the Insane at Claremont was carried down to a depth of 2,070 feet below the surface, and between the depths of 709 and 1,848 feet passed through hard grey shaley limestone with bands of crystalline limestone which was often glauconitic, and contained fragments of shells with pyrites on the faces. The bore ended in micaceous sandstone. The cores from the depths mentioned contained comminuted bryozoan remains; the lithological nature of the matrix is closely allied to that of the Gingin beds. The rocks in this bore in all probability represent the southern extension of those at Gingin, for they dip in such a direction as should carry them beneath Perth.

Glauconitic limestone has also been met with in the Claremont Show Grounds Bore No. 1, 1,506 feet, between the depths of 950 and 1,022 feet.

The artesian bore at the Perth Causeway, which was carried down to a depth of 986 feet, contained a series of fossils which seemed to indicate that the beds passed through were either of Tertiary or Mesozoic, and possibly Cretaceous Age. At 520 feet the calcareous mudstone contained comminuted shells, bryozoa, and a tooth of *Carcharodon* (?). At 590 feet the core, a grey calcareous

mudstone, was found to be full of minute shell fragments and contained *Amusium*, sp.; or a young *Chlamys*, as well as bryozoa. At 810 feet were comminuted shell fragments, bryozoa, and what bears some resemblance to *Dentalium*.

The South Perth bore yielded between the depths of 1,505 and 1,831 feet: *Tellina*, sp.; *Fusus* or *Triton*, sp., and the great chela of a burrowing crab, *Callinassa*, which ranges from the Jurassic to the present day, or *Thalassina*. These organic remains may indicate a Tertiary or Cretaceous Age for the beds; the matrix, however, appears to be lithologically identical with that of beds of the Cretaceous System.

In the deep bore at Rottnest Island—which has been carried down to a depth of 2,544 feet in search of artesian water—down to a depth of about 209 feet the beds consist of a chalk-like calcareous deposit probably representing upraised Post-Tertiary marine beds, whilst below that depth the strata are Tertiary or late Mesozoic; the matrix having a strong lithological resemblance to the rocks of Lower Cretaceous age elsewhere. At a depth of between 1,595 and 2,021 feet are portions of one of the higher Crustacea, together with a very elegant and small example of a *Pinna*.

There appears to be a considerable development of Cretaceous Rocks in the vicinity of Dandarraga, about 22 miles to the west of Moora.

Farther to the north of Gingin at Yatheroo and Dandarraga there are low hills of a chalk-like limestone at the base of which lies a phosphatised bone bed, associated with sandstones and shales, which are occasionally glauconitic. These beds, which contain *Ostrea* and *Inoceramus*, are of the same geological age as the Gingin strata with which they are coterminal.

The rock exposed near the Yatheroo Homestead contains fragments of *Inoceramus*, rounded black nodules, together with green specks and stains. The black nodules after detailed examination were found to be made up of an admixture of quartz sand, calcite, glauconite, and phosphorite; the green stains and specks being due to the presence of glauconite. The limestone from a hill near "Kajumba" contained some fine specimens of *Ostrea*, as well as a considerable proportion of glauconite.

In the neighbourhood of Dandarraga, some distance to the west of the site of the bore at Moora, 2,230 feet deep, put down in fossiliferous and Jurassic and older rocks, there are a series of sandstones and shales, which are occasionally glauconitic, overlaid in certain places with whitish chalk-like limestones. These beds are nearly horizontal, or with a slight inclination to the eastward in places.

There is a bed of white limestone about 40 feet thick covered by sandstone exposed at Euan Hill, Location 1137 (Fig. 7, Bulletin 26); immediately beneath the limestone is a bone bed ("phosphate rock") resting upon sandstones of which the thickness has not yet been proved owing to the absence of natural sections and bore-holes.

Beds of this type have been followed across country for a distance of about 22 miles, and the phosphate rock exposed at intervals.

Greenish ferruginous sandstones which are associated with these beds have in places been found to contain 14.96 per cent of phosphoric acid; the green colouration being due to the presence, in considerable quantity, of the iron phosphate Dufrenite.

There appear to be three distinct classes of rock amid the phosphatic deposits: (a) weathered rocks containing from 0.54 to 2.10 per cent. of phosphoric acid, (b) ferruginous sandstones containing phosphates mainly of iron with from 7.25 to 15.13 per cent. of phosphoric acid—the iron phosphates occurring as Dufrenite and Vivianite, and (c) fossil bone and coprolite rock containing from 15.32 to 39.34 per cent. of phosphoric acid.

The bone bed contains teeth, tusks, and other indeterminate saurian remains, as well as whitish nodules (coprolites) which have in all probability been formed by the aggregation of phosphate of lime.

The bone bed has been proved to be about three feet thick, whilst the underlying ferruginous sandstone, which has been more or less phosphatised by the interaction of ironstone and phosphoric acid derived from the bone beds, is at least 7 feet in thickness.

The bone bed is the most important of the deposits not only from its economic value but also from the fact that it marks a valuable and distinct stratigraphical horizon traceable across country for a considerable distance.

A somewhat similar phosphatic horizon occurs in the lower reaches of the valley of the Greenough River, about one and a half miles south of Wizard Peak, at an elevation of about 465 feet above sea-level. The ferruginous sandstones contain green-coloured patches which owe their origin to the presence of Dufrenite. Similar beds have been met with in a well on Location 1878, about three miles to the north-west. These occurrences indicate a considerable linear extension of this phosphate horizon in the Coastal Plain.

The Cretaceous and Jurassic beds of the Coastal Plain, according to such evidence as is at present available, owe their present position to faults which trend generally north and south.

There are some reasons for believing that in the watershed of the Minilya River beds of Cretaceous Age occur in the Mesozoic Rocks of the North-West Division.

In what is known as Bunbury's No. 4 Bore on the Minilya a band consisting of about equal parts of granular quartz and green glauconite together with a little iron phosphate (Dufrenite?) and pyrites was met with.

A similar horizon of dark-green phosphatic rock was encountered in Bensley's Bore on the Minilya at a depth of about 1,000 feet below the surface. The rock, on being examined in the Geological Survey Laboratory, was found to contain the following minerals in approximate order of frequency: ankerite (including traces of barium carbonate), dufrenite (or a closely related mineral), quartz, glauconite, pyrites, barite, some organic matter, and probably apatite. This rock when analysed in the Survey Laboratory was found to have the following composition:—

	per cent.
SiO ₂	22.94
Al ₂ O ₃	1.53
Fe ₂ O ₃	2.57
FeO	23.20
MnO ... ..	.22
MgO	2.68
CaO	12.39
Na ₂ O ... ..	.30
K ₂ O	1.20
H ₂ O ... ..	.98
H ₂ O +	1.12
TiO ₂ ... ..	.05
CO ₂	18.68
P ₂ O ₅	6.68
Po	1.34
S ₂	1.55
SO ₂ ... ..	.68
BaO	1.32
Organic Matter ... ..	.40
	99.83

Nullabor Plains, which extends from the South Australian border to the neighbourhood of Israelite Bay, have proved the occurrence of fossiliferous strata of Cretaceous Age lying beneath the Eucla Limestone, which belongs to the Tertiary System.

A more or less complete section of the beds has been obtained along the 127th parallel of East longitude from the Great Australian Bight to the Trans-Australian Railway and some considerable distance to the northwards, as far as Axe Hill, *circa* South lat. 26deg. 20deg. 30min.

The southernmost bore was put down about 30 chains south of the Hampton Range Escarpment, 350 feet high, at an altitude of 110 feet above sea level, and was carried down to a depth of 2,041 feet below the surface. According to the evidence afforded by an

examination of the bore cores, about 903 feet of limestone with flints—the Eucla Limestone—was met with, and beneath it was a considerable thickness of calcareous glauconitic mudstones and shales with occasional bands of hard compact dolomitic limestone. This bore was not carried deep enough to reach the floor of crystalline rocks upon which these sediments rest. No fossils were met with in the cores from this bore hole, but in the bore to the north, at the 337 miles 61 chains peg on the Trans-Australian Railway Line, at 567 feet above sea level definite proof of the Cretaceous Age of the beds below the Eucla Limestone was obtained. This bore hole, which was carried down to a depth of 1,372 feet, reached the floor of granitic rocks, and passed through:—Eucla Limestone (Tertiary) 603 feet; shales, sometimes glauconitic, 667 feet; fine and coarse sandstone and conglomerate, 74 feet; and granite 28 feet—the total depth of the bore being 1,372 feet.

The rocks beneath the Eucla Limestone have yielded two of the most characteristic fossils found in the Lower Cretaceous Strata of South Australia and Queensland, viz.:—*Aucella hughendensis*, Eth. Fil.; *MacCoyella corbiensis*, Moore, together with portions of a bivalve shell, possibly *Fissulunula*, which is found in the Lower Cretaceous beds of Eastern Australia. There is, therefore, little doubt of the strata pierced in this bore being the equivalent of the Rolling Downs Beds of Queensland.

In addition to the evidence afforded by this bore, Mr. W. Howchin records the fact that a bore put down at Giljirabbi, on the Nullabor Plains, about 20 miles west of the head of the Great Australian Bight and four miles from the sea cliffs, penetrated beds the lithological characters of which identified them with the Cretaceous shales of Central Australia. A few foraminifera, too badly preserved for determination, were detected in the cores.

The basal beds of the series exposed in the bores along the 127th parallel have been met with to the northward of the Railway Line near South lat. 22 degrees at altitudes varying from 1,570 to 1,900 feet above sea level. The beds at Axe Hill consist of slightly compacted current bedded sandstones and claystones associated with occasional conglomerates and boulder beds. No fossils have as yet been found in these beds, but from such stratigraphical evidence as is at present available the geological age of these beds seems to be Late Mesozoic or at least Early Tertiary. The geological section (Fig. 70) along the 127th parallel shows the mutual relationship of these beds, which cover some thousands of square miles and extend northwards from the coast for about 400 miles.

The fauna of the Cretaceous System of Western Australia is fairly rich, no less than 175 species of invertebrata having been described from it. The beds, however, have yielded an especially large number of foraminifera, 134 species having been already met with at Gingin.

In the year 1897 Mr. W. R. Philbey, of Gingin, collected a suite of fossils from that locality; these comprised Echinoderms, Worms, Brachiopods, Lamellibranchs, and Cephalopods, together with a shark's tooth. This collection, together with others made by the staff of the Geological Survey, comprising about 200 specimens, was examined and described in 1913 by Mr. Etheridge. The number of species identifiable was comparatively small, still the collection contained much that is important and new. Amongst the fossils described by Mr. Etheridge were (a) a new species of *Pero-nella*, *P. (?) globosa*, which is only the second sponge yet found in the Cretaceous Rocks of Australia; (b) a new species of *Cyclon-milia*, *C. ginginensis*, sp. nov., the third representative of the corals found in the Australian Cretaceous beds; (c) spines of several varieties of Echinoids allied to *Cidaris*: three Annelids, i.e., *Serpula fluctuata*, and indeterminate species of *Spirorbis* (*Spiralaea gregaria*); (e) a new species of *Pollicipes*, *P. ginginensis*, believed to be the first definite determination of a Cirrepede in the Cretaceous Rocks of Australia; (f) a badly preserved Coleopterous Elytron, only one other insect is known from the Australian Cretaceous, viz., a butterfly, *Aeschna flindersensis*; (g) seven new species of brachiopods—*Terebratulina ovata*; *Magas mesembrinus*; *Mag-*

gostegia, Reuss; *Cristellaria gibba*, d'Orb; *Cristellaria articulata*, Reuss; *Cristellaria subulata*, Reuss; *Cristellaria gaultina*, Berthelin; *Cristellaria rotulata*, Lamarek; *Cristellaria rotulata*, var. *microdiscus*, Reuss; *Cristellaria circumcidanea*, Berthelin; *Cristellaria diademata*, Berthelin; *Cristellaria obicularis*, d'Orb; *Cristellaria cultrata*, Monfort; *Flabellina rugosa*, d'Orb; *Flabellina inter-punctata*, von der Marek; *Polymorphina augusta*, Egger; *Polymorphina compressa*, d'Orb; *Polymorphina communis*, d'Orb; *Polymorphina lactea*, Walker and Jacob, sp.; *Sagraia mailandiana*, Chapman; *Sagraia asperula*, Chapman; *Sagraia monile*, Chapman; *Ranulina aculeata*, Linné; *Vitriobellina laevis*, Sollas; *Globigerina bulloides*, d'Orb; *Globigerina cretacea*, d'Orb; *Globigerina aequilateralis*, Brady; *Globigerina marginata*, Reuss; *Globigerina limosa*, d'Orb; *Sphaeroidina bulloides*, d'Orb; *Discorbina opercularis*, d'Orb; *Truncatulina lobatula*, Walker and Jacob; *Truncatulina convexa*, Reuss; *Truncatulina variabilis*, d'Orb; *Truncatulina wellerstorfi*, Schwager; *Anomalina ammonoides*, Reuss; *Pulvinulina elegans*, d'Orb; *Pulvinulina cordieriana*, d'Orb; *Pulvinulina spinulifera*, Reuss; *Rotalia soldanii*, var. *nuda*, Reuss; *Rotalia beccarii*, Linné; *Rotalia broeckiana*, Karrer; *Nonionina asterizans*, Fichtel and Moll.

OSTRACODA: *Paracypris siligua*, Jones and Hinde; *Bairdia arquata*, Münster; *Macrocypris simplex*, var. *africana*, Chapman; *Bythocypris howchiniana*, Chapman; *Cythere harrisi*, var. *reticosa*, Jones and Hinde; *Cythere australiensis*, Chapman; *Cythere lineatopunctata*, Chapman and Sherborn; *Cytheris ornatissima*, Reuss; *Cythereis ornatissima*, var. *nuda*, Jones and Hinde; *Cythereis ornatissima*, var. *reticulata*, Jones and Hinde; *Cythereis ornatissima*, var. *stricta*, Jones and Hinde; *Cythereis quadrilatera*, Roemer; *Cythereis rudispinata*, Chapman and Sherborn; *Cythereis tuberosa*, Jones and Hinde; *Cytheropteron concentricum*, Reuss; *Cytherella muensteri*, Roemer; *Cytherella ovata*, Roemer; *Cytherella williamsiana*, Roemer; *Cytherella chapmani*, Jones and Hinde.

PORIFERA: *Peronella* (?) *globosa*, Eth. Fil.

ACTINOZOA: *Coelosmilia* (?) *ginginensis*, Eth. Fil.

ECHINODERMATA: *Echinoidea*.

ANNELIDA: *Serpula fluctuata*, J. de C. Sowerby; *Spirorbis*, sp.; *Spirulaea gregaria*, Eth. Fil.

CRUSTACEA: *Pollicipes* (?) *ginginensis*, Eth. Fil.

INSECTA: Badly preserved *Coleopterous elytrum*.

BRACHIOPODA: *Terebratulina ovata*, Eth. Fil.; *Magas mesembrinus*, Eth. Fil.; *Trigonosemus acanthodes*, Eth. Fil.; *Magasella cretacea*, Eth. Fil.

PELECYPODA: *Ostrea*, sp. a. and b.; *Pycnodonta ginginensis*, Eth. Fil.; *Camptoneustes ellipticus*, Eth. Fil.; *Inoceramus*, sp. ind.; *Mytilus piriformis*, Eth. Fil.

GASTROPODA: *Tubulostium pyramidale*, Eth. Fil.

CEPHALOPODA: *Ammonites*, allied to (a) *Haploceras daintreei*, Eth.; (b) *Haploceras flindersi*, McCoy; (c) *Ammonites perampus*, Mantell.

PISCES: Two imperfect teeth of *Lamna*.

Economic Products.

The Cretaceous Rocks, by reason of their porosity, constitute important water-bearing strata, though the saline nature of some of the beds tends to render the water somewhat less pure and efficient than that occurring in the underlying Jurassic quartzose sandstones.

The soils resulting from the weathering and disintegration of some of the rocks produce an exceedingly rich black clayey soil which bears valuable crops of grass and cereals.

The chalk-like limestones have been burnt as a source of lime for building and agricultural purposes and occasionally in the manufacture of Portland Cement for which some of the beds seem well adapted.

The phosphatic nodules (coprolites) concretions and phosphatised fossils are found occurring on a very extensive and important horizon. These are being utilised for commercial purposes, the material being obtained from Moiceap Hill, at Gingin.

The iron phosphate, Dufrenite, is of wide distribution in certain of the ferruginous sandstones of the series.

Fairly thick beds of glauconitic sandstone and marl have been met with and have been found to have a wide distribution throughout the Cretaceous areas of the State. Glauconite is capable of being utilised as a source of pure potash compounds required for certain scientific and medicinal purposes, as well as for glass making.

TERTIARY SYSTEM.

Owing to the absence of extensive areas of valuable mineral deposits no geological surveys have yet been made of those districts in which strata of known Tertiary age occur, hence information regarding the beds of this period is somewhat limited. The Tertiary deposits of Western Australia are found chiefly in the maritime districts of the State. Maritime strata of this age occur in the coastal areas, whilst in others there are widely distributed terrestrial formations now occurring in isolated patches which may, in all probability, be of Tertiary Age, though this is still in question.

The occurrence of Tertiary rocks in south latitude 17°-18° was demonstrated by Mr. E. T. Hardman in 1884. A small outlier of a once widely spread formation was noted by him at Mount Elder, in the Ord River Valley at Trig. Station, J.40, at an altitude of 987 feet above sea-level. The beds forming this outlier, which rest directly upon the Carboniferous rocks, consist of white limestones, soft sandstones, and cherts. The chert was found to contain a new species of the gasteropod, *Planorbis*, which was named by the late Prof. McCoy *Planorbis hardmani*, thus indicating the presence of rocks of Tertiary age in the north of the Kimberley Division. Basic lavas and ashes of what are at present believed to be the same age occur in great force in Kimberley. These appear in the valleys of the Ord and Bow Rivers to have levelled up the depressions, except for certain knife-edged ridges of the older rocks, which still protrude above the general level. On the Behn River, just above what is known as the Gorge, a dome or pay of basalt which formed one of the foci from which the lavas issued, has been noted. What relation these volcanic rocks bear to the sediments of Mount Elder has not yet been investigated.

In the valley of the Oakover River in the Pilbara Goldfield a series of beds, which have been designated the Oakover Beds, occur below Carawine Pool, resting with a violent unconformity on the older Nullagine Formation. The beds consist of a series of sandstones, limestones, and cherts, which nowhere attain any great thickness. The Oakover beds at one time covered a wide extent of country, for outlying mesas of them are found extending for five or six miles up Boodalyerri Creek, resting upon the volcanic rocks which occur in this locality, whilst several outliers can be seen in the country to the northwards. These isolated mesas form impressive evidence of the amount of denudation which has gone on since the deposition of these Oakover Beds. The occurrence of these beds so far inland may be of some importance in, as has already been pointed out, enabling some realisation to be arrived at of the conditions under which the Pilbara coastal plain might have been formed by marine erosion. Though these beds have as yet yielded no fossils, there seem some reasons for believing them to be of Tertiary age.

A wide expanse of ferruginous sandstones and variegated clays have been described by Mr. Gregory as occurring in the Lower Gascoyne, and they are believed to be Upper Tertiary in age. A considerable thickness of marine Tertiary beds occur in the Coastal portion of the Gascoyne country. The fossils from the deep bore at Pelican Hill, Carnarvon, show that 1,088 feet of Middle Marine Tertiary Beds were passed through between the depths 150 and 1,238 feet. These strata penetrated by the core consisted of cal-

careous clay 28 feet; limestone 50 feet; calcareous clays (? limestone) 853 feet; black shale 95 feet, and calcareous clay shale 60 feet. The age of these beds is fixed on the evidence of specimens of bryozoan limestones, as determined by Prof. J. Gregory, formerly of the University of Melbourne, but now of Glasgow.

The basal beds of what are believed to be Tertiary Strata are seen to rest unconformably on the eroded surface of the Jurassic rocks of the Champion Bay District as well as upon the older crystalline rocks. The Tertiary rocks consist of limestones, sandy shales, and sandstones, the outcrop of which forms a relatively narrow strip of country along the coastline. The Tertiary limestones in places rise to altitudes of 800 feet above sea-level, so that they must have been deposited before the depth over this portion of the then sea bottom had been reduced to 1,000 feet. The elevation of the land was probably a very gradual one after the close of the Jurassic period and was probably followed by a depression after or towards the close of this period. These Tertiary limestones are frequently foraminiferal; a sandy current-bedded limestone containing a few corals occurs at Yardarino. Very many picturesque caves occur in the limestones of this formation.

Similar strata occur at Sharks Bay to the north, and occupy a wide expanse of country.

On the southern portion of the maritime areas of the State there is a large development of marine sediments which have been named the **Plantagenet Beds**,¹ from the Lands Department district, throughout which they are so widely distributed. These beds, which do not appear to have attained any greater thickness than 300 feet, were deposited on an irregular surface of granite which forms "bedrock" in this portion of the State. The beds, which are practically horizontal, consist of silt which is often cemented into a somewhat fine-grained sandstone of a uniformly fine grain.

"Siliceous sponges are especially abundant throughout these beds, many complete skeletons of lithistids being obtainable, whilst isolated spicules of the same and of tetractinellids form an important proportion of the whole rock. In addition, gastropods, cephalopods, lamellibranchs, and echinids are found, but, unfortunately, they are too poorly preserved for specific determination."

The Plantagenet Beds, as exposed in the brick-pit about three miles north-west of Albany, are intersected by a basic dyke which may possibly be in some way connected with those basalts occurring at Bunbury (Fig. 71), and various other localities to the south: viz., the Blackwood River, at Black Point on the South Coast near Silver Mount between the Warren and the Donnelly Rivers, and in those recorded in Nos. 1 and 3 bores of the Westralian Mining



Fig. 71.—Basaltic Lava, Bunbury, South-West Division.

and Oil Corporation on the Warren River. These may be of middle or late Tertiary Age and belong to the same period as those occurring in South Australia and Victoria.

An extensive development of Miocene (?) Tertiary rocks occurs in the Nullabor Plains.

The Nullabor Plains (or Premier Downs) in the Eucla Division form part of the relatively high plateau generally known as the "Eucla Limestone Plateau" which extends into the adjoining State of South Australia. The plateau at its southern extremity at the head of the Great Australian Bight is from 200 to 400 feet above sea-level; it is more or less abruptly truncated by cliffs which in part form the coastline and elsewhere occur at varying distances inland. The plateau steadily rises to the north, and where it is traversed by the Great Western Railway its altitude above sea-level varies from about 450 to 650 feet; from the Railway line it gradually passes northwards into the Central Division of the State, where the average altitude is about 1,000 feet above sea-level. There are no rivers on the plateau, hence few if any natural sections of the strata are to be seen.

The strata of which the Nullabor Plains are built up consist of more or less cavernous limestone (the Eucla Limestone) associated with soft sandstones, clay shales, and occasional conglomerates. Good opportunities have been afforded of obtaining some knowledge of the strata, their lithological character, thickness, etc., underlying the plateau, by means of the bores put down in connection with the water supply of the Great Western Railway. It is now known that these sedimentary rocks have attained a thickness of at least 2,000 feet. The limestone maintains a fairly uniform lithological character over its whole length, though it varies very much in thickness, being from 485 to 903 feet. The records and cores of the deep bores which have been put down on the plateau disclose the nature of the beds underlying the Eucla Limestone. The shaley beds beneath the limestone become, so far as is disclosed by the bores, much more sandy in character as the western rim of the basin is approached. The beds all have a prevailing gentle dip towards the Great Australian Bight. The strata exposed in all the

¹ Notes on the Geology and Physiography of Albany: J. T. Jutson and E. S. Simpson. Journ. and Proc. Royal Society, W.A. Vol. II, 1917, pp. 48-50.

lofty cliff sections along the coast appear quite horizontal and nowhere (Fig. 72) do they exhibit any signs of disturbance, faulting, or folding. The western margin of the limestone plateau, wherever examined, has not disclosed any actual junction between the sedimentary strata of the Eucla Plateau and the ancient crystalline rocks, owing to the surface being covered by a variable thickness of residual or other superficial deposits. Occasionally, however,

flaggy limestones may be seen outcropping beneath the light-coloured loam, which soil seems the characteristic decomposition product of the Eucla Limestone.

A fair idea can be gathered of the form of the basin in which these beds were laid down from the data furnished by the boring carried out along the Great Western Railway Line; from these data it may be inferred that the old floor of ancient crystalline



Fig. 72.—Limestone Cliffs near Twilight Cove, Eucla Division.

and other metamorphic rocks was one of topographical regularity in an east and west direction. The absence of bores reaching bed-rock to the south of the railway, however, precludes any adequate conception as to its subterranean contour in this direction. The limestones of the Eucla Plateau indicate a great depression of the land below the sea-level and its subsequent elevation.

All the available fossil evidence indicates that the age of the Eucla Limestones is Miocene Tertiary. The cores obtained from the railway bore put down at 337 miles 61 chains from Kalgoorlie show that beneath the Eucla Limestone, which is 603 feet thick at this point, the shaly beds are 667 feet in thickness and contain the fossils *Aucella hughendensis* and *MacCoyella corbiensis* characteristic of the Lower Cretaceous strata of South Australia and Queensland, indicating the occurrence of rocks the equivalents of the Rolling Downs Beds as developed in Eastern Australia.

A ferruginous pisolitic limestone recently obtained from the 170 mile peg on the Transcontinental Railway contains a solitary fossil, referable to the genus *Isodora*, one of the freshwater *Physa* group. The locality from which this shell was obtained is obviously not very far from the western margin of the great Tertiary limestone plateau.

The country to the north of the Railway Line was traversed by the Elder Exploring Expedition in the years 1891-2, and the geologist attached to the party, the late Mr. Victor Streich, described a great expanse of Recent, Tertiary, and Mesozoic Rocks extending over 7 degrees of latitude between Lake Lefroy and the Townsend

Range. The Mesozoic Rocks are described by him as consisting in descending order of clay (indurated), jasper rock, conglomerate, quartzite (desert quartzite), and sandstone, but no estimate was given as to the total thickness of the series. The conglomerates were stated to be only slightly consolidated. The boundary between the Mesozoic beds and the older crystalline and metamorphic rocks was somewhere between the Ponton River and Queen Victoria Spring, though as elsewhere in the plateau the actual junction is masked by the ubiquitous cover of superficial deposits.

Some further information as to the northern extension of these beds was obtained by Messrs. Talbot and Clarke in the geological expedition during 1916 from Laverton to the South Australian Border via the Warburton Range. This recent work by definitely proving the presence of the basal beds of the series exposed in the bores on the railway line is of considerable importance.

In the traverse from Dunge's Hill to the Townsend Range a wide expanse of practically horizontally bedded slightly compacted current bedded sandstones, and claystones with occasional conglomerates and boulder beds, was encountered.

The base of the series at Dunge's Hill rests upon granite and allied rocks at about 1,570 feet above sea-level, whilst farther north near the Townsend Range the basal beds rest with a marked unconformity upon the gently inclined Ordovician (?) sediments, the altitude of which is about 1,900 feet: these elevations are considerably higher than in the country farther to the south traversed by the party of which Mr. Streich was a member.

These beds, which have been tentatively named the Wilkinson Range Series consist of almost horizontally bedded, slightly compacted sandstones and claystones. (Fig. 73.) The finer grained beds of the series often exhibit current bedding and are underlaid

by a boulder bed fifteen feet thick. The boulder bed forms the base of the series and is covered by over 100 feet of the finer sediments; the boulders are of all sizes and generally agree in shape with one conspicuous flattened side, occasionally covered by such



Fig. 73.—Wilkinson Range Beds near soak in Millar Breakaway, Eastern Division.

scratches and other markings as result from ice action. (Fig 74.) Large boulders, weighing 2cwt. and more, are by no means uncommon. The Wilkinson Range beds have been traced for a distance of about 200 miles.



Fig. 74.—Glaciated Gneiss Boulder from the Wilkinson Range Beds, about a mile south-west of Lily Rock Hole, Eastern Division.

At the time of the formation of these beds glaciers strong enough to descend to sea-level from an area to the west of the Warburton Range occupied country as near the tropics as Lat. 26°-30' south.

No fossils have been found in the Wilkinson Range Beds, but stratigraphical and other evidence available leads to the belief that they are of a late Mesozoic or Tertiary Age.

The results of such geological investigations as have at present been made show that in east longitude 127° an extensive sedimentary formation extends northwards for about 400 miles from the coast and covers some thousands of square miles between Israelite Bay and Eucla, and eastwards between the South Australian Border and Point Sinclair near Fowler's Bay.

Collie Lake Beds.

Lacustrine beds of what is believed to be of Tertiary Age occur in the valley of the Collie River, resting directly and with a marked unconformity on the Coal Measures. An excellent section is exposed in the tunnel at the Proprietary (Bullfinch) Colliery (Fig. 75).

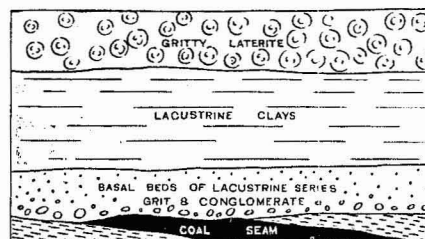


Fig. 75.—Section of the Collie Lake Beds overlying the Coal Measures, Proprietary Tunnel, Collie Coal Field, South-West Division.

The strata consist of grits, conglomerates, sands, and clays lying practically horizontally, and which have been found to attain a thickness of at least 100 feet. They are covered by a varying thickness of gritty laterite.

So far as observations have at present been carried the beds would appear to have been deposited in a lake the boundaries of which practically coincided with the area occupied by the Collic Coal Measures. It is within the bounds of possibility that these lacustrine beds may prove to extend over a much wider area.

Economic Products.

The Tertiary rocks are of considerable importance by reason of the occurrence of artesian water, and the limestones associated with them are of value as local sources of supply of agricultural lime, whilst some of the shaley beds may be of use for brickmaking and the manufacture of artificial cement. The normal soil, resulting from the decomposition of the rocks, is well suited for agricultural purposes.

POST-TERTIARY (QUATERNARY SYSTEM). PLEISTOCENE.

Coastal Limestone Series.

An area in the maritime districts of the State of over 1,000 miles in length is occupied by a formation known as the Coastal Limestone Series. Peron, in 1807, appears to have been the first to investigate this formation, which he designated the Calceiferous Sandstone and recognised its similarity to the sand dunes occurring on the Coast. The Coastal Limestone of the King George's Sound was noted by Darwin in 1816, that of the Swan River appears to have been first described in 1831 by the Rev. Archdeacon

Scott, and further additional information relating thereto was given in 1846 by Commander Stokes. The Series was also described by the late Mr. H. P. Woodward as occurring all along the South Coast, and as containing fossils identical with forms now living. The shelly limestones and sandstones which extend from Shark's Bay as far north as North-West Cape in all probability belong to the Coastal Limestone Series. Lithologically, the beds would be more correctly designated calcareous sandstones than limestones, and are made up of buff-coloured sea-sand cemented together with carbonate of lime and more or less thickly studded with varying sized concretions of phosphate of lime. Some of these contain grains of quartz, felspar, ilmenite, garnet, and amphibole, with, though rarely, small quantities of zircon, kyanite, biotite, and tourmaline. This shell sand is converted into limestone by the solution of the carbonate of lime, producing in places a rock of sufficient hardness to ring like a bell when struck with a hammer, and which weathers with a distinctive jagged surface. In addition, there are several softer chalk-like beds which pass by almost insensible gradations into a very hard and compact rock. Owing to the varying nature of these sea-sands the whole of the sand-dunes have not been cemented into solid rock. The Coastal Limestone Series, originally calcareous sand dunes, terminates landwards in a more or less smooth bank or face, to which layer after layer is added. The irregular current bedding of these deposits gives the appearance of limestones dipping at varying angles from the horizon, and apparently overlaid by nearly horizontal beds. (Fig. 76.) Magnificent examples of these dune limestones may be seen on the South Coast from Port Hughes at Torbay Inlet to Limestone Head at King



Fig. 76.—The Coastal Limestone: The Dog Rock, Penguin Island, Waribro' Sound, South-West Division.

George's Sound, where there is a line of very high perpendicular limestone cliffs which form exceptionally conspicuous and picturesque features in the landscape; the beds rise in places to a height of nearly 700 feet above sea level.

The Coastal Limestone contains large numbers of the foraminifer *Globigerina* with a few *Amphistegina*, and fragments of calcareous algae *Lithothamnium*, together with an organism allied to *Porites*. Darwin found land shells of the genus *Helix* and *Oniscus* in the solidified sand dunes of Bald Head at King George's Sound.

The geological age of the Coastal Limestone cannot at present be fixed with any degree of precision; it has been provisionally set

down as Pleistocene, though some may, however, date back to late Tertiary times.

The unequal weathering of the beds of the Coastal Limestone results in the formation of caves of which those at the Margaret River are the most noteworthy. The roofs are often hung with long tapering pendants of carbonate of lime, producing effects of great beauty.

The Mammoth Cave, on the Margaret River, is one of the finest of the many limestone caves which occur in the south of Western Australia from Cape Naturaliste to Cape Leeuwin. The cave was carefully explored for fossil remains in 1905, 1909, and 1912, with the result that no less than 10,000 bones or fragments of bones in

an excellent state of preservation were obtained. The fossils were found in a sandy bed lying beneath a layer of stalagmitic material which covered the floor of the cave. The genera represented comprised:—*Nototherium*, *Phascolomys*, *Phascolaretus*, *Sthenurus*, *Macropus*, *Bettongia*, *Dasyurus*, *Thalacomys*, *Perameles*, *Isodon*, and *Tachyglossus*; there were also specimens of *Muridae* and of reptiles and birds. The species of Wallabies included one which is now living, viz., *Macropus brachyurus*.

The following is a list of the species so far noted:—

Tachyglossus (Echidna) aculeatus (Shaw Sp. var. typicus).
The Native Poreupine or Hedgehog.

Phascolomys hacketti, sp. nov. The Wombat.

Phascolaretus cinereus. Goldfield sp. Koala or Native Bear.

Sthenurus occidentalis. Sp. nov.

Nototherium. Sp.

Diprotodon australis. Owen.

Zaglossus hacketti. Sp. Nov. Giant Echidna.

Thylacynus cynocephalus. Harris. Tasmanian Wolf or Tiger.

At the Bride's Cave, on the Margaret River, which is about three or four miles south of the Mammoth Cave, there was also found lying uncovered on a talus of coarse sand and fragments of limestone and stalactite, the skull of *Sarcophilus harrisi*, Boitard—the Tasmanian Devil—whose remains have been found in many parts of Eastern Australia.

At the Balladonia Soak, situated at the foot of a residual boss of granite about 200 acres in extent (Fig. 77), and rising to a height of about 50 feet from beneath the surrounding limestone, in the Eucla Division, there have been found a rich variety of fossilised animal bones and teeth. These were found buried in sand and silt at depths at from four to twelve feet from the surface while excavating a dam at the foot of the granite residual. The remains were

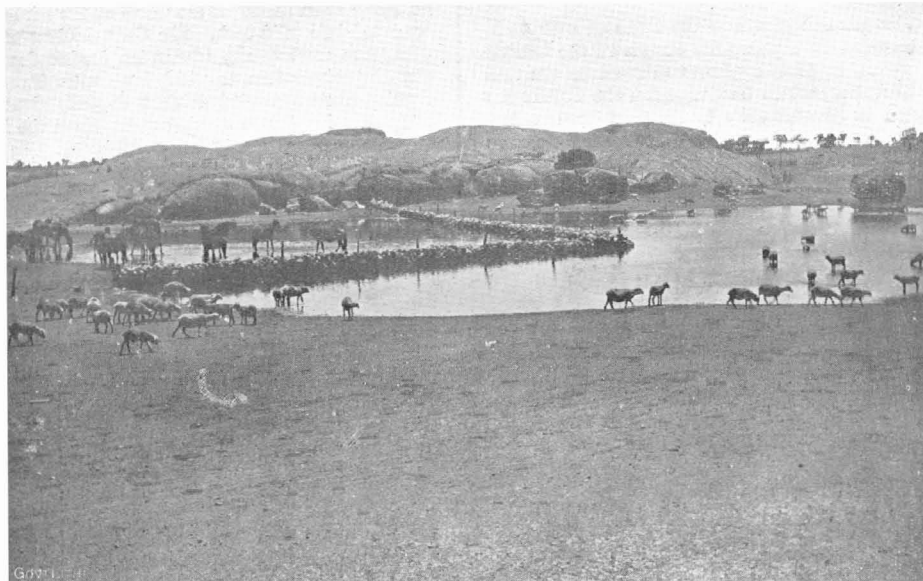


Fig. 77.—Granite Rocks, Balladonia Soak, Eucla Division.

in a good state of preservation, and their discovery has shown that several species of extinct Marsupials have had their range extended into Western Australia. The list of fossil marsupials so far recognised amongst the remains occurring at Balladonia is as follows:—

Sarcophilus lanianus.

Diprotodon australis.

Phascolomys gigas. Owen. (The Giant Wombat.)

Phascolomys latifrons. Owen. (The Hairy-nosed Wombat.)

Phascolomys parvus. Owen. (The Dwarf Wombat.)

Thylacoleo, sp. (The Marsupial Lion.)

Macropus magister. DeVis.

Macropus anak. Owen.

Sthenurus atlas. Owen.

Discoveries of fragments of bones have also been made at Cook's Rocks, twenty miles north of Balladonia, and at Womburna Rocks, twelve miles to the south, but so far the collections have not been worked out.

The rocks evidently formed the watering places for these animals, and the preservation of their remains is due either to the fact that the animals were bogged while at the waters or that they perished from the supply giving out during a bad season, as it often does at the present day.

Diprotodon australis has also been recorded from the tropical portion of Western Australia, a single bone (the head of the femur) was found in 1883 by Mr. E. T. Hardman, Government Geologist, in the bed of the Lennard River in the Kimberley Division, in lat. 17deg. 20min. S. and long. 125deg. E., about 80 miles distant from King Sound. At the point where the bone was found the Lennard River cuts a deep cañon—The Devil's Pass, 300 or 400 feet deep—through the limestone of the Napier Ranges, which is two miles wide in this locality. The limestone is honeycombed with caves, and it is believed that the bone may have been washed out of one of these during those heavy floods to which the district is subject.

It has also been reported in 1895, by the then Government Geologist, the late Mr. H. P. Woodward, that bones of *Diprotodon* were found in the ancient river gravels in the vicinity of Bridgetown.

Economic Products.

The Coastal Limestones are of value as local sources of supply of agricultural lime, and many of the unconsolidated sand dunes are of such a composition as render them of considerable use for agricultural purposes.

The large and extensive dune sands of Karridale contain 74.5 per cent. of carbonate of lime and 6.8 per cent. of magnesium carbonate; from the very finely divided nature of the material of which it is composed, the sand is admirably adapted to direct application to the land in its natural state. The Busselton dune sands, which are made up of fragments of mollusca, calcareous algae, and foraminifera, together with grains of quartz, ilmenite, tourmaline, zircon, garnet, biotite, rutile, and felspar, contain on the average 75 per cent. of the carbonates of lime and magnesia, and are in their natural condition well suited for direct application to the soil as an acid corrective. The sands to the south of Geraldton, near the mouth of the Greenough River, contain 73.5 per cent. of carbonate of lime, whilst those near Dongara average about 81.5 per cent. The foraminiferal dune sands of Dongara have been shown to be suitable for an agricultural land dressing in their raw condition.

Lacustrine and other Deposits.

One of the most extensive lacustrine deposits occurs at the headwaters of the Fortescue River, between the Hamersley-Ophthalmia Plateau and the Northern Plateau. The deposit fills in a saline depression about 120 miles in length and averaging over 25 miles in width. Shallow wells and bores have been sunk by the pastoralists to depths a little over 100 feet, and in every case detrital material ranging from fine silt to water-worn pebbles was met with, but none of the bores or wells has reached bed rock.

The dredgings beneath "Perth Water" in the Swan River, at Perth, have yielded a suite of fossils which have been determined by Mr. Hedley of the Australian Museum. In this connection it is of interest to note that no similar living shells are now to be found in the neighbourhood, and that the sea is about 14 miles distant by river and eight miles in a direct line.

The following is the list of fossils, which were collected by Dr. E. S. Simpson:—

Ostrea angasi, Sowerby; *Chama limbula*, Lamarch; *Gafrarium sulcatum*, Gray; *Paphia euglypta*, Philippi; *Desinia sculptilis*, Hanley; *Venerupis carditoides*, Lamarch; *Cardium rugatum*, Dillwyn; *Chalmys asperimus*, Lamarch; *Polinices conicus*, Lamarch; *Arcularia burckhardi*, Dunker; *Clanculus denticulatus*, Gray; *Diala* sp., *Alaba* sp., *Obolus* sp., *Liotia* sp.; *Cylichna* sp.; *Minolia lentiginosa*, A.Ad.

Mr. Hedley remarks: "Some of the species appear to be unrecorded for the State of Western Australia." He suggests that "this deposit of shells may be synchronous with others from South Australia and with that from the Hunter delta (Rec. Geol. Surv., N.S.W., Vol. II., No. 2, 1890, Pl. III., pp. 38-52, and Journ. Roy. Soc., N.S.W., XLIX., 1915, p. 26), when a climate warmer than the present prevailed." He has not enough information on the extremes to which certain species of *Clanculus denticulatus* range south to reach any decision.

RECENT FORMATIONS.

Sand Plains and Allied Deposits.

Very large areas of Western Australia are covered with extensive deposits of sand, which form one of the most distinctive features in the State.

These sand-plain areas consist of practically level country mainly made up of sand which owes its origin chiefly to the decay and disintegration of the underlying rocks (Fig. 78). In places these sand plains are from 20 to 30 miles across. A geographical classification divides the sand plains into two groups, viz., those of the interior and those of the maritime districts.

The major portion of what may be called the Interior Drainage Area is traversed by sand ridges, which have their greatest development in those areas covered by sedimentary rocks, the decay of which produces large amounts of siliceous sand which is carried across country by the prevailing winds. The ridges have equal slopes on both sides; there is little manifestation of any erosion of them,



Fig. 78.—Sand Plain near Northampton, South-West Division.

and though there is a distinct movement of the sand grains on the surface of the ridges the sand is redeposited almost as fast as it is removed. The ridges being covered with vegetation appear to be remarkably stable.

Perhaps one of the most extensive areas of the desert region of the interior in which these sand deposits are developed is to the north of latitude 25 degrees south. In this area, which lies to the north-east of Wiluna, an extensive development of what are believed to be palaeozoic sedimentary rocks, chiefly sandstones, covers an area of about 7 degrees of latitude. The disintegration of these sandstones results in the formation of an immense amount of fine siliceous sand, much of which is borne by wind across country. From such information as is available, it appears that in the interior desert region the prevailing winds are from the south-east, which during the winter months blow with considerable force. The effect of these prevailing winds is to arrange much of the loose sand in a series of parallel ridges, in the aggregate sometimes several miles in width, which trend generally north-west and south-east. As a rule these sand dunes carry a vigorous growth of vegetation, such as desert gums, various kinds of shrubs, spinifex, and occasionally grass. The sand in this northern desert area is being deposited on the ridges almost as fast as it is being removed by the wind, and there seem some sound reasons for believing that these sand dunes are slowly but surely migrating to the westward. In some cases the eastern and south-eastern slopes of the low hills and ranges are almost entirely buried by the deposits of blown sand derived from the sandstones, etc. The parallel sand dunes are at times very close together and separated by flats which vary in width from a few chains up to over a mile. The flats are underlaid by a more or less porous sand rock which is merely a superficial deposit formed by the cementation of the loose sand by carbonate of lime, and traversed by small veins of calcite. Wells in this calcareous sand rock have often yielded copious supplies of excellent water. In the area in question there are remains of one or more extensive salt lakes which are gradually being obliterated by the invasion of the sand dunes. Observations at Lake Disappointment (S. Lat. 23, E. Long. 123°) have demonstrated that this encroachment has been as much as three or four miles at the least.

There are extensive areas of almost flat plains covered with a variable thickness of soil, and underlaid by both basic and acidic rocks, the former yielding a fairly rich dark loam and the latter almost pure siliceous sand.

Much farther to the south, near latitude 26° south, there is also a development of similar sand ridges, which however have no prevailing direction, although for considerable distances they present a marked parallelism. The irregularity of the sand ridges may, in all probability, be ascribed to the greater variability in the direction of the prevailing winds, consequent upon the area being too far south to feel the effects of the steady south-east trade winds in the lower latitudes to the north. The distance between the sand ridges varies from about two hundred yards up to about a mile, whilst their average height is about thirty feet. *Spinifex* is the predominant growth in many of the sand hills, though *Parakygia* grows luxuriantly and in certain localities disputes pride of place with it.

In addition to the sand ridges there are extensive sand plains covered with spinifex and occasionally desert gums, which give the plains when viewed from a distance the appearance of open park lands. Generally speaking these sand plains overlie granite and allied rocks, and from such observations as have been recorded there seems to be a considerable amount of movement in the sand of the granite area, which appears to result in a general levelling up rather than dune building. The thickness of these residual sands appears, in these regions, to be considerable, whereas on the similar sand plain, which extends from Wilma to Kimberley, the thickness nowhere exceeded fifty feet.

In the Kimberley Division large and extensive sand plains occur on either side of the Fitzroy valley; these also extend for some considerable distance to the south, where they form what is designated on most of the Western Australian maps, Warburton's Great Sandy Desert. The sand plains are named Pindan Sands in consequence of their occurrence chiefly in the wooded country termed "Pindan" by the natives. The Pindan sands consist of reddish sands and gravels with small pea-like nodules of brown ironstone and coarse gravel; the sands are at times consolidated, the cementing medium being carbonate of lime and ferruginous material, and the resulting rock being sandstone, grit, or conglomerate. The thickness of these sands is fairly considerable; in a few places where exposed they are seen to have a thickness of from 20 to 30 feet. These sands are merely decomposition products *in situ*, with the occasional addition of "surface wash" of the sandy and gravelly rocks which make up a large portion of the Kimberley Division in which the pindan occurs. Owing to its porous nature these sand plains are, despite the heavy rainfall, waterless; nevertheless they, as a rule, support an abundant vegetation.

In the vicinity of the coast a marked increase is noticeable in the calcareous matter in the sand, which is derived from marine shells, etc.

Laterite.

No account of the geology of Western Australia would be complete without some reference to that extensive development of residual deposits which have been found over the whole length and breadth of the State.

The term laterite has been officially adopted, though in somewhat more extended sense than its original application, for all the deposits resulting from the decomposition and consolidation of rocks *in situ*.

The laterites of Western Australia consist largely of hydrated oxide of iron and alumina, producing on the one hand deposits of excellent iron ore and on the other bauxite. In some parts of the State the deposition of secondary silica in the lateritic deposits produces what are practically quartzites; these, by an increase in the ferruginous colouring matter, pass into a jasperoid form of laterite. There are thus three forms of these laterites—an aluminous, a ferruginous, and a siliceous—the composition being liable to vary considerably over a small area, it being largely governed by the nature of the underlying rocks.

The structure is sometimes massive and almost homogeneous, but is more frequently pisolitic and nodular, in which case the concretions are richer than the interstitial matter.

The lateritic deposits naturally vary in their lithological characters. They are in many places very porous and weather into caverns and cavities of all sizes (Fig. 79). The surface of the rock is often covered with a glaze of hydrated oxide of iron. When freshly broken the rock presents a mottled appearance owing to the different shades of brown, yellow, and red. The rock passes gradually into the underlying rocks without any sharp line of

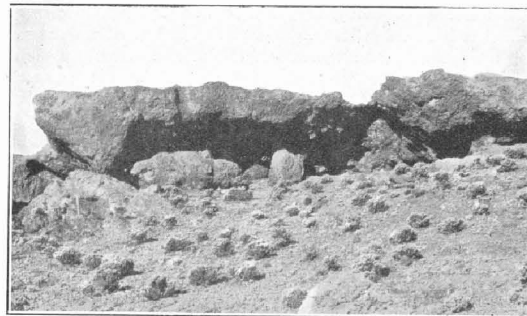


Fig. 79.—Laterite, "Golden Mount," Ora Banda, Broad Arrow Goldfield.

demarcation. That ferruginous and siliceous laterites are more commonly met with is due to the fact that deposits of this type are better able to resist disintegrating influences than the softer varieties; they thus not only remain themselves, but act as a protecting cover for the rocks beneath.

Mr. J. Beete Jukes, writing in 1850, in his almost classic "Sketch of the Physical Structure of Australia," mentions the occurrence of these lateritic deposits as seen by him in the country between Perth and York. He says:—

"For a few feet below the surface the rock was a singular concretionary ferruginous compound which looked like a clay or sandstone that, being highly ferruginous, had formed itself into a mass of small balls and irregular concretions of a black oxide of iron or hematite. Below this ironstone (which is its name in the Colony) wherever the rock was exposed it appeared for many miles to be granite or some granitic compound."

In another place he mentioned as occurring in one of the lateral valleys of the Swan River—

"A thin capping of ironstone forming a line of small crags."

In 1861 the late Mr. F. T. Gregory gives in his paper "On the Geology of a part of Western Australia," an account of this lateritic deposit capping the Darling Range, and claims for it a Devonian Age. This observer mentions the important fact that the deposit blends gradually with the upper surface of the granite, and states that it would seem to owe its origin to the decomposition of the granite *in situ*.

The Rev. W. B. Clarke, in his "Sedimentary Formations of New South Wales," remarks:—

"Mr. F. T. Gregory indicated on his map and in his report the existence of Devonian Rocks near York, and in other parts of that Colony. Having examined the rocks so indicated, I can only state my belief that they have no pretension to any such antiquity and are probably mere collections of loose granitic matter, and other drift cemented by ferruginous paste, which has since become transmuted into concretionary nodules and hematite. There are also pebbles of trap, much decomposed in the so-called Devonian. They may be perhaps more properly considered as representing the Laterite of India."

It is on these historical grounds that laterite has been adopted in Western Australia as the name for these residual deposits rather than the term saprolite, which American writers have suggested.

The various reports of the Geological Survey contain numerous descriptions of these lateritic deposits, and are often accompanied by analyses.

These analyses show variations in alumina from 7.52 to 49.82 per cent.; ferric oxide, 10.02 to 88.23 per cent.; silica, 1.53 to 23.26 per cent.; combined water, 8.10 to 26.44 per cent.; and oxide of titanium, .59 to 3.10 per cent.

A recent analysis of a ferruginous laterite from Comet Vale (North Coolgardie) is of interest:—

"On account of the high percentage of chromium, mostly in the form of a hydrate readily soluble in hydrochloric acid, the balance being present in the form of chromite."

The analysis gave 79.01 per cent. of ferric oxide, 5.30 per cent. of chromic oxide, 3.14 per cent. of silica, and of water 12.35 per cent. Some of the laterites have proved to be more than appreciably auriferous.

In the southern portion of the State where the rainfall is greatest, the lateritic deposits support an abundant vegetation, the

well-known karri and jarrah growing in all their splendour thereon. In fact the mapping of the lateritic deposits of this portion of the State would define the areas over which both karri and jarrah occur. Elsewhere in the State the laterites support but a scanty vegetation.

So far as our observations have been extended the laterites, for the reason previously given, occur as disconnected outliers (Fig. 80), which once formed part of a continuous deposit. It is difficult to escape the conviction that since they were deposited, a considerable time may have elapsed, hence the laterites may be of some geological antiquity of which possibly the thickness and the state of consolidation may be a measure.

We have, however, as yet little authentic evidence on this point though it may be mentioned that in a bore put down at Coolgardie, on Reserve No. 23, certain plant remains were found in a deposit containing what is evidently the detritus of the lateritic beds. These plant remains have, on examination, been held to belong to the *Eucalypti*. In this connection it may be mentioned that McCoy has



Fig. 80.—Laterite, near Mount George, Mount Margaret Goldfield.

described definite eucalyptus foliage from the older gold drifts in Victoria, whilst Ettinghausen describes several species from the Upper Tertiaries of New South Wales and the deep lead in the New England Tinfield. On this evidence, therefore, the laterites seem to be of earlier age than Tertiary, though there is but little doubt that lateritic deposits are forming at the present time.

Economic Products.

The laterites are of considerable economic value as sources of iron and aluminium. Some have been utilised as a source of iron

ore for fluxing purposes; owing, however, to the ease with which they can be smelted rather than on account of their richness or purity. Others have proved to be highly aluminous, approaching very closely in composition the bauxites of Europe, America, and India, which now form the chief source of aluminium. Some of the ferruginous laterites of Greenbushes, overlying the ore-bearing belt, carry a certain quantity of tin, which, however, is not evenly distributed throughout, but is concentrated in certain isolated patches. The ferruginous laterites are very largely used for road-making, railway ballast, and analogous purposes.

Assistance

to

Prospecting and Mining

by
P. J. Atkins.

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Extract from
The Mining Handbook

**Geol. Surv. Memoir No. 1.
Chapter VII.**

1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

Assistance to Prospecting and Mining

By
P. J. Atkins.

CHAPTER VII.

ASSISTANCE TO PROSPECTING AND MINING DEVELOPMENT.

By Percy J. Atkins.

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A.—FREE DETERMINATIONS AND ASSAYS.

With the object of encouraging *bona fide* prospecting, free determinations and assays of prospectors' samples* are made by the staff of the Geological Survey Department, *when not unduly interfering with official work*, under the following conditions:—

- (a) The sample must have been obtained within the State either from land not held under lease for mining purposes, or if from land so held it must be accompanied by a certificate from an Inspector of Mines, Mining Registrar, or other Government officer setting forth the circumstances which justify a free assay.
- (b) The exact locality where the sample was found must be disclosed.
- (c) The sample must be of sufficient promise to warrant an assay being made at the expense of the State.
- (d) Free assays will not be made of samples showing free gold, or of tailings or other metallurgical products, or of umpire samples.
- (e) The Department reserves to itself the right of refusing to make any particular assay, and also the right of publishing at any time the results of an assay made at the public expense.

* In cases in which the prospector does not wish to disclose the locality, or when samples do not conform with the conditions for free treatment, the Department will make assays, analyses, or determinations of any Western Australian ore or rock on the payment of fees, particulars in regard to which may be obtained at the Geological Survey Office, Beaufort Street, Perth.

In forwarding samples great care should be taken to see that the name and address of the sender are, in all cases, included in the package containing the specimens and, in an accompanying letter, it should be clearly indicated what treatment is required or for what metal, or metals, the samples are to be assayed. When more samples than one are forwarded they should be wrapped separately and numbered, or otherwise distinguished.

Frequently packages are received unaccompanied by any letter, which do not contain the sender's name and address, or any means of identifying them, and the Department is blamed for the carelessness of the sender. Again, very small samples are often forwarded on which it is impossible to furnish a satisfactory report, whilst an assay of such is quite out of the question.

It is advisable that, where possible, a duplicate sample to that forwarded should be kept by the sender for future reference, if necessary.

Much confusion of samples would be saved, and greater satisfaction attained, if the following rules were carefully observed in all cases:—

- (1.) Each sample must weigh at least 6oz., but not more than 2lb.
- (2.) Each sample must be enclosed in a separate canvas bag or strong paper wrapper, with a slip of paper bearing the name and address of the sender, together with a private mark by which it may be readily identified.
- (3) The parcel must be forwarded *prepaid* addressed to:—

THE GOVERNMENT GEOLOGIST,
Geological Survey Office,
Perth.

- (4.) A letter must be sent at the same time to the same address, stating for what metals the samples are to be assayed, or containing other instructions, as the case may be.

All samples received are dealt with, at such times as do not interfere with the regular departmental work, as far as possible in the order of their arrival.

Any prospector who wishes to become acquainted with the appearance, or who requires information with regard to the occurrence, of any particular metal or mineral, its preparation for commercial purposes or its market value, etc., would be well repaid by a visit to the Geological Survey offices, where every assistance will be personally given, and information verbally supplied, by the scientific officers.

A very valuable and comprehensive collection of minerals and rocks, etc., is on exhibit in the Mineral Gallery, which would also well repay a visit.

B.—GEOLOGICAL REPORTS.

It is not, perhaps, fully realised by the general public that the Geological Survey Department has published, in its numerous annual reports and bulletins, a very large amount of information relative to the geology, etc., of a great number of mining centres and other localities throughout the State, which is of inestimable value to prospectors.

A careful study of these reports will be the means of directing prospecting into those channels from which the best results may be legitimately expected, and will save much useless expense and waste of energies in other directions.

Unfortunately, some of these publications are now out of print, but a complete set is available for reference at the Geological Survey Office during the usual office hours, and may generally be referred to in the offices of the District Mining Registrars.*

As an assistance to those who are not intimately acquainted with the contents of the Geological Survey publications, two lists have been prepared, in alphabetical order, showing the references to the individual reports,† which have been arranged—

- (a) Under Mining Centres and other localities, and
- (b) Under the names of Metals, Minerals, etc.

The latter list does not represent a complete census, either of the minerals found in the State or of the localities in which those referred to are known to exist, but reference is only made to those minerals and occurrences on which reports, or other information of value to prospectors, have been published in the official publications.

GEOLOGICAL REPORTS ARRANGED UNDER MINING CENTRES AND OTHER LOCALITIES, WITH THE REFERENCES TO THE PUBLICATIONS IN WHICH THEY MAY BE FOUND.

(Abbreviations:—R = Annual Progress Report; B = Bulletin; p. = page.)

Geological Report.	Reference.
Abbotts Centre, Murchison	R. 14, p. 74.
Abbotts and Nannine—Country between Albany	B. 14, p. 60. R. 1897, p. 30; R. 1900, p. 16; B. 26, p. 27; R. 1915, p. 24.
Albany and Cape Riche—Country between Annie's Gap Centre, West Pilbara	R. 1898, p. 29. R. 1909, p. 20; B. 41, p. 84.
Arrino District, Yandanooka	R. 1903, p. 13; R. 1906, p. 23; B. 38, p. 25.
Arthur and Wooramel Rivers—Country between	B. 33, p. 23.
Ashburton Goldfield	B. 16, p. 20; B. 33.
Ashburton River	R. 1901, p. 9; B. 48, p. 49.
Ashburton and Minilya Rivers—Country between	B. 26, p. 10.
Avon District	R. 1898, p. 9.
Bamboo Creek, Pilbara	B. 15, p. 51; B. 40, p. 47; B. 52, p. 21, 109.
Bangemall Centre, Gascoyne	B. 33, p. 29.
Bangemall and Beelu Pool—Country between	B. 33, p. 27.
Bangemall and Mt. Blair—Country between	B. 33, p. 45.
Bardoo Centre, Broad Arrow	R. 1899, p. 25.
Barrambie Centre, Murchison	R. 1906, p. 15; B. 34, p. 7; B. 52, p. 21.
Battlefield Centre, Yilgarn	B. 71, p. 111.
Beelu Pool and Bangemall—Country between	B. 33, p. 27.
Bellochambers Centre, East Murchison	B. 31, p. 94.
Beverley District	R. 1898, p. 24; R. 1906, p. 25.
Binduli Centre, East Coolgardie	B. 56, p. 41.
Birrigiri Centre, East Murchison	B. 31, p. 100.
Blackbourne's Centre, Yilgarn	B. 49, p. 173.
Black Range District, East Murchison	R. 1903, p. 14; B. 31, p. 65.
Bonnievale Centre, Coolgardie	B. 31, p. 9.
Bonnie Venture Centre, Yalgoo	B. 64, p. 49.
Boodalyerri Centre, Pilbara	B. 15, p. 76; B. 40, p. 73.
Boogardie Centre, Murchison	R. 1902, p. 16; R. 1913, p. 23; B. 8; B. 59, p. 91.
Boorara Centre, East Coolgardie	B. 66, p. 56.
Boulder Belt	R. 1908, p. 5.
Bremer Range	R. 1913, p. 28; B. 59, p. 190.
Bridgetown	R. 1898, p. 23.
Broad Arrow Goldfield	R. 1899, p. 25; R. 1902, p. 18.
Brookman's Centre, Kimberley	B. 2, p. 10.
Brookton	R. 1907, p. 10; R. 1914, p. 12.
Broome Hill	R. 1898, p. 23.
Brunswick River	R. 1898, p. 12.
Bullfinch Centre, Yilgarn	B. 71, p. 28, 70, 305.
Bulung	R. 1900, p. 21; R. 1902, p. 19; R. 1915, p. 31, 39; B. 82; R. 1917, p. 12.

* A complete list of these publications will be found at the end of this memoir.

† The reports included are those occurring in Bulletins Nos. 1 to 82, and the Annual Progress Reports from 1897 to 1918. Bulletins 78 to 81, being as yet unpublished, are not mentioned in this list.

Geological Reports arranged under Mining Centres, etc.—continued.

Geological Report.	Reference.
Bunbury	R. 1897, p. 30; B. 44, p. 56.
Burbanks Centre, Coolgardie	B. 53.
Burtville Centre, Mt. Margaret	R. 1905, p. 10; B. 24, p. 29.
Busselton	R. 1912, p. 11.
Butterfly Centre, North Coolgardie	R. 1914, p. 20; R. 1916, p. 27.
Cane River and Westons—Country between	B. 33, p. 79.
Canning River Reservoir Site	R. 1903, p. 31; R. 1915, p. 33, 38.
Cape Naturaliste, South-West Division	B. 44, p. 67.
Capel	R. 1908, p. 15; R. 1912, p. 11.
Cape Riche and Albany—Country between	R. 1898, p. 29.
Carbine Centre, Coolgardie	B. 31, p. 42.
Carnarvon	R. 1902, p. 23; R. 1903, p. 34.
Carnarvon Range	B. 39, p. 15.
Central Division	R. 1918, p. 22.
Cheriton's—Country south of	B. 71, p. 123.
Christmas Island, Recherche Archipelago	R. 1908, p. 6.
Clackline District	R. 1905, p. 24.
Coates Siding	R. 1897, p. 10.
Colbie Coalfield	R. 1898, p. 13; R. 1908, p. 6; B. 27, p. 7, 9; B. 36, p. 107; B. 48, p. 66; B. 64, p. 7.
Comet Vale, North Coolgardie	R. 1916, p. 17; R. 1917, p. 8.
Coondary Centre, Cue	B. 57, p. 49.
Coondingnow	B. 48, p. 50.
Coolegong Tinfield, Pilbara	B. 23, p. 74; B. 40, p. 281; B. 48, p. 44; B. 52, p. 114.
Cookernup	R. 1908, p. 15.
Cook's Creek Centre, Pilbara	B. 52, p. 131.
Coolgardie	R. 1897, p. 32; R. 1909, p. 27.
Coolgardie Goldfield	R. 1897, p. 54; R. 1900, p. 22; R. 1904, p. 19; B. 3.
Coolgardie and Kalgoorlie—Country between	R. 1912, p. 14; R. 1913, p. 27.
Coongan and DeGrey Rivers—Country between	B. 15, p. 24; B. 40, p. 19.
Coongan and Shaw Rivers—Country between	B. 15, p. 23; B. 40, p. 18.
Coorang Centre, East Murchison	B. 31, p. 110.
Cosmo-Newberry Ranges	R. 1905, p. 10; B. 24, p. 67.
County Peak, Beverley	R. 1906, p. 25.
Cowramup, South-West Division	B. 44, p. 69.
Croydon Centre, West Pilbara	R. 1909, p. 20; B. 41, p. 91.
Croydon and Hamersley Range—Country between	B. 33, p. 116.
Crusoe Centre, Yalgoo	B. 64, p. 50.
Cuballing	R. 1904, p. 17.
Cuddingwarra Centre, Murchison	R. 1906, p. 13; B. 29, i, p. 80.
Cue District, Murchison	R. 1902, p. 15; R. 1903, p. 21; R. 1906, p. 13; B. 7; B. 29, i, p. 7; B. 48, p. 112, 114.
Cue and Lake Way (Wiluna)—Country between	R. 1898, p. 36.
Cue, Peak Hill, and Mt. Sir Samuel—Country between	R. 1898, p. 47.
Dandaraga District	B. 26, p. 14.
Darling Plateau	B. 48, p. 138.
Darling Range	R. 1918, p. 19.
Darlot Centre, East Murchison	R. 1906, p. 20; R. 1913, p. 24; B. 28, p. 51; B. 74, p. 65.
Darlot and Lawlers—Country between	B. 28, p. 51.
Darlot and Wilson's Patch—Country between	B. 28, p. 60.
Davyhurst Centre, North Coolgardie	R. 1903, p. 13; B. 12.
Day Dawn District, Murchison	R. 1906, p. 13; R. 1909, p. 24; B. 7; B. 29, i, p. 7.
Dead Finish Centre, Ashburton	B. 33, p. 54.
DeGrey and Coongan Rivers—Country between	B. 15, p. 24; B. 40, p. 19.
DeGrey and Oakover Rivers—Country between	B. 15, p. 27; B. 40, p. 23.
Denmark	R. 1915, p. 12.
Depot Hill, Irwin	R. 1907, p. 6.
Ditchingham Estate, Brunswick River	R. 1898, p. 12.
Dongarra	R. 1897, p. 33; R. 1913, p. 13; R. 1915, p. 12, 16.
Donnelly River District	R. 1902, p. 13; R. 1904, p. 19.
Donnybrook	R. 1898, p. 22, 50; R. 1899, p. 12, 34; R. 1900, p. 22; R. 1909, p. 11; B. 44, p. 57; B. 74, p. 75.

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Geological Report.	Reference.
Duketon Centre, Mt. Margaret	B. 24, p. 56.
Dundas Goldfield	R. 1901, p. 15; B. 21.
Dunn's Eight-Mile Centre, Coolgardie ..	B. 31, p. 45.
East Coolgardie Goldfield	R. 1897, p. 64; R. 1898, p. 60; R. 1900, p. 7; R. 1906, p. 7; R. 1909, p. 26; R. 1910, p. 21; B. 42; B. 51; B. 64, p. 52.
Eastern Agricultural Districts	R. 1898, p. 22.
Eastern Creek Centre, Pilbara	B. 52, p. 13, 133.
Eastern Division	R. 1918, p. 22.
East Mount Jackson Centre, Yilgarn ..	R. 1914, p. 30; B. 48, p. 183.
East Murchison Goldfield	B. 45.
Edjudina Centre, North Coolgardie ..	B. 11, p. 13; B. 73, p. 61.
Edjudina and Yundamindra—Country between ..	R. 1903, p. 12.
Eelya Centre, Cue	B. 57, p. 96.
Egina Centre, West Pilbara	R. 1909, p. 20; B. 41, p. 80.
Ennui and Southern Cross—Country between ..	R. 1915, p. 19.
Ennui Centre, Yilgarn	R. 1915, p. 20.
Eradu, Greenough River	R. 1907, p. 7, 11; B. 59, p. 9.
Eristoun Centre, Mt. Margaret	B. 24, p. 52.
Eristoun, North, Centre, Mt. Margaret ..	R. 1905, p. 10.
Errols Centre, Murchison	R. 1906, p. 15; B. 34, p. 12.
Eucalyptus Centre, North Coolgardie ..	B. 11, p. 60; B. 73, p. 49.
Eucala Division	R. 1900, p. 29; R. 1903, p. 33; R. 1910, p. 13.
Eulamina, Mt. Margaret	R. 1907, p. 8; B. 32, p. 76.
Ferguson River	R. 1900, p. 11.
Feysville Centre, East Coolgardie ..	B. 66, p. 60.
Field's Find, Duketon	B. 74, p. 41.
Mora Valley and No. 26 Well—Country between ..	B. 39, p. 45.
Flora Valley and Tanami—Country between ..	B. 39, p. 59.
Ply Brook	B. 65, p. 27.
Portrostan Centre, Yilgarn	R. 1915, p. 20; B. 71, p. 128.
Portescue Valley Centre, West Pilbara ..	B. 41, p. 115.
Gabiantha Centre, Murchison	B. 14, p. 44, 81.
Garden Gully Centre, Murchison	R. 1913, p. 25; R. 1914, p. 24; R. 1915, p. 26; B. 68.
Gascoyne District	R. 1900, p. 26; R. 1901, p. 11; R. 1902, p. 23; B. 10; B. 26, p. 10; B. 48, p. 49; B. 58.
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Gascoyne River Valley	B. 33, p. 8.
Gascoyne and Roebourne—Country between ..	R. 1907, p. 6.
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Geraldton	R. 1897, p. 34; R. 1910, p. 15; R. 1915, p. 17.
Gibraltar Centre, Coolgardie	B. 52, p. 22.
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Golden Ridge Centre, East Coolgardie ..	B. 59, p. 176; B. 66, p. 43.
Golden Valley Centre, Yilgarn	B. 48, p. 124; R. 1915, p. 19; B. 71, p. 309.
Goomalling	R. 1898, p. 28.
Goongarrie	R. 1917, p. 9.
Granites, Tho, North Coolgardie	B. 11, p. 38.
Grassmere	B. 74, p. 49.
Grass Valley	R. 1917, p. 7.
Great Fingal Mine, Day Dawn	R. 1909, p. 24.
Greenbushes Tinfield	R. 1899, p. 7, 15, 52; R. 1900, p. 12; R. 1905, p. 18; R. 1909, p. 14; R. 1914, p. 25; B. 32, p. 7; B. 59, p. 156, 168.
Greenmount Centre, Yilgarn	B. 49, p. 164.
Greenough River District	R. 1907, p. 7, 11; B. 26, p. 34; B. 36, p. 29.
Gum Creek Centre, Nannine	B. 34, p. 15.
Hall's Creek Centre, Kimberley	B. 2, p. 8; R. 1916, p. 29.
Hall's Creek, Wiluna and Tanami—Country between ..	R. 1909, p. 28.

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Hamersley Range and Croydon—Country between ..	B. 33, p. 116.
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Hancocks Centre, East Murchison	B. 31, p. 85; B. 62.
Hayes New Find Centre, Kanowna	R. 1899, p. 11, 23.
Highbury, Narrogin	R. 1908, p. 15.
Holdens Find Centre, Peak Hill	R. 1913, p. 26; B. 59, p. 65.
Hongkong Centre, West Pilbara	R. 1909, p. 20; B. 33, p. 114; B. 41, p. 82.
Hope's Hill Centre, Yilgarn	B. 49, p. 159.
Hopetoun to Fitzgerald R.—Country between ..	R. 1918, p. 11.
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Humphry's Find, Peak Hill	B. 60, p. 186.
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Ilgarero Leascs, Peak Hill	B. 69, p. 186.
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Island, Lake Austin	R. 1901, p. 12.
Jasper Hill, Murchison	R. 1916, p. 21.
Jourdie Hills Centre, Coolgardie	B. 31, p. 48.
Just-in-Time Centre, Pilbara	B. 23, p. 39; B. 40, p. 249.
Kalgoorlie Goldfield	R. 1897, p. 64; R. 1898, p. 60; R. 1900, p. 7; R. 1906, p. 7; R. 1909, p. 26; B. 1910, p. 21; B. 42; B. 51; B. 64, p. 52; B. 69; R. 1915, p. 27, 40.
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Kanowna, North Lead	R. 1899, p. 8, 38; R. 1900, p. 20.
Katanning	R. 1898, p. 23; R. 1917, p. 7.
Kelmscott	R. 1907, p. 8; B. 48, p. 63.
Kendenup	R. 1916, p. 12; B. 74, p. 94.
Kennyville Centre, Yilgarn	B. 49, p. 169.
Kimberley Division	R. 1901, p. 8; R. 1907, p. 5; B. 25; B. 36, p. 111; B. 68; B. 64, p. 11; B. 72, p. 89.
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Kintore Centre, Coolgardie	B. 31, p. 37.
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Kojonup	R. 1898, p. 23.
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Koolan Island	R. 1908, p. 13; B. 64, p. 64.
Koolyanobbing Centre, Yilgarn	R. 1914, p. 29; R. 1916, p. 13; B. 71, p. 188.
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Kurnalpi District, North-East Coolgardie ..	B. 59, p. 13.
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Lake Clifton	R. 1912, p. 11.
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Lake Way	R. 1898, p. 39.
Lake Way and Cue—Country between ..	R. 1898, p. 36.
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Laverton Centre—Mount Margaret	R. 1905, p. 10; B. 24, p. 13.
Laverton—Country between it and South Australian border ..	R. 1916, p. 15; B. 75.
Lawlers Centre, East Murchison	R. 1906, p. 17; B. 28, p. 10.
Lawlers and Darlot—Country between ..	B. 28, p. 51.
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Lawlers and Sandstone—Country between ..	R. 1910, p. 14.
Lawlers and Sir Samuel—Country between ..	B. 28, p. 45.
Lennonville Centre, Murchison	R. 1902, p. 16; R. 1913, p. 23; B. 8; B. 59, p. 91.

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Geological Report.	Reference.
Leonora Centre, Mount Margaret	R. 1903, p. 11; R. 1908, p. 13; R. 1913, p. 17; B. 13; R. 1918, p. 22.
Leschenault Inlet to Lake Preston	R. 1918, p. 14.
Leviathan Centre, East Murchison	B. 28, p. 27.
Linden Centre, North Coolgardie	B. 11, p. 30; B. 73, p. 50; B. 74, p. 102.
Linger and Die Centre, Mount Margaret ..	B. 28, p. 65.
Linger and Die and Wilson's Patch—Country between	B. 28, p. 65.
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Lower Nicol Centre, West Pilbara	B. 41, p. 112.
Lyndon River Valley	B. 32, p. 22.
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Mallina Centre, West Pilbara	R. 1909, p. 19; B. 41, p. 77.
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Marble Bar and Roobourne—Country between	R. 1904, p. 9.
Marda Centre, Yilgarn	R. 1914, p. 30; B. 48, p. 183; B. 71, p. 175.
Margaret River District	B. 36, p. 53.
Marvel Loch Centre, Yilgarn	B. 63, p. 151.
Mary River Centre, Kimberley	B. 2, p. 16.
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* Only those occurrences on which reports have been published are included in this list.

* Now known as Kumalina.

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	Ravensthorpe, Phillips River	R. 1901, p. 17; B. 4, p. 82; B. 5; B. 6, p. 30; B. 16, p. 54; B. 30, p. 39; B. 35, p. 53.
	Red Hill, Ashburton ..	B. 6, p. 29; B. 30, p. 26; B. 33, p. 33.
	Roebourne, West Pilbara	R. 1909, p. 20; B. 4, p. 81; B. 30, p. 26; B. 41, p. 131; B. 52, p. 78, 86, 148.
	Uaroo, Ashburton ..	R. 1909, p. 9; B. 6, p. 29; B. 30, p. 26; B. 33, p. 60.
	Warrawoona, Pilbara ..	B. 52, p. 118.
	Westons Find, Ashburton	R. 1906, p. 28; B. 30, p. 75.
	West River, Phillips River	B. 30, p. 44.
	Whim Creek, West Pilbara	R. 1909, p. 18; B. 4, p. 81; B. 6, p. 29; B. 30, p. 21; B. 41, p. 128; B. 52, p. 77, 86, 147.
	Wongan Hills, South-West	B. 4, p. 82; B. 6, p. 30.
	Yalgoo District ..	B. 30, p. 27.
	Yandanooka District ..	R. 1907, p. 11; B. 6, p. 31; B. 16, p. 54; B. 30, p. 35; B. 38, p. 25.
	Yannery Hill, West Pilbara	B. 52, p. 85.
GERMANIUM— Stibiotantalite ..	Greenbushes, South-West	B. 59, p. 46.
	Bardoe, Broad Arrow ..	R. 1902, p. 9; B. 6, p. 36; B. 30, p. 100.
	Boogardie, Murchison ..	B. 67, p. 118, 119.
	Coates Siding, South-West	R. 1897, p. 10; B. 4, p. 95.
	Collie River District ..	R. 1902, p. 9; B. 6, p. 38.
	Comet Vale, North Coolgardie	B. 67, p. 118, 119.
	Coolgardie District ..	R. 1902, p. 10; B. 4, p. 94; B. 6, p. 37; B. 30, p. 100.
	Darling Range, South-West	R. 1902, p. 10; B. 6, p. 37.
	Edjudina, North Coolgardie	B. 11, p. 15.

Reports on Metals and Minerals, etc.—*continued*.

Metal or Mineral.	Locality.	Reference.
IRON—(continued)—	Gabamitha, Murchison ..	R. 1903, p. 11; B. 14, p. 46, 81; B. 30, p. 99.
	Glenroebourne, West Pilbara	B. 41, p. 133.
	Greenbushes, South-West	R. 1902, p. 10; B. 4, p. 95; B. 6, p. 37; B. 30, p. 100.
	Herdman's Lake, South-West	B. 6, p. 36.
	Horseshoe Range, Peak Hill	B. 4, p. 93.
	Jackson, Yilgarn ..	B. 71.
	Kalgoorlie, East Coolgardie	R. 1902, p. 10; B. 6, p. 37; B. 67, p. 120.
	Kimberley District ..	B. 4, p. 92.
	Koolan Island, Yampi Sound	R. 1908, p. 13.
	Koolyanobbing, Yilgarn ..	R. 1915, p. 37; B. 67, p. 128, 129; B. 71, p. 192, 221.
	Mount Baker, South-West	R. 1902, p. 10; B. 4, p. 95; B. 6, p. 37; B. 30, p. 100.
	Mount Caudan, Yilgarn ..	B. 17, p. 39; B. 30, p. 98; B. 63, p. 74.
	Mount Edith, Ashburton	B. 33, p. 69.
	Mt. Gibson, Yalgoo ..	R. 1916, p. 9.
	Mount Gould, Murchison	R. 1897, p. 18; B. 4, p. 94.
	Mount Hale, Murchison ..	R. 1897, p. 18; R. 1902, p. 8; B. 4, p. 94; B. 6, p. 35, 36; B. 14, p. 82; B. 16, p. 67; B. 30, p. 97.
	Mount Jackson, Yilgarn ..	R. 1902, p. 9; B. 6, p. 36; B. 30, p. 100.
	Mount Mason, North Coolgardie	B. 45, p. 30; B. 67, p. 126, 127.
	Mount Narryer Range, Murchison	R. 1897, p. 17; R. 1902, p. 8; B. 4, p. 94; B. 6, p. 35, 36; B. 14, p. 82; B. 16, p. 67.
	Mount No-Name, Peak Hill	R. 1902, p. 9; B. 6, p. 36.
	Mount Taylor, Murchison	R. 1897, p. 18; R. 1902, p. 8; B. 4, p. 94; B. 14, p. 82; B. 16, p. 67; B. 30, p. 97.
	Munara Hills, Murchison	R. 1902, p. 9; B. 6, p. 36; B. 30, p. 100.
	Murrin Murrin, Mount Margaret	R. 1902, p. 10; B. 6, p. 37; B. 30, p. 100.
	Norseman, Dundas ..	B. 67, p. 130, 131.
	Ora Banda, Broad Arrow	B. 67, p. 118, 119.
	Pinyalling Range, Yalgoo	R. 1902, p. 9.
	Serpentine, South-West ..	R. 1902, p. 10; B. 6, p. 37.
	Star of the East, Murchison	B. 14, p. 46, 81; B. 30, p. 99.
	Wanneroo, South-West ..	B. 6, p. 36.
	Wilgie Mia, Weld Range..	R. 1902, p. 9; R. 1903, p. 11; B. 4, p. 93; B. 6, p. 36; B. 14, p. 78; B. 16, p. 67; B. 30, p. 96; B. 67, p. 73, 74.
	Wiluna, East Murchison..	R. 1902, p. 9; B. 6, p. 36; B. 30, p. 100.
	Wongan Hills, South-West	B. 4, p. 95.
	Yampi Sound (See Koolan Island).	
	Yorilla, North Coolgardie..	B. 73, p. 21.
	Andover, West Pilbara ..	B. 6, p. 32; B. 30, p. 98.
LEAD		

Reports on Metals and Minerals, etc.—continued.

Metal or Mineral.	Locality.	Reference.
LEAD—(continued)—	Balla Balla, West Pilbara	B. 6, p. 32; B. 30, p. 88.
	Coolgardie District ..	B. 6, p. 32; B. 30, p. 88.
	Gerakdine, Northampton	B. 6, p. 32; B. 9, p. 20, 23; B. 30, p. 88.
	Gorge Creek, Ashburton ..	R. 1897, p. 49; B. 6, p. 32; B. 30, p. 88.
	Hall's Creek, Kimberley ..	B. 6, p. 32; B. 30, p. 88.
	Mallina, West Pilbara ..	B. 6, p. 32; B. 30, p. 88.
	Mount DeCourcy, Ashburton ..	B. 6, p. 32; B. 30, p. 88.
	Mount Edith, Ashburton ..	B. 6, p. 32; B. 30, p. 88.
	Mount Stewart, Ashburton	B. 6, p. 32; B. 30, p. 88.
	Mundijong, South-West ..	B. 30, p. 87.
	Napier Range, West Kimberley	R. 1906, p. 11; B. 30, p. 79.
	Narlarla (see Napier Range)	
	Narra Tarra, Northampton	B. 6, p. 32; B. 9, p. 15, 23; B. 30, p. 83; B. 59, p. 223.
	Northampton District ..	R. 1897, p. 11, 64; R. 1906, p. 20; B. 4, p. 78; B. 6, p. 31, 32; B. 9; B. 16, p. 62; B. 30, p. 81.
	Panton River, Kimberley	B. 6, p. 32; B. 30, p. 88.
	Tambourah, Pilbara ..	B. 6, p. 32; B. 23, p. 86; B. 30, p. 88; B. 40, p. 293.
	Uaroo, Ashburton ..	B. 6, p. 32; B. 30, p. 80, 88; B. 33, p. 60; B. 52, p. 88.
	Yalgoo District ..	B. 6, p. 32; B. 30, p. 88.
	Yandanooka District ..	B. 4, p. 82.
	Yannerie Creek, North-West	B. 6, p. 32; B. 30, p. 88.
LITHIUM—		
Amblygonite ..	Ubini, Coolgardie ..	B. 53, p. 17; B. 59, p. 37.
Lepidolite ..	Cocanarup, Kent District	B. 59, p. 37.
	Londonderry, Coolgardie ..	B. 6, p. 57; B. 53, p. 19; B. 59, p. 37.
	Ravensthorpe, Phillips River	B. 59, p. 37.
Lithia Biotite ..	Ubini, Coolgardie ..	B. 48, p. 95.
	Ravensthorpe, Phillips River	B. 6, p. 57; B. 59, p. 37.
Spodumene ..		
MANGANESE ..	Balladonia, Eucla Division	B. 30, p. 103.
	Hamersley River, etc. ..	R. 1918, p. 11.
	Kimberley District ..	B. 4, p. 99.
	Mount Barren Ranges ..	B. 30, p. 103.
	Mount Decker, Phillips River	B. 30, p. 103.
MERCURY ..	Kalgoorlie, East Coolgardie	B. 6, p. 27.
MOLYBDENUM ..	Coolgardie District ..	R. 1897, p. 49.
	Callie Soak, Murchison ..	B. 59, p. 52; B. 64, p. 55.
	Cullewa, Murchison ..	R. 1914, p. 34.
	Linger and Die, Leonora ..	R. 1918, p. 22.
	Mulgine, Yalgoo ..	R. 1916, p. 9; R. 1918, p. 16.
	Poona, Murchison ..	B. 64, p. 55.
	Southern Cross, Yilgarn ..	B. 49, p. 123; B. 59, p. 52; B. 63, p. 100.
	Swan View, Darling Range	R. 1914, p. 23; B. 59, p. 52.
	Warriedar, Yalgoo ..	R. 1915, p. 37.
	Westonia, Yilgarn ..	B. 71, p. 101, 106, 227, 243, 258.
NIOBIUM (see Tantalum).		
RADIUM AND URANIUM	Cooglegong, Pilbara ..	B. 59, p. 53.
	Wodgina, Pilbara ..	R. 1909, p. 10; B. 48, p. 9; B. 59, p. 53.

Reports on Metals and Minerals, etc.—continued.

Metal or Mineral.	Locality.	Reference.
SILVER	Balla Balla, West Pilbara	B. 6, p. 27.
	Coolgardie District ..	B. 6, p. 27.
	Donnybrook, South-West ..	B. 6, p. 26.
	Gorge Creek, Ashburton	R. 1897, p. 49; B. 6, p. 32; B. 30, p. 88.
	Hall's Creek, Kimberley ..	B. 6, p. 27.
	Horseshoe, Peak Hill ..	B. 6, p. 27.
	Kalgoorlie, East Coolgardie	B. 6, p. 26.
	Mallina, West Pilbara ..	B. 6, p. 27.
	Mount Edith, Ashburton ..	B. 6, p. 27.
	Nannine, Murchison ..	B. 6, p. 26.
TANTALUM AND NIOBIUM	Panton River, Kimberley	B. 6, p. 27.
	Red Hill, Coolgardie ..	B. 6, p. 26.
	Tambourah, Pilbara ..	B. 6, p. 27.
	Uaroo, Ashburton ..	B. 6, p. 26; B. 16, p. 65; B. 30, p. 80; B. 52, p. 88.
	Weston's Find, Ashburton	R. 1906, p. 23.
	Yalgoo District ..	B. 6, p. 27.
	Cooglegong, Pilbara ..	B. 59, p. 51.
	Greenbushes, South-West	R. 1905, p. 20; B. 6, p. 42; B. 59, p. 50, 51.
	Green's Well (see Mount York).	
	Londonderry, Coolgardie	R. 1909, p. 27; B. 59, p. 50.
	Moolyella, Pilbara ..	B. 59, p. 49.
	Mount Francisco, Pilbara	B. 30, p. 111.
	Mount York, Pilbara ..	R. 1905, p. 20; B. 23, p. 68; B. 30, p. 108; B. 59, p. 51.
	Poona, Murchison ..	B. 59, p. 49, 51.
	Wodgina, Pilbara ..	R. 1904, p. 21; R. 1905, p. 20; R. 1906, p. 29; B. 23, p. 47, 65, 85; B. 30, p. 109; B. 40, p. 273, 292; B. 52, p. 119; B. 59, p. 49, 51.
	Yalgoo District ..	B. 59, p. 50.
	Kalgoorlie, East Coolgardie	R. 1897, p. 47; B. 6, p. 14; B. 42, p. 163; B. 69, p. 66, 71, 101, 136, 138.
	Mulgabbie, North-East Coolgardie	R. 1904, p. 14.
	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
THORIUM—		
Euxenite ..	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
Fergusonite ..	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
Monazite ..	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
	Moolyella, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
Mackintoshite ..	Wodgina, Pilbara ..	B. 48, p. 12; B. 59, p. 44.
Pilbarite ..	Wodgina, Pilbara ..	B. 48, p. 11; B. 59, p. 44.
Thorogummite ..	Wodgina, Pilbara ..	B. 48, p. 15; B. 59, p. 44.
TIN	Brookton, South-West ..	R. 1907, p. 10; R. 1914, p. 12.
	Coodardie, Murchison ..	B. 57, p. 49.
	Cooglegong, Pilbara ..	B. 23, p. 74, 85; B. 30, p. 54; B. 40, p. 281, 292; B. 52, p. 114.
	Coongan River, Pilbara ..	B. 4, p. 90.
	Greenbushes, South-West	R. 1899, p. 7, 15, 52; R. 1900, p. 12; R. 1905, p. 18; R. 1909, p. 14; R. 1914, p. 25; B. 4, p. 84; B. 6, p. 33; B. 16, p. 67; B. 30, p. 67; B. 52, p. 7; B. 59, p. 156.

Reports on Metals and Minerals, etc.—*continued.*

Metal or Mineral.	Locality.	Reference.
TIN—(continued)—	Green's Well (see Mount York).	
	Kimberley District ..	B. 4, p. 90.
	Federal Downs, West Kimberley ..	B. 59, p. 232.
	Londonderry, Coolgardie ..	R. 1909, p. 27.
	Marble Bar, Pilbara ..	B. 6, p. 34; B. 16, p. 53.
	Moolyella, Pilbara ..	R. 1903, p. 9; B. 15, p. 35, 102; B. 16, p. 58; B. 23, p. 35; B. 30, p. 50; B. 40, p. 99, 291; B. 52, p. 21, 113.
	Mount York, Pilbara ..	B. 23, p. 63; B. 30, p. 55.
	Nannup, South-West ..	B. 30, p. 74.
	Old Shaw, Pilbara ..	B. 4, p. 90; B. 23, p. 74, 76, 85; B. 30, p. 54; B. 40, p. 283, 292.
	Pilbara, West Pilbara ..	R. 1909, p. 20; B. 33, p. 125.
	Poona, Murchison ..	B. 57, p. 54.
	Stannum, Pilbara ..	B. 23, p. 46, 48, 61; B. 30, p. 60; B. 40, p. 269; B. 52, p. 72, 116.
	Wodgina, Pilbara ..	R. 1905, p. 8; R. 1909, p. 17; B. 23, p. 46, 85; B. 30, p. 56; B. 40, p. 256, 291; B. 52, p. 61, 114.
	Yulgering Spring, South-West ..	R. 1909, p. 10; B. 48, p. 105, 174.
TITANIUM	Yulgering Spring, South-West ..	R. 1909, p. 10; B. 48, p. 105, 174.
	Yulgering Spring, South-West ..	R. 1909, p. 10; B. 48, p. 105, 174.
	Yulgering Spring, South-West ..	R. 1909, p. 10; B. 48, p. 105, 174.
TUNGSTEN— Scheelite	Callie Soak, Murchison ..	B. 59, p. 52; B. 64, p. 55.
	Mosquito Creek, Pilbara ..	R. 1904, p. 21; B. 23, p. 85; B. 30, p. 115; B. 40, p. 293.
	Poona, Murchison ..	B. 57, p. 58; B. 64, p. 55.
WOLFRAM	Ravensthorpe, Phillips River ..	B. 30, p. 117.
	Westonia, Yilgarn ..	B. 71, p. 248.
	Brookton, South-West ..	R. 1907, p. 10; B. 30, p. 116.
URANIUM (see Radium).	Coodardy, Murchison ..	B. 57, p. 51.
	Federal Downs, West Kimberley ..	R. 1908, p. 14.
	Mount Singleton, Yalgoo ..	R. 1915, p. 6.
VANADIUM— Pucherite	Poona, Murchison ..	B. 57, p. 58; B. 64, p. 55.
	Westonia	B. 71, p. 95, 96, 100, 106, 248, 258.
	Westonia	B. 71, p. 95, 96, 100, 106, 248, 258.
VANADIUM— Roscoelite	Niagara, North Coolgardie ..	B. 59, p. 48.
	Kalgoorlie, East Coolgardie ..	B. 6, p. 42; B. 59, p. 48.
	Various localities ..	B. 67, p. 118-123.
YTTRIUM— Gadolinite	Cooglegong, Pilbara ..	B. 59, p. 41.
	Cooglegong, Pilbara ..	B. 48, p. 44; B. 59, p. 44.
	Cooglegong, Pilbara ..	B. 59, p. 41.
ZINC	Croydon, West Pilbara ..	B. 30, p. 91.
	Mulline, North Coolgardie ..	B. 30, p. 90.
	Mundijong, Darling Range ..	B. 4, p. 98; B. 30, p. 90.
ZIRCONIUM	Murrin Murrin, Mount Margaret ..	B. 30, p. 90.
	Northampton District ..	B. 4, p. 98; B. 6, p. 40; B. 9, p. 27, 28; B. 30, p. 90.
	Greenbushes, South-West ..	B. 59, p. 45.

Reports on Metals and Minerals, etc.—*continued.*

Metal or Mineral.	Locality.	Reference.
NON-METALS.		
ASBESTOS	Bulong	R. 1917, p. 14.
	Moora	R. 1918, p. 15.
	Pilbara District ..	B. 52, p. 120.
ASBESTOS	Soanesville, Pilbara ..	R. 1906, p. 28; B. 4, p. 101; B. 16, p. 83; B. 23, p. 86; B. 40, p. 293; B. 52, p. 30.
	Tambourah, Pilbara (See Soanesville).	
	Yerilla, North Coolgardie ..	B. 73, p. 64.
ASPHALTUM	South Coast	B. 65, p. 21-24; 40-49.
	Darling Range	R. 1918, p. 19.
	Donnybrook, South-West ..	R. 1914, p. 33.
BAUXITE	Various localities ..	B. 67, p. 14-107; R. 1915, p. 9-11.
	Bellevue	B. 67, p. 104, 105.
	Belmont	B. 67, p. 106.
BUILDING STONE ..	Clackline, South-West ..	R. 1906, p. 24.
	Collie	B. 67, p. 106.
	Dongara	B. 67, p. 102.
CLAYS	Kelmscott, South-West ..	B. 48, p. 63.
	Mount Kokeby	R. 1918, p. 33.
	Newlands, South-West ..	R. 1906, p. 28.
COAL	Three Springs	R. 1918, p. 32.
	West Collie, South-West ..	B. 6, p. 58.
	Albany, South-West ..	R. 1900, p. 16; B. 4, p. 123.
COAL	Busselton, South-West ..	B. 4, p. 118, 119, 120.
	Collie Coalfield	R. 1898, p. 13; R. 1908, p. 6; B. 4, p. 106, 107, 113; 115; B. 6, p. 50.
	Collie Coalfield	B. 16, p. 73; B. 26, p. 57; B. 48, p. 66; B. 64, p. 7.
COAL	Coolgardie District ..	R. 1898, p. 58; B. 6, p. 54.
	Dardanup, South-West ..	B. 4, p. 117; B. 6, p. 53.
	Dongara, South-West ..	R. 1897, p. 33; B. 6, p. 53.
COAL	Donnybrook, South-West ..	R. 1909, p. 11.
	Eradu, Greenough River ..	R. 1907, p. 7, 11; B. 59, p. 9.
	Fitzgerald River	B. 6, p. 64.
COAL	Fly Brook, Donnelly River ..	R. 1902, p. 14; R. 1906, p. 28; B. 4, p. 120; B. 6, p. 54; B. 48, p. 109; B. 65, p. 27.
	Irwin River	R. 1903, p. 17; R. 1907, p. 6; B. 4, p. 103; B. 6, p. 50; B. 10, p. 73; B. 20, p. 56; B. 38, p. 9; R. 1918, p. 22.
	Kimberley District ..	B. 4, p. 121; B. 64, p. 11.
COAL	Newtown, Vasse	B. 4, p. 120.
	South Coast	R. 1898, p. 29; B. 4, p. 122.
	Vasse River, South-West ..	B. 4, p. 118.
COAL	Wilga	R. 1918, p. 12.
	Wyndham, Kimberley ..	B. 4, p. 121.
DIATOMITE	Cape Arid, Eucla	R. 1906, p. 28.
	Jandakot	B. 1903, p. 29.
	Wanneroo, South-West ..	R. 1902, p. 11; R. 1903, p. 28.
GEMS AND PRECIOUS STONES—		
Chrysocolla	Murchison District ..	R. 1903, p. 27.
	Yarra Yarra Creek, Murchison ..	R. 1903, p. 27; R. 1905, p. 21; B. 16, p. 79.
	Yarra Yarra Creek, Murchison ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
Crocidolite	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
Diamond	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.
	Nullagine, Pilbara ..	B. 16, p. 80; B. 20, p. 51; B. 40, p. 152.

The Minister may sell at his discretion, as opportunity offers, the marketable products of smelting, and any balance remaining from the sale of such products, after the deduction of all expenses, inclusive of interest at the rate of 6 per cent. per annum calculated from the time of payment of such expenses up to the date of final adjustment of balances, will be paid to the sellers in final completion of the purchase of such ore or material.

The following are the regulations governing the purchase of ores at the State Smelting Works:—

Regulations for the Purchase of Auriferous Copper Ores at the State Smelting Works, Phillips River Goldfield.

1. All ores shall be delivered free of charge at the works, on such place as may be directed from time to time by the Ore-buyer. The Ore-buyer shall be the person appointed as such by the Minister.

2. The Ore-buyer shall be the sole judge as to whether any parcel of ore shall be accepted for purchase or not, and may order the removal of any ore which he thinks unsuitable; whereupon the owner of the ore shall remove it forthwith from the works.

3. As soon as practicable after receipt of a parcel of ore it shall be weighed at the works, and the weight so determined shall be taken to be the true gross weight thereof. The percentage of moisture present will be determined by assay, and deducted from the gross weight, and the net weight so obtained shall be the weight upon which the ore is purchased. The ton used shall be the standard ton of 2,240 lbs.

4. The vendor, or his representative, may be present during the weighing and sampling of parcels of ore, but shall take no part in the handling thereof, nor interfere in any way with the weighing or sam-

pling, nor approach the ore being sampled nearer than is allowed by the Ore-buyer.

5. After weighing, the ore shall be sampled according to such method as the Ore-buyer shall decide, and three samples shall be drawn—one for assay at the works, one for the vendor, and the third as an umpire sample. The umpire sample shall be sealed in the presence of the vendor or his representative, and retained at the works until required for umpire assay.

6. In the event of the vendor not agreeing with the assay of the Works, the umpire sample shall be sent to the Government Assayer, in Perth, whose analysis shall be accepted as final by both parties. The cost of the umpire assay shall be borne by the party whose assay differs most from the umpire's result. The Government Assayer shall be such officer of the Geological Survey of Western Australia or of the Government Analyst's Department as shall be appointed from time to time by the Minister to carry out such duty.

7. No charge will be made for sampling and assay of any accepted parcel of ore exceeding five tons (5 tons) net weight, but any smaller parcel shall be charged with a fee of One guinea (£1 1s.), except in the case of a *bona fide* first trial parcel from a new working.

8. All parcels of ore which, after sampling, are found unsuitable for purchase by the works shall be charged with a fee for sampling and assay of One guinea (£1 1s.) for each five tons or fraction of five tons net weight contained therein.

9. Assays for copper shall be made by such wet process as the Ore-buyer shall determine, and assays for gold and silver by fire methods, or by any combination of wet and fire methods that may appear to him most suitable.

10. After agreement of assays, the following deductions shall be made from the agreed assay values, in order to arrive at the amounts of the metals for which payment will be made:—

TABLE OF DEDUCTIONS FROM COPPER ASSAYS.

Per Cent.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20 and over.
·0	·07	·74	·81	·88	·95	1·02	1·09	1·16	1·23	1·30	1·37	1·44	1·51	1·58	1·65	1·72	1·79	1·86	1·93	2·00
·2	·08	·75	·82	·89	·96	1·03	1·10	1·17	1·24	1·31	1·38	1·45	1·52	1·59	1·66	1·73	1·80	1·87	1·94	2·00
·4	·70	·77	·84	·91	·98	1·05	1·12	1·19	1·26	1·33	1·40	1·47	1·54	1·61	1·68	1·75	1·82	1·89	1·96	2·00
·6	·71	·78	·85	·92	·99	1·06	1·13	1·20	1·27	1·34	1·41	1·48	1·55	1·62	1·69	1·76	1·83	1·90	1·97	2·00
·8	·73	·80	·87	·94	1·01	1·08	1·15	1·22	1·29	1·36	1·43	1·50	1·57	1·64	1·71	1·78	1·85	1·92	1·99	2·00

No copper under one per cent. to be paid for. Deductions for fractions of one per cent. in assays exceeding one per cent. to be taken from the next higher figure shown on the table, *e.g.*:—

Assay being 0·97 per cent., no copper would be paid for.

Assay being 6·00 per cent., deduction 1·02 would be made and 4·98 per cent. paid for.

Assay being 8·27 per cent., deduction 1·19 would be made as for 8·4, and 7·08 per cent. paid for.

Gold.—No gold to be paid for if assay return is less than 1dwt. per ton. Five per cent. to be deducted from all gold assays returning 1dwt., or more per ton.

Silver.—No silver to be paid for if assay return is less than two ounces per ton. Ten per cent. to be deducted from all silver assays returning two ounces or more per ton.

11. A charge will be made to cover the costs of receiving, sampling, and smelting the ore to matte, of thirty shillings per ton of ore (net weight); and for the further expenses of realising the values therein there shall be an additional charge per ton of ore (net weight) of three shillings and sixpence per unit of copper in the agreed assay value for copper less the schedule deduction aforesaid, and six per cent. of the agreed assay value in gold and silver less schedule deductions. The Ore-buyer may make an extra charge on any parcel of ore in which the silica (SiO_2) exceeds 40 per cent., of sixpence for each unit of silica (SiO_2) in excess of 40.

12. Any ore or metal-bearing material offered for purchase which in the opinion of the Ore-buyer requires sintering before blast-furnace treatment may be charged five shillings per ton for sintering, in addition to the regular smelting charges, and any ores which in his opinion require screening may be screened through a three-quarter inch screen, and charged seven shillings and sixpence per ton of fines passing through the screen, to cover costs of screening and sintering.

13. Ores which contain iron and sulphur in sufficient quantity to have a value as flux and fuel in the treatment of other ores, may be smelted at a reduced charge calculated on such value, at the discretion of the management.

14. A charge will be made of two shillings per ton of ore accepted at the works for purchase for smelting treatment, and shall be payable to the owners of the Smelting Works by way of rental for the use thereof.

15. Forthwith after agreement of assays advances in part payment towards purchase of the ores will be made, if desired by the sellers, after making the foregoing deductions and charges, up to 90 per cent of the net value of the ore, calculated at such prices for the metals contained in it as may be fixed from time to time by the Minister by notice in the *Government Gazette*, and which until further notice will be:—*

Copper—£56 10s. per ton of standard copper.

Gold—80s. per ounce of fine gold.

Silver—2s. per ounce of fine silver.

16. The marketable products of smelting of any ore or metal-bearing material presented to the Smelting Works for purchase will be sold by the Minister at his discretion as opportunity offers, and any balances remaining from the sale of such products after payment of all the expenses incurred by the Government on account of the purchase, receiving, and treatment of such ore or material, and the shipment and selling of the products therefrom, inclusive of interest at the rate of six per cent. per annum calculated from day to day from the time of payment of such expenses up to the date of the final payment of the balances to the sellers, will be paid, in final completion of the purchase of such ore or material, to the sellers thereof in proportion to the percentages which the values of the separate lots form of the total value of all the lots smelted from which the aforesaid products have been derived, calculating such values on the prices assumed as above for the purpose of making advances.

17. All accounts against the State for payments due on account of ore sold to the works shall be rendered on the usual forms of accounts against His Majesty's Government, and shall be certified as correct by the Ore-buyer before being paid.

(d)—Assistance for Boring.

Under Part V. of the Act, the Minister may agree with any Miners' Association, or other body of persons, or with any person, to pay a proportion, not exceeding one-half the total, of the cost of boring either for gold, minerals, or water in any mining centre

* As the market value of copper considerably fluctuates, the ruling fixed price should be ascertained from the State Mining Engineer at Perth or from the Ore-buyer at the State Smelting Works.

Reports on Metals and Minerals, etc.—continued.

Metal or Mineral.	Locality.	Reference.
GEMS AND PRECIOUS STONES (continued)—		
<i>Emerald</i>	Poona, Murchison ..	B. 57, p. 59.
<i>Garnet</i>	Uaroo, Ashburton ..	R. 1903, p. 27; B. 16, p. 79.
<i>Moonstone</i> ..	Bowes River, Victoria District ..	R. 1903, p. 27; B. 16, p. 79.
<i>Opal</i>	Coolgardie District ..	R. 1904, p. 19; B. 16, p. 79.
<i>Tourmaline</i> ..	Coconarup, Kent District ..	R. 1903, p. 27; B. 16, p. 79.
GRAPHITE		
	Allnutt's, Bridgetown ..	B. 4, p. 124.
	Champion Bay District ..	B. 4, p. 124.
	Donnelly River, South-West ..	R. 1905, p. 21; B. 4, p. 124; B. 6, p. 55; B. 67, p. 115-117.
	Kendenup, South-West ..	B. 4, p. 124; B. 67, p. 117; B. 74, p. 34.
	Mount's Brook, South-West ..	B. 6, p. 56.
	Munglinup	B. 76; R. 1918, p. 11.
GYPSUM		
	Northampton	B. 67, p. 115.
	Cliffy Head, Victoria District ..	R. 1903, p. 28; B. 38, p. 37.
LIMESTONE AND LIME SANDS		
	Southern Cross, Yilgarn ..	B. 63, p. 99.
	Busselton, South-West ..	R. 1912, p. 11.
	Capel, South-West ..	R. 1912, p. 11.
	Denmark	R. 1915, p. 12.
	Dongara	R. 1915, p. 12-18.
	Eucula Division	B. 6, p. 62.
	Leschenault Inlet to Lake Preston ..	R. 1918, p. 14.
	Lake Clifton, Waroona ..	R. 1912, p. 11.
	Lime Lake, Wagin ..	R. 1905, p. 14.
	Pinjarra, South-West ..	R. 1912, p. 11; B. 48, p. 82.
	Southern Cross, Yilgarn ..	B. 63, p. 98.
	South-West Division ..	R. 1912, p. 11; R. 1913, p. 18; B. 48, p. 82.
	Various localities ..	B. 67, p. 80-95.
MAGNESITE		
	Bulong, North-East Coolgardie ..	R. 1915, p. 7, 31; B. 82; R. 1917, p. 12.
MICA —		
<i>Biotite</i>	Yerilla, North Coolgardie ..	B. 73, p. 65.
<i>Lepidolite</i> ..	Ubini, Coolgardie ..	B. 48, p. 95; B. 59, p. 37.
<i>Muscovite</i> ..	Londonderry, Coolgardie ..	B. 6, p. 57; B. 53, p. 19; B. 59, p. 37.
	Bellinger, Eucula Division ..	B. 48, p. 103.
	Bindoon, South-West ..	B. 4, p. 100.
	Bussel's Brook, Collie River ..	B. 4, p. 100.
	Darling Range	B. 4, p. 100.
	Londonderry, Coolgardie ..	B. 4, p. 100.
	Mullalyup, Darling Range ..	B. 4, p. 100.
	Nokenena Brook, Northampton ..	B. 4, p. 100.
OCHRES		
	Tambourah, Pilbara ..	B. 4, p. 100.
	Cossack, West Pilbara ..	R. 1906, p. 28.
	Kundip, Phillips River ..	R. 1906, p. 28.
PETROLEUM		
	Albany, South-West ..	R. 1913, p. 16; B. 26, p. 27.
	Donnelly River, South-West ..	R. 1902, p. 14; R. 1904, p. 19; R. 1913, p. 17.
	Nullabor Plains	R. 1918, p. 7.
	Warren River, South-West ..	R. 1902, p. 13; R. 1904, p. 19; R. 1913, p. 16; B. 65.
	Wonnerup	R. 1915, p. 25, 26; B. 74, p. 65.
PHOSPHATES		
	Christmas Island, South Coast ..	R. 1908, p. 6.
	Dandaraga, South-West ..	B. 26, p. 14.
	Western Australia ..	B. 74, p. 1.
POTASH SALTS		
SALT	Lake Cowan, Dundas ..	R. 1914, p. 11.
	Esperance, South Coast ..	B. 16, p. 84.

Reports on Metals and Minerals, etc.—continued.

Metal or Mineral.	Locality.	Reference.
SALT—continued ..		
	Hutt Lagoon, Lynton ..	B. 38, p. 90.
	Lake Polaris, Southern Cross ..	B. 49, p. 44.
	Perenjori	R. 1918, p. 78.
	Rottneet Island	B. 6, p. 44; B. 16, p. 84.
SULPHUR		
	Fraser's Mine, Southern Cross ..	B. 49, p. 123.
	Mount Caudan, Southern Cross ..	B. 63, p. 88.
TALC		
	Mount Taylor, Peak Hill ..	R. 1908, p. 17; B. 48, p. 107.
WATER		
	Various localities ..	B. 67, p. 141-187.

C.—GEOLOGICAL MAPS.

A large number of Geological Maps (*see* Plate 111) have been published, mainly in conjunction with the annual progress reports and bulletins, which it is advisable to study along with the reports in order to render them fully intelligible.

The two following tables have been compiled showing the references to the publications in which these maps appear, arranged in alphabetical order, for easy reference—

(a) Under Mining Centres and individual localities, and

(b) Under Goldfields, Mining Districts, etc.

In the second table, in those cases where the maps do not refer to any particular goldfield or other mining area, they are classed under the Land Divisions into which the State is divided.

GEOLOGICAL MAPS ARRANGED UNDER MINING CENTRES AND INDIVIDUAL LOCALITIES WITH THE REFERENCES TO THE PUBLICATIONS IN WHICH THEY MAY BE FOUND.

(Abbreviations :—R = Annual Progress Report; B = Bulletin; pl. = Plate.)

Geological Map.	Reference.
Abbotts	B. 14, pl. ix.
Arrino	R. 1899, pl. i., ii.
Bamboo	B. 15, pl. iv.; B. 40, pl. iv.
Bangemall	B. 33, pl. ii.
Bardoo	R. 1899, pl. iv.
Barrambie	B. 34, pl. i.
Binduli	B. 56, pl. ii.
Birrigrin	B. 31, ii., pl. iii.
Bonnievale	B. 31, i., pl. vi.
Boogardie	B. 8, pl. ii.; B. 59, pl. ix.
Boorara	B. 66, pl. i.
Boulder Belt	*
Bremer Range	B. 59, pl. xix.
Bullfinch	B. 71, pl. vii. and xi.
Bunbury	R. 1897, pl. iv.
Burtville	B. 24, pl. iv.
Canning River Valley	R. 1899, pl. v.
Cheritons	B. 63, pl. iv.
Collie	R. 1898, pl. i.; B. 64, pl. i.
Coodardie	B. 57, pl. iv.
Coolgardie	R. 1897, pl. vii.; B. 3, pl. ii.
Corinthian	B. 71, pl. viii. and x.
Cuddingwarra	B. 29, i., pl. xvi.
Cue	B. 7, pl. i.; B. 29, i., pl. xvi.
Dandaraga	B. 26, pl. iii.
Davyhurst	B. 12, pl. ii.
Day Dawn	B. 7, pl. i.; B. 29, ii., pl. ix.
Donnybrook	R. 1899, pl. v.; B. 74, pl. vii.
Dulcie	B. 63, pl. iv.

* Issued separately.

† Also 6-sheet map issued separately.

Geological Maps arranged under Mining Centres, etc.—*continued.*

Geological Map.	Reference.
Edjudina	B. 11, <i>pl. i.</i>
Ennuin	B. 71, <i>pl. vi.</i>
Eucalyptus	B. 73, <i>pl. iii.</i>
Feyersville	B. 66, <i>pl. i.</i>
Field's Find, Duketon	B. 74, <i>pl. iii.</i>
Gabanintha	B. 14, <i>pl. vi.</i>
Gindalbie (see Hayes' New Find).	
Glenroobourne	B. 41, <i>pl. v.</i>
Golden Ridge	B. 59, <i>pl. xvi.</i> ; B. 66, <i>pl. iii.</i> to <i>viii.</i>
Grassmore	B. 74, <i>pl. iv.</i>
Great Victoria	B. 63, <i>pl. iii.</i>
Greenbushes	R. 1890, <i>pl. i.</i> ; B. 32, <i>pl. v.</i>
Greenough River	B. 26, <i>pl. v.</i> ; B. 59, <i>pl. i.</i>
Hayes' New Find	R. 1899, <i>pl. iii.</i>
Heaphy's Find	B. 24, <i>pl. iii.</i>
Helona River Valley	R. 1899, <i>pl. vi.</i>
Holden's Find (see Mikhaburra).	
Horseshoe	R. 1897, <i>pl. iii.</i>
Ida H. (see Heaphy's Find).	
Irwin River	R. 1899, <i>pl. iii.</i> ; B. 38, <i>pl. i.</i>
Island, Lake Austin	B. 14, <i>pl. ii.</i>
Jackson	B. 71, <i>pl. xvii.</i>
Just-in-Time	B. 23, <i>pl. iv.</i> ; B. 40, <i>pl. xviii.</i>
Kalgoorlie	B. 42, <i>pl. i.</i> ; B. 51, <i>pl. xii.†</i> ; B. 69, <i>pl. xii. to xiv.</i>
Kanowna	R. 1897, <i>pl. vi.</i> ; B. 47, <i>pl. i.</i> ; B. 77, <i>pl. i. and ii.</i>
Kanowna, North Lead	R. 1899, <i>pl. vi.</i>
Kendenup	B. 74, <i>pl. viii.</i>
Kundip	B. 35, <i>pl. ii.</i>
Kurnalpi	B. 59, <i>pl. ii.</i>
Lake Austin	B. 14, <i>pl. ii., iii.</i>
Lake Barlee	B. 45, <i>pl. i., ii.</i>
Lake Way (see Wiluna).	
Lalla Rookh	B. 15, <i>pl. ii.</i> ; B. 40, <i>pl. ii.</i>
Lancefield	B. 24, <i>pl. ii.</i>
Laverton	B. 24, <i>pl. i.</i>
Laverton to South Australian Border	B. 75, <i>pl. i. to iii.</i>
Lawlers	B. 28, <i>pl. vii.</i>
Lennonville	B. 8, <i>pl. i.</i> ; B. 59, <i>pl. ix.</i>
Leonora	B. 13, <i>pl. i.</i>
Linden	B. 73, <i>pl. ii.</i>
Lindsays	R. 1899, <i>pl. iii.</i>
Mainland, Lake Austin	B. 14, <i>pl. iii.</i>
Marble Bar	B. 20, <i>pl. vii.</i> ; B. 40, <i>pl. xiv.</i>
Marda	B. 71, <i>pl. xviii.</i>
Marvel Loch	B. 63, <i>pl. ii.</i>
Meekatharra	B. 14, <i>pl. viii.</i> ; B. 68, <i>pl. ii.</i> to <i>xv.</i>
Monzies	R. 1899, <i>pl. vii.</i> ; B. 22, <i>pl. vii.</i>
Mikhaburra	B. 59, <i>pl. vii.</i>
Minilya River	B. 26, <i>pl. ii.</i>
Moolyella	B. 15, <i>pl. vii.</i> ; B. 40, <i>pl. vii.</i>
Mosquito Creek	B. 15, <i>pl. vi.</i> ; B. 40, <i>pl. vi.</i>
Mount Desmond	B. 35, <i>pl. ii.</i>
Mount Koith	B. 59, <i>pl. viii.</i>
Mount Magnet	B. 8, <i>pl. ii.</i> ; B. 59, <i>pl. ix.</i>
Mount Morgans	R. 18, <i>pl. i.</i>
Mulgabbie	B. 18, <i>pl. ii.</i>
Mulgabbie	R. 1899, <i>pl. ii.</i>
Mulline	B. 12, <i>pl. i.</i> ; B. 64, <i>pl. xvi.</i>
Mulwarrie	B. 12, <i>pl. ii.</i>
Munglinup	B. 76, <i>pl. i.</i>
Murchison River	R. 1898, <i>pl. v.</i>
Nannine	B. 14, <i>pl. vii.</i>
Narra Tarra	B. 59, <i>pl. xxi.</i>
Norseman	B. 21, <i>pl. vi.</i>
Northampton	R. 1897, <i>pl. i.</i> ; B. 9.
Nullagine	B. 20, <i>pl. i.</i> ; B. 40, <i>pl. viii.</i>
Nungarra	B. 31, <i>ii.</i> , <i>pl. iv.</i> ; B. 62, <i>pl. v.</i>
Olga	B. 63, <i>pl. iv.</i>

Geological Maps arranged under Mining Centres, etc.—*continued.*

Geological Map.	Reference.
Ora Banda	B. 54, <i>pl. i.</i>
Parker's Range	B. 63, <i>pl. iii.</i>
Peak Hill	R. 1897, <i>pl. ii.</i> ; B. 48, <i>pl. ii.</i>
Pennyweight Point	B. 73, <i>pl. iii.</i>
Poona	B. 57, <i>pl. v.</i>
Princess Royal Harbour, Albany	B. 26, <i>pl. iv.</i>
Pyke's Hollow	B. 73, <i>pl. iii.</i>
Quinns	B. 14, <i>pl. v.</i>
Ravensthorpe	B. 35, <i>pl. i.</i>
Rod Hill	B. 33, <i>pl. ix.</i>
Roobourne	B. 33, <i>pl. xi.</i>
Royal Standard, Yuin	B. 59, <i>pl. xii.</i>
Ruby Well	B. 59, <i>pl. iv.</i>
Sandford River	R. 1898, <i>pl. v.</i>
Sandstone	B. 31, <i>ii.</i> , <i>pl. iv.</i> ; B. 62, <i>pl. v.</i>
Sir Samuel	B. 28, <i>pl. vi.</i>
Southern Cross	B. 17, <i>pl. i.</i> ; B. 32, <i>pl. vi.</i> ; B. 49, <i>pl. ii.</i>
Speakman Syndicate Properties	B. 66, <i>pl. ix.</i>
Stannum	B. 23, <i>pl. vi.</i> ; B. 40, <i>pl. xx.</i>
Star of the East	B. 41, <i>pl. vi.</i>
Station Peak	B. 33, <i>pl. xii.</i>
Talga Talga	B. 15, <i>pl. iii.</i> ; B. 40, <i>pl. iii.</i>
Tambourah	B. 23, <i>pl. i.</i> ; B. 40, <i>pl. xv.</i>
Tampa	B. 74, <i>pl. i. and ii.</i>
Transcontinental Railway Route	B. 37, <i>pl. i.</i>
Tuckanarra	B. 14, <i>pl. iv.</i>
Uaroo	B. 33, <i>pl. v.</i>
Wanneroo	R. 1899, <i>pl. iv.</i>
Warrawoona	B. 20, <i>pl. iii.</i> ; B. 40, <i>pl. x.</i>
Weerianna	B. 41, <i>pl. vi.</i>
Western Shaw	B. 23, <i>pl. ii.</i> ; B. 40, <i>pl. xvi.</i>
Westonia	B. 71, <i>pl. ix., xiv., and xv.</i>
Whim Creek	B. 41, <i>pl. iii.</i>
Wiluna	R. 1898, <i>pl. vi.</i> ; B. 34, <i>pl. ii.</i>
Wodgina	B. 23, <i>pl. v.</i> ; B. 40, <i>pl. xix.</i>
Wongan Hills	R. 1898, <i>pl. iv.</i>
Wonnerup	B. 74, <i>pl. v. and vi.</i>
Woodline Rush	B. 59, <i>pl. xiii.</i>
Yandicoogina	B. 15, <i>pl. v.</i> ; B. 40, <i>pl. v.</i>
Yarri	B. 11, <i>pl. i.</i>
Yerilla	B. 64, <i>pl. iii., v.</i>
Yerilla District	B. 73, <i>pl. i. to viii.</i>
Yilgami	B. 73, <i>pl. vii. and viii.</i>
Yuin	B. 59, <i>pl. xii.</i>
Yundamindora	B. 73, <i>pl. iii.</i>

GEOLOGICAL MAPS ARRANGED UNDER GOLDFIELDS, MINING DISTRICTS, ETC., WITH THE REFERENCES TO THE PUBLICATIONS IN WHICH THEY MAY BE FOUND.

(Abbreviations :—R = Annual Progress Report ; B = Bulletin ; *pl.* = Plate.)

Goldfield, Mining District, Etc.	Reference.
Ashburton Goldfield	B. 33, <i>pl. ii., v., ix.</i>
Broad Arrow Goldfield	R. 1899, <i>pl. iv.</i> ; B. 54, <i>pl. i.</i> ; B. 64, <i>pl. xv.</i>
Collie Coalfield	R. 1898, <i>pl. i.</i> ; B. 64, <i>pl. i.</i>
Coolgardie Goldfield	R. 1897, <i>pl. vii.</i> ; B. 3, <i>pl. ii.</i> ; B. 31, <i>i., pl. vi.</i> ; B. 53, <i>pl. i., ii.</i> ; B. 56, <i>pl. i.</i> ; B. 66, <i>pl. i., ii.</i>
Dundas Goldfield	B. 21, <i>pl. vi.</i> ; B. 59, <i>pl. xix.</i>
East Coolgardie Goldfield	B. 42, <i>pl. i.</i> ; B. 51, <i>pl. xii.</i> ; B. 56, <i>pl. i., ii.</i> ; B. 59, <i>pl. xvi.</i> ; B. 64, <i>pl. xv.*</i> ; B. 66, <i>pl. i. to ix.</i> ; B. 69, <i>pl. xii. to xiv.</i>

* Also 6-sheet map issued separately. † Excluding Goldfields and other Mining Areas.

Geological Maps arranged under Goldfields, Mining Districts, etc.—*contd.*

Goldfield, Mining District, Etc.	Reference.
Eastern Division	B. 39, <i>pl. i.</i> ; B. 75, <i>pl. i. to iii.</i>
East Murchison Goldfield	R. 1898, <i>pl. vi.</i> ; B. 28, <i>pl. vi.</i> , vii.; B. 31, ii., <i>pl. iii.</i> , iv.; B. 34, <i>pl. i.</i> , ii.; B. 45, <i>pl. i.</i> , ii.; B. 59, <i>pl. viii.</i> ; B. 62, <i>pl. v.</i>
Eucia Division †	B. 37, <i>pl. i.</i> ; B. 76, <i>pl. i.</i>
Gascoyne Goldfield	B. 33, <i>pl. ii.</i>
Greenbushes Tinfeld	R. 1899, <i>pl. i.</i> ; B. 32, <i>pl. v.</i>
Kimberley Division	B. 25, <i>pl. i.</i>
Mount Margaret Goldfield	B. 13, <i>pl. i.</i> ; B. 18, <i>pl. i.</i> ; B. 24, <i>pl. i.</i> , ii., iii., iv.; B. 74, <i>pl. iii.</i> ; B. 75, <i>pl. i.</i>
Murchison Goldfield	R. 1898, <i>pl. v.</i> ; B. 7, <i>pl. i.</i> ; B. 8, <i>pl. i.</i> , ii.; B. 14, <i>pl. ii.</i> , iii., v., vi., vii., viii., ix.; B. 29, i., <i>pl. xvi.</i> , xvii.; ii., <i>pl. ix.</i> ; B. 57, <i>pl. iii.</i> , iv., v.; B. 59, <i>pl. ix.</i> ; B. 68, <i>pl. ii. to xxv.</i>
Northampton Mining District	R. 1897, <i>pl. i.</i> ; B. 9.
North Coolgardie Goldfield	R. 1899, <i>pl. vii.</i> ; B. 11, <i>pl. i.</i> ; B. 12, <i>pl. i.</i> , ii.; B. 18, <i>pl. ii.</i> ; B. 22, <i>pl. vii.</i> ; B. 64, <i>pl. xvi.</i> ; B. 73, <i>pl. i. to viii.</i> ; B. 74, <i>pl. i. and ii.</i>
North-East Coolgardie Goldfield	R. 1897, <i>pl. vi.</i> ; R. 1899, <i>pl. ii.</i> , iii., vi.; B. 47, <i>pl. i.</i> ; B. 59, <i>pl. ii.</i> , xiii.; B. 77, <i>pl. i. and ii.</i> ; B. 82, <i>pl. i. and ii.</i>
North-West Division †	B. 26, <i>pl. i.</i> , ii.
Peak Hill Goldfield	R. 1897, <i>pl. ii.</i> , iii.; B. 48, <i>pl. ii.</i> ; B. 59, <i>pl. iv.</i> , vii.
Phillips River Goldfield	B. 5, <i>pl. i.</i> ; B. 35, <i>pl. i.</i> , ii.
Pilbara Goldfield	B. 15, <i>pl. ii.</i> , iii., iv., v., vi., vii.; B. 20, <i>pl. i.</i> , ii., iii., vii.; B. 23, <i>pl. i.</i> , ii., iv., v., vi.; B. 40, <i>pl. i.</i> , ii., iii., iv., v., vi., vii., x., xiv., xv., xvi., xviii., xix., xx.; B. 52, <i>pl. x.</i>
South-West Division †	R. 1897, <i>pl. iv.</i> ; R. 1898, <i>pl. iii.</i> , iv.; R. 1899, <i>pl. i.</i> , ii., iii., iv., v., vi.; B. 26, <i>pl. iii.</i> , iv., v.; B. 38, <i>pl. i.</i> ; B. 44, <i>pl. i.</i> ; B. 59, <i>pl. i.</i> , xiii.; B. 65; B. 74, <i>pl. iv. to viii.</i>
West Pilbara Goldfield	B. 33, <i>pl. x.</i> , xi., xii.; B. 41, <i>pl. ii.</i> , iii., v., vi.
Yalgoo Goldfield	B. 59, <i>pl. xii.</i>
Yandanooka Mining District	R. 1899, <i>pl. i.</i> , ii.
Vilgarn Goldfield	B. 17, <i>pl. i.</i> ; B. 32, <i>pl. vi.</i> ; B. 45, <i>pl. i.</i> , ii.; B. 46, <i>pl. i.</i> ; B. 49, <i>pl. ii.</i> ; B. 63, <i>pl. i.</i> , ii., iii., iv.; B. 71, <i>pl. i. to xviii.</i>

† Excluding Goldfields and other Mining Areas.

D.—ASSISTANCE UNDER MINING DEVELOPMENT ACT.

Under "The Mining Development Act, 1902," power is given to subsidise and enable companies or miners to further develop existing gold and other mines, and to render assistance in other directions, which have been dealt with under the following headings:—

- (a) Advances for Pioneer Mining.
- (b) Advances to Miners for Prospecting.
- (c) Establishing of Plant for Crushing, Ore-dressing, Cyaniding, or Smelting—
 - i.—State Batteries.
 - ii.—Subsidised Batteries.
 - iii.—State Smelting Works, Phillips River.
- (d) Assistance for Boring.
- (e) Miscellaneous Assistance.

(a) Advances for Pioneer Mining.

Advances by way of loan may be granted to persons or companies for:—

- (1) Carrying on pioneering mining.
- (2) Procuring, erecting, and connecting machinery, plant, or appliances for such purpose.
- (3) Providing other works and things which, in the opinion of the Minister, may be necessary for such purpose.

As defined by the Act, pioneer mining means carrying on mining operations at places where the expenditure of large sums of money extending over a considerable period of time will be necessary to test or develop the mine.

An application for an advance must be made on the prescribed form, verified by a statutory declaration, giving full particulars of the mine and workings, machinery, and plant, and encumbrances, if any; also a description must be given of the pioneering mining proposed to be done, its object, and a list of the plant required to be purchased, together with an estimate of the cost. It must be clearly set out how it is proposed to expend the advance, the period over which such expenditure will be spread, and the time when instalments will be required and the amounts of each, and such further information, etc., as the Minister may require. In the case of a company, evidence of the incorporation and registration is required, together with a copy of its memorandum and Articles of Association and particulars as to the amount of uncalled capital, assets and liabilities.

After a report from a professional officer, the Minister may, with the approval of the Governor, grant the application with or without modification, and enter into an agreement to advance by way of loan, subject to the Act and regulations, any sum or sums not exceeding in the whole £1,000, which shall be payable in instalments of such amounts and at such times as specified in the agreement on the basis of £1 for every £1 expended by the borrower.

No instalment will be paid until the Minister is satisfied that the borrower has properly expended, in mining operations on the mine, all previous instalments advanced, and has paid all interest (if any) due on any such instalment.

Interest is payable on advances, calculated from the dates of payment of the respective instalments, at the rate of £5 per centum per annum, on dates to be specified in the agreement.

To secure the repayment of the advance and interest and the due performance of the terms of the agreement, a first mortgage of the whole of the mine and, in the case of a company, its other property and assets (except uncalled capital) must be executed by, and at the cost of, the borrower, and no dividends or profits shall be paid to any member or members of the company until all the terms of the agreement have been carried out.

Until all moneys advanced have been repaid and the terms of the agreement complied with, the Minister is empowered to appoint any person to inspect and report on the works and the state of the property and plant of the borrower. Such person shall have access to all books and documents, and any information relative to the undertaking must be supplied by the borrower on demand.

In the case of default, after giving due notice, the Minister may appoint some person to enter into possession of the mine and of all other property and assets of the borrower comprised in the mortgage, who may exercise the powers and authorities of a receiver and manager of the mine, and may carry on the business of the borrower, or may cause the mine, machinery, and other assets comprised in the mortgage to be sold. After repayment, from the proceeds of the sale, of the money advanced and all expenses incurred, the balance, if any, will be paid to the borrower.

(b)—Advances to Miners for Prospecting.

Any miner who is the holder of a miner's right* may be granted by the Minister, after a favourable report by a professional officer, an advance by way of loan, not exceeding £300, for the purpose of enabling and assisting him to prospect for gold or minerals.

* See Chapter VI. in this bulletin for particulars as to who may hold Miner's Rights (Sec. VIII.), privileges conferred by the same (Sec. IX.), and method of taking up and renewal (Sec. XI.).

The applicant must supply a description of the mine upon which is proposed to prospect for gold or minerals, and set out the means by which such prospecting is to be carried on, stating also the period of time over which the advance is to extend, and the instalments in which the same is required, together with the security offered, and how and when the applicant intends to repay the advance. These statements must be verified by statutory declaration, and an agreement entered into with the Minister as to terms and security.

No instalment will be paid until the Minister is satisfied that the applicant has spent, since making the application, £1 out of his own resources for every £1 advanced, and that he has actually and properly expended in mining operations on the mine all previous instalments advanced under the agreement.

(c)—Establishing of Plant for Crushing, Ore-dressing, Cyaniding, or Smelting.

Under Part IV. of the Act, the Minister may purchase and erect or hire plant for testing the value of, or treating, metalliferous material for the public or subsidise companies or persons willing to erect and work such plant at such rates as may be agreed upon.

Such plant will be erected or subsidised only in those districts in which, after a report from a professional officer, the Minister is satisfied that—

- (a) Large deposits of metalliferous ores exist; and
- (b) The plant and appliances for testing or treating such deposits in bulk at reasonable rates are not available; and
- (c) The establishment of such plant is necessary for the development of mining.

Under this part of the Act, assistance has been rendered—

- (i.)—by the erection of State batteries;
- (ii.)—by subsidising private batteries for public treatment; and
- (iii.)—by the purchase and treatment of auriferous copper ores at the State Smelting Works, Phillips River.

(i.) —STATE BATTERIES.

By the regulations under which stone is crushed at the State batteries, power is given to the battery manager to refuse any parcel considered too poor to pay crushing charges, unless a deposit is paid in advance.

The charges for crushing, which vary at the different batteries, are fixed from time to time by the Hon. the Minister for Mines, and may be ascertained from the battery managers. Payment must be made on completion of the crushing or sufficient gold will be retained to cover the amount due.

Where a cyanide plant is erected at a battery, tailings (sands and slimes) resulting from the crushing may be purchased by the Government on their assay value, but the manager is given discretion to refuse to buy any tailings which he may consider unsuitable for cyanide treatment. Tailings will be paid for within two months of the date of agreement of assays at the rate of 75 per cent. of the gold contents after deducting 3dwts. per ton to cover loss and costs of treatment. No payment is made for tailings assaying less than 3dwts. per ton. The number of tons to be paid for is determined by the manager.

In the case of dispute of values, the umpire assay of the Government Assayer, attached to the Geological Survey Department in Perth, shall be accepted as final, and the fee for the umpire assay must be paid by the party whose assay differs most from the umpire's result.

The following are the Regulations governing State batteries:—

Regulations under which Stone will be crushed and Tailings purchased at the State Batteries.

(1.) All stone accepted for treatment at State batteries shall be estimated at 22 cubic feet per ton, except where weighing machines are provided, when stone must pass over same to ascertain weight.

(2.) The manager of the battery may refuse any stone considered too poor to pay crushing charges, unless a deposit is paid in advance.

(3.) The charge for crushing at each battery, as determined from time to time by the Hon. the Minister for Mines, shall be posted up at each battery and strictly adhered to while in force.

(4.) A minimum charge will be made for all parcels of less tonnage than will return five pounds on the rate charged per ton.

(5.) Payment for treatment shall be made to the manager on completion of crushing, or sufficient gold will be retained to pay the amount due.

(6.) Where a cyanide plant has been erected at a battery, tailings consisting of sands and slimes resulting from stone crushed at that battery may be purchased, but the manager may, in his discretion, refuse to purchase any tailings should he consider them unsuitable for treatment by cyanide.

(7.) The tailings (including slimes) produced from each parcel crushed may be purchased at such plants as may be approved, and will be paid for by the Department within two months of the date of agreement of assays, at the rate of seventy-five per cent. (75 per cent.) of the gold contents after deducting three (3) pennyweights per ton to cover loss and costs of cyanide treatment.

Gold to be paid for at the rate of 80s. per ounce.

(8.) The number of tons of tailings to be paid for from each parcel shall be determined by the manager, whose decision shall be final, but the amount shall not be less than 80 per cent. or more than 90 per cent. of the tons crushed.

(9.) The manager shall take samples of the tailings as they pass through the battery or from the vats into which the tailings may be deposited. The sample collected shall be thoroughly mixed and divided into four samples, one for assay by the manager, and one for the vendor; the other two shall be sealed, one being sent to the Perth office of the Mines Department, and the other kept by the manager for reference or umpire if necessary.

(10.) Within three weeks of the completion of the crushing the vendor and manager shall compare assays, and if these differ by not more than six grains per ton the mean of the assays shall be accepted as correct. If there should be a greater difference than six grains between the assays, the umpire sample shall be sent by the manager to the Government Assayer at Perth, whose assay shall be accepted as final by both parties. The cost of the umpire's assay (10s.) shall be borne by the party whose assay differs most from the umpire's result. The manager's assay shall not be made known to the vendor until he has produced his assay certificate for comparison of assays or has agreed in writing to accept the manager's assay. If the vendor does not produce an assay certificate for comparison within 21 days of the completion of the crushing, the manager's assay shall be final.

If the manager considers any sample shows an abnormal assay value for the grade of ore producing the tailings, he may refer the matter to the Minister, whose decision as to the values to be paid on shall be indisputable and final.

(11.) All tailings assaying less than three (3) pennyweights per ton shall become the property of the Government.

(12.) Where no cyanide plant has been erected at a battery, any person desirous of claiming tailings, the proceeds of his crushing, may remove them to a site clear of the settling area immediately the crushing is completed, and must notify the manager of his intention to do so previous to commencement of the crushing. All tailings not so removed shall be deemed abandoned, and may be dealt with as the Minister may direct.

(13.) All stone will be delivered and received for treatment absolutely at the owner's risk, and the Government shall not be responsible for any suspension of operations, delays in treatment, or for any loss or damage arising from any cause whatsoever.

(14.) Any customer or his deputy may be present during the crushing of his parcel, but shall take no part in the treatment except by the express permission and under the direction of the manager.

(15.) At every battery there shall be kept a book in which shall be recorded the number of tons in each parcel left for treatment, the name, locality, and number of the lease or holding from which it is obtained, and the name of the person for whom the stone is to be crushed.

(16.) A copy of the foregoing rules shall be inserted in the said book, and every person sending stone for treatment shall sign opposite the entry relating to the stone lodged by him, and such signature shall be sufficient evidence that he is cognisant of the foregoing rules and agrees to be bound by them.

(17.) For the purpose of these Regulations Government Assayer shall mean the Mineralogist and Assayer of the Geological Survey of Western Australia.

Upwards of 30 State Batteries are at present crushing for the public, these have been arranged alphabetically under Goldfields in the table below:—

STATE BATTERIES IN OPERATION ON 1ST NOVEMBER, 1918, ARRANGED ALPHABETICALLY UNDER GOLDFIELDS.

Goldfield.	State Battery.
Broad Arrow	Ora Banda.
Coolgardie	Coolgardie
	Siberia.
Dundas	Norseman.
East Murchison	Black Range.
	Darlot.†
	Mount Keith.
	Mount Sir Samuel.
	Wiluna.
	Youanme.
Greenbushes *	Bunbury End.†
	Salt Water Gully.†
Mount Margaret	Burtville.
	Laverton.
	Leonora.
Murchison	Boogardie.
	Cue.
	Meekatharra.
	Quinns.
North Coolgardie	Tuckanarra.†
	Linden.
	Mount Ida.
	Mulline.
	Mulwarrie.
	Niagara.
	Pinjin.
	Yarri.
	Yorilla.
Peak Hill	Mount Egerton.
Pilbara	Peak Hill
	Bamboo Creek.
	Marble Bar.
	Twenty-mile Sandy.
Yalgoo	Payne's Find.
	Warriedar

* Tinfeld. † Fort treatment of Tin Ores. ‡ Leased.
See List of Subsidised Batteries, page 17.

SUBSIDIES ON CERTAIN ORE CRUSHED AT STATE BATTERIES.

As a further encouragement of mining development, Subsidies, at the rates specified in the regulations hereunder, are given on ore, the result of development work in a mine below 100 feet vertical from the surface, which is crushed at any State battery.

Development work may take the form of shaft-sinking, driving, crosscutting, rising, or sinking a winze, provided that the same shall be at least 40 feet distant from any other such development work. Certain restrictions are made as to the sizes of shafts, drives, crosscuts, rises, and winzes.

Allowance is made for the country rock or lode material removed by granting subsidy on one ton of ore, broken out and crushed from any other part of the workings, for each 13 cubic feet of solid country mined. The ore, however, must be crushed within six months of the stoppage of the development work in respect of which the subsidy is claimed.

Notice in the prescribed form, accompanied by a plan of the existing workings, must be lodged with the battery manager by the applicant for subsidy, and the proposals made must be approved, in writing, by the Inspector of Mines, or in his absence by the battery manager, prior to work being commenced, and, after the resultant ore has been crushed, the applicant must lodge with the manager a claim for subsidy in the prescribed form. Crushing charges must be paid at the time of crushing at the ordinary rate, and, if the application is approved, the amount of the subsidy due will be made available through the battery manager. No development work will be eligible to be subsidised unless the proposals in respect thereto have been first approved, in writing, by the Inspector of Mines or battery manager.

The Minister may refuse to allow a subsidy unless he is satisfied that the work has been done in a workmanlike and advantageous manner, or if the mine is known to be of such a payable character that the granting of a subsidy is not justified.

The regulations relating to subsidies are given below:—

Regulations relating to Subsidies for the Crushing of Ore at State Batteries.

1. Subject to these Regulations subsidies at the rates herein stated may be given on ore the result of development work done in a mine below 100 feet from the surface, when such ore is crushed at any State battery, viz:—

s.	d.	
2	0	per ton on ore raised from depths of 100 to 110 feet.
2	3	" " " 110 to 125 "
2	6	" " " 125 to 150 "
2	9	" " " 150 to 175 "
3	0	" " " 175 to 200 "
3	3	" " " 200 to 225 "
3	6	" " " more than 225 "

The depth shall be taken as the vertical depth below the natural surface at the mouth of the shaft or adit in or from which the said work is performed, and in the case of work done from a level, the depth of the level will be taken as the depth thereof at the shaft from which it is driven.

2. Development work shall mean—

- (a) Sinking a shaft;
- (b) Driving;
- (c) Crosscutting;
- (d) Rising, or
- (e) Sinking a winze.

provided each drive, crosscut, rise, or winze shall be at least 40 feet distant from any other drive, crosscut, rise, or winze recognised as development work. No subsidy will be paid on stone taken from shafts of less dimensions than 5 feet by 3 feet, or from rises or winzes less than 4 feet 6 inches by 2 feet, or from drives or crosscuts less than 4 feet 6 inches by 2 feet (mean width), and any shaft, rise, winze, drive, or crosscut of greater dimensions than 6 feet 6 inches by 3 feet 6 inches (mean width) shall for the purposes of these Regulations be deemed to be 6 feet 6 inches by 3 feet 6 inches as maximum dimensions.

3. In approved development work, carried out in accordance with these Regulations, the amount of country rock or lode material removed shall be allowed for by granting subsidy on one ton of ore broken out and crushed from any other part of the workings of the mine, for each 13 cubic feet of solid country so mined. Provided that no claim for subsidy will be entertained unless the ore is crushed within six (6) months of the stoppage of development work in respect of which it is claimed.

4. Any person intending to proceed with development work with the object of participating under these Regulations must give notice in the form of Schedule A hereto, and deposit with the manager of the State battery a plan of the workings as they then exist, otherwise he will not be eligible to receive a subsidy, and on completion of the work, and after the ore resultant therefrom shall have been crushed, he shall lodge with the manager a claim for subsidy in the form of Schedule B hereto. The crushing charges on all stone crushed for any person having given notice as prescribed shall, at time of crushing, be paid at the ordinary crushing rate, provided that if after inspection by an officer of the Department the application is approved, the amount of subsidy due will be made available through the manager, who shall in each case forward all applications to Head Office, with his recommendation on same.

5. No development work shall be eligible to be subsidised unless the applicant's proposals in respect thereto shall have first been approved, in writing, by the Inspector of Mines, or by the Manager of the State Battery if the Inspector is not readily available.

6. The Minister may, if he think fit, refuse to allow a subsidy on development work in any mine unless he is satisfied from the reports of the inspecting officer that the mining operations have been carried on in a workmanlike manner, and that the development work is laid out to the advantage of the mine, or if the mine is known to be of such payable character that in his judgment the granting of a subsidy is not justified.

SCHEDULE A.

Notice of Intention to claim Subsidy.

Place,.....
Date,.....

Inspector of Mines,

I hereby give notice that I propose to proceed with development work on my Lease (or Claim) No....., known as..... in theGoldfield, and I intend making application for subsidy on same in accordance with the Regulations.

The proposed development work is as follows:—

.....
and I attach a sketch or plan which shows the workings of the mine as they now exist.

....., Signature.
Received at the State Battery.....
on the.....day of.....

Battery Manager.

SCHEDULE B.

Application for Subsidy.

Inspector of Mines,

In accordance with Regulations issued by the Department of Mines herein, I hereby apply for subsidy of..... per ton on tons of ore crushed at the..... State Battery, the result of development work performed by me on Lease No..... known as..... in theGoldfield.

I declare that the sketch of workings (as shown hereunder), although not to scale, indicates truly the nature and position of the work on which the claim is put forward, and the following particulars are correct.

Depth (in feet) at which work is carried out.	Nature of Work.	Length (feet).	Dimensions. (feet and inches).
	Sinking a shaft ..		
	Driving		
	Cross-cutting ..		
	Rising		
	Sinking a Winze ..		

....., Signature.

....., Date.

Sketch of Workings.

(ii).—SUBSIDISED BATTERIES.

In addition to the State batteries, many privately-owned batteries are subsidised by, or are under an arrangement with, the Government for public treatment in localities where the erection of special State batteries is not considered justifiable owing to the existing plants being able to deal with the stone raised in the district. As regards public crushings at these batteries, the terms and conditions of crushing are more or less based upon those in force at the State batteries; but vary considerably in different instances.

These conditions and the crushing charges may be ascertained from the battery managers.

The batteries which are under obligation to crush for the public have been alphabetically arranged under Goldfields and Centres in the following table:—

BATTERIES UNDER OBLIGATION TO CRUSH FOR THE PUBLIC IN OPERATION ON 31ST DECEMBER, 1917, ALPHABETICALLY ARRANGED UNDER GOLD-FIELDS AND DISTRICTS.

Goldfield.	District.	Battery.
Coolgardie	Kunanalling	Blue Bell.
East Murchison	Birriguin	Reply.
Do.	Curran's Find	Red, White, and Blue.
Do.	Lawlers	Queen.
Do.	do.	Great Eastern.
Mt. Margaret	Leonora	King of the Hills.
Murchison	Holden's Find	Waterloo.
Do.	Ruby Well	Harder to Find.
Do.	Tuckanarra	State Battery (leased.)
Northampton	Northampton	Kirkton's South.
North Coolgardie	Edjudina	Nota.
Do.	Pingin	State Battery (leased.)
Do.	Tampa	The Grafton.
Do.	Yundamindera	Battlesville.
North-East Coolgardie	Mulgarrig	Lady Pratt.
Phillips River	Knudip	Gem.
Yilgarn	Golden Valley	Violet.
Do.	Hope's Hill	Lakoside.
Do.	Marda	Butcher Bird.
Do.	Marvel Loch	Great Victoria.
Do.	do.	Howlett's.
Do.	Parker's Range	Spring Hill.
Do.	Westonia	Edna May Battler.
Do.	do.	Greenfinch.

(iii).—STATE SMELTING WORKS, PHILLIPS RIVER.

The Government will, under certain conditions, purchase auriferous copper ores at the State Smelting Works situated in the Phillips River Goldfield.

All ore must be delivered free of charge to the works, and deposited where directed by the Ore-buyer, who is given discretion to refuse to purchase any particular parcel of ore, in which case the owner must forthwith remove the same from the works. Ore parcels are subject to a fee of one guinea for each five tons or fraction thereof to cover the cost of sampling and assaying.

Advances will be made, if desired, after allowing for the deductions and charges enumerated below, up to 90 per cent of the net value of the ore calculated at such prices as may from time to time be fixed by the Minister.*

In the event of the vendor not agreeing with the works assay, the umpire sample will be sent to the Government Assayer, attached to the Geological Survey Department, whose result must be accepted as final, and the cost of the umpire assay must be borne by the party whose assay differs most from the umpire's result.

No copper under 1 per cent. is paid for, and all assay values of 1 per cent. or over are subject to certain deductions as laid down in the regulations. No gold is paid for when the assay return is less than 1dwt. per ton, and 5 per cent is deducted from all gold assays returning 1dwt. or more per ton. Silver is not paid for when the assay return is less than 2ozs. per ton, and 10 per cent. is deducted from all silver assays over that value.

A charge of 30s. per ton of ore (net weight) is made to cover the cost of receiving, sampling, and smelting the ore to matte, and a further charge is levied to cover the costs of realisation. Discretion is given to the Ore-buyer to make an extra charge in cases where the percentage of silica is excessive, or where the material requires screening or sintering before blast furnace treatment, or, where the ore contains iron and sulphur in sufficient quantity to be valuable as flux and fuel in the treatment of other ores, to allow a reduction in the smelting charges.

* The ruling fixed prices may be ascertained from the State Mining Engineer at Perth or from the Ore-buyer at the State Smelting Works.

The Minister may sell at his discretion, as opportunity offers, the marketable products of smelting, and any balance remaining from the sale of such products, after the deduction of all expenses, inclusive of interest at the rate of 6 per cent. per annum calculated from the time of payment of such expenses up to the date of final adjustment of balances, will be paid to the sellers in final completion of the purchase of such ore or material.

The following are the regulations governing the purchase of ores at the State Smelting Works:—

Regulations for the Purchase of Auriferous Copper Ores at the State Smelting Works, Phillips River Goldfield.

1. All ores shall be delivered free of charge at the works, on such place as may be directed from time to time by the Ore-buyer. The Ore-buyer shall be the person appointed as such by the Minister.

2. The Ore-buyer shall be the sole judge as to whether any parcel of ore shall be accepted for purchase or not, and may order the removal of any ore which he thinks unsuitable; whereupon the owner of the ore shall remove it forthwith from the works.

3. As soon as practicable after receipt of a parcel of ore it shall be weighed at the works, and the weight so determined shall be taken to be the true gross weight thereof. The percentage of moisture present will be determined by assay, and deducted from the gross weight, and the net weight so obtained shall be the weight upon which the ore is purchased. The ton used shall be the standard ton of 2,240lbs.

4. The vendor, or his representative, may be present during the weighing and sampling of parcels of ore, but shall take no part in the handling thereof, nor interfere in any way with the weighing or sam-

pling, nor approach the ore being sampled nearer than is allowed by the Ore-buyer.

5. After weighing, the ore shall be sampled according to such method as the Ore-buyer shall decide, and three samples shall be drawn—one for assay at the works, one for the vendor, and the third as an umpire sample. The umpire sample shall be sealed in the presence of the vendor or his representative, and retained at the works until required for umpire assay.

6. In the event of the vendor not agreeing with the assay of the Works, the umpire sample shall be sent to the Government Assayer, in Perth, whose analysis shall be accepted as final by both parties. The cost of the umpire assay shall be borne by the party whose assay differs most from the umpire's result. The Government Assayer shall be such officer of the Geological Survey of Western Australia or of the Government Analyst's Department as shall be appointed from time to time by the Minister to carry out such duty.

7. No charge will be made for sampling and assay of any accepted parcel of ore exceeding five tons (5 tons) net weight, but any smaller parcel shall be charged with a fee of One guinea (£1 ls.), except in the case of a *bona fide* first trial parcel from a new working.

8. All parcels of ore which, after sampling, are found unsuitable for purchase by the works shall be charged with a fee for sampling and assay of One guinea (£1 ls.) for each five tons or fraction of five tons net weight contained therein.

9. Assays for copper shall be made by such wet process as the Ore-buyer shall determine, and assays for gold and silver by fire methods, or by any combination of wet and fire methods that may appear to him most suitable.

10. After agreement of assays, the following deductions shall be made from the agreed assay values, in order to arrive at the amounts of the metals for which payment will be made:—

TABLE OF DEDUCTIONS FROM COPPER ASSAYS.

Per Cent.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20 and over.
+0 ...	·07	·74	·81	·88	·95	1·02	1·09	1·16	1·23	1·30	1·37	1·44	1·51	1·58	1·65	1·72	1·79	1·86	1·93	2·00
+2 ...	·68	·75	·82	·89	·96	1·03	1·10	1·17	1·24	1·31	1·38	1·45	1·52	1·59	1·66	1·73	1·80	1·87	1·94	2·00
+4 ...	·70	·77	·84	·91	·98	1·05	1·12	1·19	1·26	1·33	1·40	1·47	1·54	1·61	1·68	1·75	1·82	1·89	1·96	2·00
+6 ...	·71	·78	·85	·92	·99	1·06	1·13	1·20	1·27	1·34	1·41	1·48	1·55	1·62	1·69	1·76	1·83	1·90	1·97	2·00
+8 ...	·73	·80	·87	·94	1·01	1·08	1·15	1·22	1·29	1·36	1·43	1·50	1·57	1·64	1·71	1·78	1·85	1·92	1·99	2·00

No copper under one per cent. to be paid for. Deductions for fractions of one per cent. in assays exceeding one per cent. to be taken from the next higher figure shown on the table, *e.g.*:—

Assay being 0·97 per cent., no copper would be paid for.

Assay being 6·00 per cent., deduction 1·02 would be made and 4·98 per cent. paid for.

Assay being 8·27 per cent., deduction 1·19 would be made as for 8·4, and 7·08 per cent. paid for.

Gold.—No gold to be paid for if assay return is less than 1dwt. per ton. Five per cent. to be deducted from all gold assays returning 1dwt., or more per ton.

Silver.—No silver to be paid for if assay return is less than two ounces per ton. Ten per cent. to be deducted from all silver assays returning two ounces or more per ton.

11. A charge will be made to cover the costs of receiving, sampling, and smelting the ore to matte, of thirty shillings per ton of ore (net weight); and for the further expenses of realising the values therein there shall be an additional charge per ton of ore (net weight) of three shillings and sixpence per unit of copper in the agreed assay value for copper less the schedule deduction aforesaid, and six per cent. of the agreed assay value in gold and silver less schedule deductions. The Ore-buyer may make an extra charge on any parcel of ore in which the silica (SiO_2) exceeds 40 per cent., of sixpence for each unit of silica (SiO_2) in excess of 40.

12. Any ore or metal-bearing material offered for purchase which in the opinion of the Ore-buyer requires sintering before blast-furnace treatment may be charged five shillings per ton for sintering, in addition to the regular smelting charges, and any ores which in his opinion require screening may be screened through a three-quarter inch screen, and charged seven shillings and sixpence per ton of fines passing through the screen, to cover costs of screening and sintering.

13. Ores which contain iron and sulphur in sufficient quantity to have a value as flux and fuel in the treatment of other ores, may be smelted at a reduced charge calculated on such value, at the discretion of the management.

14. A charge will be made of two shillings per ton of ore accepted at the works for purchase for smelting treatment, and shall be payable to the owners of the Smelting Works by way of rental for the use thereof.

15. Forthwith after agreement of assays advances in part payment towards purchase of the ores will be made, if desired by the sellers, after making the foregoing deductions and charges, up to 90 per cent. of the net value of the ore, calculated at such prices for the metals contained in it as may be fixed from time to time by the Minister by notice in the *Government Gazette*, and which until further notice will be:—*

Copper—£56 10s. per ton of standard copper.

Gold—80s. per ounce of fine gold.

Silver—2s. per ounce of fine silver.

16. The marketable products of smelting of any ore or metal-bearing material presented to the Smelting Works for purchase will be sold by the Minister at his discretion as opportunity offers, and any balances remaining from the sale of such products after payment of all the expenses incurred by the Government on account of the purchase, receiving, and treatment of such ore or material, and the shipment and selling of the products therefrom, inclusive of interest at the rate of six per cent. per annum calculated from day to day from the time of payment of such expenses up to the date of the final payment of the balances to the sellers, will be paid, in final completion of the purchase of such ore or material, to the sellers thereof in proportion to the percentages which the values of the separate lots form of the total value of all the lots smelted from which the aforesaid products have been derived, calculating such values on the prices assumed as above for the purpose of making advances.

17. All accounts against the State for payments due on account of ore sold to the works shall be rendered on the usual forms of accounts against His Majesty's Government, and shall be certified as correct by the Ore-buyer before being paid.

(d)—Assistance for Boring.

Under Part V. of the Act, the Minister may agree with any Miners' Association, or other body of persons, or with any person, to pay a proportion, not exceeding one-half the total, of the cost of boring either for gold, minerals, or water in any mining centre

* As the market value of copper considerably fluctuates, the ruling fixed price should be ascertained from the State Mining Engineer at Perth or from the Ore-buyer at the State Smelting Works.

or other locality where he is satisfied, after receipt of a report from a professional officer, that such boring has a reasonable prospect of success.

All wages and expenses incidental to the boring must be paid by the persons or person to whom assistance is granted and, on production of receipted pay-sheets or vouchers, the Minister, on being satisfied that the boring is being carried out with due care and despatch, will refund such proportion of the expenditure as may have been agreed upon. The Minister, if satisfied, after a report from a professional officer, that such boring is in the general interest of the State, may, with the approval of the Governor, pay

When boring has been undertaken, the Minister may reserve any area of Crown land adjacent to the site as will, in the opinion of his professional advisers, be tested by such boring and may grant, on such terms as he may think fit and with the approval of the Governor, a claim, lease, or other holding to the persons or person by whom the boring was undertaken in priority to any other person, and may require the applicants to pay, by way of premium, such proportion of the cost of boring, and in such manner as he may consider reasonable. The Minister may also call tenders for such lease and may, at his discretion, apply any premium, or part thereof, to reimburse any persons or person the moneys expended by them or him in boring.

(e)—Miscellaneous Assistance.

In addition to the foregoing, the Minister may advance, or himself expend, money for the following purposes:—

- (1) To drain any mining area;
- (2) To assist mining by sinking or cross-cutting for further make of stone;
- (3) To sink shafts for the purpose of prospecting for gold, or any mineral or metal, at great depths below the surface, at places in respect of which the expenditure of large sums of money, extending over a considerable period, will be necessary; or
- (4) To provide means of transport for miners to prospect unproved country.

The Minister is empowered to call for tenders and enter into contracts for any such works.

E.—ASSISTANCE UNDER INDUSTRIES ASSISTANCE ACT.

Under Part 3, Section 24, of "The Industries Assistance Act, 1915," the Colonial Treasurer may render financial assistance by making advances, or guaranteeing the repayment of advances to be made, to any person engaged in mining or any other industry, if it is proved to his satisfaction that assistance should be given in the interests of the State, and that it is not practicable for the applicant to obtain such assistance through the ordinary financial channels.

Advances shall be repayable as may be determined by the Colonial Treasurer, who shall fix the rate of interest on the same, which shall not be less than 6 per cent. per annum, calculated on the daily balance. Such advances shall be secured by a mortgage or other security as may seem fit to the Colonial Treasurer who may, at his discretion, exempt such securities from stamp duty or registration fees.

F.—ADVANCES ON ORES.

The Government will undertake the shipment to market and sale of metalliferous ores and concentrates, the produce of mines or mining operations in the State, on behalf of owners, and will make Cash Advances thereon on the following terms and conditions:—

Regulations under which Advances on Ores are made to Owners.

1. The ores and concentrates shall be such as contain lead, tin, or copper as their principal metallic constituent, but the Minister for Mines from time to time may direct that any other ores, minerals, or

metalliferous products of marketable value may be accepted and dealt with similarly.

2. All such ores, concentrates, minerals, and products shall be the produce of mines and mining operations in the State of Western Australia, and hereinafter shall be deemed to be included in the words "ore" or "ores."

3. All ores shall be delivered, at the cost of the owner thereof, at the sampling floor of the Mines Department, in the J Shed, North Wharf, Fremantle, or at such other place as may be directed from time to time by the Minister, and shall be packed suitably for long distance shipment in boxes, cases, or new strong ore-bags of good quality, marked with distinctive legible and indelible letters and marks plainly and readily visible. Unless otherwise allowed by the State Mining Engineer on account of the nature of the material, all large lumps of ore before being bagged or packed shall be broken into pieces small enough to pass easily through a circular metal ring of three inches internal diameter. To facilitate correct sampling, the whole of the ore in each parcel for shipment shall be thoroughly mixed before being packed or bagged, so as to have approximate uniformity in the values of the contents of each bag or case. If it be found, when sampling, that any parcel of ore has not been broken and mixed as aforesaid, the owner may be charged with the whole cost of so breaking and mixing it and rebagging it at the sampling floor, in addition to the usual sampling charges.

4. The person appointed as Sampler shall sample each lot of ore, in accordance with instructions from time to time given to him by the State Mining Engineer, and shall thereupon forward the samples to the Geological Survey Laboratory in Perth for assay. The owner of the ore or his representative may watch the sampling, but shall not interfere therewith in any way, nor touch anything in connection therewith, nor approach nearer than is allowed by the Sampler. If he so desire he will be supplied with a portion of the final sample.*

5. For the purpose of making advances, the net weight of the ore as determined by the State Mining Engineer, and the assay value as determined at the Geological Survey Laboratory, shall be deemed to be correct, and shall not be subject to appeal to any umpire.

6. No ore will be shipped for sale until the results of assay have been obtained, unless the Sampler is fully satisfied that the value thereof is amply sufficient to cover all forwarding and selling expenses. Any ore which is considered by the State Mining Engineer, after receipt of the Laboratory report, to be unsuitable for sale, by reason of absence of sufficient values or presence of deleterious constituents, shall not be accepted, and shall be removed by the owner at his own expense.

7. A charge of 2s. per ton will be made for sampling, and 10s. 6d. for each sample assayed.

8. The Government will forward accepted lots of ore to such market as from time to time shall be approved by the Minister for Mines, and will dispose of them there as he may think to the best advantage at such times as he shall think fit to do so.

9. Any owner wishing to have his ore sent to any particular market specified by him instead of that selected by the Minister, may have it so forwarded by the Government at his own risk, but the amount of advances thereon may be reduced at the discretion of the State Mining Engineer, and the proceeds of sale must pass through the hands of the Government for deduction of advances and expenses.

10. Any owner having his ore sampled at the Government sampling floor, but who ships it for sale otherwise than through the Government, shall pay a sampling charge of 5s. per ton of ore and arrange for his own assays.

11. If in any case the net proceeds of sale of any parcel of ore are not sufficient to pay the expenses upon it incurred by the Government, in addition to repayment of the advances with interest thereon, the balance shall be a debt due by the owner to the Government, recoverable at law. No person shall have any claim against the Government for loss or damage to his ore in transit unless negligence can be proved on the part of some agent of the Government, and no person shall have any claim on the grounds that his ore has not been sold to the best advantage.

12. Advances will be made in accordance with the following procedure, viz.:—

(a) Such allowances for moisture, tare of bags or cases, and loss of material in transport, as may be fixed by the State Mining Engineer, shall be deducted from the gross weight of each parcel as ascertained by the sampler, and the net weight so arrived at shall be the weight on which advances will be made.

* It should be remembered, however, that this sampling is merely for the purpose of determining the amount of advances which may be made and as a guide to the Government in negotiating for the ore. The actual sale of ore is not made upon it, but on a later and quite independent sampling made at the place at which the ore is finally sold, at which also the weight of the parcel and the deductions for moisture and tare are finally determined. Any purchase tentatively based upon the Government weighing and sampling at the port of shipment is subject to adjustment in accordance with the weights and assays finally agreed upon by the buyer's and seller's agents at the place of actual sale.

(b) The saleable constituents of the ore will be valued for advances at the following rates or such other rates as may be fixed from time to time by the Minister, viz.:—

Lead, at £13 per ton of metallic lead shown by the assay.

Tin, at £130 per ton of metallic tin shown by the assay.

Copper, at £56 10s. per ton of metallic copper shown by the assay less 1.3 units.

Gold, at £4 per oz. fine shown by the assay.

Silver, at 2s. per oz. fine shown by the assay.

If the valuable constituents of the ores are other than the above-named, they will be valued, as occasion may arise, by the State Mining Engineer at rates not less than the minimum average prices for such commodities on the London market in any year since the beginning of A.D. 1900, and not more than the general average prices of the same for the whole period since the same date.

(c) The advances will be at the rate of 50 per cent. of the values of the parcels calculated as in (b) above, less such sums as will be sufficient to cover all expenses incurred by the Government in receiving, storing, sampling, and assaying, shipping, insuring, and selling the ores, according to estimates of such expenses to be made from time to time by the State Mining Engineer from the best information available to him.

(d) The ores having been sold, any balances remaining after payment of all expenses actually incurred by the Government on account thereof, together with repayment of advances and interest due, will be paid over to the owners of the ores.

(e) The interest on the advances and on any moneys expended by the Government in payment of freight and other expenses of dealing with the ores shall be at the rate of six per cent. per annum, and shall be calculated from day to day from the date on which each sum was expended by the Government to the date of the final payment of the balance.

ADVANCES ON LEAD AND COPPER ORES AT ONSLOW.

To assist in the development of the Lead and Copper Mines of the State of which the port of shipment is Onslow, the Government is prepared to make cash advances on lead and copper ores suitable for smelting treatment, on the following terms and conditions:—

Regulations under which Advances are made on Lead and Copper Ores at Onslow.

1. The ores shall be the produce of mines in the State of Western Australia, and shall be of value sufficient to pay all expenses of transport to and treatment at Smelting Works approved by the Government.

2. The ores shall be thoroughly mixed before being bagged, so that each bag in each lot forwarded shall be of approximately the same value as the others in the same lot. All large lumps of ore shall be broken to pieces small enough to pass easily through a circular metal ring of three inches internal diameter. The ores shall be bagged in good sound bags, which shall be legibly and indelibly branded with distinctive letters and marks. Ores which do not comply with these instructions may be refused, or charged with the cost of breaking, mixing, re-bagging, and marking. It is recommended that the bags when filled with ore should weigh approximately 80lbs. each.

3. The ores shall be delivered to the person at Onslow appointed by the Government to receive them, and shall be weighed by him, and the owner of the ore or his appointed representative may be present to see the parcels weighed.

4. The owner of the ores or his representative shall deliver to the person at Onslow appointed by the Government to receive such, a certificate from a competent assayer that he has sampled and assayed each lot of ore, and stating the amount of the valuable constituents therein, together with a check sample consisting of a portion of about one pound in weight of the actual assay sample as drawn by such assayer. The cover of such check assay sample shall be labelled or endorsed so as to show clearly from which lot of ore it has been taken. It is recommended that check assay samples be taken by the assayer and sent on whenever possible before the ore leaves the mine, so that assay results may be available on its arrival at Onslow.

5. The person appointed by the Government will then telegraph the weight of each lot of ore received and the assay thereof, as shown on the assayer's certificate, to the State Mining Engineer in Perth,

† As the market value of these metals considerably fluctuates, the ruling fixed prices should be ascertained from the State Mining Engineer at Perth.

and shall post to him by first opportunity the check sample received from the assayer.

6. The State Mining Engineer will then take into account the costs of transport of the ore from Onslow to the works at which it will be treated, and the costs of smelting thereat, together with the condition of the market for sale of the metal, and may certify to such advances being payable as in his discretion the net value of the ore will justify after payment of all expenses incurred by the Government, but such advances shall not exceed three-fourths of the estimated net value. The amount of the advances will then be telegraphed to the Treasury Officer at Onslow, for payment by him to the owner of the ore or his representative.

7. The check samples shall be assayed at the Laboratory of the Geological Survey of Western Australia in Perth, by such officer or officers thereof as may be instructed to do so from time to time by the Minister.

8. The State Mining Engineer may refuse to accept the assay certificate of any person who does not forward to him satisfactory evidence of being a competent assayer, or of any assayer whose assay results are not found to correspond satisfactorily with those of the check samples forwarded, or whose samplings and assays are found not to correspond satisfactorily with those finally agreed upon at the Smelting Works where the ores are sold.

9. The ores, after being handed over to the person appointed by the Government at Onslow, shall be deemed to be the property of the Government for all purposes of transport, insurance, and sale, and shall be disposed of entirely at the discretion of the Minister, and no person shall have any claim upon the Government on the ground that such ore has not been realised upon to the best advantage.

10. The net proceeds realised by the Government after payment of all expenses paid by them will be paid to the owners. Such expenses will include interest at 6 per cent. per annum on all moneys laid out by the Government. If in any case the net proceeds of sale of any parcel of ore are not sufficient to pay the expenses upon it incurred by the Government, in addition to repayment of the advances with interest thereon at 6 per cent., the balance shall be a debt due by the owner to the Government, recoverable at law.

G.—BONUS FOR GRAPHITE.

To aid the development of mining for Graphite in the State of Western Australia, a Bonus will be paid by the Government on marketable graphite mined and prepared for market within the State on the following conditions, namely:—

(1.) The graphite shall be "flake" graphite, and shall be, in the opinion of the Government officer appointed by the Minister to supervise all payments of bonuses under his notice, of good marketable quality.

(2.) The producer shall notify the Department of Mines when he forwards any parcel of the mineral on which a bonus is to be claimed, and shall give opportunity and authority for an officer of the Department to inspect the same before it is delivered finally to any manufacturer or consumer of graphite within the State, or is exported from the State, and shall give particulars of how it is intended to dispose of the parcel. He shall render an account for the bonus payable on each parcel on Treasury account forms together with account sales showing all particulars and details of the actual sale of each parcel, and a statutory declaration that all information given is true and correct, and that the graphite is the produce of his mine within the State of Western Australia.

(3.) The bonus shall be at the rate of five per cent. of the net proceeds at the mine of sale of each parcel as paid to the producer directly or indirectly by the manufacturer or consumer within the State or the purchaser outside the State.

4. For the purpose of these conditions, the company or person immediately controlling the working of the mine from which the graphite is raised shall be deemed to be the producer, and any bonus payable shall be paid to him or to his authorised agent. No bonus shall be payable to any intermediate sellers between the producer and the final buyers. The supervising officer may require, and shall be supplied with full information as to any intermediate sales, and his decision as to what is the sale price on which the bonus is payable shall be final.

5. The amount of bonus payable in any year to any one producer shall not exceed £500.

6. The bonuses shall be payable on ore sold after the date of this notice for which accounts are received up to but not later than 30th June, 1919.

7. The supervising officer, if not satisfied with the information regarding the sale of any parcel, may require further information to be supplied under statutory declaration, and no bonus shall be payable unless and until he is fully satisfied that all transactions are genuine business deals.

The Antimony Deposits

of

Western Australia

by

A. Gibb Maitland.

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Geographical Distribution of the Deposits—

West Pilbara—

Sherlock.

Mallina.

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Balla Balla.

East Murchison—

Wiluna.

Extract from

The Mining Handbook.

Geol. Surv. Memoir No. 1.
Chapter II., Economic Geology,
1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

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PART III.—Section 10.—ANTIMONY.

GENERAL STATEMENT.

Ores of antimony are known to exist at Mallina, Pecawah, and Sherlock River, in the West Pilbara Goldfield, at 20-Mile Sandy, near Nullagine, in Pilbara, and at Wiluna, in the East Murchison Goldfield. The first discovery of antimony ore in Western Australia appears to have been at Mallina, in the West Pilbara Goldfield.

The ore in each case is mostly hydrated oxide of antimony (stibiconite) and other oxides in the outcrops of the veins, and sulphide of antimony (stibnite) at a short distance below the surface. Another antimony ore "Tetrahedrite" or "Fahlore," has been found in the Phillips River Field, occurring in small quantities in combination with copper. A few tons of this ore, which proved to be rich in silver, were smelted at the State Smelting works for the recovery of the copper and silver, the antimony, however, being lost. The antimony deposits of Western Australia consist chiefly of veins of quartz, which contain more or less gold and belong to the type of antimonial gold quartz veins; the stibnite itself being often gold-bearing. In the West Pilbara Field, at Mallina and Pecawah, the gold is associated with stibnite and quartz near the surface, and like other quartz reefs the gold values have been found to rapidly decrease from the surface downwards, giving out at a depth of about 40 feet, below which the ore consists solely of stibnite and quartz.

The production of antimony in Western Australia has not been great; the first recorded production being in 1903, when 22 tons, valued at £230, were exported from the State. The whole quantity exported up to the end of 1918 amounted to 86 tons, valued at £1,698. The quantity of antimony raised in Western Australia up to the end of 1918, so far as may be judged from the data furnished to the Department of Mines, only amounts to 20.78 tons, valued at £491. It will be noticed that there is a discrepancy between the export figures and those in the Mines Department's tabulated statistics, which latter are compiled from the returns furnished by the mine owners in compliance with the law.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

WEST PILBARA.

Sherlock.—The Sherlock Antimony Mine is situated on the north-eastern bank of the Sherlock River, at a point upon the road about 39 miles from Roebourne, 23 from Balla Balla, and 15 from Croydon.

The deposit occurs in greenstone country just under the foot of the plateau made up of the beds belonging to the Nullagine Formation. The lode, which is a quartz-bearing antimony, has been traced for a distance of about 60 chains and opened up by means of a series of shallow shafts, open-cuts, and trenches, in one of which it proved to be about 12 feet wide. Two shafts have been sunk on the lode; the deepest being 40 feet, and two others of about 25 feet each.

The quartz carries sulphide of antimony disseminated through it and is very rich in gold; it also contains some very pure solid stibnite (sulphide of antimony) and cervantite (oxide of antimony). Considerable quantities of very solid and pure stibnite are said to have been obtained from the lode; and the rich gold ore occurs in a short shoot in a reef of some considerable size.

It is stated that 16 tons of dressed ore from this lode yielded 53 per cent. of antimony and from 7 to 47 dwts. of gold per ton. In April, 1916, 5 tons 13 cwt. of ore from the Sherlock River deposit were shipped to Sydney and gave 42.2 per cent. of antimony and half an ounce of gold to the ton.

Mallina.—In the immediate vicinity of Mallina the country rocks consist of highly plicated schists and sandstone, which form the matrices of the gold-bearing antimony lodes. What is known as Martin's lode is a quartz reef, which has been traced for over 1,200 feet in a series of trenches and shallow shafts; the strike of the lode is about 10 degrees to the north-west, with an underlay of about 70 degrees to the north. Near the centre of the outcrop several shafts have been sunk to a depth of 45 feet, from which the lode is said to have been driven in for about 400 feet. The lode at the outcrop is seen to be a large quartz reef lying between well-defined walls and is from 6 to 8 feet wide. The antimony ores (stibnite, cervantite, and a little valentinite) occur in bunches.

In 1903 a shipment of 22 tons of hand-dressed ore was sent to England, but the proceeds of the sale failed to cover the expenses of mining and shipment; at a later date, 1907, a parcel of 7 tons 2 cwt., assaying 36.20 per cent. of metallic antimony, was shipped for sale in England.

Pecawah.—Some small antimony veins containing gold occur about five miles to the eastward of Mallina, near the Pecawah River. These veins differ from the Mallina deposits in that they are small and contain less quartz, though they carry high gold values near the surface. One of the veins was followed down to a depth of 47 feet in a calcareous slate, and at this depth contained some good stibnite ore, though practically destitute of gold. In February, 1916, five tons 16 cwt. of ore from this deposit, assaying 57.36 per cent. of metallic antimony and 5.5 dwts. of gold per ton, were shipped to Sydney, New South Wales; and in the month of May in the same year 14 tons 19 cwt., assaying 55.2 per cent. of antimony and 6 dwt. 18 grains of gold per ton were shipped to Bendigo, in Victoria.

Balla Balla.—About 20.78 tons of antimony ore, valued at £491, have been raised from a lease (M.L. 185, Star) at Balla Balla, but no particulars are available as to the nature and mode of occurrence of the deposit.

EAST MURCHISON.

Wiluna.—Some of the auriferous quartz reefs of Wiluna, on the East Murchison Goldfield, have been found to carry masses of stibnite (antimony sulphide) and cervantite (antimony oxide).

The country rock of the neighbourhood of Wiluna consists of fine-grained hornblende rocks, approaching quartz-diorite in composition; the greenstone is traversed by well-defined narrow belts of schist, which merely represent crush zones or shear lines, and it is along these belts that the main lines of reefs and lodes occur.

The lodes are frequently found to contain patches of massive stibnite, usually occurring as small lenticular bodies containing, perhaps, up to a ton or more of antimony ore, which can be readily separated from the rest of the ore. Some of the antimonial gold ores have assayed from 56 to 58.5 per cent. of antimony and .65 to .32 ozs. of gold per ton, in addition to .25 to .50 ozs. of silver.

The Darlington Main Reef, north of the Wiluna Township, is of hard, white quartz, three or four feet in width, and contains more or less antimony. The Weelona Reef, which is a long lens-shaped quartz vein, forming part of the long line of reefs *en echelon*, about two miles in length, extending southwards from the Highland Mary, contains amongst other minerals the sulph-antimonate of lead and copper. The Lone Hand Reef, which lies about half a mile to the south, is about 18 chains in length and varies in thickness from 4 to 6 feet; it contains, in addition to the gold, a good deal of stibnite and stibiconite (sulphide and hydrated oxide of antimony). The

Moonlight Reef trends about at right angles to the general strike of the main ore bodies of Wiluna, and is traceable for about 40 chains in an east-north-east direction. The deposit varies from three to five feet between the walls, although the quartz vein occurring in it is as a rule somewhat smaller. A fair amount of work has been done on the lode, and a considerable amount of cross-cutting in various directions between the walls of the defined lode has been done. About 400 to 500 feet of driving and cross-cutting have been carried out. Some of the antimonial ore in the reef is stated to have assayed as much as 4ozs. of gold per ton; near the surface the stibnite is mostly oxidised, taking the form of cervantite and stibi-

conite. The extension of the Moonlight reef into the adjoining lease, The Adelaide (G.M.L. 940) has been worked to some extent; it is about 4 feet in width and lies between smooth walls. The quartz carries varying proportions of stibnite.

The Gwalia Consolidated Lode, which is one of the largest at Wiluna, being from 50 to 100 feet wide, with a total length of at least 1,750 feet, and is associated with a quartz reef carrying some stibnite and its oxidation product stibiconite. This antimonial quartz reef trends generally north-north-east, and from its general behaviour seems to be of younger formation.

The Artesian Water Resources

of

Western Australia

by

A. Gibb Maitland.

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North-West Basin.

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Extract from

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PART II.—Section 24.—ARTESIAN WATER.

GENERAL STATEMENT.

The value of underground water as an economic mineral is becoming more and more fully recognised on account of the direct dependence of the requirements of the community upon artesian supplies, which are destined to play an important part in the future in the development of certain portions of Western Australia. As there is some misconception as to the nature of artesian water, and the conditions which govern its occurrence, a brief statement as to the requisite and qualifying geological conditions may not be out of place.

Artesian water is that portion of underground water which is confined in the earth's crust at a lower level than its static head, and which will rise if encountered in a well, or other natural opening affording an outlet.

Sub-artesian water is that in which the water is under a natural pressure, but which is not sufficient to force it above the surface of the ground.

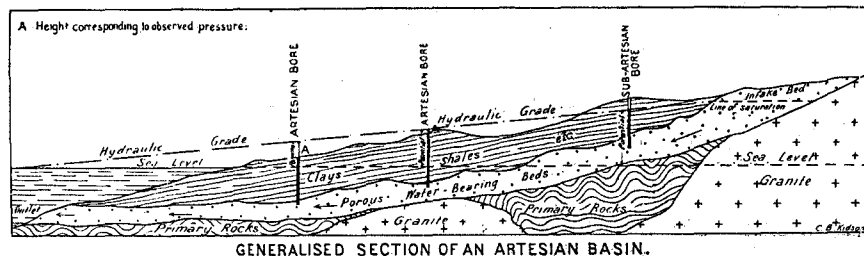
An *artesian basin* is the whole area within which artesian or sub-artesian may be obtained by boring.

Results more important to the community at large can be obtained from artesian water supplies in connection with pastoral pursuits than with those relating to agriculture. The occurrence of artesian water in certain more or less restricted areas of the State is now no longer a matter of theory, and its utilisation is capable of considerable expansion.

The area over which the artesian water-carrying strata occur has been indicated with as near an approach to accuracy as has been found possible, upon the map which forms Fig. b, Map of Western Australia, showing the known artesian basins; these more or less restricted areas have been designated (a) the Gulf Basin; (b) the Desert Basin; (c) North-West Basin; (d) Coastal Plain Basin; and (e) Eucla Basin. The limits of the known artesian basins are not as yet fully and accurately defined; such cannot be carried out without very much more detailed geological surveys than have yet been found possible. The stock-carrying capacity of the pastoral districts has been greatly increased through the success of the boring and is reflected in the increased woolclip, etc.

As may be seen from the Geological Sketch Map (Plate I.), the known geological formations of the State, when viewed broadly, can be divided into three distinct groups, viz.:—

Fig. a.



The conditions which govern the occurrence of artesian water are as follow:—

1. A more or less continuous stratum sufficiently porous to absorb and transmit water, arranged in such a way as to permit its passage.
2. The occurrence of relatively impervious rocks so disposed as to confine the water within the more porous beds.
3. The strata arranged in such a way that the exposed edge at which the water enters (intake) is high enough above the surface at the bore site to compensate for the loss of head due to frictional resistance and leakage.
4. The absence of an easy escape for the water at a lower level than the surface of the bore site.
5. A source of supply of water, perfectly free from anything that would be hurtful to its purity, sufficient to ensure a steady and abundant supply of water to the well or outlet.

These fundamental conditions are simple and easily understood, though in actual practice they are very often associated with more or less complicated problems.

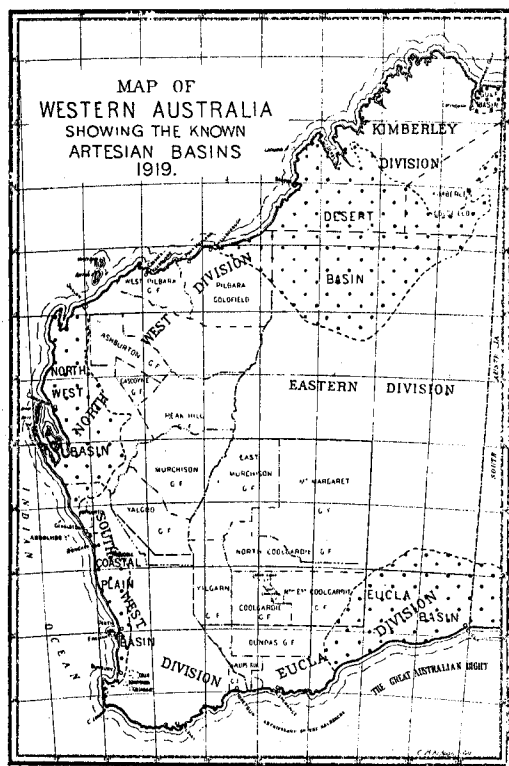
1. The crystalline, schistose, and metamorphic rocks of Pre-Cambrian and Archaean Age, which occupy fully one-third of the superficial extent of the State.
2. The Sedimentary Beds which range with many blanks from the Cambrian to the most Recent, and
3. The Volcanic Rocks, which are so largely developed in the northern portion of Western Australia.

It is, however, only the sedimentary rocks that are of any real value from the point of view of Artesian Water. The results of boring operations in the State have revealed the fact that the bulk of the artesian water supplies are drawn from Carboniferous and Cretaceous strata to that which may be added the supplies from what are believed to be Tertiary and Recent Beds. Artesian water has not only been searched for where it was likely, as well as (under protest), in one case in granite, where it was impossible.

The history of the exploitation of the artesian water resources of Western Australia commenced with the discovery of an overflowing supply of water in a bore put down in the year 1871 near the Canning River, a few miles south-east of Perth, in the vicinity of Kelmseott, and close to the foot of the Darling Range. The bore-hole was carried down to a depth of 171 feet, and it is of

some historical interest to note that artesian water is still flowing from the bore.

Fig. b.



Since that date, up to the end of June, 1918, there have been so far as can be ascertained, 119 bores sunk in Western Australia, reaching an aggregate depth of 117,748 feet, or over 22 miles.

The deepest bore is that at the 67-mile, Derby-Lennard Road, 3,012 feet, which gives an estimated daily flow of 140,000 gallons. The warmest is the Pelican Hill, near Carnarvon, 140° Fahr., where a daily flow of 515,000 gallons was met with at 2,527 feet. The largest flow is that of Gladstone, estimated at 2,000,000 gallons per day.

The total output of the 119 bores is 30,340,828 gallons per day, which is equivalent to 11,074,402,220 gallons per annum.

An estimation of the quantity of surface waters can be arrived at by methods known to engineers, but the determination of the total quantity of artesian water contained in the known basins cannot be even approximately ascertained. Artesian water is almost wholly, if not entirely, derived from rainfall which percolates beneath the surface under the influence of hydraulic conditions. Rainfall is disposed of in three ways: evaporation, surface "run off," and percolation; it is the balance that is left after evaporation and "run off" which is available for absorption by the permeable strata, and which is capable of being reached by artesian wells. The fact that the total quantity of artesian water contained in the known basins cannot be even approximately arrived at is not a matter of any particular moment, seeing that all that is of importance is the quantity which when withdrawn annually is restored by natural means. When excessively drawn

upon artesian water will, in fairly arid regions, be less rapidly replenished because, although the actual quantity stored therein may be enormous, if more is withdrawn than the water-bearing beds annually absorb and transmit, a time must come when the flow of water over the surface will diminish or possibly cease altogether. A lessening or even a cessation of flow would not of necessity indicate permanent exhaustion, for there are always fluctuations in the level of artesian water. In the case of such bores in Western Australia as have come under official investigation, a marked decrease in flow has been noticed. Several instances of a decrease in the flow of private bores in different portions of the State have been brought under notice, but such have never been officially verified. In the absence of any systematic gaugings in Western Australia, it is impossible to give any definite answer as to whether such diminution in the supply of water from artesian wells as has been noticed will tend to cause any serious depletion in the quantity of water stored under ground. A decrease in the flow due to the exhaustion of the head by a constant draft is irremediable, but the possibility of such can be minimised by shutting off the water at such times as the supply is not required.

On the other hand a diminished flow, due to either (a) lateral leakage through superincumbent porous beds; (b) the choking of the bore due to "ereep"; (c) the accumulation of sand, fine mud, or some mineral product; and (d) the wearing out of or defects in the casing, can be remedied by methods known to engineers.

As artesian water supplies are limited, it is essential that such must be carefully safeguarded and conserved. Artesian wells which are allowed to flow without restriction tend to seriously lower the head of water in the basin, and if this depletion exceeds the amount which is replenished, it follows that a state of affairs may be brought about which cannot be faced with equanimity. The gravity of the situation depends largely upon the extent to which new wells are put down, their mutual interference, and the care with which bores now flowing are regulated.

GEOGRAPHICAL DISTRIBUTION OF THE WELLS.

GULF BASIN.—The Gulf Basin is a small area at the mouth of the Old River in Cambridge Gulf, and extends into the northern Territory, but its limits have not yet been defined. A very large portion of the district consists of a plain of considerable extent, covered with deposits of estuarine origin. The rocks which make up the area are of Carboniferous Age, and are divisible into an upper, or sandstone, and a lower limestone series. The upper beds are well developed in the Bastion Range at Wyndham and extend northwards down the western arm of the Estuary which widens out into Cambridge Gulf. The beds dip at low angles to the south-east. The sandstones are white, and owing to the deposition of secondary silica, become almost quartzites; they are associated and interbedded with bluish-grey shales which vary in thickness up to 100 feet. The northern face of the Bastion Range, at the foot of which the town of Wyndham lies, exposes a section of sedimentary rocks, in which several wells have been sunk. The most important of these is the well at the gaol, 96 feet deep; from the bottom of this boring has been carried down to a depth of 690 feet below the surface, which gave a section of 690 feet of strata commencing about 4,000 feet below the level of the Mount Bastion Sandstone Series, without any artesian water having been obtained.

Another deep bore was carried down to a depth of 1,440 feet below the surface; it passed through over 1,000 feet of hard dark shales, and ended in quartzite about 240 feet thick.

Three bores have been put down in the Gulf Basin, but none struck an overflowing supply of water.

DESERT BASIN.—The Desert Basin, which is shown on most of the maps of Australia as the Great Sandy Desert, is made up of sedimentary rocks disposed in such a way as to form an ideal

artesian water basin. This country extends from Flora Valley to somewhere about the neighbourhood of Lake Disappointment. The sandy beds continue westward and form the low country which flanks the Ninety Mile Beach between La Grange Bay and Poissonier Point.

The southern margin of the Desert Basin lies somewhere to the north of the Oakover River Valley, and may be seen in the Paterson Range and vicinity. The basal beds of the series are seen to rest unconformably upon the much older Nullagine Formation in the Paterson Range at an altitude of about 1,250 feet above sea-level, and at Rooney's Creek and Christmas Pool. The strata of the Paterson Range beds consist of slightly inclined sandstones sufficiently porous to absorb and transmit water, and are tentatively believed to be of Carboniferous Age. The rainfall in this region is very small, and it is therefore very unlikely that any large quantity of water can be added to the basin from this area; the bulk of the supplies from the Desert Basin are in all probability derived from the intake area in Kimberley, where the average rainfall is about 21 inches.

The basal beds of the Carboniferous Formation which probably underlie part of the desert country, outcrop along the northern flanks of the valley of the Fitzroy, and in one or two instances the catchment or intake area has been breached almost at right angles by the Lennard and the Barker Rivers, as well as some other creeks of lesser magnitude.

The occurrence of *Otozamites* in a well at Madinganarra, near Point Torment in King's Sound, is of importance, as indicating the presence of plant-bearing beds of Jurassic Age, and points to the wide distribution of rocks of Mesozoic Age in the Kimberley Division. The widespread occurrence of these beds is further confirmed by the discovery in the No. 2 bore at Broome of fragments of *Belemmites* from a depth of 1,300 feet.

The very wide expanse of porous sedimentary rocks, disposed in such a way as to form an ideal artesian water basin, has led to some more or less successful boring operations.

At Derby a bore known as Mayhall's Well has been put down to a depth of 1,056 feet, and yields 69,400 gallons of water per day.

Two bores have been sunk at Broome through Mesozoic strata; No. 1 was carried down to 1,469 feet and yielded an overflowing supply at the rate of 142,000 gallons per diem with a temperature of 103 degrees Fahr.; the second, No. 2, not far distant from No. 1, reached 1,775 feet below the surface and passed through four distinct water-carrying horizons. At a depth of 1,550 feet the flow of water drawn from a sandy shale measured 1,000,000 gallons per day.

Two shallow bores have been put down in the Fitzroy Valley at Liverynga Station: one yielded 7,000 gallons and the other 1,500 gallons per day. There are sound geological reasons for believing the strata in these two bore-holes to be of the same age as those encountered in the bores at Broome.

A deep bore at the 67-mile peg on the Derby-Lennard Road was carried down to 2,129 feet and yielded 140,000 gallons per day; the water was derived from a limestone occurring at 1,040 feet, and believed to be of Devonian Age.

All the available geological evidence points to the fact that boring for artesian water in this as yet practically untested Desert Basin may be carried out with a reasonable degree of confidence.

NORTH-WEST BASIN.—The North-West Basin constitutes a portion of the maritime district of the North-West Land Division; it extends, so far as determined by such geological mapping as has been carried out, from the mouth of the Murchison River to somewhere about North-West Cape, thus covering about 6 degrees of latitude, with a maximum width of over 130 miles. The strata of which the basin is constituted are made up of representatives of the Palaeozoic, Mesozoic, Tertiary, and Post-Tertiary Ages, all of which are of importance from the hydro-geological standpoint.

The basal beds of the Palaeozoic strata, which rest directly upon the older crystalline rocks, and which carry a considerable

portion of the more or less potable artesian water in this part of the State, consist of conglomerates, sandstones, and limestones. These, when viewed broadly, have a very gentle dip to the westward, which carries them below the level of Shark Bay.

The sandstones of the Kennedy Range, which make a bold outcrop of about 200 miles in length, and the beds lying at the base of the Permo-Carboniferous rocks, are well adapted for the absorption and transmission of considerable quantities of water, and in addition are of some thickness. The structure of the beds is, omitting all minor details, that of almost one-half of a synclinal trough, the eastern rim of which is at a considerable altitude above sea-level. The water supply of these beds is received along the continuous outcrop which forms the catchment area from the head of the Murchison to the Yanarrie River. The country to the eastward of this is made up of impervious crystalline rocks which send all their drainage to the westward, conveying the rainfall directly to the outcrop of the water-bearing beds which form a fairly wide belt along the margin of the area.

The strata forming the Kennedy Range consists of fine-grained sandstones, which attain a considerable thickness; they have been so denuded that the valley of the Lyons River forms a huge ditch along the inner edge of the sandstones, which aids in conveying to and keeping the water in the Kennedy Range sandstones.

The strata have been pierced in the bore at Pelican Hill (Bibbawarra), near Carnarvon, at the mouth of the Gascoyne River, which was carried down to a depth of 3,011 feet. The record of this bore showed that the first 150 feet comprised clays and limestone of newer or Post-Tertiary Age; Middle Tertiary marls and shales were passed through to a depth of 1,238 feet; Mesozoic (and possibly Cretaceous) clay shale and glauconitic sandstone down to 1,361 feet; and the balance of the beds, 1,650 feet in thickness, revealed limestone, black shale, and sandstone, the age of which, as determined by the organic remains, being Permo-Carboniferous.

The Pelican Hill bore is of importance owing to the fact that it yields an overflowing supply of water at the rate of 520,000 gallons per day, drawn from a bed of sandstone 448 feet in thickness, which forms the lowest bed of the Permo-Carboniferous series penetrated. Had it been possible to continue boring operations until the base of the formation had been unequivocally reached, a much more generous flow would doubtless have been obtained.

According to the latest information available there are 26 bores in the North-West Basin, representing an amount of boring equal to 36,608 feet, or about 7 miles, and the total output from which is 4,672,773,800 gallons of water per annum. The deepest bore is at Pelican Hill, 3,011 feet; and the largest flow at Gladstone, 2,000,000 gallons per day.

COASTAL PLAIN BASIN.—The most important portion of the South-West Division, when viewed in the light of the occurrence of artesian water, is the Coastal Plain Basin, which practically extends from latitude 29° to 33° south. The plain is really formed by a fringe of strata in the maritime districts, having a more or less gentle slope to the seaward. It is from the strata underlying this plain that supplies of artesian water have been obtained.

The Tertiary rocks of the Coastal Plain Basin are made up for the most part of partially consolidated shallow water deposits; and consist of sandstones, conglomerates, and thin shales, with occasionally incoherent sands and marls. In the neighbourhood of Bunbury these strata are associated with basaltic lavas. There are in addition ordinary river alluvium, raised beaches and æolian drifts. These æolian drifts are partially consolidated by the action of rain-water into sandy limestones and calcareous sandstones, and constitute a formation collectively designated the "Coastal Limestone."

The Mesozoic rocks of the Coastal Plain Basin consist chiefly of shales, sandstones, and limestones reposing at a low angle upon

the older crystalline and Palæozoic Rocks. These Mesozoic beds occupy a considerable area of the surface to the northward of Perth, and are in many cases met with in the strata beneath the Tertiaries during the course of boring operations. Many of the beds exposed at the surface are of Jurassic Age, as determined by their plant and other remains. The importance of the Jurassic rocks from the hydrological standpoint is their general permeability, which lends itself to the absorption and transmission of large quantities of water, whilst the great thickness of the formation gives it a large storage capacity.

The Jurassic beds are overlaid to the north of Gingin by white chalky limestone, which passes downwards into a greenish glauconitic marl, resting upon a clay shale. The organic remains of the Gingin beds indicate the geological age of the formation to be Cretaceous. The beds beneath the Metropolitan Area are also of Cretaceous Age. In the bores put down in the Royal Agricultural Show Ground, the Hospital for the Insane at Claremont, and Rottnest Island, a considerable thickness of solid crystalline limestone, associated with glauconitic sands or sandstones, have been encountered; these beds are in all probability representatives of the cretaceous beds outcropping to the northward at Gingin.

The structure of the Coastal Plain differs in many important respects from the typical areas in which artesian water has been obtained in other portions of Australia. The strata are nearly horizontal, though occasionally there is a slight local dip of from 5 to 8 degrees. The effect of this comparative horizontality is shown in the fact that the water-carrying beds do not outcrop on the surface near the eastern margin of the plain, but impinge directly against that portion of the main range which is concealed from view. The strata do not attain a uniform thickness throughout, but are disposed in the form of lenticular beds, some of which

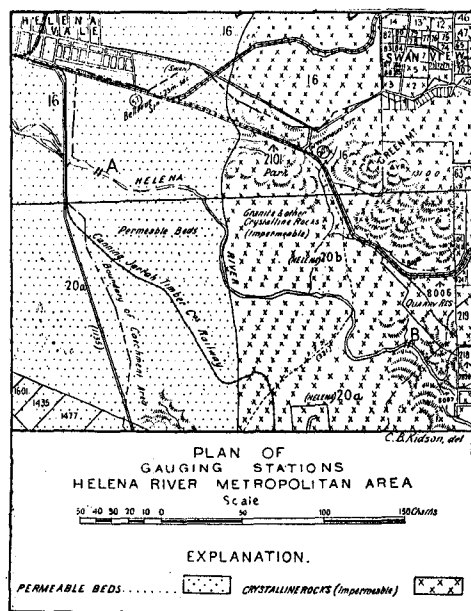
atic observations have as yet been undertaken to ascertain the actual discharge of the numerous rivers which flow across the plain, so that no estimate of the amount of water available for absorption can be even approximately arrived at; that such must be considerable is obvious from the data collected and tabulated with reference to the discharge of the Helena River, near Perth. The observations were made at two stations, one near Midland Junction, and the other near Greenmount; the westernmost locality is situated on the outcrop of the permeable strata of the Coastal Plain and the other on the crystalline (or impermeable) rocks. (Fig. c). From the figures obtained it appears that about 22,000,000,000 gallons of water per annum disappears underground, and is capable of being reached by wells.

The conditions which prevail over large areas of the Coastal Plain demonstrate that rivers of a much larger catchment discharge their drainage into the plain, and it is therefore only reasonable to assume that a large proportion of the water from the catchments also disappears beneath the surface and helps to feed the artesian reservoir below.

A small isolated artesian basin is in the Collie River, where a copious supply of water is flowing from Bores No. 2, 951 feet deep, and No. 4, 900 feet deep, put down with the object of testing the Coal Measures. The yield of artesian water from No. 2 bore is 50,000 gallons, and from No. 4, 25,000 gallons per day. The beds, which cover an area of about 500 square miles, consist of sandstones, shales, and grits. The amount of water flowing from the bores in the Collie River increases and diminishes in a manner which points to dependence upon seasonal variations.

So far as the latest official data with reference to the extent of boring operations show that there are 70 artesian wells in the Coastal Plain Basin, reaching an aggregate depth of 52,748 feet, or about 10 miles, and yielding a total flow of 16,305,008 gallons of water per day, equal to 5,951,327,520 gallons per annum.

Fig. c.



are of exceptionally absorptive properties. The chalky limestones of the Gingin type, while on the whole highly absorbent, seem only to permit water passing through its mass sparingly.

The mean annual rainfall of the Coastal Plain Basin is from 20 to 30 inches; a precipitation which is considerable. No system-

EUCLA BASIN.—The Eucla Basin forms part (and the largest) of the relatively high plateau known as the Nullabor Plains, or Premier Downs, which extends into the adjoining State of South Australia. This plateau, at its southern extremity at the head of the Great Australian Bight, is from 200 to 400 feet above sea-level; it is more or less abruptly truncated by cliffs which, in part, form the coastline, and elsewhere occur at varying distances inland. The plateau steadily rises to the north, and where it is traversed by the Great Western Railway its altitude above sea-level varies from about 450 to 650 feet; from the Railway Line it gradually rises to the northward, where, so far as the meagre evidence at present goes, the average altitude is about 1,000 feet above sea-level. There are no rocks on the plateau, and the rainfall, except on the coast, is under 10 inches per annum; such rain as does fall is absorbed by the rocks, and at times, after heavy rains, considerable streams may be seen running into the "blow holes" with which the plateau is studded. The only surface water procurable on the limestone plateau occurs in those small rock-holes worn out of the upper crust of the limestones; these hold water only for a comparatively short time after rain and are to be found few and far between.

The strata of which the Eucla Basin is built up consists of more or less cavernous limestone (the Eucla Limestone) associated with soft sandstones, clay shales, and occasionally conglomerates into which the rainfall is rapidly absorbed, and some of it discharged seawards in the form of fresh water springs. The very extensive cover of superficial deposits almost entirely masks the boundary between the sedimentary series of the plains and the crystalline and allied rocks, so that the precise geological delineation of the area of the basin presents very many difficulties.

Good opportunities have been afforded of obtaining some knowledge of the strata, their lithological character, thickness, etc., underlying the basin by means of the bores put down in connection

with the water supply of the Great Western Railway. It is now known that these sedimentary beds have a thickness of not less than 2,000 feet. The Eucla Limestone, which is of Miocene Tertiary Age, maintains a fairly uniform lithological character over its whole extent and varies in thickness from 485 to 903 feet. The shaley beds beneath the limestone become much more sandy in their character as the western rim of the basin is approached. The beds all have a prevailing gentle dip towards the Great Australian Bight, and, as disclosed by the bores, the dip amounts to from 4 to 5 degrees to the south.

The shaley beds beneath the limestone in a bore put down at 337 miles 61 chains from Kalgoorlie along the Great Western Railway Line, contain the fossils *Aucella hughendensis* and *Mac-Coyella corbiensis* indicating a Cretaceous Age for the beds, and the occurrence of rocks, the geological equivalents of the Rolling Downs Beds as developed in Eastern Australia.

The whole of the thickness of the strata underlying the basin have been pierced by several bore-holes put down in Western Australia as well as some in South Australia. The floor of ancient crystalline rocks having been unequivocally reached at depths of 990, 1,084, 1,277, 1,371 and 1,372 feet respectively, it may be inferred that the old floor of ancient crystalline and other metamorphic rocks was one of topographical regularity in an east and west direction. The absence of bores reaching bedrock to the south of the Railway precludes any adequate conception as to its subterranean contour in that direction.

Very little is known of the geology of the country to the north of the Railway Line, but what are believed to be the basal beds of the series exposed in the bores on the Railway Line have been noticed, in 1916, in the vicinity of the Townsend Range (S. Lat. 26° 30'). These consisted of slightly compacted current-bedded sandstones and claystones, with occasional conglomerates and boulder beds. The altitude of the base of the beds was at Dunge's Hill 1,570 feet, near the Townsend Range 1,900 feet, and on the west from 700 to 1,300 feet above sea-level. No fossils were found in these beds, but from such meagre stratigraphical evidence as is at present available their geological age seems to be late Mesozoic or at least early Tertiary. The beds are probably the inshore representatives of the strata lying beneath the Eucla Limestone.

The results of such geological investigations as have at present been made, show that in east longitude 127 an extensive sedimentary

formation extends northwards for about 400 miles from the coast, and covers some thousands of square miles between Israelite Bay and Eucla, in Western Australia. The whole of these beds in the southern portion of the basin have been proved by actual boring operations to be more or less artesian and sub-artesian-water carrying, but the waters in the different horizons have not yet been fully developed.

The most southerly bore in the Eucla Basin is that at Madura, not far from the coast, at a height of about 110 feet above sea-level, and a depth of 2,041 feet was ultimately attained. The site of the bore is about 30 chains south of the face of the escarpment of the Hampton Range, which is 350 feet high. The strata pierced consisted of—Eucla Limestone, 903 feet; shales, thin bands of dolomitic limestone, and glauconitic mudstones, 1,138 feet. At 2,041 feet a supply of good stock water was encountered, which issued from a standpipe two feet above the surface at the rate of 5,700 gallons per day. The bore-hole did not, unfortunately, pierce the whole of the thickness of the water-bearing beds, and was not carried deep enough to reach the floor of crystalline rocks upon which the water-carrying strata rest.

There have been thirteen bores put down in the Eucla Basin, and in five of them the water has been found to rise to a height equal to that of the sea-level.

The following is a summary of the flowing and non-flowing artesian wells in Western Australia, so far as can be gathered from official data.

SYNOPTICAL TABLE OF ARTESIAN AND SUB-ARTESIAN WELLS IN WESTERN AUSTRALIA.

Basin.	No. of Bores.	Depth in feet.		Artesian. Continuous daily flow in gallons when uncontrolled.	Sub-artesian. Volume pumped or available daily in gallons.
		Max.	Min.		
Gulf	3	1,337	203	700	...
Desert	7	3,012	319	1,172,000	90,000
North-West ...	26	3,011	523	12,802,120	...
Coastal Plain ...	70	2,586	30	15,305,008	2,166,900
Eucla	13	2,041	348	61,000	47,000
Total	119	...	...	30,340,828	2,303,900

The Bauxite Deposits

(Aluminous Laterite)

of

Western Australia

by

A. Gibb Maitland.

Extract from

The Mining Handbook.

Geol. Surv. Memoir No. 1.
Chapter II, Economic Geology,
1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

The Bauxite Deposits (Aluminous Laterite) of Western Australia

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PART II.—Section 8.—BAUXITE (Aluminous Laterite).

GENERAL STATEMENT.

Owing to the very great extent of those residual deposits for which the term 'laterite' has been officially adopted, Western Australia possesses an asset of great value. Some of these lateritic deposits have been utilised in the past as a source of iron ore for fluxing purposes owing to the ease with which they could be smelted rather than on account of their richness or purity. Some of the laterites have been proved to be highly aluminous, approaching very closely in composition the bauxites of Europe, America and India, which now form the chief source of aluminium. Aluminium, being perhaps the most abundant of the metals, possesses so many valuable properties which ought to give it a very important place in our national economy; though the difficulties of its more abundant use would seem, however, to have in the past arisen rather from the cost of extraction.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

DARLING RANGE.—So far, the most extensive aluminous deposit yet known in Western Australia is that which caps the Darling Range and is situated in close proximity to railway lines connect-

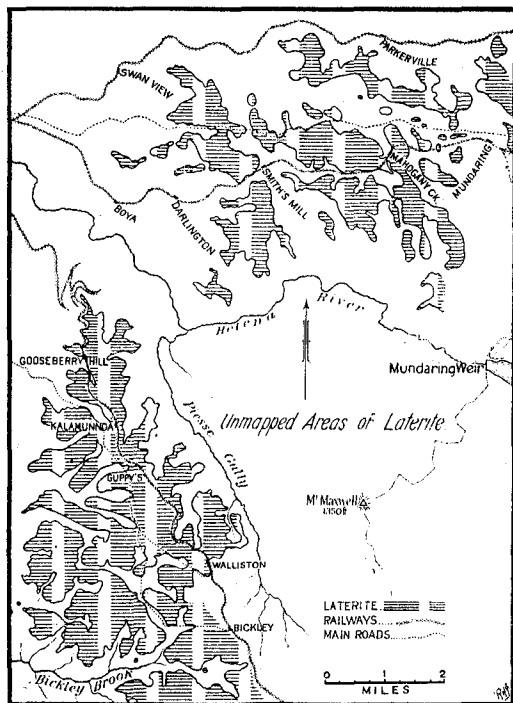


Fig. a.—Map of Laterites in the Darling Range.

ing with the Metropolis, hence no serious difficulties arise in connection with transport should the exploitation of the deposits be undertaken at any time. A tabulated list showing the composition

of some of the aluminous laterites of the South-Western Division made in the Geological Survey Laboratory, will be found in Bulletin 67—Analyses of Western Australian Rocks, Meteorites and Natural Waters.

The figure shows the distribution of the laterites in the vicinity of the metropolis, and is the result of detailed instrumental surveys carried out by the Geological Staff as opportunity presented itself with, *inter alia*, the object of discovering whether or not they contain deposits of iron ore or aluminium ore of possible commercial value.

The laterite at Smith's Mill, of which analyses show to contain from 13.98 to 50.66 of alumina, were examined and reported on in 1902, whilst in 1912 a further investigation was made of the deposits, and samples when analysed were found to contain in parts per hundred:—

	a.	b.	c.
Bauxite	9.53	35.10	55.87
Kaolin	17.55	26.64	23.70

The Smith's Mill bauxite does not attain very great thickness, and is seen to pass by almost imperceptible gradations from an ironstained and white clay into the underlying granite and gneiss of which it is the decomposition product.

This laterite extends eastward to Baker's Hill, 47 miles from Perth; it is, however, much more ferruginous than the Smith's Mill ore; that from Gooseberry Hill, on the Midland Junction to Karragullen railway line, distant about 19 miles from Perth and south-west from Smith's Mill, is also very ferruginous.

A considerable number (46) of samples of bauxitic laterite from different portions of the Darling Range have been analysed in the Geological Survey Laboratory; under conditions at present prevailing it appears that the lowest grade of bauxite which may be regarded as payable is that which contains not less than 35 per cent. of alumina soluble in acids.

The analyses of the Darling Range laterite show that they can be grouped as follows:—

Acid soluble, Al_2O_3	under 35	per cent.	.. 20
" "	from 35-40	"	.. 15
" "	" 40-45	"	.. 6
" "	" 45-50	"	.. 5
			46

Those varieties of bauxitic laterite which contain the highest percentage of acid soluble alumina are composed of a light coloured yellow matrix, through which nodules of brown iron hydrate, or decomposed quartz rock of about the size of peas, are scattered, and may be readily distinguished by the unaided eye.

So far as observations have at present been carried it appears that in the Darling Range the laterites situated on the highest ground are richer in soluble alumina than those at the lower levels, hence it appears possible to distinguish at sight between bauxitic laterites of low and of high grade. According to the researches of Dr. Simpson in the Survey Laboratory, it appears that the higher grade bauxites weigh 157lbs. to the cubic foot; so that assuming the average thickness of the bauxitic laterite to be two feet, each acre of ground should yield at least 6,000 tons of aluminium ore.

Having regard to the known extent of the deposit it appears that there are hundreds of thousands of tons of high grade laterite within easy access of those railway lines which cross the Darling Range.

Analyses of the laterites of the Darling Range are given in the two tables:—

PARTIAL ANALYSES OF BAUXITIC LATERITES OF THE DARLING RANGE.

—	Smith's Mill.				Mahogany Creek.				
	2027	2028	2029	2037	3032	2033	2034	2035	2036
Geol. Surv. Lab. No....	2027	2028	2029	2037	3032	2033	2034	2035	2036
Alumina, Al_2O_3 *	35.22	28.56	39.56	27.42	30.62	30.48	42.88	29.94	38.38
Ferric Oxide Fe_2O_3 ...	32.96	37.94	30.14	45.14	36.72	27.84	29.96	16.98	17.14
Insoluble ...	...	...	...	...	...	...	15.44	...	...

—	Guppy Siding.			Sawyers' Valley.		Bickley.
	2080	2081	2082	2085	2086	
Geol. Surv. Lab. No....	2080	2081	2082	2085	2086	2078
Alumina, Al_2O_3 *	43.52	40.06	47.91	37.96	37.11	37.58
Ferric Oxide Fe_2O_3 ...	29.52	30.14	9.79	29.68	26.01	21.12
Insoluble ...	3.96	8.24	16.89	18.59	19.98	19.50

*Includes TiO_2 .

ANALYSES OF LATERITES FROM THE DARLING RANGE.

General Locality.		Between Kalamunda and Walliston Stations.						
Geol. Surv. Field No. ...		B1.	B2.	B3.	B4.	B5.	B6.	C1.
Geol. Surv. Lab. No. ...		2974E.	2975E.	2976E.	2977E.	2978E.	2979E.	3354E.
Soluble in Acids—								
Al_2O_3 ...		35.44	32.20	39.77	31.23	25.43	30.59	34.59
Fe_2O_3 ...		25.26	30.44	23.06	35.59	44.00	27.13	29.70
TiO_2 ...		.80	.94	1.01	.96	1.80	1.56	1.41
Insoluble in Acids—								
SiO_2 ...		17.22	...	11.48	...	11.38	12.62	12.20
Al_2O_3 , etc. ...		1.70	14.82	1.54	12.50	...	...	29.56
Ignition Loss—								
Combined water, H_2O †		10.34	15.60	22.78	20.00	17.30	29.26	22.04
Hygroscopic water, H_2O —								.85
Total ...		99.86	100.00	100.21	100.28	100.00	100.26	100.16
Analyst ...		E. S. Simpson.	E. S. Simpson.	E. S. Simpson.	E. S. Simpson.	E. S. Simpson.	H. Bowley.	D. G. Murray.

General Locality.		Between Kalamunda and Walliston Stations.				Between Wooroloo Northam Road and Sanatorium.			
Geol. Surv. Field No. ...		C3.	C4.	C5.	C6.	C7.	C8.	C9.	...
Geol. Surv. Lab. No. ...		3356E.	3357E.	3358E.	3359E.	3422E.	3423E.	3424E.	3179E.
Soluble in Acids—									
Al_2O_3 ...		44.92	38.81	24.34	35.24	49.82	39.76	39.04	44.93
Fe_2O_3 ...		22.14	29.46	33.84	33.81	10.22	16.44	22.56	21.67
TiO_2 ...		3.14	4.45	5.30	3.05	.96	1.52	2.44	.94
Insoluble in Acids—									
SiO_2 ...		4.16	3.70	26.38	6.72	11.50	18.34	12.84	10.12
Al_2O_3 , etc. ...		...	...	...	...	...	...	...	...
Ignition Loss—									
Combined water, H_2O †		25.40	23.23	14.98		27.15		22.26	
Hygroscopic water, H_2O —		.73	.88	1.47		.05		.74	
Total ...		100.49	100.53	100.31	100.36	100.10	99.86	99.88	...
Analyst ...		D. G. Murray.	D. G. Murray.	D. G. Murray.	H. Bowley.	D. G. Murray.	E. S. Simpson.	D. G. Murray.	...

Notes.—B1, B2, B4, B5, from laterite on ground 50ft. or more below level of B3, B6, C3 and C4.
 B6 from laterite lying against a dolerite dyke.
 C2 soft clayey gravel from gravel pit about 20 chains east of Kalamunda Railway Station.
 C5 Soft clayey gravel from gravel pit near Guppy's Siding.
 C1 Bulk sample (C3b.), Guppy's Siding.
 C6 Bulk sample (C3b.), Walliston Siding.
 C8 Bulk sample (50lb.), Wooroloo-Northam Road near Keenline Well.
 C9 Laterites along road south of C8.
 C7 Laterite from gravel pit 10 chains south of Wooroloo Sanatorium, and probably more than 100ft. above level of C8 and C9.
 3179E Small sample collected by Mr. B. S. Welsh in the same locality as, and prior to, C8.

ANALYSES OF THREE SAMPLES OF BAUXITE FROM THE MINKADINE RANGE.

(South of the Railway Line between Tammin and Kollerberrin.)

Geological Survey Laboratory No. ...	3685	3686	3687	3688
Insoluble in Acids ...	52.44	57.88	60.96	57.18
Titanium oxide, TiO_2 ...	.58	.66	.70	.62
Ferric oxide, Fe_2O_3 ...	9.16	7.48	4.94	9.02
Alumina, Al_2O_3 ...	26.10	23.74	22.92	23.98
Water (combined) H_2O + ...	10.78	9.63	9.37	9.84
Water (hygroscopic) H_2O — ...	1.18	1.04	.93	.78
	100.24	100.43	99.82	100.42

Alumina and Silica soluble in 10 per cent. Sodium hydrate after heating on a water bath for 1 hour:—

—	Alumina, Al_2O_3 .	Silica, SiO_2 .
3685 ...	10.18 per cent.	9.26 per cent.
3687 ...	11.16 „	9.70 „

WONGAN HILLS.—An extensive deposit of fairly high-grade laterite (44.66 per cent. of alumina), of which a complete analysis (N977) will be found in the table below, occurs in the Wongan Hills, 132 miles from the metropolis, on the Perth-Mullewa railway line, and distant about six miles west from it.

The Wongan Hills laterite does not form a horizontal tableland, but is a residual deposit which has adapted itself to the original form of the ground on which it occurs. Outliers of the laterite occur in several localities, and it is quite evident that it originally spread over a wide area and that extensive denudation has taken place since the deposit constituted one continuous formation. The rock is very porous and weathers readily into caverns and cavities of all sizes, and when freshly broken it presents a mottled appearance owing to the different shades of brown, yellow and red. Lithologically, the deposits present all gradations from ferruginous claystone to pure limonite, the former, however, predominating. As the laterite is seen to pass by insensible gradations into the underlying rocks without any sharp line of demarcation, its formation would seem to have been due to the alteration *in situ* of the rocks beneath.

(S.M. No. 997N. Rock laterite. Locality: Wongan Hills.

SiO_2	5.96
Al_2O_3	44.66
Fe_2O_3	19.08
MnO_2 .....	..
MgO	Trace
CaO	Trace
H_2O — .....	.58
H_2O +	26.44
TiO_2	3.10
SO_2 .....	.18
P_2O_5	Trace
Cr_2O_3 .....	..
V_2O_5 .....	..
Total	100.00

Analyst E.S.S. 1901.

(GREENBUSHES.—At Greenbushes, on the Perth to Bridgetown railway line, and distant 159 miles from the metropolis, there is a very large area of laterite nowhere exceeding 20 feet in thickness, some portions of which appear to be of high grade. Partial analyses of the bauxitic laterites from Greenbushes and Donnybrook are given in the table:—

PARTIAL ANALYSES OF BAUXITIC LATERITES FROM GREENBUSHES AND DONNYBROOK.

Gool. Sur. Lab. No.	Greenbushes.						Donnybrook.
	2056	2057	2058	2059	2060	2061	2062
Alumina, Al_2O_3 *...	28.70	33.24	33.10	26.28	25.62	27.00	29.98
Ferrie Oxide Fe_2O_3	35.50	34.12	18.82	19.44	32.90	23.56	12.54
Insoluble ...	20.44	17.68	30.40	40.44	32.04	35.16	40.12

* Includes TiO_2 .

The most important constituent of these laterites is, next to ferric oxide, gibbsite ($\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$). The latter contains iron sesquioxide as an impurity in variable amounts, sometimes exceeding that of the alumina, and affords a ready basis of classification into (a) the light coloured or non-ferruginous, and (b) the red coloured or ferruginous varieties.

Working the laterite deposits presents no serious difficulty as such may be taken out by ordinary quarrying methods; hand pick-

ing would have to be resorted to where there is much segregated iron ore, though by careful attention to mining, etc., the iron ore could probably be entirely eliminated. There seems to be sound reasons for believing that the production of pure alumina from clays and other silicates may ultimately become commercially practicable, in which case many of the lower grade laterites (bauxites) which contain admixtures of clay would become available.

From such official information as is available it appears that what is known as the Serpet Process renders the utilisation of some of the aluminous laterite deposits quite possible. By this process bauxite and coal are heated in an electric furnace with the production of aluminium nitride; this being treated with a solution of caustic soda forms sodium aluminate and ammonia. The alumina is extracted from the aluminate in the usual way and the ammonia converted into the valuable manure, ammonium sulphate.

It is difficult to estimate the value of these Western Australian deposits. They might, however, be developed by (a) exporting the raw material for use in alumina factories; (b) manufacturing pure alumina locally for export to aluminium works; or (c) manufacturing the metal in the State. The local manufacture of pure alumina would, on the whole, seem to be the one most practicable and need not involve any very heavy capital expenditure.

Aluminium being producable from bauxite by means of the electric furnace, it naturally suggests itself as to whether the reserve of energy in the coals of the Collie Field could not be utilised for the production of the electric power necessary for this and any other allied purpose.

The Coal Deposits

of

Western Australia

by

A. Gibb Maitland.

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General Statement.

Geographical Distribution of the Deposits—

Collie Coal Field.

Wilga.

Irwin River Coalfield.

Greenough River.

Fly Brook Coal Deposits.

The Vasse.

Donnybrook.

Millbrook.

Kimberley.

Extract from
The Mining Handbook.

Geol. Surv. Memoir No. 1.
Chapter II., Economic Geology,
1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

The Coal Deposits of Western Australia

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PART II.—Section 1.—COAL.

GENERAL STATEMENT.

Coals of different geological ages are known in Western Australia. Geologically, the distribution of the Western Australian coal deposits lies in strata ranging from the Carboniferous to the most Recent, viz., the Carboniferous Beds of the Irwin River, the Permo-Carboniferous Strata of the Collie, the Mesozoic Beds of the Maritime districts, and the Tertiary and Post Tertiary Rocks of the South-West and elsewhere.

Coal, however, has only been extensively mined in one district, the Collie Field, in strata of Permo-Carboniferous Age.

Lignites and brown coal, mostly of poor quality, are known to occur in various portions of the State, but so far little active work has been done upon any of them. No geological surveys have yet been undertaken such as would enable even an approximate estimate to be made of the area or quantity of coal available in these Mesozoic, Tertiary, and Recent Strata.

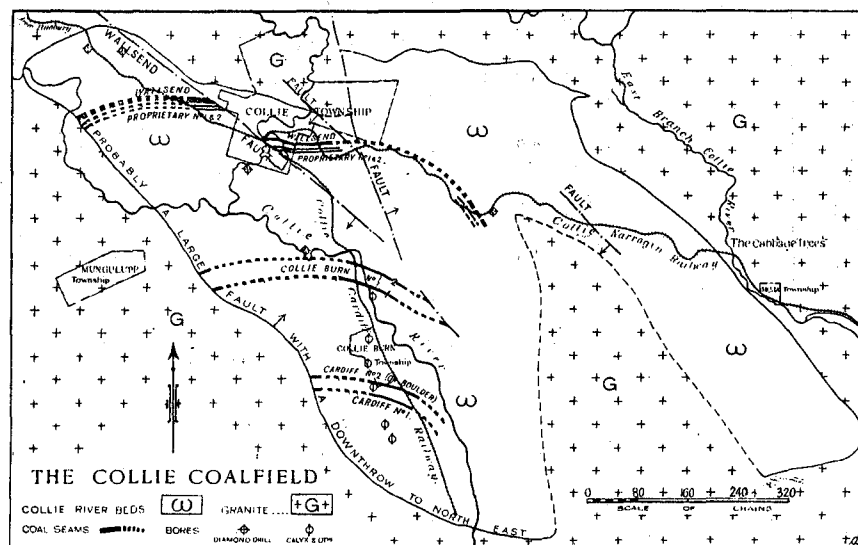
The strata consist of alternations of micaceous shales, cross-bedded sandstones and grits of Permo-Carboniferous Age. The Collie Coalfield owes its preservation to being faulted down into the Archean Rocks. On the south-western side of the field the boundary fault has been estimated to have a downthrow to the north-east of at least 2,000 feet. The effects of the faulting or the relative softness of the beds has determined the direction of the valley of the Collie River in which the field is situated; it is possible that the coal measures were continuous over a very much larger area.

Three well defined series of productive coal measures are recognisable in the Collie Coalfield, viz.:

- (a) Upper or Cardiff Phase.
- (b) Middle or Collie Burn Phase.
- (c) Lower or Collie Phase.

The Collie River Beds attain a thickness, so far as can be judged from the evidence afforded by bores, shafts, etc., of over 2,000 feet, and contain coal seams to a total thickness of about 137

Fig. a.



GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

COLLIE COAL FIELD.—The Collie Coal Field is the only one in the State upon which any active mining operations are being carried on, though there are other areas in Western Australia in which lignites and brown coals occur. The Collie Coalfield lies in a depression near the north-western edge of the tableland, which succeeds the Coastal Plain. The field is situated in the Collie River, about 100 miles to the south of the metropolis, and is connected by rail with the three south-western ports, Fremantle being 136 miles via Perth, Bunbury 41 miles, and 270 miles from Albany via Narrogin.

The area occupied by the Coal Measures is, so far as is known, approximately 50 square miles, and lies at an altitude of about 600 to 700 feet above sea level. (Fig. a.).

feet. A generalised section (Fig. b) across the field is as follows:—

		feet.	in.
Pleistocene	Strata (Lako Beds)	80 to 120	0
Upper, or Cardiff Phase	Cardiff No. 1—		
	Coal	9 to 12	0
	Strata	23	0
	Cardiff No. 2 or Boulder—		
	Coal	7	0
	Strata	245	0
	Coal	5	0
	Strata	66	0
	Coal	3	7
	Strata	90	0

Middle, or Collie Burn Phase	Collie Burn No. 1—		ft.	in.
	Coal ...	...	28	0
	Strata ...	...	28	0
	Coal ...	...	2	10
	Strata ...	...	34	0
	Coal ...	...	3	6
	Strata ...	...	55	0
	Coal ...	...	2	0
	Strata ...	...	22	0
	Coal ...	...	2	0
	Strata ...	...	16	0
	Collie Burn No. 2—		6 to 7	10
	Coal ...	...	17	0
	Strata ...	...	3	3
	Coal ...	...	105	0
	Strata ...	...	78	0
	Coal ...	...	4	0
	Strata ...	...	45	0
	Coal ...	...	5	1
	Strata ...	...	33	0
	Coal ...	...	4	9
	Strata (unexplored or explored only by an unsatisfactory boro)		390	0
	Coal ...	...	3	6
	Strata ...	...	97	0
	Coal ...	...	2	6
	Strata ...	...	73	0
	Coal ...	...	2	0
	Strata ...	...	42	0
Lower, or Collie Phase	Proprietary No. 1—		4 to 8	0
	Coal ...	...	10	0
	Strata ...	...	...	...
	Proprietary No. 2—		5 to 7	6
	Coal ...	...	...	...
	Strata ...	...	...	...
	Wallsend—		9 to 0	17
	Coal ...	...	52	0
	Strata ...	...	4	6
	Coal ...	...	6	0
	Strata ...	...	7	8
	Coal ...	...	14	0
	Strata ...	...	3	11
	Coal ...	...	180	0
	Strata (approximately granite, gneiss, and other crystalline rocks)		...	...

feet; coal 4 feet; coal 6 feet; coal 6 feet 4 inches; coal 5 feet 4 inches; coal 4 feet, and coal 5 feet.

The dip of the coal measures on the field is fairly uniform, averaging from 8 to 12 degrees to the south; this prevailing southerly dip is perhaps the most dominant structural feature.

The field is traversed by several major faults of which the Wallsend Fault, trending north-west and south-east, has a downthrow to the south of about 240 feet.

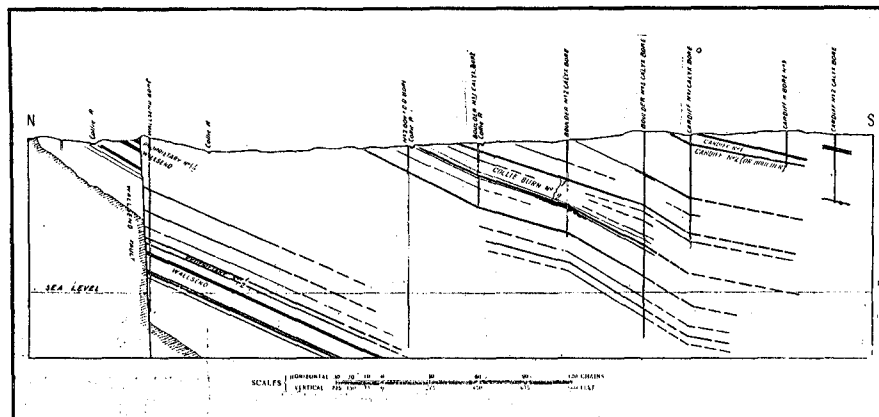
A fairly extensive wedge-shaped mass of granite occurs to the south of the Premier Mine at Shotts, which is probably continuous with that outcropping to the south-east, in the neighbourhood of the Mineral Leases Nos. 145, 146, and 149, shown on the Geological Map of the Collie, issued in 1898. This wedge-shaped mass of granite may represent a faulted block; in any case its occurrence indicates a serious interruption in the continuity of the Coal Measures in this portion of the Collie Coalfield.

The coals of the Collie Coalfield are hydrous, semi-bituminous, non-caking coals which approach very closely to lignite in some parts; between the various varieties the differences are only of degree. The coal is black, dirty to handle, and partly composed of bright layers alternating with soft bands, which present the appearance of compressed soft wood charcoal. The coal is singularly deficient in volatile materials; for this latter reason the coals are specially suited for use in suction gas plants.

The coals appear to be mainly of drift origin and to have been deposited by current action on an extensive basin or river valley, which corresponds with that of the Collie River. The banded appearance of most of the coals and their relatively high percentage of ash probably results from their mode of origin. No underclays appear to have been noticed in the Collie Field. Investigations into the composition and properties of the coals from the Collie Coalfield have been made in the Geological Survey Laboratory by Dr. E. S. Simpson, and from these it appears that while all the coals belong to one general class, there are two distinct types of coal which may be designated the Proprietary type and the Collie Burn type.

"The former, or Proprietary type, is characterised by a dull porous appearance, a thinly-banded structure, and the presence of much 'Mother of Coal,' which makes it dirty to handle; also by its comparative fragility and consequent tendency to crumble on exposure to the air and, finally, by its freedom in burning and lack of smoke."

Fig. b.



In addition to these beds, another series of seams in the north-east corner of the field, at Shotts, have been opened out; these, however, have not as yet been correlated with any of those referred to previously. The seams from the new locality consist in descending order (omitting all those under three feet in thickness):—Coal 3

"The Collie-Burn' type is characterised being very bright and compact in appearance, much less laminated than the other type, almost free from 'Mother of Coal,' clean and firm to handle and, while burning less freely, giving out an appreciable amount of smoke."

These prominent characteristics of the two types of coal are accompanied, and are probably governed by, well marked differences in composition.

The following table gives the mean results of analyses of Coals of the Proprietary type (Proprietary and Co-operative Colliery No. 2), and the Colliburn type (Colliburn No. 1; Cardiff Nos. 1 and 2).

Table showing the Mean Composition of two types of Collic Coal.

Type.	Proprietary Type.	Colliburn Type.
Specific gravity	1.392	1.321
Proximate Analysis—		
Moisture	18.62	23.32
Volatile hydrocarbons	24.79	32.17
Fixed Carbon	48.48	40.20
Ash	8.11	4.31
	100.00	100.00
Ultimate Analysis (neglecting moisture)—		
Carbon	70.56	69.44
Hydrogen	3.86	4.65
Oxygen	13.74	18.10
Nitrogen	1.31	1.42
Sulphur ... ..	.55	.77
Ash	9.98	5.62
	100.00	100.00
Ratios—		
Volatile hydrocarbons to Fixed carbon	1	1.25
Hydrogen to Carbon	18.3	14.9
Oxygen to Carbon	1	1
	5.14	3.83
Calorific Values—		
Including moisture	9,695	9,516
Excluding moisture	11,911	12,409

The above table, which contains the analytical results made in the Geological Survey Laboratory in 1908, brings out the salient differences in the composition of the two types of coal.

On grinding it appears that the coals of the Proprietary type give a black powder, whilst those of the Colliburn type give a dark-brown powder. The Colliburn type of coal would appear to be less completely carbonised coal than that of the Proprietary type.

The following figures give the average results of the analyses of the coal of the Collic Coalfield, made by Mr. I. H. Boas of the Technical School, on behalf of the Royal Commission on the Collic Coal Industry of 1914:—

Table of Average Results of the Analyses of the Coals of the Collic Coalfield.

Collieries.	Co-operative.	West-tralian.	Pro-prietary.	Scottish.	Cardiff.
Ash	7.69	8.12	6.40	3.95	4.50
Moisture	19.26	19.3	24.7	24.7	25.1
Sulphur	0.42	0.50	0.40	0.64	0.78
Nitrogen	1.12	1.13	1.15	1.04	0.92
Volatile hydrocarbons	26.4	26.9	26.2	38.3	32.1
Calorific Value B.T.U. as received	9,803	9,779	9,112	9,354	8,988
Calorific Value B.T.U. Ash, moisture free	13,374	13,486	13,231	13,079	12,670

The table shows that the coals are divisible into three groups:—

- (1) The Co-operative and Westralia, characterised by low moisture, high ash, low sulphur, high carbon, and low oxygen.
- (2) Scottish and Cardiff, characterised by high moisture, low ash, high sulphur, low carbon, and high oxygen.
- (3) Proprietary, characterised by intermediate values.

The ashes from the various coals of the Collicfield vary both in quantity and quality, as is indicated by the following table:—

Colliery.	Geological Survey. E. S. Simpson.	Royal Commission, 1914. I. H. Boas.
	%	%
Proprietary	9.08	8.44
Co-operative No. 2	7.14	...
" Tops ... ..	...	8.11
" Bottoms ... ..	...	10.72
Westralia Tops ... ..	...	10.55
" Bottoms ... ..	...	9.52
Cardiff No. 1A	5.45	...
" No. 1B	3.94	...
" No. 2	5.11	...
Cardiff ... ..	...	6.00
Colliburn No. 1A	3.72	...
" No. 1B	2.52	...

The Composition of the Ashes has been investigated in the Geological Survey Laboratory with the results shown in the table.

Table showing the Composition of Collic Coal Ashes.

Seam.	Proprietary.	Co-operative No. 2.	Cardiff No. 1A.	Cardiff No. 1B.	Cardiff No. 2.	Colliburn No. 1A.	Colliburn No. 1B.
	%	%	%	%	%	%	%
Silica, SiO ₂	35.29	61.18	51.36	36.04	45.49	28.20	22.73
Titanium oxide, TiO ₂	1.38	1.66	.83	1.08	1.14	1.75	1.71
Phosphoric oxide, P ₂ O ₅ ... ..	.16	trace	2.92	3.79	1.72	8.31	8.71
Vanadic oxide, V ₂ O ₅ ... ..	.21	.10	.07	.04	.05	.02	trace
Sulphur trioxide, SO ₃	2.43	.58	1.43	1.70	.94	3.30	1.00
Potash, K ₂ O ... ..	.18	.20	.23	.27	.07	.32	.12
Soda, Na ₂ O ... ..	.39	.72	.43	.94	.76	.80	.99
Lime, CaO	2.94	1.61	2.92	4.51	3.29	5.39	5.69
Magnesia, MgO	2.18	.51	2.76	3.70	2.59	3.99	2.98
Manganese oxide, Mn ₂ O ₄	1.35	.43	.29	.77	none	minute	.86
Iron Peroxide, Fe ₂ O ₃	36.57	5.67	13.33	19.95	18.93	23.38	28.85
Alumina, Al ₂ O ₃	16.59	27.63	13.58	27.35	25.59	24.58	29.02
	99.67	100.29	100.18	100.14	100.57	100.04	99.75

"From calculations based on these figures it is apparent that the chief constituents of the ashes of Collic Coal are aluminium silicate, free silica, iron oxide, calcium sulphate, and a metallic phosphate, probably phosphate of alumina. These substances are not the original minerals present in the coal but the products derived from them by roasting during the burning of the coal. The free silica represents free quartz sand. The iron oxide is partly, but not altogether, altered pyrites. From concentration tests and sulphur determinations it is evident that the amount of pyrites in the original coal ranges from 0.5 to 1.1 per cent. The balance of the iron was found to occur in the form of ferrous carbonate, either pure as siderite or associated with carbonates of lime and magnesia. The phosphoric oxide in the ashes calls for special comment. In the ash from the Proprietary and Co-operative Coals it occurs in normal quantities of less than one quarter of one per cent. In the Cardiff Coal ashes it rises to quite abnormal amounts, whilst in the

Colliburn ash it reaches the unparalleled figure of $8\frac{1}{2}$ per cent., equal to 14.6 per cent. of aluminium phosphate. This is in such a fine state of division that it should be made available as plant food so that the ashes might be used as a low grade phosphatic fertiliser."

The coal production of the State up to the end of 1918, which is entirely that of the Collie Coalfield, amounted to 4,207,946.26 tons valued at £2,053,556.

The principal consumer in Western Australia is the Railway Department, and during recent years the local coal consumed in connection with that branch of the service has shown a steady increase, the total amount used for this purpose up to the end of 1917 being 2,333,661 tons, equal to 65.84 per cent. of the total production of the collieries on the Collie Coalfield.

Up to the end of 1916, 407,615 tons, valued at £326,175, have been exported from the State, and of this quantity 400,648 tons, valued at £326,175 have been used for bunkering purposes, indicating that this phase of the industry is assuming considerable importance.

The Royal Commissioner of 1904 on the Collie Coalfield estimated the total amount of coal available in the field to be 310,080,576 tons.

As the result of later investigations, the Royal Commissioners of 1914 on the Collie Coal Industry, however, estimated that at a depth not exceeding 2,000 feet the available coal on the field amounts to 3,500,000,000 tons.

WILGA.—What appears to be an extension of the Collie Coalfield occurs on the upper reaches of the Collie River about five and a half miles to the north-east of Wilga Siding on the Donnybrook-Preston Valley Railway.

Several prospecting shafts have been put down in the area, the deepest vertical shaft being about one hundred and twenty-five feet from the surface, and several seams of coal have been met with.

The extent of the area, in the absence of a geological survey, cannot be evenly approximately arrived at, though there is very little doubt that the beds accompanying the coal belong to the Collie River Series, and the seams make a considerable addition to the coal reserves of that formation.

The following figures give the results of analyses of the Wilga Coals, as made in the Geological Survey Laboratory:—

Geol. Surv. Lab. No. ...	3631E.	3677E.	4108E.	4216E.
Moisture	18.43	18.57	18.76	15.09
Volatile hydrocarbons ...	29.20	33.88	33.50	30.43
Fixed carbon	47.13	42.60	40.40	45.62
Ash	5.24	4.95	7.28	8.26
Total	100.00	100.00	100.00	101.00
Calorific value, B.T.U. ...	9,253	8,717	9,606	9,471

3631E. Five miles south-west of Wilga.—"This is a thin-bedded coal of the hydrous bituminous class, similar in all respects to that found in the lower parts of the Collie basin. It loses moisture rapidly on exposure to the air, increasing thereby in calorific value, but losing cohesion to a large extent. It does not cake when retorted."

3677E. Coal.—O'Grady's shaft 670 paces E. 11deg. N. of Traverse peg C. 54, N.E. of Wilga Railway Station.

4108E.—Coal from P.A. 286H, Wilga.

4216E.—Bottom half of seam from about 125 feet deep. Ashburton Colliery, Wilga.

The following additional calorific values and moisture content were also made of coals from this field:—

Geol. Surv. Lab. No. ...	4481E.	4482E.
Moisture	17.06	17.04
Calorific value, B.T.U. ...	10,458	8,822

4481E.—Bottom seam, O'Grady's Coal Mine.

4482E.—Sample in east cross-cut, O'Grady's Coal Mine.

IRWIN RIVER COALFIELD.—The Carboniferous Rocks occupy a fairly large area in the valleys of the Lockier and the Irwin Rivers, and the upper portion of Koekatea Creek. The strata, which are fossiliferous, consist of shales, clays, sandstones, and limestones, together with occasional bands of ironstone. The Irwin River beds are known to contain coal seams, and the associated fossils, of which a list has already been given, show that the strata belong to the Permo-Carboniferous Formation, which has proved so valuable elsewhere.

The coal seams of this series occur in a belt of sandy and shaly rocks estimated at about 150 feet in thickness, which strike north and south and dip to the eastward at an angle of about 10 degrees. The same coal-bearing series has been found 18 miles to the south-south-east in Woolgar Creek, where a seam of about a foot in thickness has been noted. This occurrence is of importance, since it indicates that the horizontal extent of the coal-bearing horizon in the Irwin-Lockier River valley is considerable.

The north-eastern boundary of the field is marked by a fault which throws the beds against the crystalline rocks; in the vicinity of this fault the strata have been thrown into a series of gentle folds, though the whole series has, in this locality, a prevailing dip to the eastward.

Coal seams outcrop in the valley of the Irwin River in Reserve 2297, and a drive put in on a seam about five feet thick, for a distance of about 200 feet. The coal, which is a hydrous bituminous non-caking coal, when analysed in the Geological Survey Laboratory in 1907, gave the following results:—

	Top of seam. 1ft. 3in.	Middle of seam. 1ft. 9in.	Bottom of seam 2ft. 0in.
	%	%	%
Moisture	22.04	22.74	24.25
Volatile hydrocarbons ...	23.84	27.12	26.73
Fixed carbon	37.25	31.98	37.97
Ash	16.87	16.16	11.05
	100.00	100.00	100.00
Sulphur ... ..	.52	.75	1.69
Calorific Value B.T.U. ...	7,020	7,182	7,965

In 1912 another analysis was made of this seam, and the results are as follow:—

	Per cent.
Moisture	18.39
Volatile hydrocarbon ...	29.87
Fixed carbon	40.13
Ash	11.61
	100.00

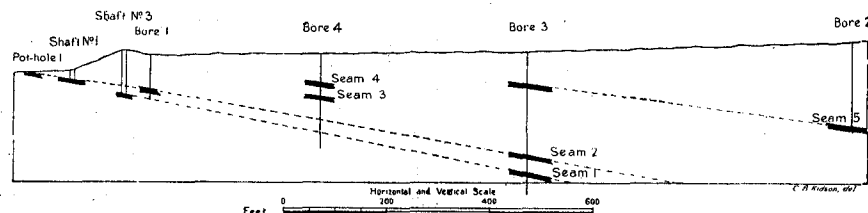
Calorific Value B.T.U.—8593.

After having been abandoned for some years, prospecting operations were carried out on Mining Reserve No. 900 during the year 1917, and disclosed five lenticular coal seams in the 150 feet of strata pierced in the workings.

In addition to boring, three shallow shafts have been sunk in the south branch of the Irwin River, and from a seam in a shaft

were taken up and some prospecting operations carried on. A number of bores were put down by hand, the deepest of which was 128 feet, and this passed through no less than 17 seams of coal aggregating 20 feet in thickness. The largest of the seams measured five feet four inches in thickness, but had a six inch clay parting and another two feet three inches with a two inch parting.

Fig. c.



SECTION SHOWING COAL SEAMS ON THE IRWIN RIVER.

at a depth of 42 feet the coal, analysed in the Geological Survey Laboratory, had the following composition:—

	Per cent.
Moisture	9.48
Volatile hydrocarbon	32.59
Fixed carbon	49.17
Ash	8.76
	<hr/> 100.00

Calorific Value B.T.U. 10494, which is the highest yet recorded from this field. If there is any large area of coal of this high grade and of workable thickness on the field, then the possibility of its exclusive use on the Murchison Railway system becomes a matter of serious consideration.

GREENOUGH RIVER.—In 1906 boring operations, having for their object the testing of what were believed to be the northern extension of the Irwin River Coal Measures, were commenced in the valley of the Greenough River, where it is crossed by the Geraldton-Meckatharra Railway. The bore, which passed through sandstones and shales, was carried down to a depth of 297 feet and in it at 118 feet a six feet seam of somewhat weathered coal was encountered. The bottom two feet of this seam gave, on analysis in the Geological Survey Laboratory, the following composition:—

	Per cent.
Moisture	9.59
Volatile hydrocarbon	42.28
Fixed carbon	37.97
Ash (white)	12.16
	<hr/> 100.00

Calorific Value, B.T.U.—9900.

Sixteen shallow bores, the deepest being about 300 feet, were put down in Kockatea (or Tenindewa) Gully, but though the coal measures were met with in some of them, no coal seams were encountered.

FLY BROOK COAL DEPOSITS.—Coal seams have been known to occur for many years past at Fly Brook, one of the branches of the Donnelly River, on the South Coast.

The coal-bearing rocks consist of sandstones, grits, and micaceous clay shales, the whole being overlain by a bed of conglomerate which is often very ferruginous, and is made up of large waterworn pebbles of quartzite, quartz, and crystalline rocks such as constitute one of the walls of the Darling fault, between the Warren and the Blackwood Rivers. In the year 1888 a number of coal mining leases

In the No. 3 bore put down on the Warren River by the Oil Corporation, 500 feet of these measures were passed through, but only small seams of coal were encountered.

The Fly Brook coal is a lustrous black coal, having a sub-conchoidal fracture resembling jet, though lacking its hardness, while woody structure is clearly visible on the weathered surface.

A hard bright brown coal from the lower seam in the deep bore in Fly Brook had the following composition:—

	per cent.	per cent.*
Moisture	13.31	10.17
Volatile hydrocarbons	37.42	42.49
Fixed carbon	40.45	43.73
Ash	2.82	3.61
	<hr/> 100.00	<hr/> 100.00
Calorific Value, B.T.U.	10,167	10,098

* Air dried for several years.

THE VASSE.—A good deal of experimental boring has been carried out since the year 1892 in the neighbourhood of the Vasse River, which enters Geographe Bay near Wonnerup, some miles to the north of Cape Naturaliste. In all there have been six recorded bores, in the whole of which 25 coal seams have been reported. The greatest thickness of coal in any one bore was about 3 feet 6 inches. So far as may be judged from the bore journals, the strata consist largely of sand—in all probability incoherent sandstone—shales with pyritous nodules and dark and yellow clays; they may in all probability represent the northward continuation of the Fly Brook beds.

No analyses of the most promising of the coal appears to have been made, and beyond the fact that the boring seems to indicate that the deepest portion of the basin is in the valley of the Vasse River, there does not appear to be any geological reason for believing that the neighbourhood contains workable coal seams of commercial value.

DONNYBROOK.—Some prospecting operations have been carried out, some years ago, to the south-west of Donnybrook, near the headwaters of the Capel River not far from that powerful fault which separates the crystalline rocks from the more recent strata. Such operations as have been carried out disclosed the occurrence of impure brown coals of low calorific value at a relatively shallow depth. Some of the seams exposed in the workings are impure brown coals with occasional traces of lignitic structure and averaging about ten inches in thickness. The seams are separated by a similar thickness of arenaceous and carboniferous shales.

The strata associated with the coals near Donnybrook bear a very close lithological resemblance to those of Collie, but it is more

than likely that they are the representatives of the beds exposed in the bores at the Vasse, to which reference has already been made.

Several analyses have been made of these seams in the Geological Survey Laboratory, and the composition of the seam on Prospecting Area 155H was shown to be as follows:—

Number	1. Parts per 100.	2. Parts per 100.	3. Parts per 100.	4. Parts per 100.
Moisture	26.95	31.34	31.28	35.00
Volatile hydrocarbons	25.46	28.43	31.57	28.60
Fixed carbon	21.98	24.37	20.12	24.70
Ash	25.61	15.86	11.03	11.70
	100.00	100.00	100.00	100.00
Calorific Value, B.T.U.	5,710	6,315	6,928	6,429

In Murphy's shaft No. 1 a seam of brown coal about five feet in thickness was exposed at a depth of 73 feet, the shaft, however, having been carried down to 210 feet from the surface. Two analyses were made from the seams, and their composition shown to be as follow:—

Number	A. Parts per 100.	B. Parts per 100.
Moisture	36.28	33.48
Volatile hydrocarbons	27.67	29.12
Fixed carbon	22.60	22.06
Ash	13.45	14.74
	100.00	100.00
Calorific Value, B.T.U.	6,072	6,364

A.—Main seam.

B.—Fault seam.

MILLBROOK.—Coal was first discovered about 20 years ago in a well sunk to supply water to the timber mill at Millbrook (now renamed Jarrahwood), one of the tributaries of the Blackwood River. At a much later date two bores were put down on Prospecting Area 8627, one of which lies about one chain east of the crossing of the brook by the Wonnerup-Nannup Railway. Several seams of coaly matter were reported in the two bores, which were 222 and 144 feet deep respectively; these, however, proved to be lignite of little or no value. The seams met with in these two bores are said to agree very closely both in character and depth with those originally opened in the well at Millbrook Mill, which are inter-stratified with sandy pyritous shale.

KIMBERLEY.—In the Kimberley Division in the far north of Western Australia a seam of hydrous bituminous non-caking coal, somewhat similar in character to the type prevailing at Collie, has been found in a well on Lower Liveringa Station, some distance to the south of Derby, in the valley of the Fitzroy River.

The seam, which proved to be 12 feet thick, was met with at a depth of 50 feet from the surface in strata which there seem geological reasons for believing to be of Upper Carboniferous Age.

An analyses of a sample of this coal, made in the Geological Survey Laboratory, showed its composition and calorific value to be as follows:—

	Per cent.
Moisture	8.87
Volatile hydrocarbons	29.73
Fixed carbon	33.99
Ash	27.41
	100.00

Calorific Value, B.T.U.—7722.

Having regard to the very large area covered by the Carboniferous Rocks in Kimberley, there seem good reasons for believing that other seams than that exposed in the well at Liveringa exist.

The Copper Deposits

of

Western Australia

by

A. Gibb Maitland.

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PART III.—Section 2.—COPPER.

GENERAL STATEMENT.

The history of mining in Western Australia began with the discovery of the Waueranooka Copper Lode at Northampton in the year 1842, and in 1845 the first consignment of copper ore left the State to be smelted in Wales. Since that date copper mining cannot be said to have made continued progress, though doubtless such will increase as time goes on. The annual production of copper ore has shown much variation, and up to the end of 1918 this amounts to 224,546 tons, valued at £1,540,930.

Copper ores are plentifully distributed throughout the length and breadth of the State, but so far copper deposits have only been worked to any extent in a very few districts and there are not many producing mines. The principal sources of copper are Northampton, West Pilbara, Mount Morgans, and the Phillips River.

The workable deposits of copper so far known to occur in Western Australia are everywhere met with in areas which have been subject to more or less violent earth movement, and concomitant volcanic activity. They all show a marked similarity in their associations, mineralogical characters, and structural relations.

The copper deposits of Western Australia, when viewed in the light of their mode of occurrence and geological relationships, may be divided into three distinct categories: (a) lodes of the fissure vein type, (b) impregnations and stockworks, and (c) those along shear zones and shatter belts. The majority of the workable deposits apparently belong to the former class.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

KIMBERLEY.

Pandanus Creek.

Some good copper ore is said to occur at Owl's Gap on Pandanus Creek at the end of the Leopold Range, about 7 miles west of the Fitzroy River, in the Kimberley Division, but so far nothing has been done to in any way exploit the deposit.

Yampi.

A very promising copper deposit has been opened up at Yampi Sound, in West Kimberley, distant about 10 or 12 miles from the iron deposit at Koolan Island.

The lode occurs on the beach, and being not very far from deep water, facilities for mining are good. The ore is mostly chalcocite of good quality, and is associated with a little green carbonate of copper and quartz. The lode, so far as has been developed, is from five to six feet wide, and underlies to the east, and so far as may be judged from specimens forwarded to the department, it occurs in a faulted zone of metamorphic crystalline rocks. The lode is a sericitised and carbonated quartz-porphry.

Up to the end of 1918 there have been raised from this locality 92.86 tons of copper ore, containing 22.80 per cent. of copper; the ore also contained a little gold and a small quantity of silver. A good deal of systematic and judicious prospecting is required to thoroughly test this occurrence.

Napier Range.

At the north end of the Napier Range in the watershed of the Lennard and Barker Rivers, the crystalline limestone which constitutes the larger portion of the Range, gives place to mica schist and basic dykes, which have a dominant strike of east and west. A copper-bearing quartz reef occurs alongside one of the basic dykes and has been traced across the surface for about 300 yards. Wherever this reef has been opened up it proved to be small and to carry very little copper of such a grade as would pay expenses. A few tons of copper might, however, be picked from the lode.

Mount Nellie.

Copper ores were discovered in 1905 at Mount Nellie, on the Taragee River about 60 miles north-east of Derby and 15 miles south-west of Colin Bay. The belt of country in which these deposits occur is schist and slate intersected by basic dykes and quartz reefs and extends north-westerly from Mondooma, on the Robinson River, to Mount Nellie, and is, in all probability, co-terminous with that series which carries the copper deposits of Yampi Sound. A series of dyke-like mineralised quartzose ridges containing quartz veins, often very much copper-stained, occur in this belt of schist. These veins are of considerable size and length, and, in addition to being much stained, often contain copper either in veins, bunches, or disseminated through the quartz itself. On what is known as Grant's Reward Lease (named after the discoverer, J. S. Grant), the lode mass rises in the form of a razor-backed ridge to a height of about 100 feet, having a width at the base of about 50 feet, and it can be traced for over one and a-quarter miles in length. In this body there are three distinct quartz veins or shoots, the central one of which is the largest, being seven chains in length and varying from two to 17 feet in thickness on the surface.

The ore is mostly green carbonate and red oxide of copper, and is met with at one or two points in the form of small veins or bunches of high grade ore; it generally, however, occurs intimately mixed with quartz when it varies from low-grade siliceous ore to stained quartz.

There are a number of other similar lode masses occurring in the locality, of which Wilson's Reward, six miles south of Grant's Reward, is one. The following assays have been made of samples from these localities:—

	Grant's Reward.	Grant's Reward.	Wilson's Reward.
	per cent.	per cent.	per cent.
Copper (oxide) ..	34.63	23.22	37.58
Lead .. .. .	.72	nil	nil
Zinc	†	†	†
Silver	4dwts. 22grs. per ton.	1dwt. 15grs. per ton.	11dwts. 10grs. per ton.
Gold	20grs. per ton.	20grs. per ton.	20grs. per ton.

PILBARA.

Copper ores have a wide distribution in the Pilbara Goldfield, though no copper mining is being carried on. At a point about eight miles north of the mining centre of Yandicoogina a fairly well defined copper lode has been exploited in a more or less desultory fashion at what is known as Lennon's Find. The lode, which can be traced across country for about two miles, consists chiefly of quartz stained with green carbonate of copper, with, in some portions, an iron oxide gossan.

The country rock of the lode is schist and the ore body occurs parallel to the planes of foliation of the schist, which trends generally 55 degrees east. The schist adjacent to the lode, on both its walls, is often silicified and impregnated with metallic minerals. The lode which seems to be a distinct fissure vein, varies in width from 12 inches up to as much as 10 feet. Assays of samples taken without any regard to selecting the more valuable ore from different localities along the outcrop, made in the Geological Survey Laboratory, gave the following results:—

G.S.L. No.	3373.	3374.	3375.
	per cent.	per cent.	per cent.
Copper	14.61	6.68	5.33
Lead .. .. .	.80	3.85	2.79
Zinc	16.33	4.45	5.52
Silver	23ozs. 3dwts. 12grs. per ton.	2ozs. 6dwts. 20grs. per ton.	4ozs. 13dwts. 10grs. per ton.
Gold	17grs. per ton.	17grs. per ton.	17grs. per ton.

G.S.L. No.	3376	3377	3378	3379
	per cent.	per cent.	per cent.	per cent.
Copper ..	17.20	6.01	6.40	nil
Lead ..	1.66	.36	5.55	13.89
Zinc ..	6.93	.86	8.37	.37
Silver ..	20ozs. 18dwts.	5ozs. 8dwts.	12ozs. 1dwt.	39ozs. 14dwts.
Gold ..	13grs. per ton.	4grs. per ton.	11grs. per ton.	8grs. per ton.
	13grs. per ton.	9grs. per ton.	17grs. per ton.	1dwt. 15grs. per ton.

The copper exists as malachite with a little cuprite and chrysocolla; the lead probably as anglesite with possibly some cerussite, and the zinc as hemimorphite (zinc silicate). The principal gangue minerals are quartz, limonite, calcite and barytes in varying proportions. The metallic contents are not nearly so high as in the ore that would be picked for shipment in the course of actual working.

Further assays from this copper lode made at a later date gave the following results:—

G.S.L. No.	3065	3087	3507
	per cent.	per cent.	per cent.
Copper ..	1.10	12.81	18.23
Lead ..	2.39	2.57	.76
Silver ..	6ozs. 1dwt. 23grs.	21ozs. 2dwts. 12grs.	22ozs. 12dwts. 6grs.
Gold ..	13grs. per ton.	13grs. per ton.	1dwt. 6grs. per ton.

Assay 3507 represents the careful sampling of 7 tons of ore, taken while the ore was being raised in sinking a shaft 15 feet deep, and afterwards crushed, sieved, and then thoroughly mixed.

At what is known as Snell's claims, situated about 90 miles east-north-east from Marble Bar, a lode of copper, said to be about 7 feet wide, has been worked. The ore is said to occur in bunches varying from 5 to 20 tons in quantity and assaying 30 per cent. of copper. A parcel of 12 tons 18 cwt. of the ore was shipped to Liverpool, England, and gave an assay value of 22.72 per cent. of copper, and 3.20 ozs. of silver per ton.

A fairly well defined, though small but persistent, copper vein occurs at the south end of the main Warrawoona range of hills near the site of the old Iron Clad Battery, and has assayed 30 per cent. of copper, but very little work has been done upon it.

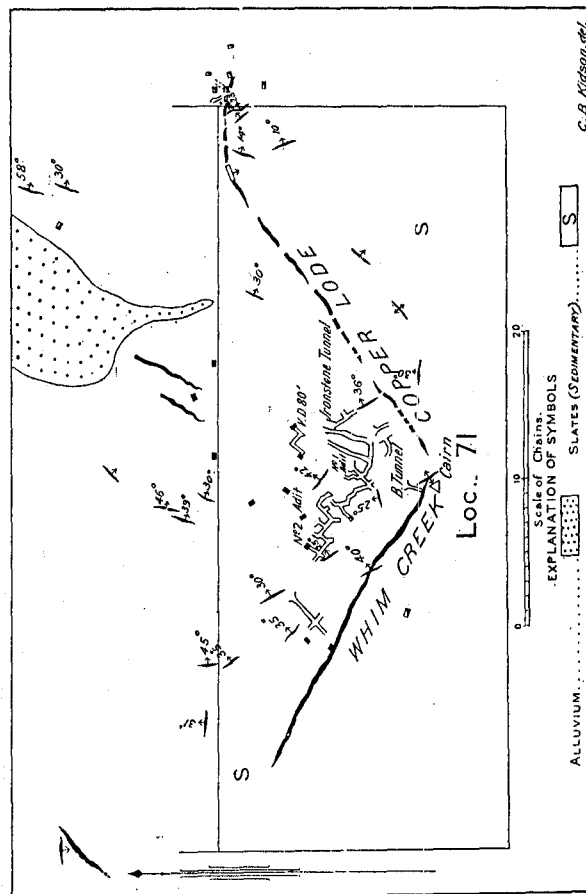
WEST PILBARA.

The West Pilbara Goldfield has been a very large producer of copper which, however, has been chiefly obtained from one property, the Whim Well Copper Mine, the other deposits consisting mainly of small, short shoots, occurring in ore channels in the basic greenstones; some of these shoots contain a high percentage of copper and, in one instance, high values in gold. The mining history of this portion of Western Australia commenced with the discovery of rich copper and lead deposits in 1872, and in the following year 60 tons of copper are stated to have been shipped from Cossack. Since that time the district has produced, up to the end of 1918, 10,240.07 tons of copper valued at £674,268, obtained from 78,450.17 tons of ore.

Whim Well.

The Whim Well copper lode is the largest and richest ore body yet discovered in Western Australia in the oxidised zone; it has, up to the end of 1918, produced 9,236.59 tons of copper valued at £596,247, extracted from 71,951.25 tons of ore. The outcrop of the lode forms the face of a low ridge running for about half a mile, and which rises steeply from the surrounding flat country to an elevation of about 120 feet; it is upon the crest of this ridge that the Whim Well copper lode outcrops for a distance of about 55 chains (Fig. A) in a north-westerly direction. The rocks in the vicinity

Fig. A.



Plan of the Whim Creek Copper Lode.

of the mine are highly fissile clay slates of sedimentary origin which are traversed by dolerite dykes. To the north of the cairn there is no well defined outcrop, the lode being represented by a series of more or less detached lenses which can be traced for a distance of about 60 chains in a north-easterly direction.

The lode dips to the north-east at an angle of from 25 to 35 degrees, though at one or two places it conforms to the shape of the ground, the hanging wall having been removed by denudation, thus exposing considerable areas of the lode.

The lode consists of lenticular masses of ore generally large, though naturally varying in size and richness contained in a copper-stained kaolinic deposit, which has been found to be from 3 to 30 feet in thickness. One of the largest of these lenses yielded 1,035 tons of ore assaying 26 per cent. of copper; it was made up chiefly of the blue and green carbonates of copper and "tile ore," a mixture of the oxides of copper and iron, as well as considerable sized bunches of chalcocite (copper glance) and black oxide of copper.

Several tunnels at different portions of the hillside have intersected the lode at 120 feet vertically below the outcrop, or 400 feet as measured along the underlay, without any difference in the character of the ore being apparent. Eleven bore holes have been put down to test the lode; three of these, however, did not reach the ore body; eight of the bores pierced the ore formation and gave varying

results, one yielding an average of 10 per cent. of copper over a width of 40 feet, whilst the others showed its thickness to vary from 30 to 90 feet. In the assay of the latter the major portion of the formation consisted of schistose country rock more or less impregnated with copper pyrites.

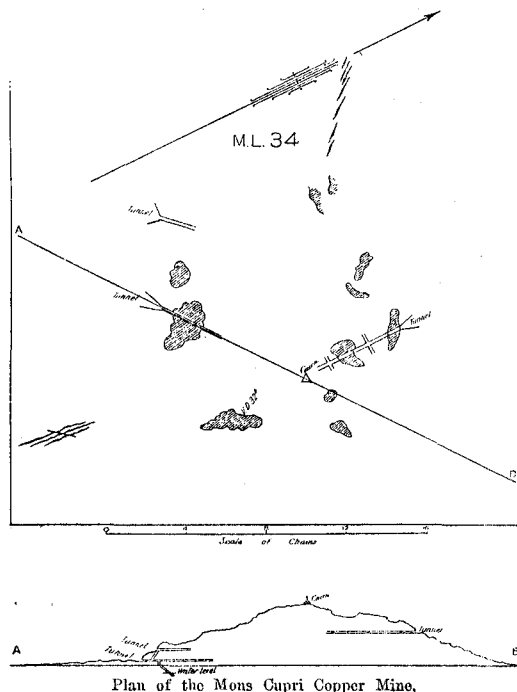
The maximum depth to which the lode has been proved is about 800 feet from the surface, as measured along its underlay; this, as disclosed in the bore holes, below the level of the lowest tunnel, proved to be about 25 degrees.

The average composition of the ore in the Whim Creek Mine is stated to be:—

	Parts per hundred.
SiO ₂	55.00
Cu	6.00
Fe ₂ O ₃	20.00
Al ₂ O ₃	7.00
CaO ... ..	...
MgO	2.00
S ... ..	...
Ni ... ..	...
Co	1.00
Zn ... ..	...
Pb ... ..	...
Alkalies ... ..	.05
H ₂ O ... ..	...
CO ₂	8.5

A copper deposit known as Mons Cupri, which lies about 2½ miles south-west from Whim Well, has produced 2,291.50 tons of copper ore, from which 200.00 tons of metallic copper valued at £15,915 were obtained. The ore deposit is of an irregular nature, no defined lode having yet been discovered. The deposit occurs in a dome-shaped hill, rising to about 300 feet above the general level of the surrounding country and riddled with small ferruginous copper veins which, as a result of weathering, has stained large areas of rock with green carbonate of copper, thus giving rise to its name, Mons Cupri (Fig. B).

Fig. B.
PLAN & SECTION
OF THE
MONS CUPRI COPPER MINE
WEST PILBARA G. F.



Plan of the Mons Cupri Copper Mine.

The copper-bearing rocks have been opened out nearly all round the hill by a series of quarries and trenches, and two long tunnels, totalling in all about 500 feet in length, have been driven from opposite sides of the hill. The rock in which the copper veins occur is a fine-grained quartzite associated with felspathic grits or arkoses. The ore, which is mostly carbonates and oxides of copper, is found in veins and bunches and facing crevices in the country rock. In the tunnels which were driven below the points which proved richest on the surface, no ore body of any size appears to have been cut. The largest vein was met with in the south tunnel where it was followed down to about 50 feet to water level, at which depth it is small and proved to be made up chiefly of iron pyrites.

The quantity of copper-bearing rock is very large and there is probably a considerable quantity of ore near the surface which could be dressed up to about 10 per cent., though the value of the copper is, on the whole, poor.

Egina.

A deposit of copper ore, much higher in grade than that of Mons Cupri, occurs at Egina, some 40 miles west of Whim Creek, and which has yielded 542 tons of ore containing 104.15 tons of metallic copper valued at £6,643. The copper lode occurs in slate and schist country and can be traced in a north-east and south-west direction for about 100 feet, and has a high underlay to the west. The ore consists of a massive botryoidal malachite in a quartz matrix which, in the lower levels, gives place to chalcocite. The lode has been opened up by several shafts and exposes a width of from 3 to 14 feet. In the oxidised zone the lode, which on the whole was small, contained some very good bunches of ore. The Egina copper lode lies almost due south of Mount Langebeck, which is a bed of bold quartzite associated with ridges of laminated carbonated chert.

Croydon.

In the upper reaches of the Sherlock River, about three miles to the east of Croydon Station, is a copper deposit which has been worked intermittently since its discovery in 1898. About 604 tons of ore has been raised from the lode; this yielded 108.65 tons of metallic copper valued at £7,333.

The lode, which has a general north-easterly strike, is vertical, and has been followed by means of trenches and shafts for a distance of about 800 feet along the outcrop. At the surface the lode, which varied greatly in width, consisted mostly of oxide or iron and clayey matter with very many large bunches and veins of oxides, carbonates, silicates and sulphide of copper, encased in laminated greenstone.

An analysis of an average sample of the ore, which contained chrysocolla, malachite, cuprite, tile ore, chalcocite, a little chalcocite, zinc blende and smithsonite, quartz, and limonite encrusted with calcite, gave in the Geological Survey Laboratory:—

	Parts per hundred.
Moisture at 100°	3.86
Silica, SiO ₂	19.45
Alumina, Al ₂ O ₃	3.08
Magnesia, MgO	1.89
Lime, CaO	7.04
Iron, Fe	20.51
Zinc, Zn	1.73
Copper, Cu	15.18
Sulphur, S ... ..	.36
Oxygen, Carbonic Acid, etc., O.CO ₂	26.90
	100.00

The composition of the ore shows it to be excellent for smelting purposes. Below water level there is a good deal of iron pyrites and marcasite which may give place at lower depths to pyrites and chalcocite. Some samples from the lode have yielded from 2 to 14 per cent. of zinc. The main shaft has been carried down to a depth of over 85 feet and was put down on a rich patch of ore, which at the surface was 36 feet long and 16 feet in thickness, made up chiefly of carbonates and oxides of copper together with some oxide of iron and clayey matter. This shoot or pipe, which had a pitch to the south-east, was at the 45 feet level, 45 feet long and

8 feet thick, whilst at 65 feet it proved to be 65 feet long and 6 inches in thickness. The lode has not been tested beyond the termination of the shoot, hence the existence or otherwise of other lenses of this nature in the ore channel at no great distance from the existing workings has not been determined.

Roebourne.

In the more immediate vicinity of Roebourne, which from the point of view of mining history ranks next to Northampton, several copper lodes were first worked in the early seventies of last century. The lodes being all situated close to seaport, have been enabled to be worked under the most economic conditions possible. Since the inception of copper mining, the Roebourne district has produced up to the close of 1918, 3,031.42 tons of ore, from which 585.10 tons of metallic copper valued at £48,780 have been extracted.

In its salient geological features the neighbourhood of Roebourne consists of a variety of igneous rocks and others of sedimentary origin of at least two distinct ages. The most ancient sediments consist of quartzite, conglomerate, and silicified cherty dolomite; those at the mining centre of Weerianna are associated with a banded quartz-chlorite rock of obscure origin. These ancient sediments are associated with dolerites (diabases), which have been in places transmuted into greenstone schist and form the matrices of the copper and gold deposits. Amongst the more noteworthy of these deposits are the following:—

Fortune (Aurora Australis).—The deposit which has been worked on this property consists of two well-defined ferruginous quartz reefs, arranged *en échelon*; one dying out and the other beginning opposite the western end, though a little further to the north-west. The ore body can be traced for a distance of over 1,500 feet on the surface, in a direction a little south of west and with an underlay to the north.

The lode is made up mostly of quartz stained with the oxides of iron and copper, as well as occasionally with the copper carbonates. In places the ore body attains as much as 20 feet in width, though the average is from 4 to 6 feet. The richer portions of the lode are more contracted in size, the ore consisting of green carbonates of copper and ferruginous oxides between well marked smooth walls contained in a belt of schistose rocks surrounded by gabbro; the schistosity in all probability results from the transmutation of the gabbro along a shear zone. A considerable amount of work has been done upon the eastern vein, several shafts having been sunk to a depth of from 40 to 60 feet, whilst the richer portions of the ore have been stoped out for a considerable length. The Western Vein, which has a length of about 800 feet, has had a good deal of work done on it, several shafts having been put down to depths of about 60 feet and along section of the lode stoped to the surface. The Fortune (Aurora Australis) is a good strong lode and its mineralogical composition shows it to be a good smelting ore and practically self-fluxing. An analysis of a grab sample of the ore in the Geological Survey Laboratory is shown in the table below.

The wide extent of country intervening between the Fortune copper lode and the Carlow Castle ore bodies to the north contains several small copper-bearing veins which, in the aggregate, appear capable of yielding a fair quantity of copper ore.

One of these which has been worked under the name of the *Azurite* (M.L. 129) lies about a mile to the north of the Fortune. The lode trends generally east and west with an underlay to the north; the ore channel, which lies in a coarse gabbro, is narrow and the ore occurs in the form of narrow shoots, which are characteristic of the lodes in this locality. The deposit has been worked by means of a vertical shaft, 36 feet deep, and a shallow open cut along the lode west from the shaft for a distance of about 50 feet.

Messrs. North and Brown opened up another of these east and west copper-bearing lodes to the north of the Fortune. The lode which had been worked to a depth of 70 feet, was only about 18 inches thick at the surface and 3 feet 6 inches at the bottom of the shaft. The average strike of the lode is about north 80deg. west, with a perceptible underlay to the south. The walls of the lode are smooth

and well defined, and the ore body apparently conforms to the general dip and strike of the foliation of the gabbroid country rock. As seen near the surface the lode carries the oxides and carbonates of copper, which in depth were found to give place to chalcocypite and malacchite. The lode at the foot of the shaft proved to be a nice strong ore body capable of yielding a fair quantity of ore. The composition of two samples of ore from this deposit is shown in the table given below.

About 15 chains south of the *Azurite* is a small narrow lode striking east and west which, however, has a considerable length along the outcrop. The deposit which occurs in the gabbro has only been worked to a shallow depth. A sample of the sulphide ore from the shallow workings yielded an assay in the Survey Laboratory a return of 12.85 per cent. of copper and 2dwts. 2grs. of gold per ton.

The Carlow Castle group of lodes were first opened up in the early days of the history of mining in the vicinity of Roebourne, and from them a considerable quantity of copper ore was obtained. In 1898 two shipments of copper ore were despatched from here; the first of 9 tons gave 31 per cent. of copper and 3 dwts. of gold per ton, and the second 1½ tons gave 16 per cent. of copper and 1½ ozs. of gold per ton. There are eight lodes distinguishable in the vicinity of Carlow Castle, these which were all included with in the boundaries of Mineral Lease 65, present considerable variation both in dip and strike. The deposits occur in a schistose dolerite which lies to the south of a pronounced belt of laminated quartz rock, which may represent a silification of the schists through metasomatic action. The lodes naturally vary in their dimensions as well as their mineral contents; four of them, however, being, owing to their short length and low grade, of little importance as sources of copper ore.

One of the lodes, No. 1, or the Big Lode, has a length along the outcrop of 700 feet; it is quite 8 feet wide between the walls and has been followed down to a vertical depth of about 70 feet. The lode consists chiefly of schist and quartz stained with oxides of iron and carbonates of copper. At a depth of 50 feet a little driving has been done in the lode, and in a winze a pipe of ore 8 feet wide was followed. A crosseut of 6 feet put into the western wall from the 50 feet level exposed a seam of chalcocite. The lode near the northern end of the outcrop has been opened up by means of an underlay shaft 30 feet deep, sunk on an ore body consisting of ferruginous oxide and carbonate of copper of from 3 to 4 feet in width.

The northern extension of the No. 1 or Big Lode has been worked in an adjoining lease, the No. 1 (M.L. 150), by means of a shaft carried down on the underlay of the lode to a depth of 100 feet upon a rich shoot of copper sulphide (Copper Glance) which carried about 1 oz. of gold per ton. Some of the ore was found to contain a little cobalt, an assay made in the Geological Survey Laboratory gave 1.63 per cent. of cobalt and .13 of nickel. During 1908, 78.10 tons of ore were raised from this portion of the lode and yielded 19.30 per cent. of copper together with a total of about 89 ounces of fine gold.

Composition of Glen Roebourne Copper Ores.

Constituents.	Fortune Lode.	North & Brown's P.A.	
		Black Sulphide of Copper & Pyrite.	Clean Chalcocyprite.
	per cent.	per cent.	per cent.
Moisture	1.30	0.40	0.19
Silica	20.09	27.93	18.98
Alumina	.64	7.47	trace
Magnesia	.69	3.00	.22
Lime	trace	trace	trace
Iron	25.12	10.12	30.94
Nickel	.23	.72	.79
Copper	18.15	23.95	15.25
Lead	trace	trace	trace
Sulphur	1.21	17.96	28.02
Oxygen	Carbonic		
Acid, etc.	23.51	2.45	7.61
	100.00	100.00	100.00

The ore from the Fortune lode contained, in addition, 5 ozs. 0 dwts. 8 grs. of silver and 2 dwts. 13 grs. of gold per ton; whilst that from North & Brown's P.A. had 6 ozs. 10 dwts. 16 grs. and 2 ozs. 5 dwts. 18 grs. of silver per ton, as well as 5 dwts. 11 grs. and 3 dwts. 19 grs., respectively, of gold per ton.

Weerianna.

In the neighbourhood of Weerianna, about two miles to the westward of Roebourne upon the northern edge of the Mount Welcome Range, a little copper mining has been carried out in deposits which occur in a belt of basic schists lying between the large masses of gabbro to the east and the dolerite to the north. Both of these rock masses are intersected by hornblende granite.

The most important of these copper deposits is what is known as the Lilly Blanche. The lode as seen on the surface is small, and can, in most parts, only be detected by copper stains in the rocks. The deposit has a general north-easterly trend and has been opened out by two shafts to a depth of 40 feet. When followed down from the surface the lode soon opened out, showing at first some very fair oxide of copper which ultimately gave place to chalcopyrite. A shoot of ore about 76 feet in length was exposed to a depth of 40 feet from the surface. The walls were well defined and the lode, which consisted of quartz, containing copper and iron pyrites in varying proportions was from 3 to 4 feet in width. About 997 tons of this ore was dressed up to about 18.75 per cent. of copper.

Some little distance to the south-east of the Lilly Blanche a group of copper lodes has been worked to a limited extent in what is known as the Ena (M.L. 118). There are seven lodes on the property on which a little prospecting has been carried on. One of these, which is practically vertical, trends north 50 degrees east and is enclosed by walls of basic schist which passes into the normal diorite (?) at a little distance from the lode; the ore channel being merely a shear zone. The outcrop as seen in the trenches is made up of rubbly iron and copper-stained quartz.

Two lodes lying very close together, are situated a little to the north-east of this; they have an average strike of north 20 deg. east, and consist of ferruginous oxide and carbonate of copper. To the eastward there is a fairly long line of lode trending north 10deg. east, upon the north end of which is a shaft 3 feet deep at the bottom of which is about 3 feet of ore. The outcrop of the lode is a copper-stained rubbly quartz, containing a small amount of fairly good oxide of copper.

Yannery Hill.

A series of copper lodes occurring in altered sediments, believed to belong to the Nullagine Formation, are situated at Yannery Hill, about 26 miles south of Roebourne. The outcrop consists of about nine parallel veins occurring over a width of about 300 feet, and which trend north 60 degrees west and underlay at a high angle to the north-east. The veins are made up largely of ironstone containing green carbonates and red oxide of copper disseminated throughout. Upon one of the veins a vertical shaft has been sunk to a depth of 32 feet, which proved to be from 2 to 7 feet thick.

About a mile to the south-west is the Trouble Copper Lode, which trends north 50 degrees west and underlays to the north 40deg. east, and can be followed along the surface for almost the full length of the lode.

ASHBURTON.

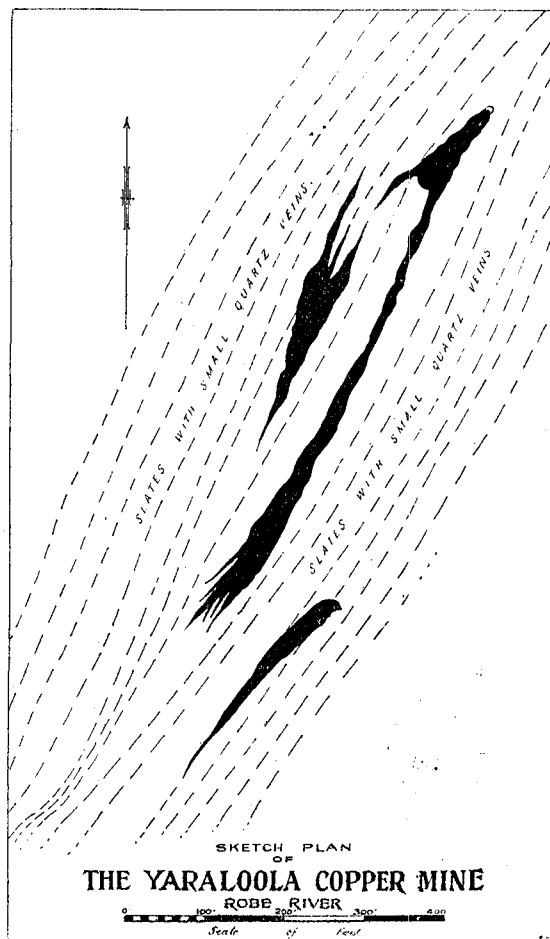
Copper ores have a fairly wide distribution in the Ashburton Goldfield, and according to the official returns, 351.07 tons of copper ore were raised up to the end of 1918. From this quantity of ore 97.13 tons of metallic copper, valued at £6,408, were extracted. The whole of the output from the field, with the single exception of 6.32 tons of ore containing .79 tons of metallic copper, valued at £24, has been obtained from the deposits at Uaroo or Red Hill. The copper deposits occur under different geological conditions throughout the Ashburton, and have been found in association with iron-stained

quartzite, metamorphic limestone stained with iron oxide and copper carbonates along belts or zones of fracturing, crushing, shearing or jointing. There are, however, no deep workings anywhere on the Ashburton, and the deposits of commercial importance seem to be mainly those which contain the oxidised ores.

Yaraloola.

A copper-bearing quartz lode occurs near Yaraloola Station on the Robe River. The lode is situated about three and a-half miles south-east of the station on a low isolated hill on the northern bank of the river, near the pool which is known as Saddleback. The rise is made up of vertical metamorphic sedimentary rocks which have a general strike of north 35 degrees east. These rocks are traversed by large lenticular veins of quartz, the mode of occurrence of which is indicated in Fig. C. Beyond the fact that copper ore is showing freely as stains and impregnations over a belt about 250 feet wide and at least 400 feet in length, no definite lode occurs. The ore is largely green carbonate of copper, red oxide and copper glance. Assays of the ore made in the Geological Survey Laboratory yielded 18 per cent. of copper, together with a little bismuth.

Fig. C.



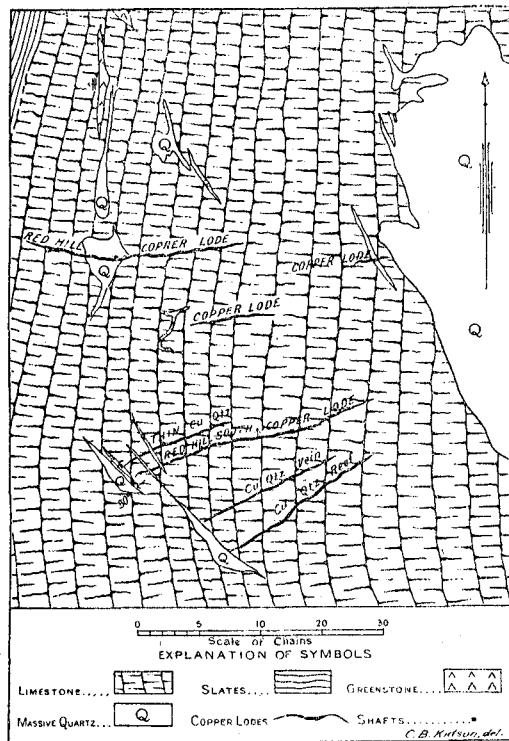
Plan of the Yaraloola Copper Lode.

Red Hill.

What are known as the Red Hill Copper Mines are situated due east of Stock Route (9701) Well No. 45, and about two miles from it. The country in the vicinity is made up of a series of highly inclined metamorphic sedimentary rocks, upon the upturned edges of which are coarse conglomerates, believed to belong to the Nullagine Formation. In the more immediate vicinity of the copper lodes the older sediments occur in great force; they consist of limestone embedded with quartzites and micaceous shales. By far the larger portion of the copper-bearing area is made up of beds of siliceous dolomite, dipping westward at about 30 degrees and resting upon micaceous sandstones and shales.

The dolomitic limestone is intersected by irregular masses or veins of quartz which have a general northerly trend, the largest masses being that which forms the easternmost margin of the area (Fig. D).

Fig. D.



Plan of the Red Hill Copper Lodes.

The copper lodes, which are quartz reefs, trend generally easterly and are of later date than the large masses of quartz, for they traverse them almost at right angles. Prospecting on the copper lodes has not gone on very much beyond the most rudimentary steps and of these only two, the Red Hill Copper Mine and the Red Hill South, have had very much work done on them.

The Red Hill Copper Lode (Fig. D), which is a quartz reef, containing narrow veins of ores of copper and iron and, in some cases, secondary siliceous, outcrops for a length of about 1,200 feet and has been exploited by two shallow shafts in which the lode was found to vary from 18 inches to 2 feet 6 inches in thickness and is situated in limestone. A typical sample of the siliceous ore assayed in the Geological Survey Laboratory about 4.74 per cent. of copper; a much more ferruginous type of oxidised ore returned 28.15 per cent. of copper. Exceptionally rich patches yielded 55.69 per cent. of copper, whilst an average sample of the limonitic ore returned 14.54 per cent. of copper and 28.35 of iron. The deposit is, on the

whole, small and of low grade. About 1,400 feet south is what is known as the Red Hill Copper Lode (Fig. D), which has a length of about 2,000 feet and is also situated in limestone country. The lode, which is a copper-bearing quartz reef, has been exploited by a vertical shaft 25 feet deep. The thickness of the reef at the surface near the mouth of the shaft is about 2 feet 6 inches in thickness and of very high grade ore. At the bottom of the shaft the reef is about 2 feet in width, though between that and the surface it is represented by only a few inches of quartz carrying a little copper ore. The ore itself contains large quantities of malachite and chrysocolla.

There are five other similar copper-bearing quartz reefs close to the Red Hill Lodes, but none of them have been worked.

A small copper-bearing quartz vein (Beechworth's) a little to the north of the Red Hill Lode has been opened up to a very shallow depth by a vertical shaft. The lode has an average strike of north 50 deg. west with a westerly underlay. The shaft had been put down on a thin copper-bearing quartz vein which, at 20 feet below the surface was 12 inches in thickness. About three or four tons of hand-picked and dressed ore has been taken from the lode.

A few narrow veins occurring a little to the south of Beechworth's, containing ores of iron and copper, which trend generally north and south, have been opened up and a very small quantity of ore raised.

What is known as Niven's Copper Lode lies a little distance west from Beechworth. The lode is a copper-bearing quartz reef occurring in dolomitic limestone and is parallel to the Red Hill lode. The outcrop is of considerable length.

Cane River.

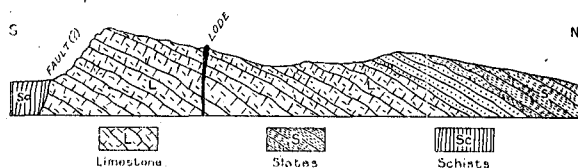
The Cane River group of copper lodes are situated on the bendwaters of the Cane River, about 2½ miles to the south of the Red Hill, and about 2 miles from the limestone hill known as Rundle's Hill, alongside the main road to Roebourne.

The Cane River Copper Lode outcrops on level ground some considerable distance away from any of the hilly country and can be followed continuously for about 1,400 feet on an average bearing of N. 35 deg. W.; at both ends of the outcrop the lode gradually tapers out into the enclosing micaceous schist which forms the matrix, and believed to be of sedimentary origin. When the lode was first discovered it presented a very bold outcrop, rising about 3 feet above the level of the surface and carrying some very good green carbonate of copper. The lode is in a quartz reef containing the ores of iron and copper in varying proportions and has a high underlay to the south-west. The quartz is in certain parts traversed by minute veins and kernels of copper pyrites and its decomposition products. Portions of the outcrop carry fairly large quantities of "tile ore," the red oxide of copper and iron, whilst others contain relatively large proportions of copper glance (chalcocite). The lode had been worked by means of four shafts, none of which reached 50 feet in vertical depth. There are two main ore shoots about 400 feet apart, the southernmost being about 100 and the northernmost about 85 feet in length. The thickness of the lode in the southern shoot varied from 2 feet 6 inches to 5 feet in width, whilst in the northern shoot the thickness fluctuated between a few inches and 3 feet. The ore shoots dip to the north.

The Rundle's Hill Copper Lode is situated about a mile and three-quarters south-east from the Cane River lode and occurs in dolomitic limestone covered by quartzites and siliceous

Fig. E.

SECTION ACROSS RUNDLE'S HILL COPPER LODE, ASHBURTON G.F.



The Rundle's Hill Copper Lode.

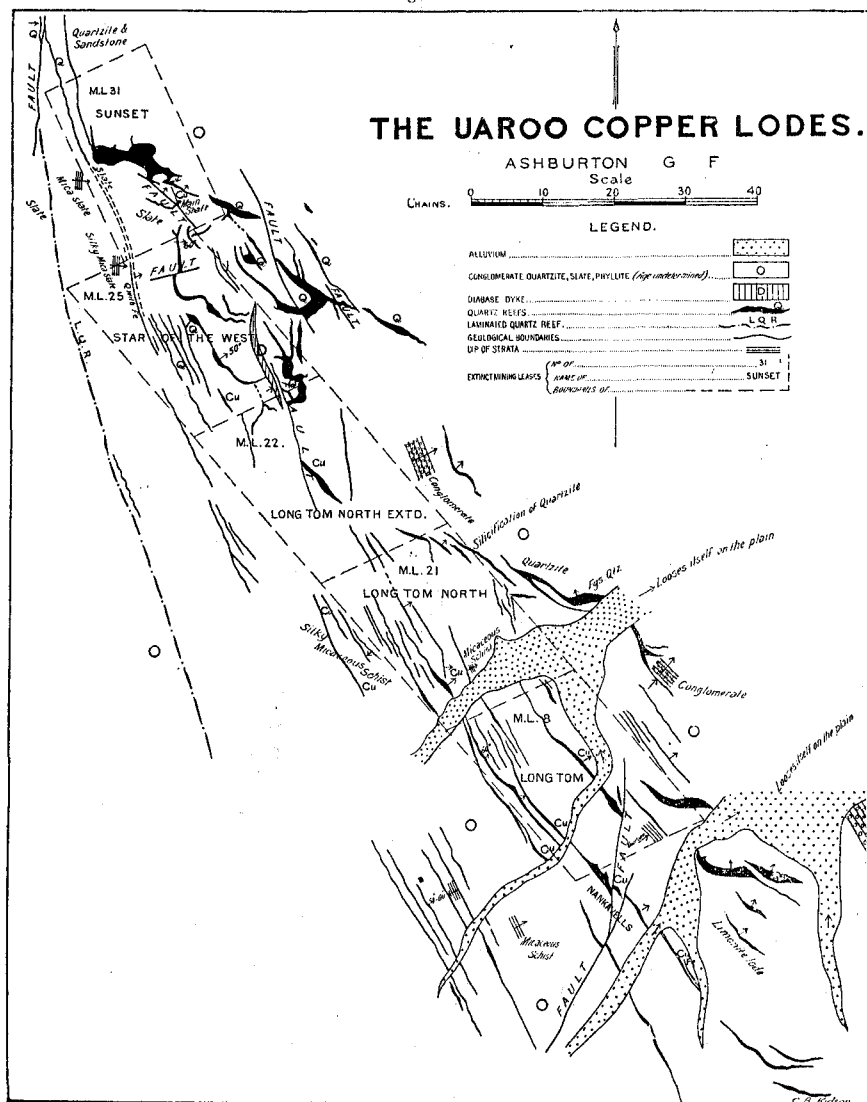
sandstone (Fig. E). The lode consists of three quartz veins arranged *en echelon*, and having a total length of about 1,400 feet. Only one shallow shaft has been sunk on the lode, which is of variable width. An open cut on the surface shows about 3 feet of quartz with green carbonate of copper disseminated throughout its mass, occasionally veins of fairly high grade copper ore merely an inch or two in thickness occur traversing the quartz parallel to its strike. The lode in the shaft is of honey-combed quartz, 2 feet 6 inches wide, and containing copper pyrites and its decomposition products. The cellular nature of the quartz shows that a very large quantity of ore must have been leached out. An average sample of this honey-combed quartz yielded an assay in the Geological Survey Laboratory 11.59 per cent. of copper. The limestone which forms the walls of the lode is also impregnated with carbonate of copper. The interest attaching to the Rundle's Hill Copper Lode is the fact that they traverse a much newer series of strata than the schists and point to a deposition of copper ore at a much later geological period than the formation of the underlying schistose rocks.

Locke's Copper Mine lies about three and a-half miles north-west of the Cauc River Lode. The deposit is a copper-bearing quartz reef occurring in a soft fissile phyllite associated with dolomitic limestones, and its outcrop trends generally at right angles to the average strike of the country, which is north-east and south-west. The lode has been opened up by a shallow prospecting shaft, from which quartz containing green carbonate of copper, copper glance, bunches of copper pyrites, and tile ore have been obtained.

In close proximity to Locke's lode and along its strike, in close proximity to the junction of the limestones with the other rocks, are some east and west copper-bearing quartz veins which range in thickness from 18 inches to 2 feet. These carry small quantities of copper and iron ores, but no work has been done upon them.

Not far distant from Locke's Lode is The Big Blow, which consists of a large lenticular vein of quartz from 7 to 8 feet thick carrying small bunches and shoots of good copper ore. Beyond opening out one or two shoots a few inches in thickness little work has been done upon them. This large vein forms part of a system of parallel quartz veins occurring along a shear zone.

Fig. F.



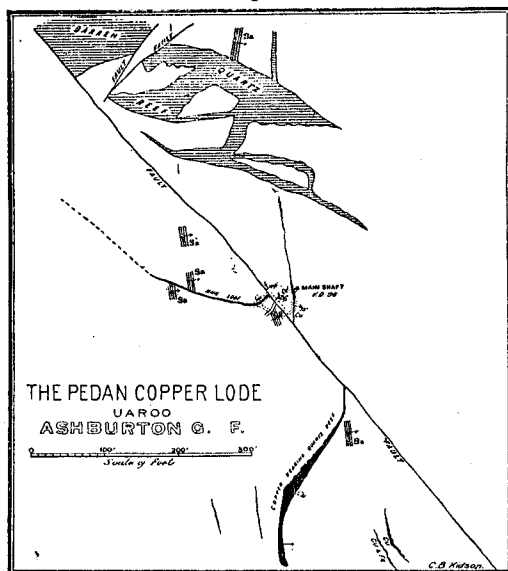
Uaroo.

The copper mining centre of Uaroo is situated upon Rous Creek, about 80 miles from Onslow. The mining area is formed of a series of lofty precipitous serrated ridges the trend of which (north-west and south-east), has been determined by that of the siliceous rocks and veins of which they are made up.

The ore-bearing area is occupied by one geological formation which consists of a series of sedimentary rocks, some bands in which have undergone more or less mechanical deformation. The rocks consist of quartzites, phyllites, and conglomerates, trending north-west and dipping to the north-east. Many of the beds have been subjected to secondary silicification to such an extent that it is at times difficult to differentiate between quartzite and reef quartz. The micaceous beds are represented by phyllites, some bands are garnetiferous, and others haematite-bearing, and in some cases these form the matrices of the copper lodes. The beds are traversed by a dolerite dyke about 1,000 feet in length and is the only igneous rock occurring in association with the copper deposits. The rocks are intersected by several faults, which, however, are of later date than the mineralisation, for in all cases the faults affect both the lodes and the barren quartz veins. After the mineralisation of the area the district was subjected to considerable earth stresses for many of the large massive quartz reefs have been rendered more or less fissile, and several of the conglomerates are intersected by both vertical and horizontal joints, some of which cut clean through the component pebbles.

The copper deposits of Uaroo are quartz reefs (Fig. F) which traverse the whole length of the field, and which exhibit a general parallelism to the strike of the main structured features of the district. There are, however, in addition to several large and important masses of rock which can be sharply differentiated both in appearance and habit from the ore-bearing quartzes. These high quartz bosses, etc., are in all probability of igneous origin, and perhaps represent the final product of differentiation and constitute the ultra-acid portion of that granite batholite which occurs just to the eastward of the metamorphic sediments. These vitreous quartz masses do not appear to have been in any way impregnated with metalliferous minerals. The Pedan (Sunset), the Long Tom, and the Dark Horse copper deposits are typical of those occurring in the Uaroo mineral belt. The Pedan (Sunset) deposit (Fig. G) consists of three

Fig. G.



Plan of the Pedan Copper Lode.

copper-bearing quartz reefs intersected by a north-east and south-west fault. The most pronounced feature, however, is the very large white quartz reef lying immediately to the north of the main shaft. This mass of quartz rock reaches a maximum thickness of about 2,300 feet, and both on the north and south it gradually tapers out until it is represented by a film of quartz no thicker than a sheet of paper. This quartz reef is, so far as can be seen on the surface, entirely devoid of any mineral. The main lode (a copper-bearing quartz reef) can be followed along the surface for a distance of 250 feet and appears to be along a line of fault. At the surface, in the openwork near the north-west fault, the lode is six feet in thickness, and at 12 feet lower down it has dwindled to four feet. For a distance of about 130 feet along the outcrop the lode proved to be very thin, and does not appear to be rich in copper. The northern extension of the main lode, on the east side of the main fault, has been opened out by a vertical shaft about 100 feet deep in which the ore body proved to be five feet wide, mostly in good ore averaging about 30 per cent. of copper. A parcel of 5 tons 19 cwt., shipped to England in 1907, assayed on dry ore, copper, 20.33 per cent.; silver, 20zs.; and gold, .20 ozs. Several other quartz veins more or less copper-bearing occur in close proximity to the south of the main lode, but no work has been done upon them. One is a short thin vein of quartz parallel to the bedding planes of the phyllites, which carry a little green carbonate of copper. The copper in the vein is more or less confined to a band in the centre; it weathers into a very honey-combed mass containing both green carbonate of copper and oxide of iron, which probably result from the decomposition of the sulphides of copper and iron.

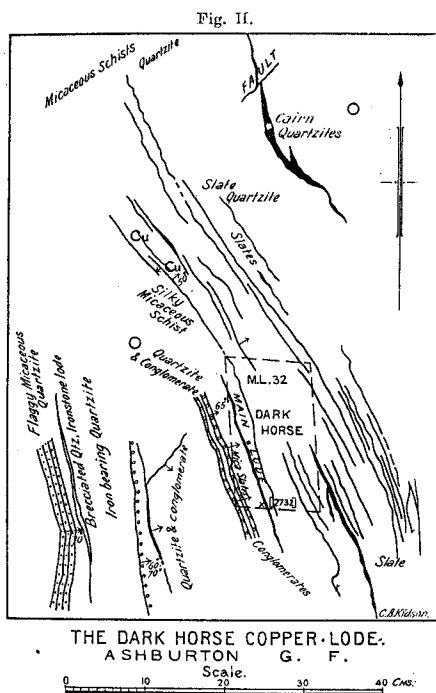
The Long Tom group of copper-bearing veins extend over a considerable horizontal distance and are contained in a zone having a width of about 600 feet. They consist of several parallel quartz veins, one about 1,000 feet long dipping to the south-east at about 65 degrees. The ore consists of atacamite, chrysocolla, malachite, and tile ore, occurring in fairly well defined though short shoots. One sample of the prevailing green carbonate ore assayed in the departmental laboratory 47.36 per cent. of copper, 0.10 per cent. of lead, and 1 oz. 5 dwts. 19 grs. of gold per ton.

At the southernmost extension the lode is known as Nankiwell's and consists of a quartz reef of variable width, and at least 20 chains in length, carrying more or less copper, sometimes in the reef itself, and sometimes on either wall. Adjacent to it is a haematite limonite vein of from 12 to 18 inches in thickness, containing a little green carbonate and chloride of copper; it passes by imperceptible gradations into a pure quartz reef. An assay in the Survey Laboratory gave 5.00 per cent. of copper, 33.97 of iron, and of gold a minute trace per ton.

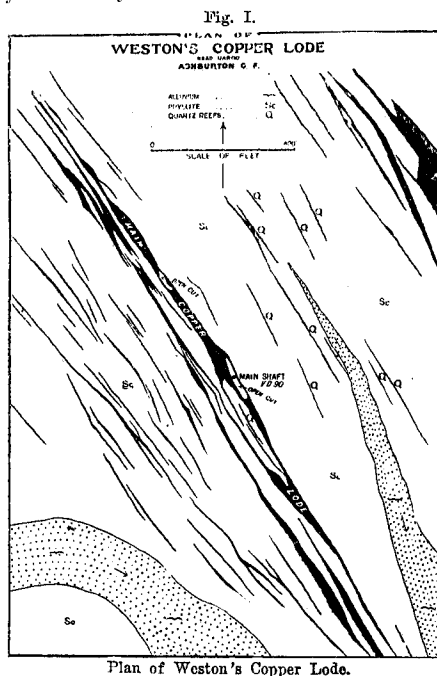
The Dark Horse Main Lode (Fig. H) lies in a belt of white silky micaceous schist, a haematite-phyllite, resting conformably upon a massive bed of quartz conglomerate and covered by quartzite. The lode has an average strike of about 153 deg. and a length of about 1,600 feet, and contains more or less copper along the outcrop. The lode, a quartz reef, contains small quantities of green carbonate of copper, grains of copper glance, with occasionally small veins of copper glance up to 6 inches in thickness. A sample of this assayed in the Geological Survey Laboratory, 55.73 per cent. of copper, a minute trace of gold, and 10 ozs. 15 dwts. 15 grs. of silver per ton. The deepest shaft on the lode is about 50 feet, though not very much work has been done on it.

Weston's.

The Weston's Copper Lode lies about 17 miles to the westward of Uaroo, and makes a very bold outcrop extending for a distance of about 2,000 feet in a north-west and south-east direction. The strata in the more immediate vicinity of Weston's consist of coarse calcareous grit (arkose) and impure quartzite, both of which have been subject to a considerable amount of crushing; associated with these are bands of limestone and phyllite. A well-cleaved silvery tourmaline-phyllite forms the matrix of the lode (Fig. I). The



lode itself is merely a quartz vein, about 50 feet in width in its widest part, and forms part of a silicified and sheeted zone (Fig. 1) in a silvery tourmaline-phylite about 400 feet wide. Copper ores, however, seem to be confined to the veins in the more immediate vicinity of what may be called the main vein.



The ore which makes up Weston's lode consists essentially of quartz, a little green carbonate of copper, copper glance (chalcocite), small quantities of haematite, titanite, and a little black mica. Some of the larger masses of copper glance contain fragments and broken crystals of quartz, the surfaces of which are coated with a film of a green mineral which may be malachite. Free gold is showing in some of the copper-bearing quartz.

As seen at the outcrop it is noticed that the system of quartz veins is traversed by several minor fractures approximately at right angles to the general trend of the zone; whilst the workings disclosed a second set of fractures which are practically horizontal; it has been found that at the intersection of these two fractures rich pockets (almost flat floors) of copper ore frequently occur.

The Weston's copper lode has been exploited in two localities, the most northerly consisting of a shallow open cut about 60 feet in length, from which a small quantity of low grade ore had been raised. About 250 feet south-east of this is a shallow open cut 130 feet in length, in which the main shaft is situated; the shaft is 90 in vertical depth. At 30 feet from the surface two short cross-cuts have been put in at right angles to the trend of the lode and a small quantity of copper ore obtained from a horizontal vein ("Floor").

There does not appear to be any record of the quantity of ore raised from the lode; two small trial parcels of picked stone of 16½ and 7 tons respectively returned after treatment at the Fremantle Smelters 35 per cent. of copper and 10 ozs. of silver.

About a quarter of a mile north-east of Weston's is the outcrop of a large copper-bearing quartz vein, which stands up in bold relief and trends across country for some considerable distance; the quartz contains a few lenticular veins of green carbonate of copper.

Six miles north of Weston's are the *Buro Copper Deposits*.—The deposit, which is in the same mineral zone as that of Weston's, is about a mile in length and attains a maximum thickness of 50 feet. The deposit is merely a mass of quartz veins and leaders containing more or less copper, which in some portions is concentrated into small lenticular patches. The ore consists chiefly of malachite, with a little azurite, chalcocite, and small quantities of seleniferous tetradyrite (sulpho-telluride of bismuth). Some of the quartz shows a little gold and it is noteworthy that about 60ozs. of alluvial gold have been obtained from some of the small gullies in the vicinity of Weston's.

Black's Copper Lode is situated about six miles north-east of Peak Station in the watershed of Metawandy Creek, a tributary of the Ashburton River. The deposit is situated on a hill about 300 feet in height, made up of much weathered basic schists, the trend of the foliation planes of which are about east and west with an underlay of from 25 to 40 degrees to the south. The surface of the weathered rocks has been hardened by the deposition of secondary silica. The schists are traversed by a number of large quartz reefs, which conform to the general trend of the country. From these major quartz reefs a network of smaller veins ramify in all directions. There does not appear to be any defined ore channel, though the veins, etc., are stained with green carbonate of copper, as well as the adjoining country rock. A few tons of ore were raised from the locality, but very little work has been done owing to the low average grade of the deposits.

PEAK HILL.

A little copper mining has been carried out at different times in the Peak Hill Goldfield which has produced up to the end of 1918, 965.33 tons of copper ore valued at £30,458, from which 334.38 tons of metallie copper have been extracted. Copper mining has been carried out at different centres, Ilgarere and Kumarina.

Ilgarere.

At Ilgarere, situated about 10 miles west of the 112 mile-post on the Peak Hill-Nullagine telegraph line, there are some copper deposits, which can be traced at intervals along a belt of about a mile

The Copper Deposits of Western Australia

By
A. Gibb Maitland.

PART III.—Section 2.—COPPER.

GENERAL STATEMENT.

The history of mining in Western Australia began with the discovery of the Waueranooka Copper Lode at Northampton in the year 1842, and in 1845 the first consignment of copper ore left the State to be smelted in Wales. Since that date copper mining cannot be said to have made continued progress, though doubtless such will increase as time goes on. The annual production of copper ore has shown much variation, and up to the end of 1918 this amounts to 224,546 tons, valued at £1,540,930.

Copper ores are plentifully distributed throughout the length and breadth of the State, but so far copper deposits have only been worked to any extent in a very few districts and there are not many producing mines. The principal sources of copper are Northampton, West Pilbara, Mount Morgans, and the Phillips River.

The workable deposits of copper so far known to occur in Western Australia are everywhere met with in areas which have been subject to more or less violent earth movement, and concomitant volcanic activity. They all show a marked similarity in their associations, mineralogical characters, and structural relations.

The copper deposits of Western Australia, when viewed in the light of their mode of occurrence and geological relationships, may be divided into three distinct categories: (a) lodes of the fissure vein type, (b) impregnations and stockworks, and (c) those along shear zones and shatter belts. The majority of the workable deposits apparently belong to the former class.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

KIMBERLEY.

Pandanus Creek.

Some good copper ore is said to occur at Ord's Gap on Pandanus Creek at the end of the Leopold Range, about 7 miles west of the Fitzroy River, in the Kimberley Division, but so far nothing has been done to in any way exploit the deposit.

Yampi.

A very promising copper deposit has been opened up at Yampi Sound, in West Kimberley, distant about 10 or 12 miles from the iron deposit at Koolan Island.

The lode occurs on the beach, and being not very far from deep water, facilities for mining are good. The ore is mostly chalcocite of good quality, and is associated with a little green carbonate of copper and quartz. The lode, so far as has been developed, is from five to six feet wide, and underlies to the east, and so far as may be judged from specimens forwarded to the department, it occurs in a faulted zone of metamorphic crystalline rocks. The lode is a sericitised and carbonated quartz-porphry.

Up to the end of 1918 there have been raised from this locality 92.86 tons of copper ore, containing 22.80 per cent. of copper; the ore also contained a little gold and a small quantity of silver. A good deal of systematic and judicious prospecting is required to thoroughly test this occurrence.

Napier Range.

At the north end of the Napier Range in the watershed of the Lennard and Barker Rivers, the crystalline limestone which constitutes the larger portion of the Range, gives place to mica schist and basic dykes, which have a dominant strike of east and west. A copper-bearing quartz reef occurs alongside one of the basic dykes and has been traced across the surface for about 300 yards. Wherever this reef has been opened up it proved to be small and to carry very little copper of such a grade as would pay expenses. A few tons of copper might, however, be picked from the lode.

Mount Nellie.

Copper ores were discovered in 1905 at Mount Nellie, on the Taragee River about 60 miles north-east of Derby and 15 miles south-west of Colin Bay. The belt of country in which these deposits occur is schist and slate intersected by basic dykes and quartz reefs and extends north-westerly from Mondooma, on the Robinson River, to Mount Nellie, and is, in all probability, co-terminous with that series which carries the copper deposits of Yampi Sound. A series of dyke-like mineralised quartzose ridges containing quartz veins, often very much copper-stained, occur in this belt of schist. These veins are of considerable size and length, and, in addition to being much stained, often contain copper either in veins, bunches, or disseminated through the quartz itself. On what is known as Grant's Reward Lease (named after the discoverer, J. S. Grant), the lode mass rises in the form of a razor-backed ridge to a height of about 100 feet, having a width at the base of about 50 feet, and it can be traced for over one and a-quarter miles in length. In this body there are three distinct quartz veins or shoots, the central one of which is the largest, being seven chains in length and varying from two to 17 feet in thickness on the surface.

The ore is mostly green carbonate and red oxide of copper, and is met with at one or two points in the form of small veins or bunches of high grade ore; it generally, however, occurs intimately mixed with quartz when it varies from low-grade siliceous ore to stained quartz.

There are a number of other similar lode masses occurring in the locality, of which Wilson's Reward, six miles south of Grant's Reward, is one. The following assays have been made of samples from these localities:—

	Grant's Reward.	Grant's Reward.	Wilson's Reward.
	per cent.	per cent.	per cent.
Copper (oxide) ..	34.63	23.22	37.58
Lead .. .. .	.72	nil	nil
Zinc	†	†	†
Silver	4dwts. 22grs. per ton.	1dwt. 15grs. per ton.	11dwts. 10grs. per ton.
Gold	20grs. per ton.	20grs. per ton.	20grs. per ton.

PILBARA.

Copper ores have a wide distribution in the Pilbara Goldfield, though no copper mining is being carried on. At a point about eight miles north of the mining centre of Yandicoogina a fairly well defined copper lode has been exploited in a more or less desultory fashion at what is known as Lennon's Find. The lode, which can be traced across country for about two miles, consists chiefly of quartz stained with green carbonate of copper, with, in some portions, an iron oxide gossan.

The country rock of the lode is schist and the ore body occurs parallel to the planes of foliation of the schist, which trends generally 55 degrees east. The schist adjacent to the lode, on both its walls, is often siliceified and impregnated with metallic minerals. The lode which seems to be a distinct fissure vein, varies in width from 12 inches up to as much as 10 feet. Assays of samples taken without any regard to selecting the more valuable ore from different localities along the outcrop, made in the Geological Survey Laboratory, gave the following results:—

G.S.L. No.	3373.	3374.	3375.
	per cent.	per cent.	per cent.
Copper	14.61	6.68	5.33
Lead .. .. .	.30	3.85	2.79
Zinc	16.33	4.45	5.52
Silver	23ozs. 3dwts. 12grs. per ton.	2ozs. 6dwts. 20grs. per ton.	4ozs. 13dwts. 10grs. per ton.
Gold	17grs. per ton.	17grs. per ton.	17grs. per ton.

and a half in length. The strata in the neighbourhood are almost flat and consist of sandstones and shales, believed to belong to the Nullagine series, and which are traversed by dykes of dolerite.

The copper lode exposed trends generally north-east and south-west, and underlays to the south-east at an angle of about 68 degrees. It consists of a solid band of oxides, carbonates, and silicate of copper, without any gangue matter whatever, and has a width of from one foot to three feet nine inches. In one portion, however, the ore body consists almost entirely of ironstone. Field evidence indicates that the copper lode occurs along a line of fault.

As the longitudinal extent of a lode bears an intimate relationship to its vertical depth, there is every probability of the Ilgarere deposit carrying ore over a considerable vertical range. The lode has yielded up to the close of 1917 558.86 tons of ore, valued at £18,810 and carrying 203.9 tons of metallic copper; these being the latest figures available to the department.

Kumarina.

At Kumarina (Humphry's Find, twenty-three miles to the south of Ilgarere) are a series of quartz reefs from which 278.25 tons of copper ore, containing 97.55 tons of metallic copper, valued at £8,751, have been raised. The country rock in the neighbourhood consists of sandstones and shales capped with quartzite, the whole series dipping at a low angle to the northward, though here and there along the strike the beds are thrown into a series of sharp folds. About a mile to the north of the copper lodes there is a broad gabbro dyke of varying texture. The main lode, which is a quartz reef occurring on what is known as Humphry's Reward Lease, trends in a general north-easterly and south-westerly direction for a distance of about 1,500 feet. The maximum width of the ore body is 30 feet; it contains bunches of copper ore, made up of the carbonates and oxides as well as copper stains at intervals over the whole width of the quartz. Several other copper-bearing quartz reefs occur in the neighbourhood, but they do not appear to have been exploited to any extent.

EAST MURCHISON.

Copper mining has been carried out to a slight extent in the East Murchison Goldfield, which has produced up to the end of 1918 238.56 tons of copper ore, valued at £4,364; this ore contained 38.42 tons of metallic copper.

In the neighbourhood of Kathleen Valley, the country rock is made up of epidiorites, resulting from the metamorphism of gabbro, diabase or norite, which extend as far as Mount Sir Samuel. The gold-bearing reefs which traverse these rocks carry notable proportions of copper, and some small lodes have been worked for their copper contents. These copper lodes exhibit a general parallelism to the series of granitic dykes which occur near the western boundary of the townsite of Kathleen.

One ore body taken up under the name of *The Shepherd* (M.L. 12) trends generally north 15deg. west, with an underlay to the W.S.W. of about 60deg. The lode, which is merely a belt of shattered greenstone of from 1½ to 4 feet wide, contains chrysocolla, malachite, "live ore" and oxides of copper, as well as enriched sulphides, such as bornite, chalcocite and covellite, which near water level passed into crystalline iron pyrites and some chalcopyrite. About 660 feet to the southward this lode is made up chiefly of kaolin, stained with copper minerals.

The *Cobar Copper King Lode* (M.L. 15), though small is of considerable horizontal extent, is a distinct fissure vein lying between the walls of crushed country rock. The lode contains malachite, chrysocolla and chalcocite; it trends generally north-west, with an underlay of from 45 to 60deg. to the south-west.

The copper lodes of the vicinity of Kathleen have not had much done on them, though they present fairly promising prospects.

The *Bungarra Copper Lode* and sundry other copper deposits near Lawlers have yielded 148.35 tons of copper ore, valued at £2,981, and containing 24.95 tons of metallic copper, but there are no details as to the nature, etc., of the deposits available.

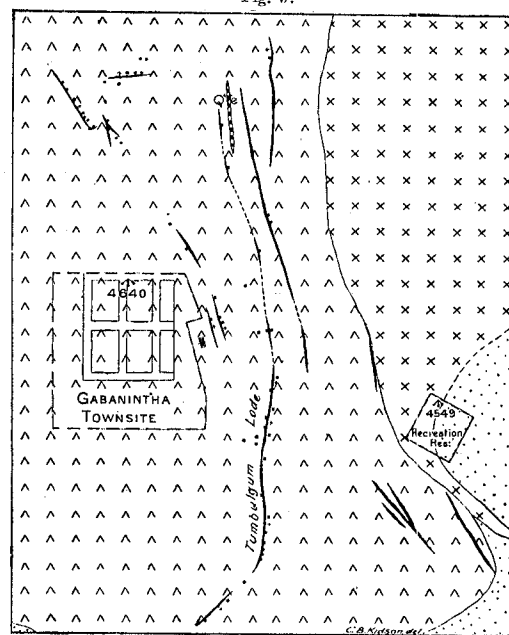
MURCHISON.

The districts of Gabanintha, Holden's Find, Yaloginda, and Day Dawn have, up to the end of 1918, produced 951.65 tons of copper ore, valued at £10,337, and from which 128.10 tons of metallic copper have been obtained.

The principal centre at which copper mining has been carried out in the Murchison Goldfield is Gabanintha, which is situated about 21 miles east of Nannine. Massive basic rocks (greenstones) constitute the staple formation at Gabanintha, and they have been invaded by large masses and dykes of granite. The basic rocks exhibit a high degree of foliation in close proximity to their junction with the granite, the foliation is always found to be parallel to the boundary separating the two rocks and to extend over a width of about four or five chains.

The lodes and reefs of Gabanintha are found occurring both in the granites and the greenstones, at no very great distance from the junction of the two rocks, those occurring in the granite and generally not far from the boundary of the greenstones usually take the form of very large quartz reefs of considerable horizontal extent; these in all probability represent an ultra-acid phase of the granite magma. Some of the reefs in the greenstone are very large, notably that forming the *Tumbulgum Reef*, which outcrops for about a mile and is in places a little over 66 feet in width (Fig. J). As a rule

Fig. J.



EXPLANATION OF SYMBOLS
 ALLUVIUM.....
 GREENSTONES.....
 GRANITE.....
 JASPER.....
 QUARTZ REEF (Copper-bearing in places)
 LINES OF FOLIATION.....
 SHAFTS.....
 Plan of some of the Gabanintha Copper Lodes.

the quartz reefs are irregular and bunchy, and contain, in addition to the gold, considerable quantities of copper. Some of the lodes have been worked for their copper contents. The Gabanintha lodes have produced 938.17 tons of copper ore, from which 125.58 tons of metallic copper has been obtained.

The *Mountain View* group has an ore body, which as exposed near the surface is made up of an admixture of quartz and highly foliated greenstone, which is very much broken and irregular,

and varies in width from 2 to 4 feet. Both the quartz and the shattered country rock, which constitutes the lode, carries a high percentage of the carbonates of copper, and in places the lode matter itself proved to be exceptionally rich, small pockets of ore occurring which average over 30 per cent. of copper. At a depth of 240 feet the belt of fractured country was found to be enclosed between two main walls about 40 feet apart, and to be traversed by three defined though not distinct bands of schistose lode stuff containing more or less quartz, and a good deal of copper pyrites. In the deeper levels of the mine the copper ores gradually change into sulphides.

The Tulbulgum Reef is one of the most extensive of those occurring at Gabanintha. The ore body varies in thickness from 3 to 8 feet and consists of a vertical belt of highly schistose greenstone, which contains veins and bunches of quartz. Some of these quartz bunches, while varying in thickness from a few inches up to 6 to 8 feet, seldom extend for any great distance either longitudinally or vertically. Both the quartz and the lodestuff carry considerable quantities of carbonate of copper right through the entire length of the reef, and, in one or two cases, small pockets of very rich ore were obtained.

About three and a-half miles south-east from Gabanintha is a lode known at different times as The Lady Aima or The Copper King, upon which two copper-bearing lodes had been worked. The outcrop of the lodes which trended generally north-west and south-east contained chrysocolla (silicate of copper), a good deal of tile ore (earthy red oxide of copper), and malachite (the green carbonate of copper), in addition to iron oxide.

Two shafts have been sunk on the main or eastern lode. In the workings from the Northern shaft the lode proved at a depth of 40 feet to be 6 feet in width, though it did not carry very much copper. A drive, however, along the lode for a distance of 25 feet north-west from the main shaft, met with some very good copper ore four feet in width. The ore contained cuprite, limonite, bornite, malachite, quartz and dolomite, with a little mica and chalcocite. When analysed in the Survey Laboratory the ore was found to have the following composition:—

Moisture	...	...	...	...	1.23
Copper	...	...	...	...	28.64
Lead	...	...	...	...	.06
Bismuth	...	...	...	...	Nil
Iron	...	...	...	...	22.60
Zinc	...	...	...	...	Nil
Nickel	...	...	...	...	.11
Alumina	...	...	...	...	2.20
Lime	...	...	...	...	1.01
Magnesia	...	...	...	...	6.50
Silica	...	...	...	...	6.02
Carbonic Anhydride	...	...	...	...	10.89
Combined Water	...	...	...	...	5.25
Sulphur	...	...	...	...	3.40
Oxygen (by difference)	...	...	...	...	12.09
					100.00

In addition, there were present gold at the rate of 2dwts. 11grs. per ton, and silver 5ozs. 15dwts. 25grs. per ton.

The formation at 90 feet below the surface was shown in the workings to consist of broken country rock with veins and bunches of quartz extending over a width of 25 feet from wall to wall. The lode contained above that level some good copper glance and black sulphide of copper carrying a little chalcocite. The shoot in which this occurred proved to be short and to pitch steeply to the south.

To the south of the main shaft the lode contains several small veins of rich copper oxide in the joints of the wall rock. The outcrop of the lode as exposed near the southern shaft proved to be a strong body of brown iron ore (gossan) from which some fair copper ore has been raised.

Near Yalginda, some distance to the south of Meekatharra, a small copper lode, known as The Mount Gibbs, has produced 6.76 tons of high-grade copper ore, valued at £150, and which contained 1.41 tons of metallic copper. The ore was chiefly malachite, the green carbonate of copper.

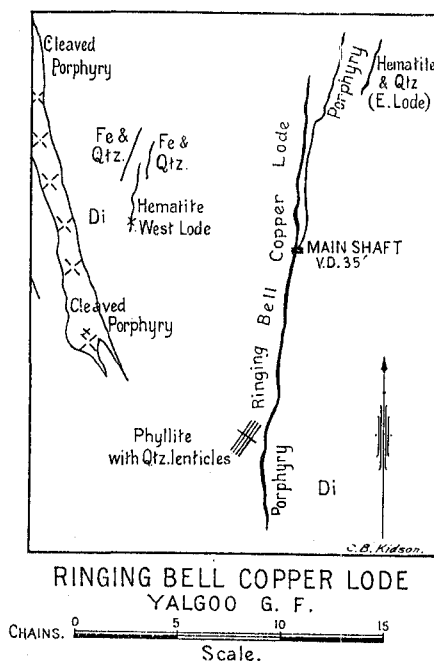
In the neighbourhood of Day Dawn some copper lodes have been worked and 55.56 tons of copper ore, valued at £522, taken out. This ore contained 8.10 tons of metallic copper. From such information as is available, these ore bodies are quartz reefs which carry near the surface a high percentage of carbonate of copper.

YALGOO.

A little copper mining has been carried on at three centres on the Yalgoo Goldfield, but the production up to the end of 1918 has been small, only 38.40 tons, valued at £413, having been recorded. The total quantity of metallic copper obtained from this tonnage amounted to 5.57 tons. The centres at which mining for copper had been carried out were Mount Gibson, Twin Peaks, and Wadgingarra.

The Ringing Bell Copper Lode (Fig. K) is situated not far from the head station at Twin Peaks. The lode, which lies in close proximity to a well-defined pegmatite or porphyry

Fig. K.



dyke, can be followed continuously for about 1,300 feet on an average bearing of North 5 deg. East; has a high underlay to the East of between 80 and 90 deg. At both ends of the outcrop the lode gradually tapers out into the enclosing country rock. The ore-carrying matrix is a more or less siliceous ironstone, passing in places into an almost pure quartz, containing small quantities of malachite and chrysocolla. The lode has been opened out in five localities, though mining operations have been confined to the central portion of the outcrop, where a vertical shaft has been put down to a depth of 35 feet. The lode varies from 6 to 18 inches in thickness. An average sample taken from about 3 tons of ore yielded, on assay at the Survey Laboratory, copper 15.54 per cent., iron 28.64, and of silica 21.41 per cent., in addition to 1oz. 11dwts. 23grs. of silver per ton and a trace of gold.

One portion of the lode to the North of the main shaft consists of a mass of magnetite in a siliceous limonite matrix. The lode at the northernmost end of the outcrop consisted of quartz stained with green carbonate of copper, but destitute of other minerals. The southernmost extremity of the outcrop showed merely copper stains over a width of about 5 feet.

An abandoned and now inaccessible copper lode, situated about a mile and a-half to the south, was worked during the year 1907-8, and produced about 19.5 tons of copper ore; whilst from the Ringing Bell lode only 8 tons were raised, thus bringing the total yield of the district up to 27½ tons of copper ore.

MOUNT MARGARET.

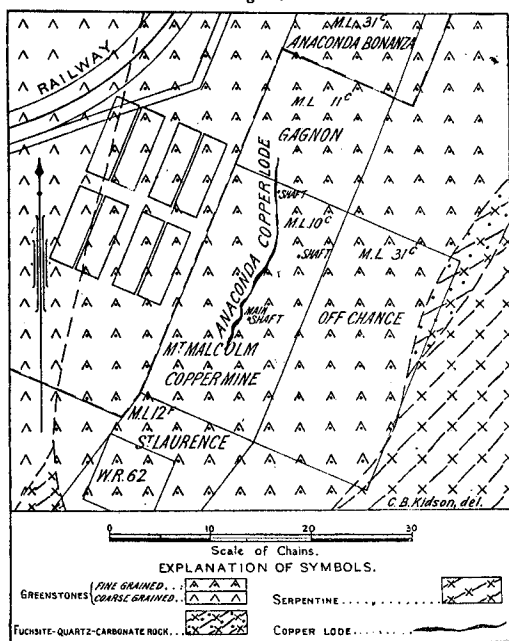
The Mount Margaret Goldfield has produced, up to the end of 1918, 47,860 tons of copper ore, valued at £230,846, from which 4,448 tons of metallic copper have been extracted; the ore was obtained from four centres, viz., Eulaminna, Mount Margaret, Murrin Murrin, and Burtville. It is, however, from the Eulaminna Centre that by far the greater quantity of the copper raised on the Mount Margaret field has been obtained.

Eulaminna.

The Anaconda (Mount Malcolm) Copper Mine, which has yielded .63 per cent. of the total copper production of the State, is situated near the Eulaminna Railway Station, 538 miles from Perth. The country rock of the lode is a fine-grained greenstone (fibrous amphibolite), which there are some reasons for believing to have resulted from the dynamic metamorphism of a basaltic dolerite.

The ore body consists of somewhat irregular-shaped masses extending longitudinally for a distance of over 1,300 feet, in a belt of shattered and fissured country, trending generally from north to north-east, and underlying to the eastward at angles which vary from 50 to 60 degrees.

Fig. L.



Plan of the Anaconda Copper Lode.

The copper deposits of Eulaminna are made up of azurite, malachite, chalcocite, with copper pyrites, bornite, iron pyrites, and

other minerals in a siliceous gangue. At the outcrop the copper in the deposits has been almost entirely oxidised and, to a large extent, leached out, so that the ore consists of a more or less porous, rusty, siliceous mass (gossan).

The lode has been exploited by three groups of workings, of which the southern are the most extensive.

In the Southern Group the ore down to water level consists of blue and green carbonates of copper, with oxide of iron, contained in a siliceous matrix, the whole carrying a small quantity of gold and silver. Below the water level, the lode passed into a ferruginous gossan, with silicate of copper (chrysocolla) and chalcodony, which in turn gave place to a rich red oxide of copper (cuprite), and some native copper. This ultimately passed into dense black copper sulphides, viz., copper glance (chalcocite) and iron pyrites, with some bornite and a little zinc blende.

In the Middle Group the ore consists of a solid mass of chalcocite and iron pyrites, capped by a small quantity of cuprite and native copper, above which was a layer of siliceous oxide of iron and gossan.

The ore in the Northern workings, like those at the Southern end, consisted of blue and green carbonates of copper with oxide of iron passing into cuprite with malachite and native copper, which in turn gave place to copper sulphides. A brecciated jasper vein occurs on the hanging wall of the lode, and the whole mass has been re-cemented with secondary silica, after the deposition of a considerable quantity of metallic copper. The ore deposit has been worked to a depth of a little over 300 feet vertically below the surface, and at this depth the bulk of the ore is of iron pyrites. Of this pyritic ore, 52,082.03 tons have been raised up to the end of 1917, valued at £19,598, and used as a source of sulphur. The sulphur is utilised in the production of sulphuric acid, required in connection with the manufacture of fertilisers.

The total quantity of copper ore raised from this locality up to the end of 1918 amounts to 47,857.07 tons, containing 4,448.00 tons of metallic copper, valued at £230,820.

The commercial copper mined came from that part of the deposit below the iron capping and above the unoxidised sulphide of copper and iron, the latter being in the lower workings in excess.

NORTH COOLGARDIE.

The North Coolgardie Goldfield has produced a very small quantity of copper ore, viz., 6.12 tons, valued at £51, containing .82 tons of metallic copper. This ore came from Goongarrie in the Menzies district.

A copper lode occurs to the north-east of the township of Goongarrie, on the old Providence Lease, and is situated just near the junction of an extensive belt of fine-grained epidiorite, and the schists derived from it through dynamic metamorphism. These quartz-carbonate-chlorite schists are economically the most important of the rock series on the field, in that they form the matrices of the ore bodies of Goongarrie. Several shafts and open cuts have been sunk on the lode which occurs in the schists. It consists chiefly of malachite, the green carbonate of copper, in a band of ironstone which varies in thickness from 6 to 18 inches.

The lode is vertical, and lies parallel to the foliation of the soft grey schists, which are also impregnated with copper to a slight degree at their junction with the ironstone. Ore is also present on the joint faces, as well as cracks and fissures. The copper ore is likewise associated with secondary silica, though no ore occurs in the ordinary quartz vein.

EAST COOLGARDIE.

A little copper mining has been carried on in the vicinity of Boorara on the East Coolgardie Goldfield, from which locality there have been recorded up to the end of 1918 50.67 tons of copper ore, valued at £330, and containing 6.22 tons of metallic copper.

This quantity of ore was obtained from the Premier Copper Mine (M.L. 100E) in the year 1908.

Boorara consists geologically of a series of greenstones associated with metamorphic sediments, porphyry dykes, and serpentine. There is, however, no information as to the geological relationships of the Premier Copper Lode.

PHILLIPS RIVER.

The mining history of the Phillips River began in the year 1892, with the discovery by Stennett Bros. of gold in conjunction with copper and iron pyrites. Since its proclamation in 1900, Phillips River field has been a large producer of copper, the ore having been obtained from four different mining centres, viz., Kundip, Mount Desmond, Ravensthorpe, and West River. From these centres there have been raised, up to the end of 1918, 95,232.91 tons of copper ore, valued at £578,546, and from which 8,264.46 tons of metallic copper have been extracted.

The field is situated on the South Coast, its port of Hopetoun being about 150 miles to the Eastward of Albany. The port of Hopetoun is connected with Ravensthorpe, the official centre, by a railway line 40 miles in length, which also serves the mining centre of Kundip and Mount Desmond.

The principal and most striking feature in the Phillips River Field is the Ravensthorpe Range, which owes its orientation to its geological structure. It consists of schists of both igneous and sedimentary origin, which have, in part, lost their individuality and geological identity. It is upon the south-western flanks of this range that the auriferous copper lodes of the Phillips River field occur.

In its geological constitution, the ore-bearing area is made up of metamorphic sedimentary rocks, associated with a complex series of crystalline rocks, which latter are of igneous origin, into which a

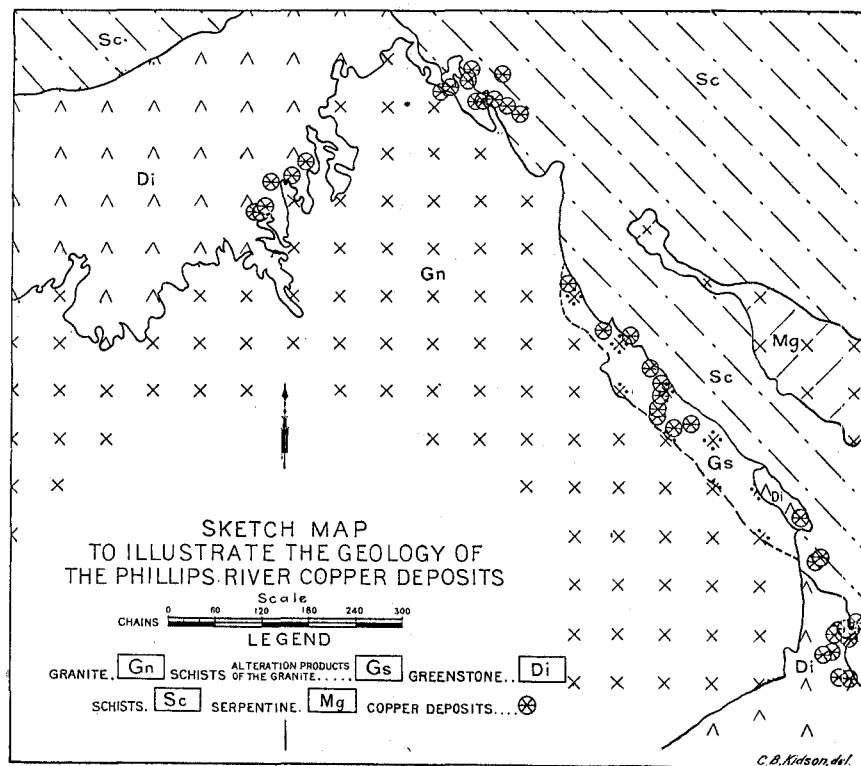
large dome-shaped mass or batholith of soda-granite has been intruded. There are in addition dykes of diabase, quartz-diorite, and their derivatives, as well as intrusions of soda-porphry and pegmatite. A large mass of serpentine occurs in the schists to the east of the Ravensthorpe Range.

The basic dykes traverse the granite, in which they occur in great numbers. They appear to emanate from the large mass of greenstone lying to the westward of Ravensthorpe, and drained by the waters of Annabelle Creek.

The copper lodes are all restricted to or occur near, the margin of the granite which occupies a considerable area in the Phillips River field (Fig. M). This concentration of the mineral deposits bears a close relationship to the rock structure of the district. The ore deposits being controlled by the system of fracturing to which the district has been subjected, and the resulting fissures have afforded numerous channels up which the mineral-bearing solutions, etc., have been able to find their way. The introduction of the copper would appear to have followed very closely on the cooling of the granitic magma, and the fracturing, etc., by which it was accompanied at a later geological date; as a result of powerful earth stresses, a number of fault planes were developed which have dislocated some of the greenstone dykes as well as the lodes and, in consequence, have some effect upon mining development.

The lodes at the surface present all the characteristics which are usually associated with deposits of copper ore, viz., highly ferruginous outcrops, often of considerable size and usually highly siliceous, the only indications of copper, when present, being traces of the green carbonate (malachite).

Fig. M.



The copper lodes of the Phillips River are of more than one type. They may, however, be tentatively grouped into two classes, viz., (a) auriferous copper-bearing quartz veins, and (b) basic dykes, occurring along shear lines and shatter belts, and which are impregnated with copper.

The copper ore, as a rule, consists in the oxidised zone of the blue and green carbonates, grey copper ore (tetrahedrite), a small quantity of oxides of copper, and usually a rather large percentage of quartz and oxides of iron, below the oxidised zone. The ore consists of massive sulphides of copper and iron. The transition from the oxidised to the sulphide zone is usually sudden: in the sulphide zone the chalcocopyrite is associated with pyrites, marcasite and pyrrhotite.

The lodes of the first type generally have smooth walls, of which there are frequently several parallel to one another. Between the walls there is more or less sheared and shattered country rock, traversed by veins and strings of quartz, in which the more important ore bodies occur as lenses and shoots. Many of the smaller veins of quartz are seen to ramify through the main mass of the schistose country rock which lies between the walls of the lode.

The quartz forming the auriferous copper reefs is rather dense but granular, and carries more or less pyrites disseminated throughout its mass, in addition to some copper pyrites, galena and tetradyomite (sulphotelluride of bismuth).

The Plantagenet Floater, Maori Queen, Jubilee, and Jim's Wonder, and other mines of the Ravensthorpe gold group belong to this first type. In the lodes of the Kundip centre, the gold is of more importance than the copper, some of the deposits, however, have contained free-milling gold ore. The gold-bearing copper lodes of Phillips River have produced up to the end of 1918, 82,694.34 ounces of fine gold, and of silver 15,688.17 fine ounces from 95,232.91 tons of ore.

The deposits of the second class, viz., basic copper-bearing dykes, are very numerous in the Phillips River field. These at the surface develop a schistose structure, where weathered. This, however, is not so noticeable in the lower levels of the mines. The ore in these copper-bearing dykes is in the form of shoots and lenses, occurring along the walls of the dykes and in fissures which lie parallel to them. The ore is chiefly quartz, together with the sulphides of iron and copper, and sometimes marcasite and pyrrhotite.

The two principal producing mines, and the deepest, are the Elverton at Mount Desmond, and the Mount Cattin at Ravenssthorpe. These have produced 41,090.96 and 24,758.99 tons of copper ore respectively, from which 3,271.53 and 1,302.19 tons of metallic copper have been obtained.

The Elverdton Copper Deposit is situated close to the western side of the Ravensthorpe Range, upon a ridge that divides the waters of the Steere from the Jerdacartup Rivers. The deposits proved in its earliest stages to be of exceptional richness, so much so that the purchase price was paid from the proceeds of the sale of the ore raised during the period over which the right of purchase was held.

The Elverdton lode or ore channel trends generally north-north-west and south-south-east; it departs, however, somewhat from a straight line owing to the pressure to which it has been subjected, and has been locally dislocated by faults. The channel has a length of about a mile and a width of 400 feet. The lode is a crushed basic dyke, impregnated with copper, lying on the western side of the ore channel, which is intersected by several more or less parallel diabase dykes, and a broad north and south quartz-diorite dyke, 250 feet wide, neither of which are carriers of copper ore. The ore shoots in the mine are often intersected and their regular continuity interrupted by faults, which are represented by smooth walls. So far as underground operations have up to the present been carried, two distinct systems of faulting have been recognised, viz.,

the first and older striking north-west and south-east, and dipping at steep angles to the north-east or south-east, which are formed prior to the intrusion of the diabase dykes; the second, striking generally from north and south to north-north-east and south-south-west with a high inclination to the east. These are lines along which a great deal of movement and crushing has taken place; they pass through and intersect the diabase dykes.

The Elverdton lode has been worked down to the 500 feet level. The ore in the upper workings consisted of ferruginous carbonate of copper, associated with a large quantity of quartz, which below water-level changed into pyrites and chalcocopyrite with some quartz.

The Mount Cattin Copper Lode is situated about a mile north of the township of Ravensthorpe, and lies in the schist country about 300 or 400 feet to the north of the junction of the main mass of soda-granite, an offshoot from which a soda-porphry intersects the lode.

The schists are mica-chlorite, biotite-hornblende, and a dense siliceous schist of obscure origin; some varieties of the schists are garnetiferous. The lode, which has a general strike of North 63 deg. East, and an average underlay to the west-north-west of about 85 deg., lies close to the northern boundary of an east and west diorite dyke, about 300 feet in width. The lode exhibits a foliated structure, consisting of alternating bands of greenstone, quartz and chalcocopyrite, whilst the poorer portions are made up of greenstones and quartz, and the pyritic minerals, pyrrhotite, marcasite, and chalcocopyrite disseminated throughout its mass. The walls of the lode are often fairly smooth, though at times they present a somewhat ragged appearance. "Horses" of granite have occasionally been met with in the lode channels, pointing to it being of later date than that of the granite.

Two diabase dykes intersect the ore body and unite at 400 feet below the surface. One important fault intersects the lode and, judging from the structural features of the ore-body, it appears that the diabase dykes have found their way along similar fault planes. The lode has been opened up to a depth of a little over 500 feet from the surface. The shoots of ore in the lode channel have proved to be short though fairly persistent in depth.

NORTHAMPTON.

The Northampton Mineral Field, which has the honour of claiming that within its boundaries the first mine opened in Australia is situated, has been a producer of copper ore since the year 1853, from which date up to the close of 1918, 9,532.50 tons of copper ore, valued at £150,736 have been raised. So far as can be ascertained from the official statistics, the field reached its zenith as a copper producer in 1864, when 1,076 tons of copper ore, valued at £17,216, were exported from Northampton.

The Northampton Mineral Field includes the centres of Geraldine, Northampton, Narra Tarra and Onkagee. The mining centre of Northampton, where the principal lodes are situated, occupies an elevated tract of country drained by the tributaries of the Bowes River, which all take their rise in the rugged hills forming the most northerly portion. The Geraldine centre occurs in the valley of the Murchison River, near the northern boundary of the field as legally defined by the authorities. The Narra Tarra centre is the most easterly and is situated in the watershed of the Chapman River, whilst the Onkagee area is drained by the Onkagee River and its tributaries, and forms the southernmost centre in the field.

The area within which the copper lodes of the Northampton field occurs is essentially granitic, and it outcrops from beneath a series of sedimentary rocks, consisting of sandstones, grits, conglomerates, etc.

The granitic rocks are made up of granite gneiss, mica-schists, quartz-schists, etc., intersected by veins and masses of pegmatite and greenstone dykes, they are also traversed by sheeted zones of garnetiferous gneiss, which have a general trend about north-west and south-east, and being usually very persistent. The rocks of this

series, some of which may be and, in all probability are, metamorphosed sediments, outcrop from beneath a cover of sedimentary rocks, which are possibly Mesozoic, and have been proved to extend at intervals for a distance of about 110 miles, extending from Geraldine on the Murchison River, in the north, to Arrino in the south, and having a width of about 30 miles.

The most important structural feature from the economic standpoint in the Northampton districts, is the system of basic dykes with which the whole area is seamed. These exhibit a remarkable parallelism, having a general trend of north-east and south-west; in thickness they vary considerably from a few feet to a couple of chains, but many of them are of great length, and they have in instances been traced across country for a distance of over 10 miles (Fig. N).

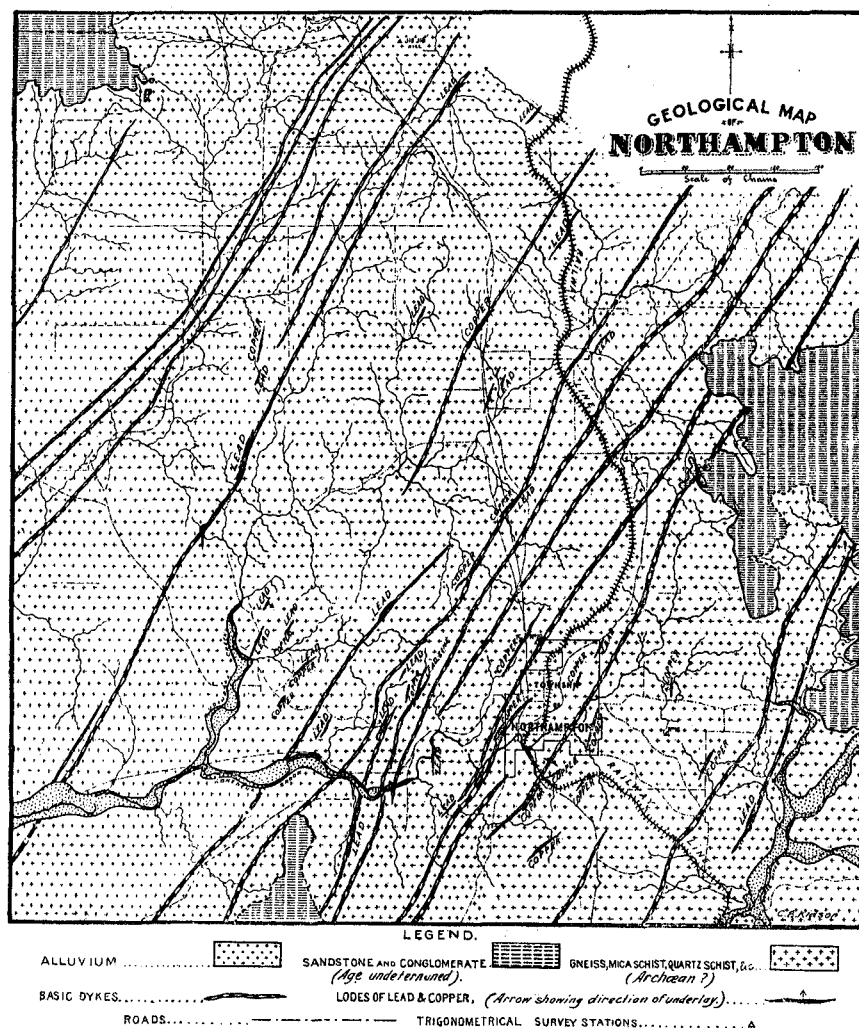
The Northampton Mineral Field as defined for purposes of administration, covers an area of 1,304 square miles; of this, how-

ever, only about 461 miles are occupied by mineral-bearing formations. The mineral-bearing area of the field is, however, fairly extensive, and contains several well-defined copper lodes, from which, as the figures above show, there is a very creditable record of production.

The facilities for mining are good and the lodes are of such a type as may be expected to live in depth. Some of the veins have, as is usually the case, received larger deposits of copper than others, and the usual variations in values in different places in the lodes themselves occur.

The lodes of the district are almost invariably found running parallel to the strike of these dykes and are often in close association with them. Generally speaking, these lodes consist of bands of crushed granite ("Formation") in which are small quartz reefs; a little ore is always found disseminated through this quartz, but bunches or shoots of payable ore are usually found in the formation,

Fig. N.



Geological Map of the Copper and Lead Lodes of Northampton.

lying alongside the quartz reefs. These bunches vary in thickness from that of a sheet of paper up to as much as a couple of feet, and both longitudinally and vertically are equally variable.

Over the whole of the Northampton Mineral Field there is not a mine which has been sunk to any great depth. The lodes which have already been opened up are, as already pointed out, parallel to the basic dykes.

Igneous dykes of this nature represent what were originally fractures in the earth's crust, which pass downwards to very considerable depths, and the lodes fill in fissures of a similar character which find their origin far below the limits of practical mining; the lodes, in consequence, will continue downwards as far as ever operations are likely to be carried. There must always be local variations not only in the size, but also in the metallic contents of ore bodies. There are no scientific grounds, however, for believing that the mines of the Northampton field have reached the limits of ore deposition, or that the ore bodies will not prove equally productive when followed either horizontally or vertically.

As ore deposition is most intimately connected with the system of fracturing to which the district has been subject, the search for further lodes must follow the direction of greatest ore deposition, which is that lying parallel to the system of basic dykes. Judicious prospecting carried out upon these lines should result in the discovery of other lodes equally productive to those already exploited.

YANDANOOKA.

The mineral field of Yandanoooka is situated near the western coastline to the south of the Irwin River and in country drained by the headwaters of the Arrowsmith River. The district which includes Arrino and Mount Misery has, at the close of 1917, produced since its discovery in 1868, 175.55 tons of copper ore, valued at £1,889, containing 27.63 tons of metallic copper. There seem good grounds for believing that these figures give an underestimate of the production, for some of the ore raised was never officially reported.

The district is of geological interest on account of the occurrence of copper ores in a series of sedimentary rocks of undetermined geological age, which form the southern extension of those occurring near the south-western boundary of the Irwin River series. These copper-bearing sediments consist of conglomerates, quartz grits, sandstones, quartzites, and volcanic tuffs which have an easterly dip ranging up to 65 degrees. The beds vary in their state of consolidation, the extent of induration and the degree of metamorphism they have undergone. These strata are intruded by granite which, with its allies, occupies a considerable area of country. Both the granite and the sediments have been subject to shearing stresses of variable intensity, and copper ore appears in the shear zones in mica schist (seared granite), sandstone and tuffs, adjacent to the eastern boundary of the granitic rocks.

At Arrino the copper lode first worked consisted of decomposed mica schist, through which rich benches and veins of green carbonate of copper were met with.

At Mount Muggawa, the principal workings are situated along a quartzose lode occurring in gneiss and mica schist, trending generally 30 degrees west of north. The width of the lode is about 2 feet 6 inches. Several tons of ore have been raised from this lode and shipped from Port Dongarra, but of the actual quantity there appears to be no official record.

A copper-bearing lode occurring along a crush zone in a chalcate tuff near Mount Misery has been worked. The lode was 2 feet 6 inches wide and has been opened out to a depth of over 50 feet; in the lode there were veins of black sulphide of copper, an assay of a sample from one of the rich pockets gave a result of 33.16 per cent. of copper in addition to 21 grains of gold, and 16 dwts. of silver per ton.

About 7½ tons of this ore are said to have been raised and despatched to Port Pirie in South Australia.

Three and a-half miles to the south of Yandanoooka Siding, and adjacent to the railway line on its eastern side, a body of copper ore from 12 to 36 inches in thickness occurs in a tuff, and has been exposed in a series of shallow open works. The lode contained some rich bunches of carbonate and sulphide of copper, samples from which gave an assay in the Geological Survey Laboratory the following results: (a) malachite and chalcocite copper, 36.16 per cent.; silver, 16dwts. per ton; gold, 21grs. per ton; (b) chalcocite, copper 55.53 per cent.; (c) carbonate ore, copper 9 per cent.

WONGAN HILLS.

Copper also occurs in the Wongan Hills, disseminated in varying quantities through the quartz reefs which exist in that locality. The copper-bearing quartz reefs have a strike coincident with that of the enclosing schists, viz., north and south. The quartz, as a general rule, is of a white sugary appearance, and carries haematite, limonite, azurite, malachite, and oxide of copper, together with actinolite, serpentine and garnets. The oxides of iron are disseminated through the quartz in the form of grains as well as in irregular veins. Assays made in the Geological Survey Laboratory showed gold to the extent of 1dwt. per ton, and copper from 8 to 16 per cent. in some of the ores.

MOUNT WAUGH (EASTERN DIVISION).

Copper ore has been found in the vicinity of Mount Waugh, near the South Australia border, somewhere about south latitude 26deg. Mount Waugh is of quartz-porphyry which occupies a considerable area in this part of the State. Mr. F. Haun found a small copper lode in the porphyry about two or three miles west of the summit. An assay showed it to contain about 12 per cent. of copper in addition to 1 oz. 5 dwts. of silver, and a trace of gold per ton. The porphyry belts in this latitude may be found to contain other lodes of a like character and possibly large low-grade copper deposits.

The Iron Deposits

of

Western Australia

by

A. Gibb Maitland.

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PART III.—Section 5.—IRON.

GENERAL STATEMENT.

Iron ores are very widely distributed throughout Western Australia, but with one or two exceptions the area in which the exploitation of such deposits is actively prosecuted is very limited, such areas being at present confined to localities where ore used as a flux in copper and lead smelting can be readily obtained. The amount of iron ore raised in the State up to the end of 1919 amounts to 57,830 tons, valued at £36,695.

The large iron deposits of the State extend over an area from Kimberley to Cape Leeuwin, some of which are probably equal in size to any others in the world, have, with the single exception of Koolan Island, Yampi Sound, Kimberley Division, remained absolutely undeveloped, and are, owing to their geographical situation and the absence of suitable coal fields, under present conditions practically valueless.

The iron deposits of the Murchison, however, stand out prominently before any of the others, so far discovered in the State, and although practically neglected they are ultimately destined to form a very important State asset.

No detailed geological surveys have yet been made of the iron deposits of Western Australia, hence even an inventory of the available iron ore supplies can only be a mere approximation, subject to modification as fresh deposits are discovered and existing ones opened up.

The iron deposits of Western Australia, when viewed from the standpoint of their geological relationships, mode of occurrence, and chemical composition, fall into four main classes:—

- (i.) Lenticular lodes of hæmatite, with a quartz gangue, associated with the crystalline schists and allied rocks.
- (ii.) Lodes of goethite, forming the weathered portions of pyritic bodies, made up largely of pyrites and pyrrhotite, with magnetite and ferruginous silicates.
- (iii.) Superficial deposits of brown iron ores of various kinds, with a gangue of gibbsite kaolin and quartz and forming masses of irregular extent within large areas of less ferruginous laterite, and
- (iv.) The soft porous deposits of bog ore of comparatively recent origin.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

CLASS 1.—ORES ASSOCIATED WITH THE CRYSTALLINE SCHISTS AND ALLIED ROCKS.

The deposits of the first class, which is by far the most important, appear to be most largely developed in the Murchison district, and the most noteworthy deposits are those at the Wilgie Mia (Weld Range), Mounts Hale, Taylor, and Matthews, and Gabanintha.

In addition to these places, however, iron-bearing schists are found almost all over the Murchison Goldfields and at numerous centres in Kimberley, Pilbara, Ashburton, Gascoyne, Peak Hill, Yalgoo, East Murchison, Mount Margaret, North Coolgardie, Yilgarn, and Phillips River Goldfields, as well as from other localities outside the limits of any legally defined mining field.

The deposits of this type consist of highly inclined beds, bands and lenses of almost pure hæmatite (or magnetite) or admixtures in all proportions of hæmatite and quartz usually laminated, some of which seem to be the result of the chemical alteration of highly

foliated and crushed belts of greenstone and associated metamorphosed sediments. The siliceous bands very often attain a width of as much as ten chains, and can often be followed across country for, in some cases, a good many miles.

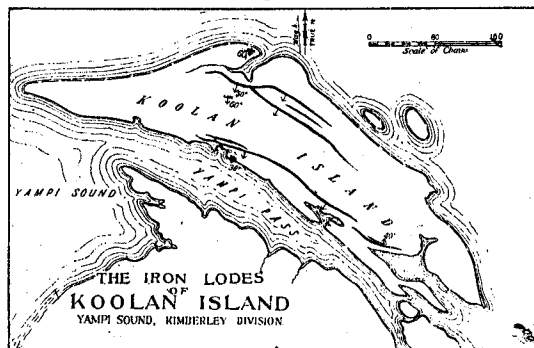
The following is a brief description of some of the richer and more important deposits:—

Yampi Sound, Kimberley Division.

Important deposits of high-grade iron ore were discovered about 30 years ago, by pearlers, in what is known as Koolan Island, Yampi Sound, about 100 miles north of Derby, but it was not until the year 1907 that active mining operations were commenced. Koolan Island, which is approachable by a navigable channel, on the south side, has a length of about eight miles and a width of about a mile. The island is traversed by a series of mountainous ridges which form the main axis, and is made up of highly inclined metamorphic sandstones, quartzites, and other schistose rocks.

The iron ores (Fig. a) are interbedded with these metamorphic rocks, which are inclined at angles of about 50 degrees to the south.

Fig. a.



These two distinct series of iron lodes on the island, that on the south side, outcrops for over two miles in length, and a width varying from 4 to 50 feet. The lode rises precipitously to a height of from 200 to 350 feet above sea level.

Upon the northern side of the island another large lode outcrops, and extends for a considerable distance in a north-west and south-east direction. The lode is a bifurcated one, and the two branches follow approximately parallel courses at a distance of about 20 chains apart. This lode, which dips at an angle of 50 degrees to the south-west, can be traced in its united form at its western extremity for a distance of 60 chains, whilst the northern arm has a length of about 100 chains, and the southern for about 160 chains. The lode at its widest part reaches about 40 feet, whilst the branch lodes vary in width from 5 to 25 feet. The southern lode averages about 20 feet in width and rises to a height of about 250 feet above sea level, has an underlay of about 40 degrees, and an outcrop of about three miles.

The northern lode also appears to average about 25 feet in width, and, if the two branches are added to its total outcrop, it has a horizontal extent of about 300 chains.

No accurate estimate has yet been made as to the actual quantity of ore available in these deposits, but it must be considerable. Other similar iron deposits on the island have been examined, and found to vary from 4 to 50 feet in width. This position and extent is shown on the map which forms Fig. (a).

Analyses of some ore made in the Geological Survey Laboratory gave the following in parts per hundred:—

	1.	11.
Iron	66.48	64.91
Silica	4.16	7.03
Sulphur	0.072	0.041
Phosphorus	0.064	0.012

(i.) Main lode (hæmatite rock, mainly hæmatite and quartz) from the centre of Koolan Island.

(ii.) East end of Koolan Island (hæmatite and quartz).

The iron contents in both of these ores is high, whilst the silica and sulphur are low, with only traces of titanium.

It is quite clear that an enormous deposit of very high grade ore exists on Koolan Island, which can be cheaply mined and shipped.

In addition to the lodes on Koolan Island, there are near the eastern extremity several small rocky islands, which consist principally of iron ore. Upon Cockatoo Island, which lies about two miles from the Western extremity of Koolan Island, is a similar iron deposit having an underlay to the south. An analysis showed it to contain 68.14 per cent. of metallic iron and 1.88 of silica. In all probability these are merely the linear extensions of the Koolan group of lodes.

Kimberley.

The sandstones of the Upper Carboniferous series of Kimberley abound in nodular and spheroidal masses of hæmatite. Spheroids, fully six feet in diameter, have been noticed at Dukes' Dome, to the south of the Fitzroy Valley.

Thick veins of iron ore have also been noticed in the limestones of the Rough Range, and in the sandstones to the east of the Mount Elder Range.

Pilbara and West Pilbara.

Iron ores occur plentifully throughout the district. Many of those laminated quartz and jasper veins, which are so plentiful in this portion of the State, and notable in the Lalla Rookh zone, are found to pass gradually into what appears to be virtually pure hæmatite. Some of these deposits could be readily concentrated into high-grade ores, which under suitable economic conditions might be turned to profitable account as sources of iron ore. Many of these belts of laminated quartz and jasper have been defined with such a degree of accuracy as is possible on the various geological sketch maps, though no attempt has been made to estimate either the tonnage or the average grade of the ore associated with them.

Large deposits of micaceous hæmatite occur in the West Pilbara Field. One of considerable importance has been noticed near Glen Roebourne; this lode is of micaceous hæmatite, and has a length along its outcrop of about half a mile, with a maximum width of 50 feet. About 100 tons of ore from this lode were raised between Balla Balla and Whim Well, and utilised as a flux at the time when copper ore was being smelted at Mons Cupri.

Ashburton District.

The Ashburton Goldfield also possesses some well marked and important iron deposits, which bid fair to become of importance in the future.

Mount Stuart.

At Mount Stuart, on the Ashburton River, is a banded hæmatite quartzite, which could be readily concentrated to a high-grade ore. Mount Stuart forms the culminating point of a little *massif*, which rises boldly from and forms a conspicuous feature in the level

plains by which it is surrounded on all sides. The Mount is composed of a succession of banded siliceous ironstones, which may, however, represent the same bed repeated by folding. Associated with these are numerous bands of felspathic schist ((?) argillaceous sandstone), the weathered surfaces of which are stained with black oxide of manganese. The southern-most spur of Mount Stuart is constituted by a band of laminated hæmatite-quartzite, having a general trend of 135 degrees, and underlaying at a high angle to the eastward. An analysis of this ore, which was made up of hæmatite, quartz, limonite, and magnetite, made in the Geological Survey Laboratory, gave the following results:—

SiO ₂	40.21
TiO ₂	nil
P ₂ O ₅ . . . . .	.24
H ₂ O (combined) . . . . .	.97
K ₂ O . . . . .	.39
Na ₂ O . . . . .	.52
CaO . . . . .	.23
MgO . . . . .	.33
MnO	1.14
FeO	nil
Fe ₂ O ₃	54.75
Al ₂ O ₃	1.80
FeS ₂ —Fe . . . . .	.04
S ₂ . . . . .	.05
H ₂ O (hygroscopic) . . . . .	.05

99.72

The ore-bearing zone varies in width from 180 to 300 feet. It has a length of about 1½ miles, and rises to a height of about 200 feet above the general level of the surrounding country. The siliceous hæmatite-quartzites of Mount Stuart have been in places converted into manganiiferous limonite and hæmatite, of which particulars are to be found under the section 9 devoted to Manganese, page 3.

Mount Edith.

At Mount Edith, some miles to the south of Mount Stuart, is also a bed of banded iron-bearing quartzite, associated with vertical beds of sandstone and fine micaceous sedimentary schists. Mount Edith is made up of a laminated iron-bearing quartzite, which dips to the south-east at an angle of about 25 degrees, and strikes generally north-west and south-east, which coincides with the dominant trend of the range of which it forms a part. Not far from the summit is a conspicuous band of crystalline hæmatite, made up of hæmatite, quartz, magnetite, and limonite, of which an analysis in the Survey Laboratory yielded:—

SiO ₂	1.70
TiO ₂ . . . . .	.06
CO ₂	nil
P ₂ O ₅ . . . . .	.06
SO ₂ . . . . .	.05
H ₂ O (combined) . . . . .	.57
CaO . . . . .	.12
MgO . . . . .	.14
MNO . . . . .	.03
FeO . . . . .	.90
Fe ₂ O ₃	96.70
Al ₂ O ₃ . . . . .	.28
H ₂ O (hygr.) . . . . .	.06

100.67

This ore, containing as it does 68.42 per cent. of metallic iron, phosphorous .026, and sulphur 0.20 per cent., is a very rich hæmatite ore. The complete analysis quoted above shows it to be low in silica, and with but a small percentage of titanium.

An analysis of this lode, which mineralogically consists of hæmatite, quartz, and limonite, made in the Geological Survey Laboratory, showed its composition to be in parts per 100:—

SiO ₂	9.33
Al ₂ O ₃	0.60
Fe ₂ O ₃	51.91
FeO	trace
MnO	trace
CaO	3.32
H ₂ O —	4.82
H ₂ O +	
P ₂ O ₅	trace
FeS ₂ . . . . .	.24
	<hr/> 100.22 <hr/>

Mount Gould.

Some high-grade iron ore occurs at Mount Gould, on the north side of the Murchison River, some miles from Mount Hale. Mount Gould is one of the most conspicuous landmarks in the upper reaches of the Murchison Valley, rising to a height of about 960 feet above the general level of the surrounding country, and may be seen from a long distance to the north and south. The flanks of Mount Gould are made up of iron-bearing schists, with which are associated a series of quartzites and tale (?) schists, from which cubes of pyrites have weathered out. The general strike of these beds is north-east, with a dip of about 50° to the south-east.

A lenticular lode of hæmatite forms the actual summit of Mount Gould. Partial analyses of samples of this ore made in the Survey Laboratory gave the following results:—

	1.	2.	3.	4.	in parts per
Ferrie Oxide Fe ₂ O ₃	91.89	95.93	96.04	96.77	hundred
Insoluble	2.77	2.51	1.51	2.33	

Gabarintha.

About half-way between Gabarintha and the Star of the East and twenty-one miles east of Nannine, is a long, low ridge consisting of almost pure hæmatite and magnetite, containing a fairly high percentage of titanium. The ridge upon which the iron ore occurs trends slightly west of north, and extends for about two and a-half miles. The belt of iron ore is from 50 to 100 feet in width and rises in places to a height of 50 or 60 feet above the general level of the surrounding country. Taking the average width of the lode as being 50 feet, an average height of 25 feet above the plain, and length of two miles, this gives approximately one and a-half million tons of ore above the general level of the plains. A partial analyses of a sample of this ore made in the Geological Survey Laboratory gave the following:—

	Parts per hundred.
Metallie Iron	52.14
Silica . . . . .	.20
Phosphorus . . . . .	.008
Sulphur	nil
Titanic oxide	12.68
Water hygroscopic . . . . .	.15
Water combined	1.15

Except for the presence of titanium, the ore is extremely pure, sulphur and phosphorus both being almost entirely absent. The somewhat high percentage of titanium presents certain metallurgical difficulties in connection with the utilisation of the ore, but these may, of course, be successfully overcome in time.

Edjudina.

In the neighbourhood of Edjudina, North Coolgardie Gold-field, and at the south-western end of Lake Raeside, is an important mineral belt about 10 miles in length, made up of laminated ferruginous quartzites (jaspilites) associated with greenstone schists of somewhat obscure origin. Some of the greenstones, believed to be basic lava flows, exhibit a marked bedded structure, and it may be that some are of sedimentary origin. Wherever these bedded rocks can be seen in section, they are either vertical or inclined at high angles to the north-east. The beds of which the Edjudina belt is composed range from almost pure quartz, through jaspilite, to high-grade hæmatite, with a little magnetite. The ridge upon which Yabboo Hill (E36) is situated, extends for about five or six miles and is made up of three bands of hæmatite-quartzite; the centre band is about 10 to 15 feet in thickness. These hæmatite quartzites occur in the form of overlapping attenuated lenses, of what appear to be shear planes of remarkable persistence.

Analyses of these iron-bearing rocks, made in the Survey Laboratory, show them all to contain a high percentage of silica and a relatively low iron content; many of them, however, could be readily concentrated to high-grade iron ores.

An analysis of six typical varieties of these Edjudina iron ores is given in the table below:—

Geol. Mus. No.	4401.	4402.	4403.	4404.	4406.	4408.
SiO ₂	45.05	60.82	55.55	51.76	43.10	61.19
Fe ₂ O ₃	53.36	36.90	38.07	47.75	54.73	32.54
FeO	Nil	Nil	present	...	Nil	Nil
H ₂ O — . . . . .	.17	.12	.05	.11	.12	.23
H ₂ O + . . . . .	.49	.87	.74	1.08	.93	4.24
P ₂ O ₅ . . . . .	.10	.14	.08	.10	.15	.20
FeS ₂ . . . . .	.06	.05	.08	.06	.05	.07
	<hr/> 99.23 <hr/>	<hr/> 98.90 <hr/>	<hr/> 94.57 <hr/>	<hr/> 100.86 <hr/>	<hr/> 99.08 <hr/>	<hr/> 98.47 <hr/>

4401. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. E. 36, Yabboo Hills, Edjudina.
4402. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. E. 36, Yabboo Hills, Edjudina.
4403. Banded hæmatite-quartzite, containing quartz, hæmatite, magnetite and limonite, Cairn C, Yabboo Hills.
4404. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Cairn C, Yabboo Hills, Edjudina.
4406. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Hill, B, Yabboo Hills, Edjudina.
4408. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Hill A, Edjudina.

Although the percentage of sulphur in these ores is low, the phosphorus would seem to be too high for what is considered requisite for the production of steel by the usual acid Bessemer process. There is a considerable tonnage of ore available at Edjudina, which it may be possible to utilise under more favourable conditions.

Mount Mason.

At Mount Mason, a hill midway between Mounts Bevan and Ida, is a large lenticular mass of very fine iron ore, suitable for the production of pig iron and steel. The ore is associated with iron-bearing quartz schists of the usual type. An analysis of a sample

An analysis of this lode, which mineralogically consists of hæmatite, quartz, and limonite, made in the Geological Survey Laboratory, showed its composition to be in parts per 100:—

SiO ₂	9.33
Al ₂ O ₃	0.60
Fe ₂ O ₃	51.91
FeO	trace
MnO	trace
CaO	3.32
H ₂ O —	4.82
H ₂ O +	
P ₂ O ₅	trace
FeS ₂ . . . . .	.24
	100.22

Mount Gould.

Some high-grade iron ore occurs at Mount Gould, on the north side of the Murchison River, some miles from Mount Hale. Mount Gould is one of the most conspicuous landmarks in the upper reaches of the Murchison Valley, rising to a height of about 960 feet above the general level of the surrounding country, and may be seen from a long distance to the north and south. The flanks of Mount Gould are made up of iron-bearing schists, with which are associated a series of quartzites and talc (?) schists, from which cubes of pyrites have weathered out. The general strike of these beds is north-east, with a dip of about 50° to the south-east.

A lenticular lode of hæmatite forms the actual summit of Mount Gould. Partial analyses of samples of this ore made in the Survey Laboratory gave the following results:—

	1.	2.	3.	4.	in parts per
Ferrie Oxide Fe ₂ O ₃	91.89	95.93	96.04	96.77	hundred
Insoluble	2.77	2.51	1.51	2.33	

Gabarintha.

About half-way between Gabarintha and the Star of the East and twenty-one miles east of Nannine, is a long, low ridge consisting of almost pure hæmatite and magnetite, containing a fairly high percentage of titanium. The ridge upon which the iron ore occurs trends slightly west of north, and extends for about two and a-half miles. The belt of iron ore is from 50 to 100 feet in width and rises in places to a height of 50 or 60 feet above the general level of the surrounding country. Taking the average width of the lode as being 50 feet, an average height of 25 feet above the plain, and length of two miles, this gives approximately one and a-half million tons of ore above the general level of the plains. A partial analyses of a sample of this ore made in the Geological Survey Laboratory gave the following:—

Parts per hundred.	
Metallic Iron	52.14
Silica . . . . .	.20
Phosphorus . . . . .	.008
Sulphur	nil
Titanic oxide	12.68
Water hygroscopic . . . . .	.15
Water combined	1.15

Except for the presence of titanium, the ore is extremely pure, sulphur and phosphorus both being almost entirely absent. The somewhat high percentage of titanium presents certain metallurgical difficulties in connection with the utilisation of the ore, but these may, of course, be successfully overcome in time.

Edjudina.

In the neighbourhood of Edjudina, North Coolgardie Gold-field, and at the south-western end of Lake Raeside, is an important mineral belt about 10 miles in length, made up of laminated ferruginous quartzites (jaspilites) associated with greenstone schists of somewhat obscure origin. Some of the greenstones, believed to be basic lava flows, exhibit a marked bedded structure, and it may be that some are of sedimentary origin. Wherever these bedded rocks can be seen in section, they are either vertical or inclined at high angles to the north-east. The beds of which the Edjudina belt is composed range from almost pure quartz, through jaspilite, to high-grade hæmatite, with a little magnetite. The ridge upon which Yabboo Hill (E36) is situated, extends for about five or six miles and is made up of three bands of hæmatite-quartzite; the centre band is about 10 to 15 feet in thickness. These hæmatite quartzites occur in the form of overlapping attenuated lenses, of what appear to be shear planes of remarkable persistence.

Analyses of these iron-bearing rocks, made in the Survey Laboratory, show them all to contain a high percentage of silica and a relatively low iron content; many of them, however, could be readily concentrated to high-grade iron ores.

An analysis of six typical varieties of these Edjudina iron ores is given in the table below:—

Geol. Mus. No.	4401.	4402.	4403.	4404.	4406.	4408.
SiO ₂	45.05	60.82	55.55	51.76	43.10	61.19
Fe ₂ O ₃	53.36	36.90	38.07	47.75	54.73	32.54
FeO	Nil	Nil	present	...	Nil	Nil
H ₂ O — . . . . .	.17	.12	.05	.11	.12	.23
H ₂ O + . . . . .	.49	.87	.74	1.08	.93	4.24
P ₂ O ₅ . . . . .	.10	.14	.08	.10	.15	.20
FeS ₂ . . . . .	.06	.05	.08	.06	.05	.07
	99.23	98.90	94.57	100.86	99.08	98.47

4401. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. E. 36, Yabboo Hills, Edjudina.

4402. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. E. 36, Yabboo Hills, Edjudina.

4403. Banded hæmatite-quartzite, containing quartz, hæmatite, magnetite and limonite, Cairn C, Yabboo Hills.

4404. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Cairn C, Yabboo Hills, Edjudina.

4406. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Hill, B, Yabboo Hills, Edjudina.

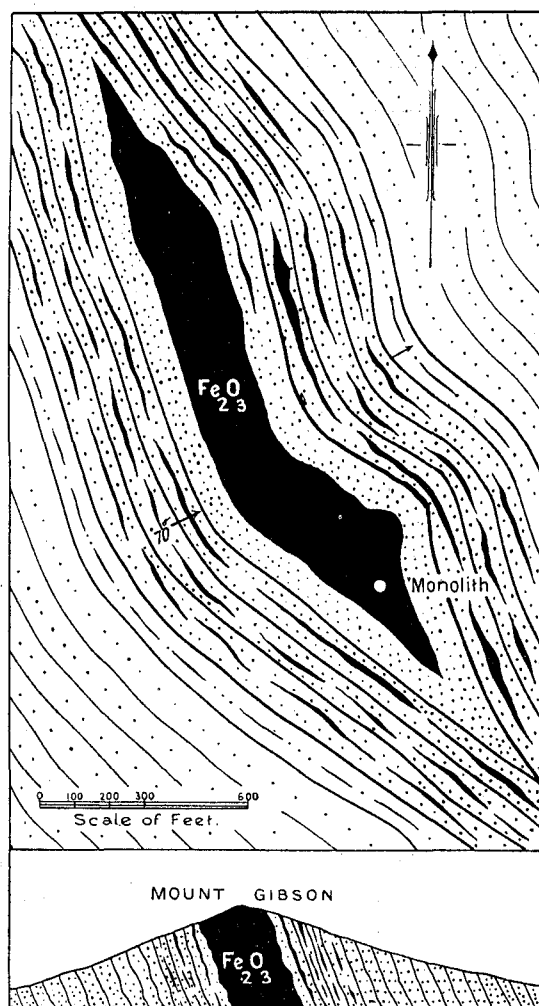
4408. Banded hæmatite-quartzite, containing quartz, hæmatite, and limonite. Hill A, Edjudina.

Although the percentage of sulphur in these ores is low, the phosphorus would seem to be too high for what is considered requisite for the production of steel by the usual acid Bessemer process. There is a considerable tonnage of ore available at Edjudina, which it may be possible to utilise under more favourable conditions.

Mount Mason.

At Mount Mason, a hill midway between Mounts Bevan and Ida, is a large lenticular mass of very fine iron ore, suitable for the production of pig iron and steel. The ore is associated with iron-bearing quartz schists of the usual type. An analysis of a sample

Fig. b.



PLAN & SECTION
OF
MOUNT GIBSON IRON DEPOSITS.
YALGOO G.F.

of this ore, which consisted of hematite, quartz and limonite, gave the following composition in parts per hundred:—

SiO ₂	74
Fe ₂ O ₃	96.98
Al ₂ O ₃	82
P ₂ O ₅	22
Mn ₂ O ₃	22
CaO	slight trace
Mgo	trace
S .....	.08
TiO ₂	nil
H ₂ O (HyS) .....	.12
H ₂ O (comb.)	1.40

100.58

The analysis shows an exceptionally high percentage of iron, and compares very favourably with the better known deposits of the Weld Range and Koolan Island, in Yampi Sound.

Mount Gibson.

Mount Gibson, one of the most conspicuous hills to the south of Lake Monger and the west of Lake Moore, on the Yalgoo Gold-field, is made up of quartz-hematite schist, in which thin veins of iron oxide alternating with jaspilite and other siliceous bands, which dip at an angle of about 70° to the north-east, and trend generally north-west. Some of the bands of iron ore reach a considerable size. The deposit makes a prominent feature in the landscape, forming as it does the back part of a long razor-backed range of hills, made up of banded quartz and jaspilite, which there are sound reasons for believing to have been originally of sedimentary origin. The ore consists mainly of hematite, with a little limonite, magnetite, and quartz. On analysis in the Survey Laboratory it has been found to contain 68.22 per cent. of metallic iron. A complete analysis of this ore is given in the table below. The iron ore is a large lens (Fig. b) about 2,000 feet in length, an average width of 200 feet and rising to a height of about 300 feet above the general level of the surrounding country. The lens is enclosed in a ferruginous jaspilite made up of quartz (57 per cent.), hematite, limonite, a little magnetite, together with some talc (?) and a little kaolin. The total iron content, as may be seen from the table below, is low, being only 28.57 per cent.; the ore, however, is too high in silica (58.08 per cent.) to be smelted without concentration. To be successfully concentrated, ore of this grade would require to be broken small, then jigged, but in view of the hardness of the ore, its low grade, and the small value of the concentrates, this does not under present conditions appear feasible.

The width of the enclosing jaspilite varies within wide limits, whilst the iron of the lens passes into it by almost imperceptible gradations. Laterally the gradation takes the form of the width of the band of ore; these, in some cases, being no thicker than a sheet of paper.

There are in reality no definite boundaries to what may be called the whole of the iron-bearing formation, the limits at Mount Gibson being defined by the locality where the siliceous element predominates to the exclusion of the iron ore; this varies from 800 to 1,000 feet. There are not less than 10 million tons of iron ore in the deposit at Mount Gibson.

Composition of the Mount Gibson iron ores:—

Constituents.	Geo. Survey Nos.	
	9849.	8887. (G.S. 1395.)
Silica, SiO ₂	58.08%	1.02
Alumina, Al ₂ O ₃ ... ..	.12	.11
Ferrio Oxide, Fe ₂ O ₃	39.97	96.68
Ferrous Oxide, FeO ... ..	.77	.55
Manganoso Oxide, MnO ... ..	.02	Nil
Magnesia, MgO ... ..	.26	Nil
Lime, CaO ... ..	.02	Nil
Alkalis, Na ₂ O, K ₂ O	Nil	...
Moisture, H ₂ O — ... ..	.05	.38
Combined Water, H ₂ O	1.01	1.59
Titanium, Oxide TiO ₂ ... ..	.01	Nil
Carbon dioxide, CO ₂	Nil	...
Phosphoric Oxide, P ₂ O ₅ ... ..	.03	.09
Iron Sulphide, FeS ₂	trace	.24
	100.34	100.66

9849. Average iron ore, Mount Gibson. Minerals present:

—Quartz (about 57 per cent.), hematite (about 33 per cent.), limonite (about 6 per cent.), magnetite (about 2½ per cent.), talc (?), kaolin. This ore is too poor in iron and too high in silica

to be smelted as it stands. Concentration to be successful would require breaking small and jigging, and in view of the hardness of the ore, its low grade, and the small value of the concentrates, cannot be considered feasible.

8887. G. Sur. 1/395. Haematite, Mount Gibson. Mainly haematite, with a little limonite, magnetite, and quartz. A very high grade iron ore suitable for the manufacture of steel by the acid process.

Southern Cross.

Haematite-bearing quartzites, in every way identical with those occurring elsewhere in Western Australia, are met with in the Yilgarn Goldfield. The greatest development of these deposits is met with in a series of ridges immediately behind the town of Southern Cross. These ridges rise to a height of about 50 to 60 feet above the level of the surrounding country. They consist of beds of almost pure banded quartz, containing in certain parts a large proportion of haematite and magnetite, in more or less parallel alternating bands. These vary in width from a few feet to over a chain, and conform to the general strike and dip of the enclosing rocks. Partial analyses of some of these rocks will be found in the table below:—

Constituents.	Geol. Sur. Mus. No.	
	5635.	5636.
Silica	50.12	41.55
Metallic Iron	33.67	37.04
Sulphur ... ..	.087	.064
Phosphorus ... ..	.072	.0187
Water (hygroscopic) ... ..	.03	.26
" (combined) ... ..	.50	3.37

5635. Frazer's West G.M.L. 505.

5636. Frazer's West Extended G.M.L. 506.

More complete analyses of specimens in other portions of Southern Cross are given in the table below:—

Constituents.	Geol. Sur. Mus. No.				
	11546.	11548.	11554.	11557.	11558.
SiO ₂	51.26	47.42	77.94	53.01	44.81
TiO ₂	trace	Nil	Nil	Nil	trace
CO ₂ ... ..	.08	trace	.79	Nil	.06
P ₂ O ₅ ... ..	.07	.41	.09	.44	.18
H ₂ O +	1.48	.59	.41	.31	.48
K ₂ O ... ..	.06	.11	.10	Nil	trace
Na ₂ O ... ..	.12	.14	.04	.19	trace
CaO	Nil	Nil	1.17	.67	.29
MgO ... ..	.30	.37	1.91	2.49	1.02
MnO	trace	Nil	.30	.22	Nil
FeO	1.13	.51	7.72	8.36	2.83
Fe ₂ O ₃	45.37	49.27	9.47	33.29	50.00
FeS ₂ ... ..	.07	...	.04	.03	.71
H ₂ O ... ..	.20	.78	.20	.41	.19
	100.14	99.60	100.27	99.42	100.57

11546. Banded haematite-quartzite, consisting of quartz, haematite, hornblende, magnetite, and limonite. Centre of Frazer's West G.M.L. 882. Southern Cross.

11548. Banded haematite-quartzite, consisting of quartz, haematite, hornblende, and magnetite. Close to south boundary of Lord Cardigan G.M.L. 613, Southern Cross.

11554. Banded magnetite-quartzite, made up of quartz, hornblende, magnetite, chlorite, and limonite. Shaft near centre of Wimmera South G.M.L. 647, Southern Cross.

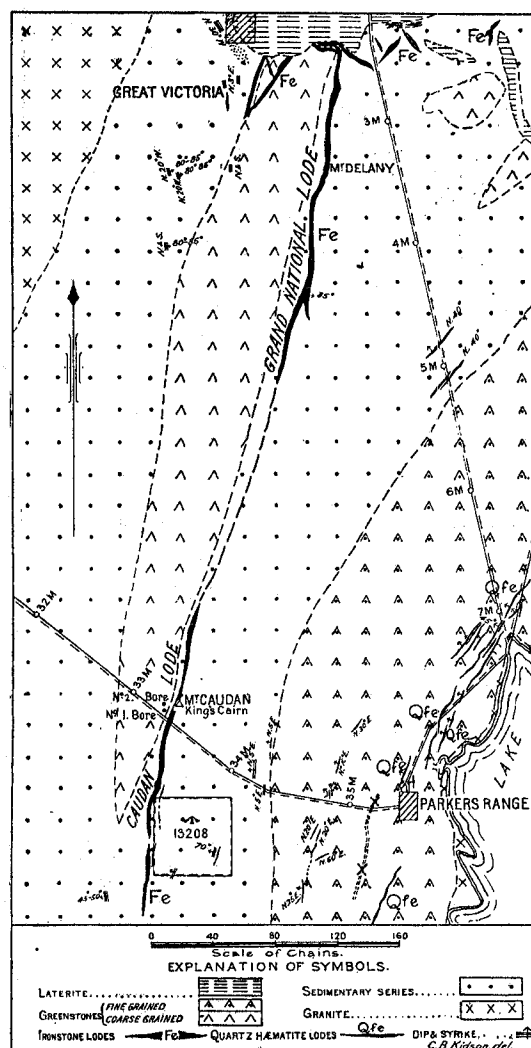
- 11557-S. Banded haematite-quartzite, composed of quartz, haematite, magnetite, hornblende, also graphite in 11558. Haddon Consolidated G.M.L. 2342, Southern Cross.

CLASS II.—LODES OF GOETHITE, FORMING THE WEATHERED PORTIONS OF PYRITIC BODIES.

Mount Caudan.

From the point of view of economic geology, the metamorphic rocks of the Yilgarn Goldfield are of considerable importance, in that along their contact with igneous rocks, the prominent ironstone lodes occur. The most noteworthy of these is what may be called the Caudan (King's Cairn) Grand National Lode, which extends northward from Dingo Tank (W.R. 13208) to Great Victoria for a distance of rather more than eight miles (Fig c). At

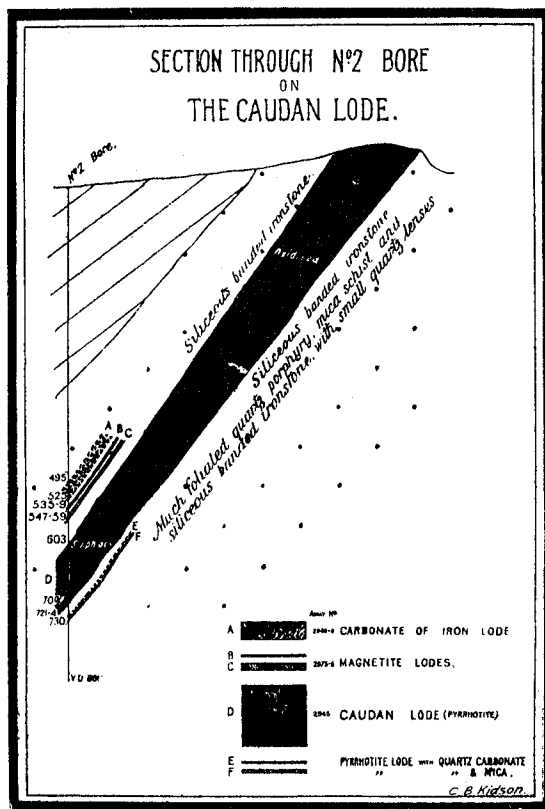
Fig c.



Mount Caudan the deposit consists of a large lode of iron hydrate (goethite), in some part manganiferous and associated with subsidiary deposits of magnetite and siderite (iron carbonate). The northern extension of this lode is interrupted at Mount Victoria by an important fault trending generally east and west.

Owing to its mineral composition, this lode presents considerable resistance to erosion, and its outcrop forms a more or less pronounced ridge, having a bold escarpment to the east.

Fig. d.



At Mount Caudan the lode (Fig. d) has been intersected by a vertical bore between the depths of 495 and 730 feet. It was found to consist of a considerable thickness of iron carbonate and magnetic iron ore, as well as a solid mass of pyrrhotite, measuring 70 feet from wall to wall. The outcrop of the lode is represented by goethite (hydrated oxide of iron) associated with masses of ferruginous oxide of manganese. At the limit of weathering, 200 to 400 feet below the outcrops, it passes into dense sulphide ores.

Typical analyses of these made in the Geological Survey Laboratory are:—

Main Lode Outcrop (mostly Goethite).

	1.	2.	3.	4.	5.
Iron ...	61.84	50.70	60.22	55.51	59.48
Manganese ...	.19	7.90	.43	4.17	.17
Chromium ...	...	...	...	...	.004
Silica ...	1.92	3.25	1.90	2.83	3.52
Phosphorus ...	.018	.048	.056	.070	.054
Sulphur ...	.018	.031	.026	.058	.086

Siderite Lode.

	6.	7.	8.
Iron ...	44.24	42.14	38.92
Manganese ...	3.55	3.07	3.21
Sulphur ...	.24	1.60	2.06
Insoluble ...	2.52	5.00	12.00

Magnetite Bodies (Lodes?).

	9.	10.
Iron ...	41.77	43.33
Sulphur ...	1.45	2.85
Insoluble SiO ₂ and Silicate ...	32.86	22.90

An average bulk sample of the sulphide lode as exposed in the vertical bore gave on analysis a total metallic iron content of 44.63 per cent. The chief minerals occurring in the lode were found to be pyrrhotite, dolomite, magnetite, and actinolite, together with small quantities of mica and chlorite. The results of an analysis of a concentrate from this lode gave 14 per cent. of magnetite, 82 of pyrrhotite, and 4 of other materials, with a trace of gold.

The greatest development of this lode, on the north, is probably at Mount Delaney, where the outcrop is represented by a massive iron ore about 200 feet in width.

At Great Victoria, the lode, which trends generally north-west and south-east, is a very highly silicified ore-body, attaining at a depth of 285 feet below the surface a thickness averaging from 100 to 150 feet, and rapidly passes into dense iron sulphides, which in turn give place to very highly coloured jaspilites. There seems to be sound reasons for believing the ore body at Victoria to be distinct from that of the Caudan-Grand National Lode. The fact that marcasite replaces pyrrhotite in the Victoria lode points to a different origin, an analysis of a sample of which gave the following results:—

Iron (Fe)	45.85
Sulphur (S)	53.69
Magnetite	0.93
Siliceous matter (SiO ₂ , etc.)	0.45
Water at 96°C. (H ₂ O—)	0.14
	101.06

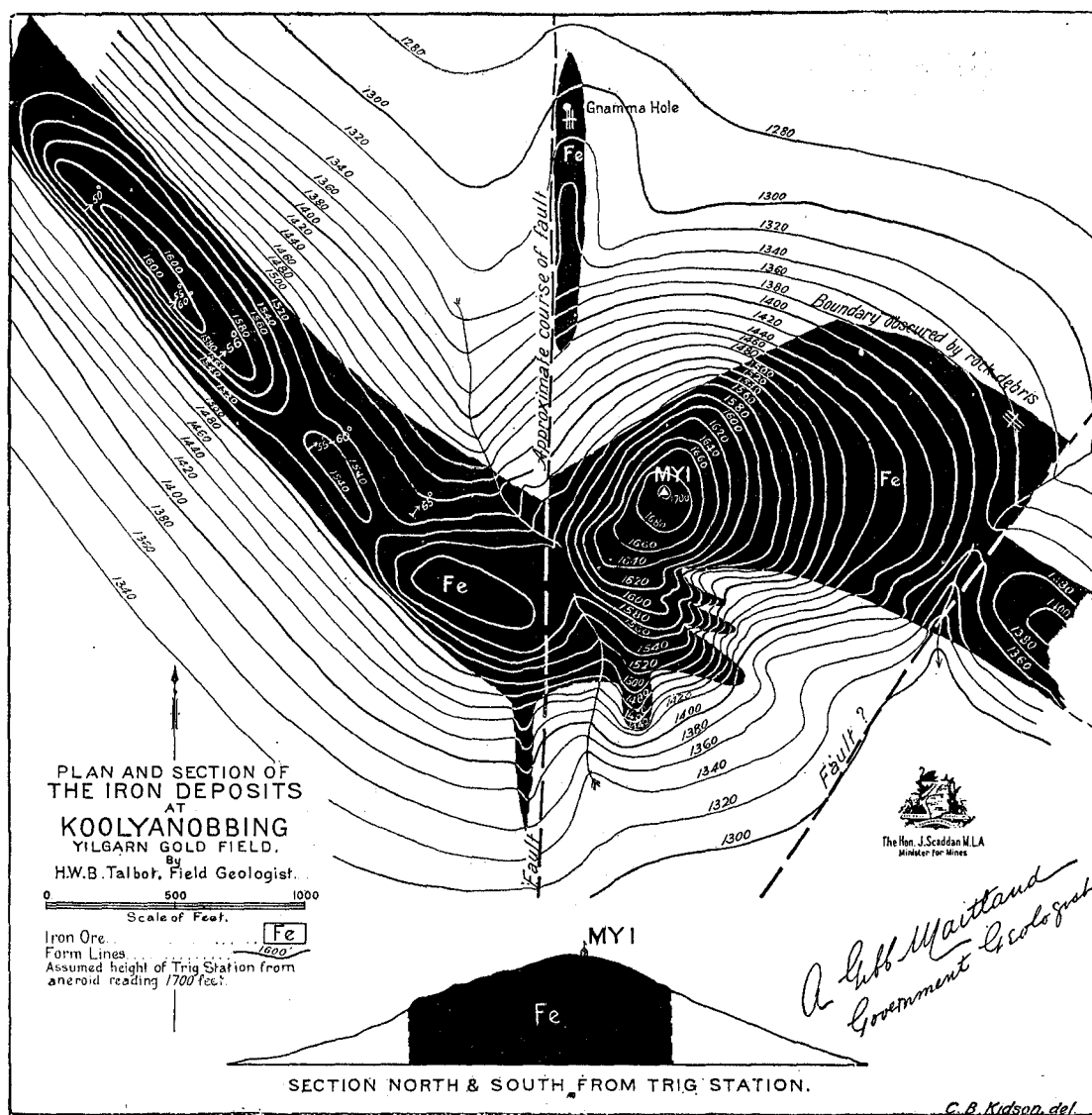
The principal interest attaching to the Great Victoria lode is in the gold contents, which, so far as operations have been carried, are remarkably regular in their distribution. Up to the end of 1917 the lode has yielded 8,983ozs. of fine gold from 79,091 tons of ore.

Koolyanobbing.

About 28 miles north-east of the Mount Jackson-Southern Cross gold belt is the mining centre of Koolyanobbing, where there is a deposit of a very high-grade micaceous iron hematite. The lode occurs in a lens-shaped belt of green rocks, believed to have affinities with rocks of igneous origin, which have a proved length of 35 miles, in a north-westerly direction, with a width of about five.

The principal iron deposit occurs in the vicinity of the Trigonometrical Survey Station on the Koolyanobbing Range, in the form of a lens of hematite, the major axis of which was 170 and the minor 70 feet (Fig. e). Veinlets of iron ore extend from the side of the lens into the surrounding rock.

Fig. e.



Extensive faulting has occurred in the Koolyanobbing Range, and it is in one of these faulted areas in which this extensive iron deposit occurs; the occurrence would appear to be a secondary deposition of ore in a zone of brecciation.

There is an extensive deposit of limonite to the west of and adjacent to the lens of hæmatite which occurs on the hill upon which the Koolyanobbing Trig. Station stands.

An analysis of two average samples from the outcrop of this lode were made in the Survey Laboratory. These were taken over a width of 200 and 150 feet respectively. One (C) was taken immediately to the west of the Trig. Station and the other (D) near the southern extremity of the lode.

Another somewhat similar lode occurs some little distance to the north-west of the Trig. Station. Two samples from this deposit were analysed with the results given in the table below. One of these (A) was taken across the dip of the lode on the face of the

escarpment over a width of 150 feet, whilst the second (B) was taken 500 feet east of the first, over a width of 200 feet.

G.S.L. No. ...	9618.	9619.	9620.	9621.
Mark ...	A.	B.	C.	D.
Fe ₂ O ₃ ...	% 90.30	% 88.33	% 86.76	% 86.44
Equal to Fe ...	63.21	61.85	60.73	60.51
SiO ₂ ...	2.02	4.78	2.40	3.08
S ...	...	0.06	...	0.04
P ...	...	0.01	...	0.006
Gold per ton ...	trace	trace	10 grs.	16 grs.

The chief mineral constituents of A and B are turgite and goethite, and of C and D goethite.

The composition of one mass of micaceous hematite (1/51) from the Koolyanobbing Trig. Station was found to be one of the purest yet found in the State.

G.S.L. 7458D.

Fe ₂ O ₃	98.75 per cent.
Equal to Fe	69.73 per cent.
SiO ₂	1.04
P . . . . .	.016
S	trace
Ignition loss . . . . .	.39

The results of these four analyses exhibit a fairly marked regularity, and all gave a high percentage of metallic iron. The proportions of silica, phosphorus, and sulphur were also very low. The ores are well suited for the manufacture of steel by the Acid, Bessemer, Open Hearth, or Electro processes. The geographical situation of the deposit presents no very serious difficulty if active exploitation becomes possible.

Ores of a similar type occur in the Mt. Jackson jasper ridge. One huge mass occurs in the gap between the Mount Jackson and Boondine Trig. Stations, and has been proved for over a mile in length. The ore which consists chiefly of goethite was found to have the following composition:—

Fe ₂ O ₃	90.26 per cent. (metallic iron 63.18)
H ₂ O	9.91
SiO ₂	trace
	<hr/> 100.17

A large deposit of goethite ore occurs near Bungabin Trig. Station, but neither surveys nor analyses have yet been made of it.

From the above description it is quite clear that in this portion of the Yilgarn Goldfield, there are very large deposits of high-grade iron ore.

Phillips River.

Some extensive iron ore deposits of the type occurring at Mount Caudan, in the Yilgarn Goldfield, are to be found outcropping in the high ground to the north-east of Kundip and Ravens-thorpe, which is made up of metamorphic schistose rocks of various types, sericite, and andalusite, mica, and chlorite schists, etc.

These ore deposits at the surface are more or less cavernous, and bear a very marked resemblance to laterite, by which colour and symbol they have been indicated on the geological maps of Ravens-thorpe, Mount Desmond, and Kundip. For deposits of this special type, the term lateroid (i.e., resembling laterite) has been used in India, and is being officially adopted as the designation of such in Western Australia. These deposits are in many places merely replacements of and impregnations in schists and allied rocks. Not very much work has been done on ores of this type, in the Phillips River district.

A bore was put down some years ago on the high ridge to the north-east of the East Chance Mineral Lease No. 225, near Mount McMahon. The bore was inclined at an angle of 45° in a direction of North 80 degrees East and had for one of its objects the testing of one of these "ferruginous dykes" at a depth. Two of these "dykes" were passed through, and one was practically solid iron pyrites. An analysis by the Company gave the following:—

	per cent.
Silica	5
Sulphur	49
Iron	46
	<hr/> 100

It appears that a pyrites lode was passed through between 170 and 338 feet, and the rest of the bore to 490 feet was in layers of laminated quartzite, with iron pyrites.

An analysis of two samples of this ore in the Survey Laboratory gave the following:—

Constituents.	Geol. Surv. Lab. No.	
	[5019.]	[5020.]
Iron Fe	44.37	45.68
Copper Ca . . . . .	.03	.02
Nickel Ni . . . . .	.06	slight trace
Antimony Sb . . . . .	.02	.01
Sulphur S	35.91	39.190
Silica SiO ₂	14.70	9.33
Alumina Al ₂ O ₃	trace	trace
Manganese Oxide MnO . . . . .	.97	1.55
Lime CaO . . . . .	.72	1.53
Magnesia MgO	3.73	4.10
Oxygen and difference	trace	7.08
	<hr/> 100.51	<hr/> 99.49

[5019] is made up chiefly of pyrrhotite and pyrites, with traces of magnetite, whilst [5020] consists of pyrites, pyrrhotite, and magnetite in about equal proportions.

A second bore was put down some distance further to the north. It is stated to have been carried down to a depth of 260 feet through a cavernous (fault?) rock without reaching the sulphide ore.

Collie River.

Deposits of very pure magnetite have been found in intimate association with the basic igneous rocks intrusive into the Fundamental Complex of the Darling Range at Serpentine and the Collie River, and which appear to be of magmatic origin. Not very much is known, however, about the deposits of this type and no geological surveys have been made of them.

An analysis of a sample of this magnetite ore from a locality about 12 miles north of Collie, made in the Geological Survey Laboratory, gave the following composition:—

Iron Fe	52.87 parts per hundred.
Silica SiO ₂ . . . . .	.45
Titanium dioxide TiO ₂	14.13

The high titanium content of this ore renders it unsuitable for smelting purposes.

CLASS III.—THE SUPERFICIAL IRON DEPOSITS.

The iron deposits comprise the laterite ores and the bog iron ores. The laterite ores, together with the gravel resulting from their denudation, are amongst the most widely distributed ores in the State, but they vary very much in their composition, ranging from a ferruginous bauxite to an almost pure limonite or turgite. The ores are most largely developed on the tops of hills or tablelands. In depth they pass gradually without any distinct line of demarcation into the underlying rock. Some of these are pisolitic iron ore.

The deposits owe their origin to the concentration of ferric oxide resulting from the surface decomposition of rocks rich in iron: nowhere do they attain any great thickness. The composition of the ores vary considerably, being in a great measure governed by the nature of the underlying rocks. When these belong to the basic series (greenstone, etc.) the overlying ores are rich in iron, but when the underlying rocks are of the acidic series (granite, etc.) the ores are poorer in iron and proportionately richer in alumina.

The ores of this class have been principally used for fluxing purposes, for which many are especially suited as the gangue is aluminous and not siliceous. The quantity raised up to the end of 1917 is set out in the table.

Quantity and Value of Lateritic Iron Ore raised.

Locality.	Quantity.	Value.
	tons.	£
North-West Division, Whim Creek ...	100.00	300
Central Division, Boulder ...	450.00	247
South-West Division, Avon ...	22,223.00	16,241
" Clackline ...	18,223.50	8,789
" Coates' Paddock ...	4,712.00	3,277
" Greenbushes ...	7,418.00	4,629
" Werribee ...	4,600.00	36,148
Total ...	57,756.50	69,631

At Clackline, on the Eastern Railway, 51 miles from Perth, is a lateritic deposit consisting almost entirely of pure limonite, of which an analysis gave the following:—

Ferrie Oxide Fe_2O_3	80.12 per cent.
Alumina Al_2O_3	3.41 "
Silica SiO_2	2.30 "
Titanium dioxide TiO_2	0.04 "
Water H_2O	14.82 "

A fairly extensive deposit occurs at Waterfall, on the south side of the Capel River, 11 miles from Capel townsite, on the main Donnybrook Road. An analysis of this ore gave the following results:—

Silica SiO_2	10.38 parts per hundred
Alumina Al_2O_3	7.56
Ferrie Oxide Fe_2O_3	70.30—metallic iron 49.21 per cent.
Titanium dioxide TiO_2 . . . . .	.70
Water H_2O	11.06
	100.00

The percentage of silica is somewhat high for use as a flux, but the ore could be used as a source of iron.

The following table gives the results of analyses made in the Geological Survey Laboratory of some typical samples of these lateritic iron ores:—

Table of Analyses of Lateritic Iron Ores.

Geol. Surv. Mus. No.	Na.	13002.	13005.	2119.	2907.	2991.	3282.	551.
SiO_2 ...	11.46	36.83	3.49	2.73	1.77	2.52	2.67	2.53
Al_2O_3 ...	...	8.48	16.44	12.76	12.29	5.97	9.92	4.32
Fe_2O_3 ...	73.81	45.67	60.61	62.67	75.41	79.41	78.38	80.02
MnO_2 ...	...	Nil	.29	.35	.41	.07	.07	.13
MgO} ...	...	trace	.28	.99	Nil	1.56	.35	trace
CaO} ...	...	Nil	Nil	Nil	Nil	Nil	Nil	Nil
TiO_2 ...	...	.06	1.35	6.00	2.55	3.10	2.01	6.06
P_2O_5 ...	.05	.05	.07	trace	trace	trace	trace	.08
Cr_2O_3 ...	...	.40	.96	.68	.05	.60	.01	.08
Zr_2O_3 ...	...	.06	.10	.15	.45	.65	.40	.55
H_2O} ...	...	9.32	16.60	14.46	7.05	6.89	6.00	7.06
	...	100.87	100.19	100.19	99.98	100.77	99.81	100.75

Na. Turgite laterite, consisting of turgite, quartz, diasporite and halloysite. Boogardie Murchison Division.

- [13002.] Limonite laterite, consisting of limonite, quartz, eantite, and halloysite, near the Enterprise Leases, Ora Banda, Central Division.
- [13005.] Limonite laterite, consisting of limonite, bauxite, halloysite, and doelterite, west of Black Flag Road, Ora Banda, Central Division.
- [2119.] Limonite laterite, consisting of limonite, bauxite, (?), halloysite, and doelterite. Eureka Extended G.M. 1275E, Kalgoorlie, Central Division.
- [2907.] Turgite laterite, consisting of turgite, diasporite, doelterite, and halloysite. Mount Ferrum G.M., Williamstown, Kalgoorlie, Central Division.
- [2991.] Turgite laterite, consisting of turgite, diasporite, hematite, doelterite, and halloysite. Thunderbolt G.M., L. 1121, Kalgoorlie, Central Division.
- [3282.] Turgite laterite, consisting of turgite, diasporite, hematite, doelterite, and halloysite. King G.M., Kalgoorlie, Central Division.
- [551.] Turgite, laterite, consisting of turgite, diasporite, bauxite (?), halloysite, quartz, and doelterite. North-east of White Prince G.M.L. 2892, Coolgardie, Central Division.

A chromiferous laterite occurs at Comet Vale, on the North Coolgardie Goldfield, resting on a belt of serpentine, from which it has evidently been derived. Chromium occurs in the serpentine, hence its occurrence in the overlying laterite is not at all surprising. The laterite is veined with secondary silica, which is associated with plamsa (green chalcidony).

An analysis of a sample of this laterite gave the following:—

Ferrie Oxide Fe_2O_3	79.01 per cent.
Chromic Oxide Cr_2O_3	5.30 "
Silica SiO_2	3.14 "
Sulphur S . . . . .	.124 "
Phosphorus . . . . .	.078 "
Water H_2O by difference	12.348 "
	100.000 "

The chromium is present in the form of a hydrate readily soluble in hydrochloric acid, the balance being present as chromite.

CLASS IV.—THE BOG IRON ORES.

The ores of this type consist of soft, porous deposits of hydrated oxide of iron of comparatively recent origin, and are known to occur at one or two places along the southern and western coastline of the State.

The occurrence of bog iron ore generally represents a concentration of iron derived from the oxidation of the surrounding rocks. This oxidation product is carried in surface waters to the bogs, etc., where by a further oxidation and hydration is precipitated as limonite (brown hematite).

On the east side of Herdsman Lake, a few miles to the north of Perth, a deposit of this ore occupies what was apparently a former extension of the lake bed. Two samples of this class of ore have been examined in the Geological Survey Laboratory, and analyses gave the following results:—

	Herdsman's Lake	Wanneroo.
Metallic Iron ...	51.75	48.61
Silica ...	2.82	8.52

Ores of this class have not yet been worked in any way.

The Lead Deposits

of

Western Australia

by

A. Gibb Maitland.

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Kimberley.

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West Pilbara.

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Northampton.

Mundijong.

Extract from

The Mining Handbook.

Geol. Surv. Memoir No. 1.

Chapter II., Economic Geology,
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PART III.—Section 4.—LEAD.

GENERAL STATEMENT.

The year 1848 saw the first discovery of lead ore on the Murchison River at what is now known as the Geraldine Mine (Loc. 1). Subsequent to that date Western Australia has produced up to the end of 1918, so far as can be ascertained from the export figures and those reported to the Mines Department, since the year 1894, 242,140.66 tons of lead ore, valued at £963,451, and containing 199,268.85 tons of metallic lead.

Lead ores may be dealt with under three different classes, according as they produce or have produced lead alone, lead and zinc, and lead and silver. There are two general sources of lead in Western Australia, the argentiferous and the non-argentiferous galena. The presence of a few ounces of silver per ton generally makes galena an ore capable of profitable extraction.

In Western Australia lead is largely derived from sulphide ores, and in some small measure from the carbonate (cerussite) and the phosphate (pyromorphite) which is found in the oxidised parts of such deposits. It sometimes occurs alone as galena, occasionally in association with sulphide of zinc and other metals, and is frequently found in the ores in many of the gold mines. The association of lead and copper at Northampton is so striking that the term lead-copper lodes applicable to the deposits would be appropriate. In only one locality in Western Australia, viz., Uaroo, on the Ashburton, is silver an important constituent of the lead ore.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

Lead ore has been raised from the following localities in Western Australia:—

Kimberley Division, Narlarla Hills; North-West Division, Roebourne, Uaroo, Westons; South-West, Geraldine, Narra Tarra, Northampton, Oakagee, and Mundijong.

KIMBERLEY.

Galena is a mineral of wide distribution in the Kimberley Division, having been found occurring in quartz reefs in the Panton, Hall's Creek, Brockman's, and Ruby Creek Districts; it occurs also in limestone at the Ord River and, in addition, massive carbonate ore has been found at Ivanhoe Station. It is only, however, at Narlarla Hills, in the Napier Range, that any active mining operations have taken place.

Narlarla.

The lead deposits are situated in the Napier Range, 75 miles due east of Derby, upon the south side of the Barker River Gorge, at a point some distance above its junction with the Leonard River at Narlarla.

The strata of the Napier Range consist of solid crystalline limestones with, at the base, a calcareous breccia and conglomerate. The beds have a prevailing strike of north-west and south-east, whilst the individual beds dip at an angle of about 20 degrees to the south-west. The basal beds of the series consist of limestone conglomerates containing fragments and boulders of the schistose and granitic rocks, upon which they rest with a violent unconformity. The Napier Range limestone is crowded with numerous crinoids, and from the fossil contents the beds are believed to be of Devonian Age. The Narlarla lead lode occurs in this formation.

The Narlarla lead deposit is situated at the top of the Range upon the south side of the Barker Gorge. The ore deposits consist of two small iron-stained "blows" of lead carbonate, about 20 chains

apart, which owe their origin to a local segregation of mineral in fissures, etc., in the limestones which also carry small quantities of metallic ores. The "blows" upon development proved to be small veins of lead ore along the bedding planes of the rocks. The ore consists of an admixture of the carbonates of lead and copper with in places, a considerable quantity of calcite and a siliceous gossan with magnetite, manganiferous iron ore and pyrites; there occur in addition varying quantities of the sulphides of lead and zinc.

The southern deposit ("blow") which at the surface contained some high-grade ore, was found at a depth of 8 or 9 feet to pass into iron pyrites without any lead. The northern deposit is somewhat better defined, having a length of about 70 feet. The ore at the surface is iron and copper stained lead carbonate, which at water level (20 feet) passes rapidly into sulphide ore; at this depth, 200 feet above the river gorge, there is a well defined vein of galena about two feet in thickness, the rest of the lode carrying a considerable quantity of zinc and iron pyrites.

Assays of samples of ore from Narlarla, made in the Geological Survey Laboratory, gave the following results:—

No.	Nature of Ore.	Lead.	Copper.	Zinc.	Gold.	Silver.
2352	Oxide ...	42.39	4.43	4.47	3 grs. per ton	4.40zs. per ton
2353	Sulphide ...	13.94	0.42	40.83	Nil.	3.30zs. per ton
2354	Transition...	39.66	0.52	1.34	trace	5.030zs. per ton

PILBARA.

There is no official record of lead mining in Pilbara, though the existence of the ore is known over a fairly wide extent of country. In the year 1909 the Engineer in charge of the survey of No. 1 Rabbit-proof Fence sent for assay samples of galena and copper and lead ore; these, which are said to have been obtained from a small leader situated about seven miles to the south-west of the 750-mile peg, midway between it and "Running Water," a large permanent pool on the Oakover River. The results of the assays made in the Survey Laboratory were as follow:—

	2740, Galena.	2741, Copper Lead Ore.
Lead (parts per 100) ...	72.6	46.5
Copper " " ...	...	8.7
Silver (ounces) " " ...	100zs. 4dwts. 17grs.	60zs. 0dwts. 20grs.
Gold (per ton) " " ...	trace	Nil

These discoveries are of considerable importance, as showing that the mineral belts of the North-West extend across the upper reaches of the Oakover River Valley. The size and extent of these lead deposits is not known.

A lead lode is recorded as having been discovered in the country between the Davis and the Oakover River, evidently in the neighbourhood of that from which the ore, near the 750-mile peg on the Rabbit-proof Fence, was obtained. The ore channel is stated to have been traced for about nine miles, and in it the lead ore occurs in bunches. The lead lode was cut into for about 14 feet, and a parcel of 3 tons 17cwt. shipped to Liverpool (England). The account sales showed an assay value of 50 per cent. of lead, 6.850zs. of silver per ton, and of copper 2.62 per cent.

WEST PILBARA.

Although lead ore has a wide distribution in West Pilbara, mining has not yet shown any indication of rising to the dignity of an important industry, there having been only 106.57 tons of ore, valued at £1,529, raised in the district up to the close of 1918. Deposits of lead ore were discovered near Roebourne in the year 1872.

What have been described as the Andover Lead Mines are situated about seven miles south of Roebourne, very close to the junction of the granite and the gabbroid and allied basic rocks which occupy a wide expanse of country in the Harding River. One lead lode had been taken up under the name of the Brother's United M.L. 67. The lode is a well defined quartz reef of the true fissure vein type, several feet in length, and occurring in greenstone country. The reef, which trends generally north and south, contains a good deal of galena and some zinc blende, and near the surface a considerable quantity of carbonate of zinc, together with a little green carbonate of copper. Several shafts have been sunk on the lode and its branches, but none of the workings exceed 50 feet in depth. An average sample of the clean galena obtained from the open cuts along the outcrop gave on assay:—

Copper	0.42 per cent.
Lead	67.17 per cent.
Silver	3ozs. 18dwt. 10 grains per ton.

The bulk of the lead ore raised from West Pilbara has been obtained from the Comstock Lease (M.L. 172), which lies close to the southern boundary of the Mons Cupri lease. The lode, which lies in slate country, is a small vein about two feet in thickness, containing the sulphide, carbonate, and phosphate of lead, which has been found to carry appreciable quantities of silver. The ore raised amounts to 104 tons. Assays of three samples of the ore from this mine, made in the Geological Survey Laboratory, gave the following result:—

	1.	2.	3.
Lead (per cent.)	57.6	41.3	41.3
Silver (ozs. per ton)	ozs. dwts. grs. 16 7 9	ozs. dwts. grs. 8 6 22	ozs. dwts. grs. 66 11 0
Gold (ozs. per ton)	trace	trace	Nil

1. Anglesite (sulphate of lead), cerussite (carbonate of lead), pyromorphite (phosphate of lead), quartz and limonite (hydrated oxide of iron).
2. Cerussite, anglesite, pyromorphite, quartz and limonite.
3. Galena (sulphide of lead), limonite, quartz, cerussite, and anglesite.

ASHBURTON.

Uaroo.—The Uaroo silver lead lode was first discovered in 1901, and is the most southerly of any of those occurring along the Uaroo mineral zone, of which a description has already been given under the heading of copper (*supra*). The silver lead lode lies in the centre of an area which is traversed by many large quartz reefs, which contain more or less copper.

The country rock in the vicinity of Uaroo consists of beds of conglomerate, quartzite and micaceous slates and phyllites dipping at very high angles to the north-east and trending north-west and south-east. Some of the conglomerate beds and quartz reefs are intersected by faults transverse to the general strike of the beds. (Fig. a.)

The Uaroo silver lead lode (Fig. b) trends generally north and south and has an average underlay to the east of about 70 degrees. The outcrop can be traced along the surface for a distance of over 800 feet, tapering out gradually at either end. Throughout its whole length the lode is enclosed in nearly vertical beds of gritty sandstone, quartzite, and conglomerate. The lode is a quartz reef of very variable dimensions. Wherever exposed in the workings the

lode consists chiefly of quartz, containing in many portions large bodies of galena, with occasionally small quantities of green carbonate of copper. The total quantity of silver lead ore raised from

Fig. a.

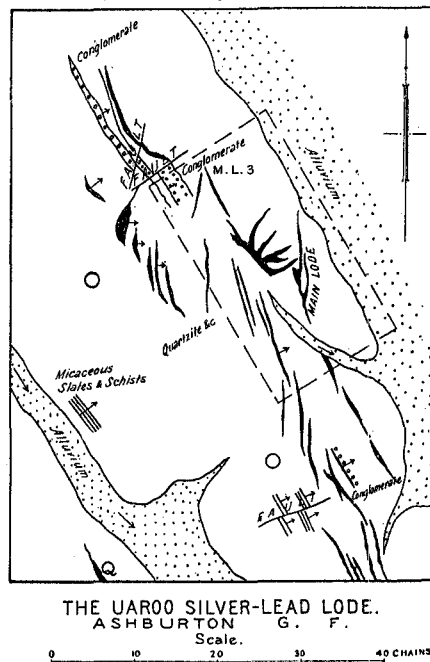
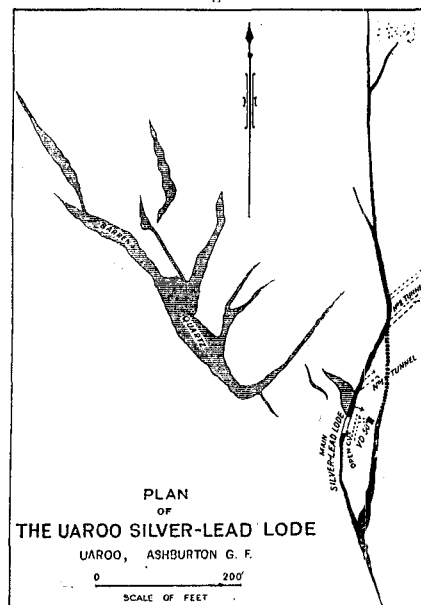


Fig. b.



Uaroo up to the close of the year 1918 amounted to 2609.29 tons, valued at £30,402. The ore contained more or less silver, the 9.09

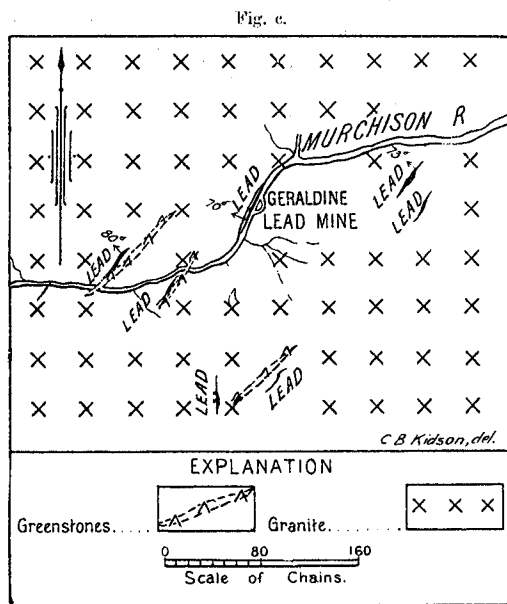
tons of ore raised in 1901 returned 356.26ozs. of silver, and the 35.85 tons raised in 1902 yielded 626ozs. of silver, in addition to 18.76 tons of lead.

NORTHAMPTON.

The chief source of the supply of lead ore has been from the mines in the Northampton District, which have produced practically the whole of the lead raised in the State. Up to the end of 1900 33,644 tons of lead ore, valued at £364,756, have been exported from the Northampton District, whilst since that date 205,958.55 tons, valued at £595,234, containing 24,266.50 tons of metallic lead, have been reported to the Mines Department, thus bringing up the total production of the district to 239,602.55 tons, valued at £959,990. Of this quantity 122,860.56 tons, valued at £288,695, was obtained from the Baddera Mine, Loc. 1472, and 71,660.05 tons, valued at £233,135 from the Narra Tarra Mine.

The Baddera Lead Mine, which was discovered in 1873, is situated about seven miles to the north of the Railway Station at Northampton, with which it is connected by rail. There are two lodes on the property (Loc. 1472), lying in the same ore channel and trending north-east and south-west and having a steep underlay to the north-west. The main or westerly lode runs right through the freehold in a north-east and south-west direction and has a length of about 2,500 feet. The lodes vary in width from six to eight inches; the larger portion often consisting of bunches of almost pure carbonate and sulphide of lead. The ore body is mostly quartz with some garnet and galena, occasionally associated with a little copper pyrites, iron pyrites and zinc blende. At the surface much of the lead ore occurred as carbonate, of which some very large solid pieces are reported to have been obtained.

Most of the work on the property has been done at the south end of the lode which has been opened out to a depth of about 450 feet. The old workings at the northern end of the outcrop have been opened out to a depth of 72 feet.



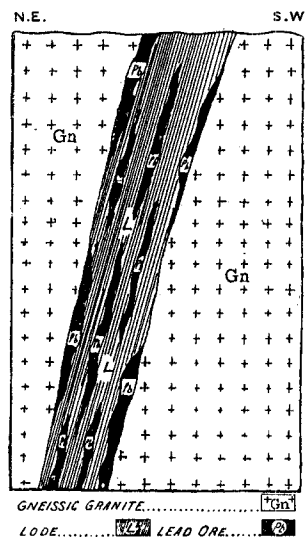
The Geraldine lead mines form a group of parallel lodes by themselves (Fig. c) and are situated in the valley of the Murchison River, about 40 miles north of Northampton.

The Geraldine Mine (Loc. 1), which is the principal one in the district, was discovered in 1848, although it was not until the year

1857 that active mining operations were undertaken, and which were continued until 1878, during which period a considerable quantity of lead ore was raised and dressed. In the early days smelting was attempted, but this proving unsuccessful the ore was shipped from Port Gregory. The lode, which occupies the lowest part of the bed of the Murchison River, trends generally north 30 degrees east, with a high underlay to the west, and can be followed for a distance of at least 320 yards. As described by Mr. A. C. Gregory, the Assistant Surveyor, who accompanied His Excellency Governor Charles Fitzgerald to the locality in 1848, "throughout the whole length the lead vein appeared to be one solid mass of galena." Some extremely rich ore was raised from this lode in the early days, which was said to have consisted of nearly three feet of solid galena. The lode has been opened up to a depth of over 320 feet on the underlay and a good deal of work done on it. At the bottom of the shaft the lode consisted of a solid mass of galena, two feet eight inches wide, assaying from 65 to 75 per cent. of lead. Owing to incomplete records having been kept in the past the exact quantity of ore raised from the Geraldine lead lode cannot be estimated; it is, however, known that there were shipped from Geraldine 6,500 tons of lead ore on behalf of Mr. Habgood, the owner of the freehold. In the year 1917, 169.67 tons of lead ore, valued at £1,080, containing 54.26 tons of metallic lead, were raised from the mine.

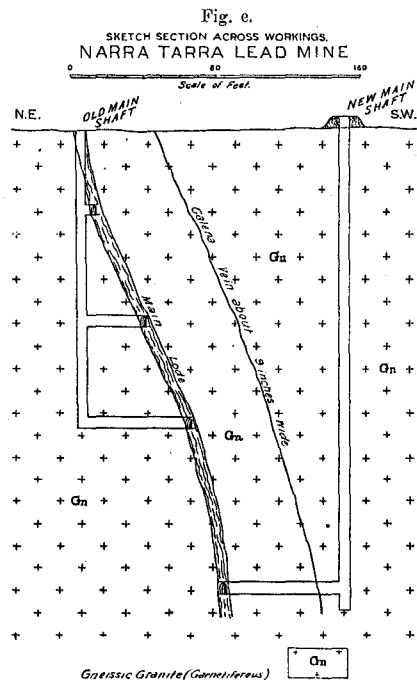
The Narra Tarra Mines are situated about thirteen miles to the south-east of Northampton and two and a half miles west-south-west from Nabawa Siding on the Upper Chapman Railway Line. The Narra Tarra Lead Mine was extensively worked between the years 1870 and 1884, during which period lead ore to the value of

Fig. d.
SKETCH SHOWING
THE OCCURRENCE OF LEAD ORE
ON
LOC. 119 NARRA TARRA.



£60,000 was raised; extensive plant and smelting furnaces were erected. The country rock in the vicinity of Narra Tarra consists of gneissic granite, in which the lines of foliation coincide with the strike of the lodes, viz., north-east and south-west. The rock varies from very fine-grained gneiss to a coarse-grained granite with incipient gneissic structure. **The Narra Tarra Lead Lode** can be traced along the surface for a distance of about 20 chains; it has a high underlay to the south-west. The lode is a highly sheared zone of gneissic granite, in which lenses of lead ore (Fig. d) of varying width have been deposited. The lode has been worked by

a vertical shaft (Fig. e) sunk to a depth of 260 feet at a point 146 feet south-east from the outcrop. There are large vugs and horizontal cracks, filled with galena, to be seen in the workings, and the



drives at the 250-foot level disclose rich bodies of lead ore extending over a length of 400 feet.

The Oakagee Lead Lode (Loc. 311) is situated near the southern boundary of the Northampton Mineral Field, about 16 miles

north from Geraldton, on the eastern side of the railway line. The lode, which carries a considerable quantity of pyrites mixed with galena, although large is not well defined, has an average strike of north-north-east and underlays to the south-west at an angle of about 80 to 85 degrees. The galena in the lode occurs as bunches and veins embedded in a mass of hard quartz schist and granitic rock, which contains much iron pyrites. The lode has been opened up by means of two shafts and is said to have produced several hundreds of tons of ore prior to the year 1870.

MUNDIJONG.

The Mundijong lead lode is situated to the south of Perth, about two miles east-south-east from the Mundijong Railway Station, near the foot of the Darling Range. The country in the vicinity is made up of highly inclined metamorphic sandstone and slate, forming the foothills of the Darling Range. These beds may be the southern extension of those which carry the copper lodes of Yandanoooka. The lode is a strong body of quartz, trending about north 35 degrees west, which can be traced for a considerable distance along the surface. Bunches of galena and zinc blende are scattered through the quartz; there is very little silver associated with the galena and less gold. The lode has been opened up for about 60 feet along the outcrop to the north-west of the main shaft and shows a good deal of galena throughout the quartz. A shaft has been sunk to a depth of 100 feet; at 70 feet a crosscut has been put in through the lode, which consists of almost solid quartz, 16 feet wide, with strings and patches of galena and zinc blende.

The following analyses have been made of ore from this lode:—

Description of Ore.	Lead.	Zinc.	Copper.	Silver.	Gold.
	%	%	%	ozs. per ton.	ozs. per ton.
Gossan, quartz with cerussite, galena, zinc blende, etc. ...	1.80	3.55	0.29	0.75	trace
Quartz with zinc blende, galena and pyrites ...	7.54	15.46	0.15	0.45	trace
Zinc blende, quartz and galena	4.63	43.75	Nil	0.75	trace
Quartz, zinc blende and galena	9.53	23.49	Nil	1.95	trace
Quartz, zinc blende and galena	12.64	7.63	0.40	3.30	trace
Quartz, zinc blende and galena	4.94	19.28	trace	0.95	trace

The Magnesite Deposits

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PART II.—Section 12.—MAGNESITE.

GENERAL STATEMENT.

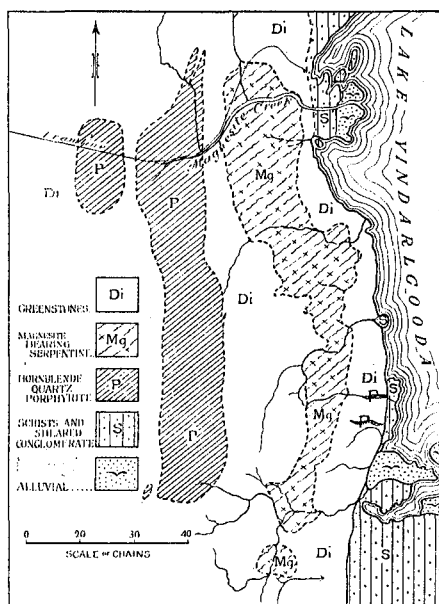
Magnesite is known to occur in many parts of Western Australia and has a fairly wide distribution, being found at a considerable number of localities where there are more or less extensive areas of serpentine and allied basic rocks which are almost entirely composed of minerals rich in magnesia. So far as is at present known, deposits of magnesite which may be capable of development are those of Bulong, Siberia, Phillips River, and Coolgardie. Up to the end of 1917, 742 tons of magnesite valued at £1,293 have been raised from the deposits at Bulong, which so far represents the entire production of the State.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

BULONG.

The only magnesite deposit hitherto worked on a commercial scale is that near Bulong, in the North-East Coolgardie Goldfield, 19½ miles east of Kalgoorlie. The occurrence of Magnesite at Bulong has been known to the Geological Survey since 1897, but it is only quite recently as a result of the war conditions that there has been any serious attempt towards its exploitation. The analyses made in the Laboratory of the Geological Survey show the Bulong mineral to be of an excellent grade of commercial magnesite. The magnesite is found (Fig. a) in a serpentine rock

Fig. a.



Plan of the Magnesite bearing rocks of Bulong,
N.E. Coolgardie Goldfield.

which forms a mass about two miles in length and averaging 18 chains in width, covering an area of about 350 acres. There are, in

addition, some other smaller areas occupied by magnesite bearing rocks, the largest covering about 80 acres. The serpentinised rock is traversed by a series of short irregular veins of magnesite of varying size which in certain parts of the mass are sufficiently numerous to form a stockwork. As a rule these veins stand out well above the surface of the ground; they are very irregular, both in strike and dip, and rarely reach two feet in width. The majority of the veins are only a few inches in width, whilst a number are mere threads. The veins appear to be most numerous in those localities in which the rock has been subject to the greatest amount of decomposition. A surface coating of a magnesite cement is exposed and covers an area of about 20 acres near the north end of the principal mass of serpentine. The magnesite hitherto worked has been obtained from quarries of variable dimensions and of shallow depth.

The analyses of the Bulong magnesite made in the Laboratory of the Geological Survey are given in the table below:—

Analyses of Magnesite from Bulong.

	1.	2.	3.
	No. 2 Quarry.		
Magnesia, MgO	47.36	44.96	44.31
Carbon dioxide, CO ₂	51.60	49.33	47.76
Combined water, H ₂ O ... ..	...	0.08	Nil
Moisture, H ₂ O —	0.15	0.97	1.17
Silica, SiO ₂	0.12	1.12	4.99
Alumina, Al ₂ O ₃ ... ..	...	...	...
Ferric oxide, Fe ₂ O ₃	0.16	0.56	0.42
Lime, CaO	Nil	1.06	Nil
Sodium chloride, NaCl	0.53	1.76	1.30
Potassium chloride, KCl	0.01	.09	0.08
Magnesium chloride, MgCl ₂	0.08	Nil	0.11
Sulphur trioxide, SO ₃	trace	0.13	0.15
Total	100.10	100.06	100.38

The analyses quoted above show the magnesite to be fairly free from lime, to contain moderate amounts of silica and iron, and to be of an excellent grade of commercial magnesite.

The result of the field observations demonstrates that there is a large quantity of high grade magnesite available in the deposits exposed near Bulong.

A total of 742 tons of magnesite has been quarried up to the end of 1917 and exported. The value of the magnesite is estimated at £1 per ton on the ground, and the export value being set down at a little under £4 per ton.

PHILLIPS RIVER.

Magnesite has been known to occur at Phillips River, at several points to the north-east of the Railway Line between Kundip and Ravensthorpe, and has been used by the Phillips River Gold and Copper Company for fluxing purposes and as a lining for the converters. An extensive area of basic rocks occurs to the north-east of the Steere River which have been converted into serpentine, and extend in a general north-easterly direction for about six miles at least. The magnesite is found on the surface as an alteration product of the serpentinised rock. A considerable quantity of magnesite would appear to have been raised, but of the actual quantity there is no record.

Two analyses of the Phillips River magnesite have been made in the Geological Survey Laboratory, which gave the following results:—

Analyses of Magnesite from Phillips River.

	Bandimup.	Kundip.
	%	%
Magnesia, MgO	46.63	46.20
Carbon dioxide, CO ₂	51.13	51.58
Combined water, H ₂ O ... ..	...	Nil
Moisture, H ₂ O—	0.99	...
Silica, SiO ₂	0.28	0.29
Alumina, Al ₂ O ₃	0.19	0.32
Ferric oxide, Fe ₂ O ₃ ... ..	...	0.24
Ferrous oxide, FeO	0.10	...
Lime, CaO	1.34	1.43
Total	100.66	100.06

The analyses of the Bandimup magnesite show it to be extremely pure and well suited for all those purposes to which the mineral is usually put; in composition it is well above the standard set for magnesite utilised for the production of oxychloride cement, viz., not less than 85 per cent. of MgCO₃, of which the local mineral contains 97.50 parts per hundred.

WAVERLEY.

A high-grade deposit of magnesite occurs at Waverley, in the Broad Arrow Goldfield, about 12 miles west-south-west from the Canegrass Railway Station. The deposit was met with while excavating the Government Water Tank, and boulders of magnesite may be seen lying on the surface of the greenstones some distance to the south-east of the tank. Boring operations showed the deposit to be somewhat extensive, though the full extent of it could not be determined.

The following is the analysis of the magnesite from Waverley as made in the Geological Survey Laboratory:—

	%
Magnesia, MgO	47.09
Carbon dioxide, CO ₂	51.62
Combined water, H ₂ O	0.16
Moisture, H ₂ O-	0.12
Silica, SiO ₂	0.16
Alumina, Al ₂ O ₃	0.61
Ferric oxide, Fe ₂ O ₃	0.20
Lime, CaO	trace
Sulphur trioxide, SO ₃	0.08
	100.04

COMET VALE.

A high-grade magnesite well suited for all industrial purposes has been found in the neighbourhood of Comet Vale, on the North Coolgardie Goldfield. Very little, however, is known of the nature of the deposit. A belt of serpentine about half a mile wide, trending generally north-north-west, and occasionally altered to a talc-schist, occurs immediately to the east of Comet Vale in intimate association with fine-grained epidiorite and amphibolite. In all probability the magnesite occurred in, or at any rate in association with, the serpentinised rock.

An analysis of this magnesite made in the Laboratory of the Geological Survey gave the following composition in parts per hundred:—

Magnesia, MgO	44.96
Carbon dioxide, CO ₂	48.10
Insoluble	5.76
Alumina, Al ₂ O ₃	—
Ferric oxide, Fe ₂ O ₃	1.38
Lime, CaO	nil
	100.20

KALGOORLIE.

The Comet Vale belt of serpentine is in all probability continuous with that of Goongarrie, about eight miles to the south, and it may be connected with that occurring on the shores of Hannan's Lake near "Serpentine Bay," which lies about 4½ miles south-south-east of Boulder City. In this belt of serpentine a few small and scattered veins of magnesite occur, and, in addition, is found occurring in fairly large nodules strewing the surface of the ground. The ferruginous magnesite (breunnerite) is largely developed in the peridotite belt occurring along the western shores of Hannan's Lake; in one locality this mineral occurred in the form of small crystalline grains to the extent of about 37 per cent. of the entire rock mass.

EULAMINNA.

A large area of serpentine occurs on the Mount Margaret Goldfield at Eulamina immediately to the eastward of the township. The serpentine is associated with basic rocks which have been derived from quartz-dolerites. Considerable quantities of boulders of magnesite are found scattered over the surface of the serpentinised rocks of Eulamina, although no veins of the mineral have so far been detected *in situ*. It is more than probable that the Eulamina serpentine belt is in some way connected with those to the southward which occur between Yundamindera and Linden. In these belts of serpentine, magnesite occurs; a very good outcrop has been found near the 12-mile post on the Yundamindera-Linden Road. There seem sound reasons for believing that a careful search of the serpentine belts in the Yerrilla District would reveal the presence of other deposits of magnesite.

COOLGARDIE.

Magnesite boulders occur on the surface of the basic rocks in the Camel Farm Reserve, about four miles north-east of Coolgardie. A little work has been done on a fair-sized vein of magnesite near Coolgardie, but the exact locality of the deposit has not yet been ascertained. An analysis of a sample of this made in the Laboratory of the Geological Survey showed its composition in parts per hundred to be:—

Magnesia, MgO	46.95
Carbon dioxide, CO ₂	51.23
Moisture, H ₂ O-	trace
Silica, SiO ₂	0.63
Alumina, Al ₂ O ₃	1.04
Ferric oxide Fe ₂ O ₃	1.04
Lime, CaO	nil
Sulphur trioxide, SO ₃	nil
	99.85

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General Statement

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The Manganese Deposits of Western Australia

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PART II.—Section 9.—MANGANESE.

GENERAL STATEMENT.

Deposits of manganese are found in many localities in Western Australia, and very many samples of high-grade manganese ore have been received from time to time at the Geological Survey Office, showing the wide distribution of such ores in the State.

Two tons of manganese ore, valued at £1, were exported from the State in 1908-9 and 3ewt. in 1914-15; the precise locality in the South-West Division from which this ore was obtained is not known.

Black oxide of manganese is found disseminated, as an accessory mineral, throughout the ironstone deposits in some of the sandstones in the Kimberley Division. The banded siliceous hematites, which are of such widespread occurrence in Western Australia, have sometimes been converted into manganiferous limonite, which, however, is merely limonite with veins of hydrous oxide of manganese. The hematite schists also, by the development of small and irregular veins of manganese ore, have been converted into manganiferous hematite. It may be that the manganese in both cases owes its origin to a concentration of the small percentage of manganese in the hematite.

Good specimens of manganese ore have been received from the West Pilbara Goldfield and from Cue, on the Murchison, though nothing is at present known as to their mode of occurrence and geological relationships.

DISTRIBUTION OF THE DEPOSITS.

ASHBURTON.

Near Mounts Stuart and Minnie, on the Ashburton River, is a banded hematite-quartzite, with which is associated manganese ore of some importance. The ore-bearing zone varies in width from 180 to 300 feet; it has a length of about 1½ miles, and rises to a height of about 200 feet above the general level of the surrounding country. Samples from this manganiferous iron ore, which consists of psilomelane, pyrolusite, limonite, and micaceous hematite yielded the following:—

	1.	2.	3.
Manganoso dioxide, MnO ₂	40.50	59.94	...
Manganoso monoxide, MnO	2.76	2.10	...
Manganoso metal	27.73	39.50	18.02
Iron metal	21.08	14.30	40.40
Insoluble gangue	14.25	5.06	3.27

A low-grade siliceous manganese ore has been noted on the Lower Henry River; in all probability this forms the southern extension of the Mount Stuart belt.

YALGOO.

What is believed to be an extensive deposit of good manganiferous iron ore (hematite and pyrolusite) occurs in the Pinyalling Hills on the Yalgoo Goldfield, in the neighbourhood of Lake Monger, but so far no attempt has yet been made to mine it.

PHILLIPS RIVER.

The most important manganiferous iron ore deposits, so far known in Western Australia, occur on the South Coast. Large deposits exist in the Eyre Range, between the Phillips and the Hamersley Rivers, near Culham Inlet, but no mining has yet been done upon them.

Manganese ore, of which it is stated that about five tons have been exported from the South Coast, but nothing is known as to the nature and geological relations of the deposit.

A manganese deposit of the true fissure lode type has been opened out to a slight extent on the Hamersley River on the South Coast. It occurs in association with the sedimentary quartzites of

the Mount Barren Ranges. The lode trends generally east and west across the Hamersley Gorge, and probably represents the cap of a more or less extensive lode.

A sample of it, collected by Mr. Blatchford, Assistant Geologist, when analysed in the Survey Laboratory, yielded the following results:—

MnO ₂	42.19	} Ma, 32.58
MnO	7.64	
Fe ₂ O ₃	21.31	
H ₂ O	6.44	
Insoluble	21.12	
Undetermined	1.30	
	100.00	

Cobaltiferous manganese ores are known from the Barren Ranges, on the Gardner River, samples of which have been assayed in the Survey Laboratory and have yielded:—

Manganese	40.15	34.67	41.86
Cobalt	0.67	0.41	0.39
Nickel	0.25	trace	trace
Copper	trace	trace	trace
Silica	15.32	16.25	17.94
Silver	2dwts. 17grs.	2dwts. 8grs.	1dwt. 20grs.

A deposit of high-grade manganese ore occurs at Desmond, in the Phillips River Goldfield, and situated upon the old Mt. Chester Lease M.L. 250.

The manganese lode (pyrolusite and psilomelane) can be followed along the surface for a distance of about 800 feet, the outcrop following the steep side of a range lying about a quarter of a mile east of the railway line at a point about 26 miles from the port of Hopetoun. The deposit, which lies in a belt of schists forming the Ravenshorpe Series, has a strike of north 75 degrees east and an underlie of from 70 to 75 degrees to the south-west. A clean body of ore, 20 feet wide, was exposed in a trench put in across the "comb" of the country. The deposit was opened up by means of a tunnel, 90 feet below the level of the outcrop, and at a distance of about 300 feet from the entrance. The lode measured 20 feet from wall to wall, and in it were two veins of manganese ore, the larger one measuring nine feet in thickness. Two samples yielded on assay in the Geological Laboratory in parts per 100:—

- (1.) Massive dense pyrolusite: Manganese, 48.20; iron, 9.80; silica, 2.20.
- (2.) Soft powdery pyrolusite: Manganese, 21.41; iron, 27.35; silica, 1.76.

A complete chemical analysis of a sample of the ore from this locality gave:—

	Per cent.	
MnO ₂	50.16	} Metallic manganese, 43.99
MnO	8.52	
CaO ... ..	.45	
NaO ... ..	.06	
Fe ₂ O ₃	7.77	
Al ₂ O ₃	3.91	
CaO	trace	
MgO ... ..	.32	
K ₂ O	3.30	
Na ₂ O ... ..	.38	
SiO ₂	10.84	
P ₂ O ₅ ... ..	.18	
H ₂ O	3.82	
CO ₂ , etc.	1.29	

BALLADONIA.

Manganese ore, containing small quantities of cobalt and nickel, is stated to occur about 30 miles to the north-west of Balladonia. An assay of a sample in the Survey Laboratory yielded 71.86 per cent. of manganese oxides. No particulars are available as to the nature and relationships of the deposit from which the sample came.

Many of the Western Australian laterites contain appreciable quantities of manganese, sometimes as more or less spherical concretions, though it is unlikely that such will ever constitute a source of exploitable manganese ores.

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Part II., Section 13.—MICA.

GENERAL STATEMENT.

Mica, one of the lesser minerals, is probably one of the most widely diffused throughout the State, and is one which bids fair to take an important place in the industrial economy of the future. In its broader sense, mica comprises a group of minerals, the chief characteristics of which, distinguishing them from all other minerals, are the highly perfect cleavage, the pronounced elasticity of the laminae, and the peculiar pearly metalloid lustre. There are three varieties of mica of commercial importance, viz., muscovite (potash or white mica); biotite (black mica); and phlogopite (magnesia mica). Another variety, lepidolite (lithia mica), may be used in the manufacture of lithia salts, though it does not as yet appear to have been utilised for any of those other purposes to which mica is ordinarily put. All these varieties of mica occur under somewhat similar geological conditions.

The mica-bearing strata are the crystalline schists and allied rocks, which cover such extensive portions of the geologically known areas of Western Australia. Generally it has been found that the mica-producing rocks are pegmatitic granite and allied rocks, which invade the crystalline schists, etc., either in the form of dykes, sheets or lenticular masses, which are often parallel to the foliation, etc., of the enclosing strata.

The commercially important deposits of mica in Western Australia are usually found occurring in dykes and veins of pegmatitic granite, sometimes of remarkable coarseness, which traverse not only the crystalline schists but also the adjacent granite and gneiss.

Quartz, felspar (orthoclase, microcline, and albite), and mica are the chief mineral constituents of the pegmatites, though in addition there are large numbers of the less common minerals, such as tourmaline, beryl, garnet, biotite, corundum, etc. The three chief minerals are not uniform in size in different portions of the dyke mass. The dykes and veins naturally vary in shape and dimensions both traversely and longitudinally; sometimes they occur as thin stringers and at others as irregular masses of considerable width.

The somewhat delicate nature of mica causes it to be amongst the first of the minerals in a rock mass to respond to the effects of earth movements, which tend to destroy the mica, and render it commercially valueless.

The major portion of the Pre-Cambrian Plateau of Western Australia having, as has already been pointed out, had a remarkably peaceful geological history, since early Palaeozoic times at any rate, the ancient mica-bearing rocks have suffered practically no mechanical deformation and present general uniform characters, one of which is their remarkable freshness and the freedom of the mica crystals or "books" from the results of crushing.

The pegmatite dykes have a wide distribution in Western Australia though, of course, they do not all contain marketable mica, some of the mineral only occurring in very small "books" or crystals of practically no value.

Experience in well established mica-mining districts indicates that under ordinary circumstances at least 1,250 lbs. of dressed mica must be extracted from every 100 tons of rock mined (the shafts being less than 300 feet deep), and in those cases in which quarrying is resorted to 750 lbs. per 100 tons of rock were required to be profitable at the prices ruling prior to the war. A deposit of fair average quality ought to yield on the whole about:—

50% of mica capable of cutting into sheets 1 inch by 5 inches.				
30%	"	"	2	3
10%	"	"	2	4
6%	"	"	3	5
4%	"	"	4	6

Before being put on the market mica is best trimmed into rectangular blocks not less than 2 inches by 1½ inches in surface area, and one-sixteenth to one-third of an inch in thickness; and it is advisable to sort the mineral according to size and pack in cases containing about one hundredweight.

Mica of good quality has been found in several localities in Western Australia, but no mining of any consequence has been carried out, and up to the present not very much of the mineral has been raised. The official records show that a total value of £653 worth of mica has been exported from the State up to the close of 1917.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

KIMBERLEY.

No marketable mica has yet been found in the Kimberley Division, though there seems to be some reason for believing that the mineral, one of the commonest of the constituents, will be found large enough to work in portions of the granite area which forms such a conspicuous feature in the geology of the country lying at the foot of the King Leopold Plateau.

NORTH-WEST.

The North-West Division comprises large areas occupied by granite, gneiss, and allied rocks, as well as very many groups of granite-pegmatite dykes which contain large quantities of mica of very variable size. On the H.M. Lease 86 at Wodgina, Pilbara Goldfield, is a large pegmatitic dyke which in one portion contains a preponderance of lithia mica in the form of minute scales.

Mica mining has, however, been carried on to the south of the Lockyer Range, in the head waters of the Gascoyne River, at what is known as the Mica Mine near the Pyramid due west of Reserve 699. The mica deposit is a coarse-grained vertical pegmatite dyke about three or four feet in width, and trending generally east and west. The dyke, which has been opened up to some extent, contained several small sized "books" of white mica, muscovite, in addition to kernels or "books" of black mica, biotite, and appeared capable of yielding a fairly large quantity of mica of a medium size. Several mica-bearing pegmatites occur in the same neighbourhood, and some contain considerable quantities of tourmaline. On Morrisey Creek, some distance to the eastward, large sized sheets of mica, 12 inches by 12 inches, containing inclusions of iron-oxide, occur, but practically no work has as yet been done upon the deposits.

COOLGARDIE GOLDFIELD.

Mica-bearing pegmatites occur in great force on the Coolgardie Goldfield, more especially in the vicinity of Ubini, Londonderry, etc.

A coarse pegmatite dyke has been met with on Mineral Lease No. 1, near the Grosmont Mine; the dyke is from 15 to 20 chains in length and not more than 20 feet in width, and has been worked for its mica contents. The mica, lepidolite (lithia mica), occurs as irregular bunches associated with quartz, felspar, and other accessory minerals. The bunches of mica never weighed more than a few pounds, and although some fine sheets measuring 12 inches by 6 inches were met with, the prevailing sheets rarely exceed 4 inches by 4 inches. An analysis of the mica from this deposit showed it to contain 5.97 per cent. of lithia. There is no official record of the quantity of mica raised from this deposit.

A small quantity of mica of somewhat inferior quality has been obtained from a pegmatite dyke, situated about three miles to the south of the Mining Centre of Londonderry.

A spheroidal form of biotite (Anomite) occurs as a constituent of an albite-pegmatite, in association with finely granular lepidolite, at Ubini, between Coolgardie and Bullabulling; the mica contains a very large proportion of alumina and fluorine.

The borders of the large tract of granite to the southward, which forms the eastern margin of the extensive granite batholith lying between the auriferous area of Coolgardie and Southern Cross, is flanked by a belt of schistose rocks, which are traversed along the planes of foliation and bedding by numbers of pegmatite and allied acid dykes. Some of these contain large quantities of almost colourless mica (muscovite), which may ultimately be found to possess commercial possibilities.

NORTHAMPTON.

Some muscovite mica has been found in the Northampton District at about seven miles east-south-east of the township in a pegmatite dyke about six feet thick, occurring in granite country on Bowes Station. The dyke trends generally north 56 degrees east, with an underlay to the north-west. On the north side of the dyke there occurred a very micaceous vein, about six inches thick; none of the mica, however, so far as discovered, is of any greater size than three inches by three inches.

GRASS VALLEY.

Small-sized flakes of muscovite, of good quality, are known to occur in the granitic areas about four miles to the eastward of Grass Valley in the Avon District.

COLLIE RIVER.

Mica has been found as far back as 1891, on Bussell's Brook, a small tributary of the Collie River. The mica, which was found in fairly large flakes, occurred in pegmatitic granite dykes, which have an average strike of north and south.

MULLALYUP.

Large-sized muscovite mica in possible commercial quantities has been met with in the neighbourhood of Mullalyup, 148 miles to the south of Perth.

The mica occurs in pegmatite dykes, which vary in thickness from one to two feet; several shallow shafts have been sunk upon them. The dykes, which contain muscovite mica in sizes up to two and three inches square associated with numerous tourmaline crystals, occur in the micaceous schists which form the staple rock in the vicinity.

ISRAELITE BAY.

Some large sheets of muscovite mica have been obtained from the granite area to the north of Bellinger Sand Patch, in the Mardabilla District, Eucla Division. Mica Hill, 18 miles north from the coast, takes its name from the mineral occurring at that locality. Nothing, however, is known of the mode of occurrence of the mica, the district not having been visited by any member of the geological staff.

The Molybdenite Deposits

of

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by

A. Gibb Maitland.

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PART III.—Section VII.—MOLYBDENUM.

GENERAL STATEMENT.

Molybdenite has a very wide distribution in Western Australia, usually, however, in small quantities. The Molybdenite deposits of Western Australia, when viewed in the light of their mode of occurrence and geological relationships, are usually found in close association with granitic rocks. Considering the immense areas of granite and allied acidic rocks throughout the State, molybdenite may be expected to be widespread. Up to the end of 1917 the production of molybdenite has only been 14 tons, valued at £148. Molybdenite is found occurring as (a) a constituent of pegmatite dykes, (b) in granite, and (c) in quartz veins.

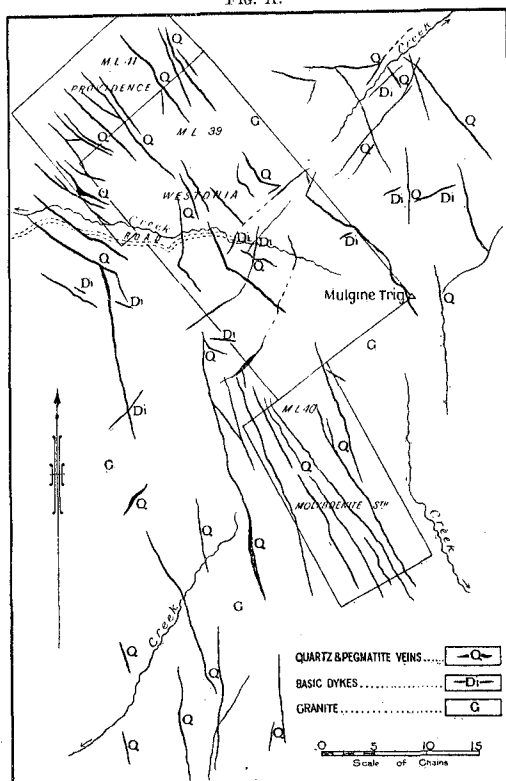
GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

MULGINE.

There has not as yet been much commercial production of molybdenum ore in Western Australia; some development work, however, has been done on the deposits at Mount Mulgine, near Warriedar, on the Yalgoo Goldfield, which may prove them to be of some economic importance. Mount Mulgine is situated about six or seven miles to the south-south-west of Warriedar and 62 miles south-east from Yalgoo.

The occurrence of molybdenite at Mulgine is of interest in that, up to the present, the entire commercial supply of the mineral in Western Australia is being obtained from this locality. The locality where operations have been carried out lies on the western slope of Mount Mulgine (Fig. a), and 180 feet below the Trig Station, or about 100 feet above the level of the main creek which crosses the

FIG. A.



Plan of the Molybdenite Deposits of Mulgine, Yalgoo Goldfield.

western boundary of Mineral Lease 39, "Westonia." The discovery of Molybdenite at this locality first came under the notice of the Department in 1915, with the receipt of a sample of ore at the Geological Survey Office which assayed 6.2 per cent. of molybdenum sulphide; molybdenite, however, had previously been reported from Gullewa, some distance to the north, where quartz containing from 1.04 to 2.60 per cent. of molybdenum sulphide occurred, indicating clearly that this western portion of the Yalgoo Goldfield lies in what may be called a molybdenite belt or zone.

Mount Mulgine is a rough isolated granite hill rising to a height of about 300 feet above the level of the surrounding country. The oldest rocks of the district are a complex of greenstone and allied rocks associated with areas of ancient sediments, all of which have been invaded by a huge granite batholith. It is not far from the periphery of the granite mass that the rough isolated hill Mount Mulgine lies. It owes its prominence to being ribbed with quartz and pegmatite veins, which in the aggregate constitute a zone of considerable width. The mount itself is made up of an acid greisenised microcline muscovite granite of varying texture, intersected by a network of veins of quartz and pegmatite which, when viewed broadly, have a north-westerly trend, and where seen in section are practically vertical. The granite, in addition to invading the neighbouring basic rocks, is traversed by several narrow dolerite dykes which have a general north-easterly trend and intersect both the quartz and pegmatite veins.

The granite is made up of large quantities of quartz, microcline, oligoclase, with muscovite and some pyrites. The feldspars are occasionally almost entirely kaolinised. The accessory minerals in the granite are zircon, epidote, zoisite, apatite, tourmaline, ilmenite (or magnetite), and chrysocolla. The pegmatites consist mostly of feldspar and quartz; some are almost entirely made up of feldspar, whilst others grade into what are practically quartz veins. The coarser pegmatites are made up mainly of microcline, quartz, and muscovite, and contain kaolin and pyrites in addition to small quantities of ilmenite and ferromolybdate.

The molybdenite occurs in the quartz and pegmatite veins as well as in the granite itself; generally it is found in flakes, which vary in size from minute specks to irregular masses, sometimes, though rarely, about half an inch in diameter. The molybdenite often appears as crusts in which the flakes lie in radiating groups, producing rosette-like forms. In some cases the molybdenite is associated with and occur in large masses and ill-defined crystals of iron pyrites. Occasionally, though not often, molybdenic ore having the characteristic yellow colour and a fibrous structure may be noticed occurring in the glassy quartz associated with damourite (?), whilst in some of the pegmatites there occurs ferrimolybdenite, the only common alteration product of molybdenite. The molybdenite rarely occurs in bunches, and when it appears in this form the mineral is usually only found along cleavages or cracks which at times cut across the main zones horizontally; the molybdenite, however, is not of secondary origin, except in the sense that these bunches and veinlets are a little later in age than the zones they intersect; there are sound scientific reasons for believing the mineralisation to extend to considerable depths, for the deposits are of deep-seated origin. The deposits seem capable of producing a fair tonnage of ore, containing about one per cent. of molybdenite.

LEONORA.

Molybdenite occurs in pegmatite at a spot about 17 miles to the north-east of Leonora, locally known as "Thomas' Show." The vein occurs in a knoll to the south of "West Terrace," made up of red orthoclase-microcline granite, which is traversed by small pegmatitic granite dykes of lenticular habit, some of which gradually merge into quartz veins. Upon one of these quartz veins, which strikes east and west and underlays to the south-east at 45 degrees, a little prospecting work has been done. The pegmatitic

quartz vein is only a few inches wide, and contains scattered through it flakes of molybdenite, some of which attain a diameter of about half an inch. The vein is continuous for about five chains, and has been found to carry more or less molybdenite over this area, though the average grade of ore is probably very low.

CALLIE SOAK.

Molybdenite associated with scheelite and wolfram has been found near Callie Soak, occurring in a pegmatitic quartz which traverses a bold bare mass of porphyritic granite, of which rock-mass this portion of the Murchison field is chiefly made up. The ore consists of a mixture of molybdenite, scheelite, and a smaller amount of wolfram in a gangue of quartz, mica, and kaolin. The ore on assay was found to contain 2.02 per cent. of molybdenite and 9.07 per cent. of tungstic oxide. The mineral composition is approximately, molybdenite, 2; scheelite, 10; wolfram, $14\frac{1}{2}$; and gangue $86\frac{1}{2}$ per cent. The veins for the scheelite and wolfram they contain; and up to the end of 1917, 24.64 tons of ore, valued at £186, have been raised.

WESTONIA.

The pegmatitic quartzes occurring at Westonia, on the Yilgarn Goldfield, contain, in addition to the gold, more or less molybdenite, which has also been found in the foliation planes of the gneiss which forms the country rock of some of the main ore bodies. The mineral has, up to the present time, never been found in sufficient quantity to render the recovery of the molybdenite

SWAN VIEW.

A little work has been done upon a deposit of molybdenite which occurs on the National Park Reserve 7537, about a mile and a half to the north-north-east of Swan View Railway Station in the Darling Range, about 14 miles from Perth. The country rock in the vicinity is a coarse-grained granite intersected by several greenstone dykes. The molybdenite occurs in small quantities in the granite, which is traversed by numerous joints running in all directions. The molybdenite in this locality is more or less confined to the vicinity of a vertical joint or fissure which had been opened out to a vertical depth of about six or seven feet; in the open work there were no signs of any lode or reef.

NORTH DANDALUP.

Further to the south of the occurrence of molybdenite at Swan View the mineral has been found in the escarpment of the Darling Range at North Dandalup, about two miles to the south of the river of that name and three miles south-east of North Dandalup Railway Station. The country in the neighbourhood consists of granite traversed by veins of chalcedonic quartz containing a little pyrites, and also dykes of pegmatite. In addition to the granite there are highly sheared greenstones. The pegmatite contains a small amount of molybdenite disseminated through it in a fine state of division and as small bunches near the contact between the granite and greenstone, and occasionally in the latter itself. The deposit has been prospected by a vertical shaft 71 feet deep; a sample of the ore assayed in the Survey Laboratory 0.11 per cent. of molybdenite.

The Tin Deposits

of

Western Australia.

By

A. Gibb Maitland.

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Geographical Distribution of the Deposits—

West Kimberley.

Moolyella.

Coonglegong.

Wodgina.

Coodardy.

Greenbushes.

Extract from

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Chapter II., Economic Geology.

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Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

The Tin Deposits of Western Australia

By
A. Gibb Maitland.

PART III—Section III.—TIN.

GENERAL STATEMENT.

Tin appears to have first been discovered in Western Australia towards the end of 1888, and has since been found to occur in several widely separated localities in the Kimberley District, the Pilbara Goldfield, the Thomas River in the Gascoyne Valley, the Murchison, Coolgardie and Greenbushes. There are, however, only two districts in the State from which any considerable output of tin has been reported, viz., Greenbushes in the South-West and Pilbara in the North-West.

The total quantity of tin ore raised in Western Australia up to the end of 1918 amounts to 15,761.83 tons, valued at £1,333,053. From Greenbushes 10,243.37 tons of tin ore have been raised, of which 9,937.14 tons represent the yield of stream tin and 306.23 tons of lode tin; Pilbara has produced 5,513.59 tons, of which amount 5,140.97 tons represent the output of stream tin and 372.62 tons of lode tin. Wherever the deposits have been examined they are invariably found to fall naturally into two distinct geological categories, viz.:-

- (1) Superficial or Secondary Deposits, which include—
 - (a) The Alluvial Deposits, and
 - (b) The Residual Sands, Gravels, etc., and
- (2) Deposits in Country Rock or Primary Deposits, which embrace—
 - (c) Tin-bearing Granite and allied rocks, and
 - (d) Tin-bearing Acid Dykes (pegmatite, quartz, etc.).

The alluvial deposits are the most important of any yet opened out in the State, having yielded 15,082.98 tons out of a total of 15,761.83 tons. These vary very largely in nature and range from an extremely hard ferruginous conglomerate to a stiff clay, or loose sand or gravel. The minerals in association with the tin in the alluvial deposits are quartz, kaolin, limonite, ilmenite, tourmaline, tantalite, stibiotantalite, garnet, zircon, gold, magnetite, rutile and topaz.

The residual deposits are either ironstone or sand, clays, etc., derived from the decomposition *in situ* of the underlying rocks, which are frequently stanniferous. The chief minerals accompanying the tin are limonite, quartz, tourmaline, clay and mica. The tin-bearing granites consist of granite passing in places into a highly foliated and highly micaceous rock, with little or no felspar. The granite (greisen) contains tin, tourmaline, zircon, garnet, etc., as accessory constituents.

In many of the tin-bearing districts of the State the granites and allied rocks are traversed by pegmatite dykes, made up mainly of quartz and albite, with subordinate mica, garnet and cassiterite. Considerable quantities of the stream tin owe their origin to the disintegration of veins of this nature.

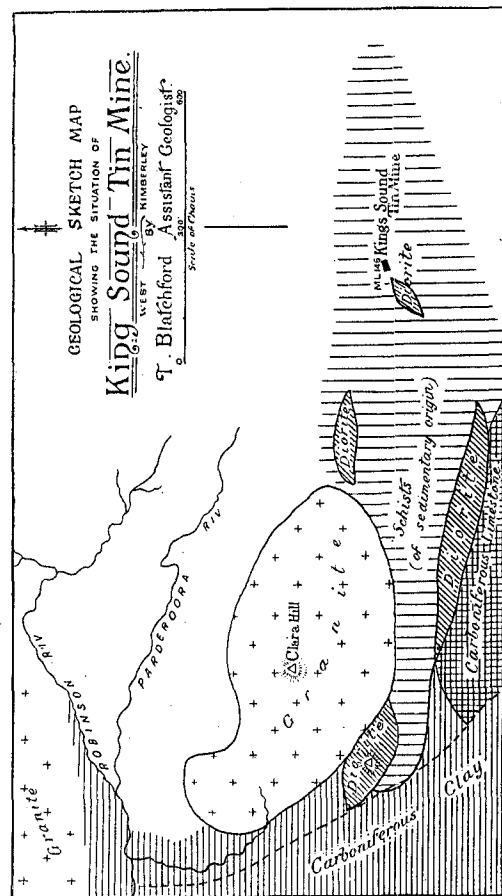
GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

WEST KIMBERLEY.

Tin has been reported to occur in greater or less quantity in sands on the head waters of the Bow and the Lennard Rivers in the Kimberley Division.

A little lode-tin prospecting has been carried out in compact quartz veins, probably acid pegmatites, in what is known as the King's Sound Tin Mine, West Kimberley. (Fig. A.) The mine is situated about 125 miles North-East from Derby, near the head of the Hawkstone Creek, eight miles to the east of the Napier Range. These tin-bearing quartz veins extend over a considerable area contained in a belt having a maximum width of from 20 to 50 feet. The tin ore in these veins is associated with wolfram; a sample of concentrates assayed in the Survey Laboratory yielded 18.69 per

FIG. A.



cent. of tin and 32.46 of tungstic oxide. There are no figures showing the actual yield from this mine; it can, however, hardly be very great.

MOOLYELLA.

Moolyella has to its credit the largest total production of tin from any of the mining centres in the Pilbara Goldfield and, in this respect, ranks next to the principal tin producer of the State, viz., Greenbushes, in the South-West.

these pegmatitic veins are albite and quartz, with occasionally scaly lepidolite mica and tourmaline; in addition, orthoclase, mangano-tantalite and tin occur in varying quantities, as well as some of the rare radio-active minerals. In the vicinity of and along the margin of many of the pegmatite dykes are bands and bunches of tourmaline, sometimes to such an extent as to make fully one-third of the entire rock.

When viewed broadly, the pegmatite dykes have a rude parallelism, coincident with that of the dominant structural features of the district which is north-east and south-west. Those, however, which traverse the schists and their allies trend generally north and south, and in all probability follow pre-existing fracture lines.

The pegmatites, which are offshoots from the main granite mass, are very regular both in width and underlie; they vary from mere threads to veins over 500 feet in width. One of the most conspicuous of the pegmatite veins, about half a mile in length and 30 feet in width, has proved to be sufficiently rich in tin and tantalum to constitute a "lode."

The tin ore appears to be an original constituent of the veins; it is, however, so far as observations have at present been carried, concentrated along certain lines in the pegmatites and does not appear to be generally disseminated in minute quantities throughout its mass. The tin occurs in all shapes, from minute grains up to pieces weighing as much as 100 lbs., besides lumpy ore in very valuable quantities.

The beds of the ravines and slopes on the hillsides carry detrital and residual tin (and tantalite) everywhere over the whole area occupied by the pegmatites, and in many cases the detrital and residual tin has been traced to the pegmatite veins.

The principal mining operations at Wodgina have been carried out on the Mount Cassiterite lease (M.L. 84), and upon it good alluvial and detrital tin has been found, in what is known as Ogilvie's Gully, where pieces weighing up to 50 lbs. have been met with. An important feature in the geology of the Mount Cassiterite property, the only developed mine on the field, is the number and extent of the pegmatite veins which intersect the country rock in all directions, and cover a fairly extensive area of the surface. What is known as the main lode is in reality an acid dyke, which varies from pure quartz to a mixture of felspar and mica, and occasionally to nearly pure felspar or mica. The width of the lode, which in places reaches as much as 14 feet, has been opened out by means of several tunnels driven from the outcrop on the face of the hill at different levels; the lowest of which is about 200 feet below the summit. The lode has thus been tested to a considerable extent both vertically and horizontally. The tin oxide occurs throughout the lode in very variable proportions in both the coarse and angular varieties, and occasionally finely disseminated throughout the rock mass. According to the official figures, it appears that the Mount Cassiterite lode has yielded up to the close of 1918, 329.02 tons of lode tin, in addition to 15.45 tons of detrital tin.

There are several other localities at which similar tin-bearing pegmatites occur, in addition to those in the Wodgina neighbourhood; these are scattered over an area of from 20 to 40 miles long and about four miles wide. Such trial crushings as have been made from the deposits in these localities indicate that the tin-ore is payable under suitable mining conditions.

As the tin in deposits of the nature of those occurring at Wodgina and the vicinity owes its origin to separation during the cooling of molten igneous rocks, the mineral is likely to persist to considerable depths provided the continuity of the deposits is not interfered with by faults of a later date. The development of tin lodes, however, is a much more lengthy process than the exploitation of residual and stream tin deposits, and, of course, cannot be carried out without capital judiciously expended in providing the necessary equipment and in exploration work.

The very large area of intrusive granite in which tin has actually been worked in the different localities throughout the North-

West, should encourage careful and judicious prospecting, more especially in those portions along the margin of the mass where it sends out veins into the surrounding rocks and, if intelligently carried out, there is every probability that other tin-mining centres will be opened up.

COODARDY.

The tin-mining centre of Coodardy is situated about 20 miles north-north-west from Cue, on the western side of the rabbit-proof fence, between the 70 and 74-mile posts. The area over which operations have been conducted is about four miles in length with a maximum width of one mile, made up of a series of greenstone and granitic schists, the lines of foliation of which have a general north-easterly trend. The majority of the rocks are crushed and altered beyond recognition and are traversed by a series of pegmatite dykes, some of which are tin-bearing, whilst one of the central belts of basic schists is intersected by a network of quartz-porphry dykes. Granitic rocks surround the mineral-bearing area. The pegmatites are of two distinct types, the first consisting chiefly of mica and quartz, while the second is made up largely of albite and is confined to the basic rocks. The albite pegmatites form the tin-bearing "lodes." The main "tin lodes" consist of a series of intersecting dykes, half a mile in length and about four chains in width. Large tin crystals occur here and there in the stone throughout the entire length of the dykes; in certain parts they are in considerable abundance though of smaller size, and arranged in seams or floors in the dyke mass. Three average samples from these richer tin floors assayed in the Geological Survey Laboratory yielded 0.046, 1.26, and 1.90 per cent. respectively. A sample of detrital matter from the lode, after picking out all the pieces known to be tin by sight, was found to have the following composition in parts per 100 by weight:—

Cassiterite	..	..	..	..	5.9
Columbite	..	..	..	..	29.2
Epidote	..	..	..	..	17.9
Jasper	..	..	..	..	15.4
Iron Hydrates, mainly Turgite	..	..	..	..	11.3
Wolfram, with a little quartz and scheelite	..	..	..	..	6.6
Tourmaline	..	..	..	..	6.5
Biotite	..	..	..	..	3.1
Quartz (black)	..	..	..	..	2.2
Magnetite	..	..	..	..	2.0
					100.0

The tin deposits are of a highly promising character. No separate figures are available as to the yield from this centre.

POONA.

The Poona Tinfield is situated about 40 miles north-west of Cue and 29 miles north-west of Coodardy. Tin was first discovered at this centre in the year 1909, and since that date 1.52 tons of tin, valued at £118, have been produced up to the close of the year 1918.

Geologically, the field is made up of crystalline schists in intimate association with two main dolerite dykes, some of which have developed a marked schistosity. The whole series of rocks have been invaded by granite, often of porphyritic habit, which occupies such a large area in this portion of the Murchison.

The pegmatites and quartz veins which emanate from the granite are of various degrees of texture and mineralogical constitution; a gradual passage from granite, through pegmatite to practically pure quartz may often be noticed. These latter veins are often of considerable size and horizontal extent.

The alluvial deposits so far discovered at Poona are confined to one small creek which has been proved to carry payable wash-dirt for a distance of about half a mile.

A sample of concentrates from the wash in this creek was found to have the following mineralogical composition in parts per 100 by weight:—

Cassiterite	..	..	..	..	33.4
Wolfram	..	..	..	..	26.2
Magnetite (and its alteration product)	..	..	..	..	13.8
Hæmatite	..	..	..	..	13.7
Epidote	..	..	..	..	6.3
Columbite	..	..	..	..	4.2
Tourmaline (and other silicates)	..	..	..	..	1.4
Ilmenite	..	..	..	..	.6
Garnet	..	..	..	..	.4
					100.0

GREENBUSHES.

The Greenbushes Tinfield is the oldest and most important in the State, its progressive development being shown by the quantity of tin raised up to the end of 1918, which amounted to 10,243.37 tons of black tin, valued at £841,890; of this only 396.23 tons have been obtained from the "lodes." The area occupied by the field is covered by some of the finest jarrah and blackbutt timber in the State, which ought, if conserved, to prove an exceptionally valuable asset for mining purposes. The average rainfall of Greenbushes is 36.75 inches, but owing to the hilly nature of the country there is no permanent surface water nearer than the Blackwood River, some five miles distant, but an abundant supply excellent in quality can be obtained by sinking, the depth at which such is struck varying from 10 to 100 feet, according to the elevation and nature of the country.

The rock formations that enter mainly into the geology of the Greenbushes Tinfield are granite and granitic gneiss, greenstones, largely referable to the dolerites, amphibolite and hornblende schist, as well as pegmatite and laterite, which latter occupies fully nine-tenths of the area included within the boundaries of the field as defined for the purposes of administration.

So far as the available evidence goes, it appears that the gneissic granite is the oldest rock occurring in the district. The greenstone occurs in both the massive and the foliated forms; the amphibolites occupy a large portion of the main ridge which forms the backbone of Greenbushes, and upon which the tin deposits occur. The hornblende schists which invariably occur in the neighbourhood of the granite and allied rocks, appear to have resulted from the dynamic alteration of the dolerites. The pegmatite dykes intersect the greenstones and all the other rocks of the tinfield and are of very variable width. The dykes are made up principally of quartz, felspar (albite), and mica; the relative proportions of the constituent minerals in the pegmatites are naturally subject to considerable variation, practically three distinct types of these dykes may be recognised, viz.:—

(a) Those which are largely made up of white felspar; (b) those of a red colour (ferruginous) and heavily charged with tourmaline; and (c) those in which mica is the dominant mineral. In addition, there are several quartz or quartz-tourmaline veins carrying a little tin, which probably represent an ultra-acid phase of the pegmatite dykes. Among the minerals occurring as accessories in these acid dykes are cassiterite, ilmenite, arsenical pyrites, tantalite, stibiotantalite, garnet gahnite, topaz, zircon and gold.

The laterite, which is often conglomeratic, covers by far the larger portion of the Greenbushes tinfield, and in some respects it is one of the most noticeable features in the structure of the district. In its mode of occurrence the laterite presents one important feature, viz., that it does not form a horizontal tableland, but occurs at different elevations, and seems to have adapted itself to the original contour of the ground on which it originated. The deposit covered a much larger area than it at present occupies and denudation has gone on to a large extent since it formed part of one continuous formation; the thickness of it is nowhere very great, mining opera-

tions having shown that it rarely exceeds 20 feet. The laterite (conglomerate) is not of sedimentary origin but has been formed by the alteration *in situ*, and subsequent cementation of the underlying rocks. In some portions of the field the laterite (as is only to be expected from its mode of origin) carries a certain quantity of tin. This laterite effectually conceals the underlying rocks over large areas and acts as a protecting cover to the tin-bearing deposits, in a measure preserving them from the denuding action of the streams.

The alluvial deposits which occupy the flanks of all the existing valleys of Greenbushes are of importance by virtue of their tin contents, are divisible into two main groups, viz.:—

(a) Old buried river courses or "deep leads"; and (b) the existing watercourses. The deep leads represent the old drainage channels the exact trend of which cannot in all cases be accurately traced.

The tin deposits of Greenbushes fall naturally into two distinct geological categories:—

(i) Superficial or Secondary Deposits—

(a) Alluvial Deposits.

(b) Residual Deposits.

(ii.) Deposits in Country Rock or Primary Deposits—

(c) Tin-bearing Granites and Allied Rocks.

(d) Tin-bearing Dykes.

The superficial deposits have been more or less extensively worked and continue to yield the larger proportion of the tin produced on the field, whilst what may be called "lode tin" (using the term to mean the ore derived from the parent rock as distinct from the detrital tin) have been worked, though, save in one or two localities, the deposits do not appear to be very rich in that mineral.

(a) The alluvial deposits are found flanking the course of all the existing watercourses. The whole of these modern alluvia are not tin-bearing; the richest or most prolific seem to be those formed by Spring Gully and its tributaries. The physical characteristics of some of the tin shows that it can only have been released from the parent rock in close proximity to where it is at present found.

The alluvial deposits of Spring Gully consist of two distinct portions: (a) an upper or "free dirt," i.e., loose gravel; and (b) a lower stiff "clayey dirt," containing irregular bands of detrital tin.

The "deep leads," so far as operations have been carried, seem to have attained their greatest development in what is known as the Three C's, named after the original holders of the Mineral Lease, Messrs. Cowan, Castella, and Clark, and forms one of the heads of Cowan's Brook. The Three C's was situated on a more or less water-logged sandy flat in which the "deep lead" was cut at a depth of a little over 96 feet in the vertical shafts. It is, however, quite possible that some, at any rate, of the sand in the Three C's is not of detrital origin, but is nothing more or less than the decomposed portions of a tin-bearing granite or gneiss which everywhere forms the staple country rock of this portion of Greenbushes.

Both the modern alluvia and the residual deposits have yielded by far the greater portion of the tin produced at Greenbushes. It by no means follows, however, that the richness of these is proof of exceptionally rich lodes or veins beneath, for owing to the extreme difficulty with which tin is acted upon by atmospheric agencies it often remains to gradually accumulate in much greater quantities than it existed in the parent rock. It is to this process of natural concentration that the richness of the superficial deposits of the Greenbushes Tinfield is due.

The tin occurring in the residual deposits is generally fairly coarse in grain, but in the alluvial and allied deposits it is very fine. The tin ores of the superficial deposits of Greenbushes are admixtures of quartz and clay together with some iron oxide and a little tourmaline; the dressed ore, however, contains the following minerals

Up to the present time the superficial deposits of Greenbushes have been extensively worked and continue to yield quantities of tin, but once the existing gullies and patches of residual tin-bearing gravel and sand have been swept by the hydraulic sluicing plants operating on the field, very little of value will remain.

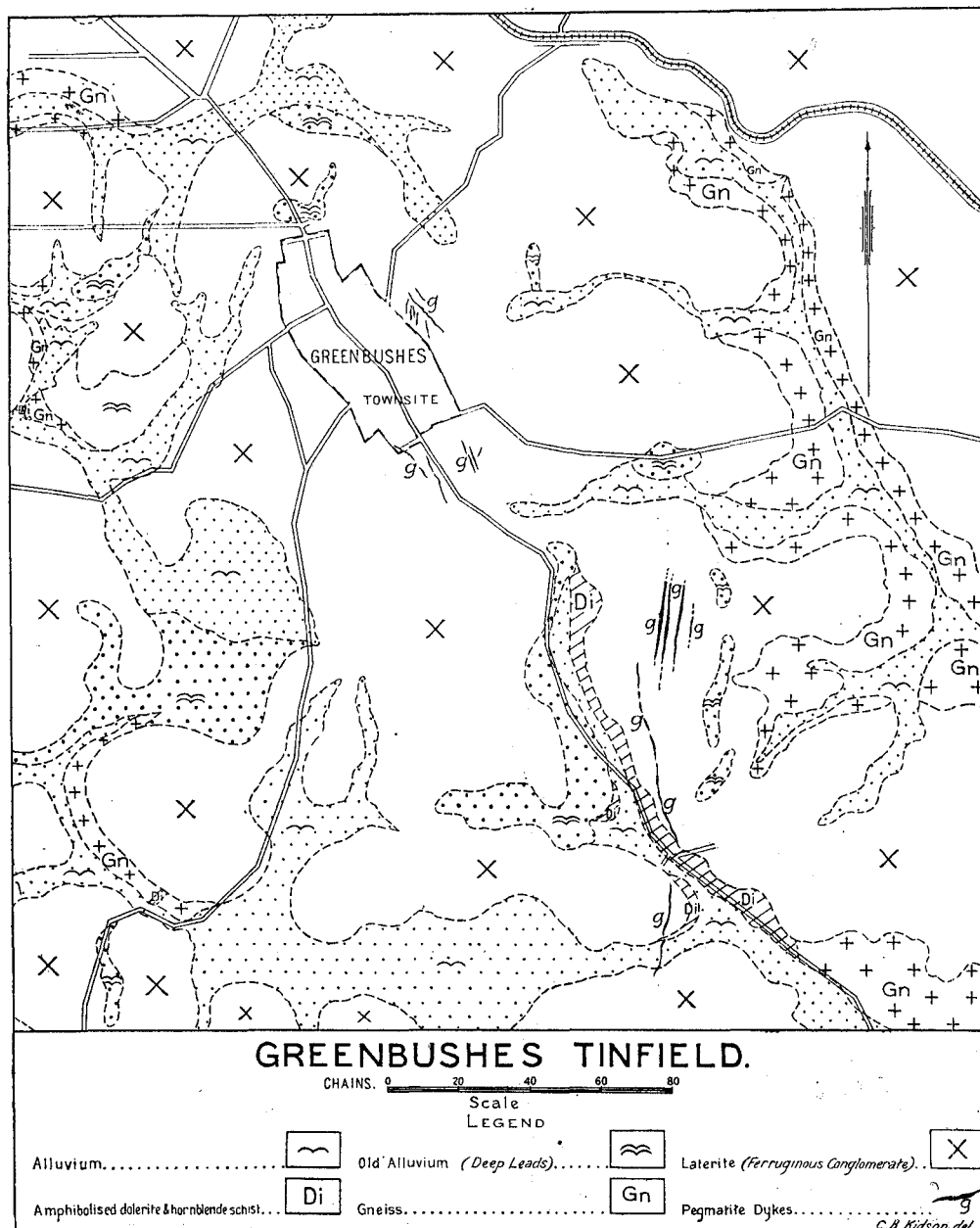
The principal primary tin deposits of Greenbushes are all situated along what may be called a mineralised zone or belt, which has a general trend of north-west and south-east, and a width of about a mile and a-half.

arranged in the relative order of frequency, viz.:—ilmenite, zircon, rutile, magnetite, staurolite, gahnite, tantalite, stibiotantalite, kyan-

ite, and occasionally native tin. These minerals are present in quantities varying from traces up to about 40 per cent., in what may be called first grade and 80 per cent. in second grade concentrates.

A sample (698) from Spring Gully containing 66.74 per cent. of metallic tin contained the following relative quantities of the minerals—cassiterite, 4; zircon, 2; quartz, 1; gahnite, 1; and of tantalite, 2.

Fig. D.



The "lodes" (pegmatites, etc.) occurring in this belt have also, when viewed broadly, a more or less definite bearing, which varies somewhat for each locality, though there are "counter lodes," the trend of which does not coincide with that of the normal ore bodies.

This mineral belt in reality represents a line or lines of weakness formed during periods of earth movement, which determined the direction of the fissures up which the pegmatite and allied tin-bearing dykes were forced to what is now the surface.

In addition to the pegmatites, etc., tin is also found occurring in a highly foliated and micaceous form of the granite (greisen), which generally consists of pale green muscovite, quartz, and feldspar, with topaz, tourmaline, zircon, garnet, etc., in addition to coarse tin as accessory constituents. In depth, one of these has been found

passing into a compact banded rock, made up of albite, with quartz, tourmaline, topaz and tin ore. Bulk samples of foliated ore of this type gave assays of 1.79, 0.55, 3.46 and 1.09 per cent. of tin, and a similar lode on the Enterprise Mine yielded a fair quantity of tantalite.

The primary deposits have been opened up to some slight extent, though on the whole they do not appear to be very rich in tin; they, however, owe their origin to deep-seated causes and are likely to be as permanent as anything in the nature of such ever can be.

The future of Greenbushes, after the exhaustion of the superficial deposits, will depend upon the successful exploitation of the primary ore deposits, and that can only be brought about by judicious expenditure on a proper system of scientific mining.

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of

Western Australia

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A. Gibb Maitland.

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PART III.—Section 6.—TUNGSTEN.

GENERAL STATEMENT.

The two principal ores of tungsten, scheelite and wolfram, have been recorded as occurring in several widely separated localities in Western Australia, but have only been worked at a few places.

Scheelite is constantly met with in gold veins, as well as in the associated alluvial deposits. Little or no attempt has been made, however, to save the tungsten minerals, and up to the present time only relatively small parcels of concentrates have been marketed. These include 238·64 tons of wolfram ore from Callie Soak, on the Murchison, 27 tons of the same mineral from Federal Downs station in West Kimberley, and small quantities from Mount Singleton on the Yalgoo Field, in addition to some parcels of scheelite from Melville, Ora Banda, and Ravensthorpe.

So far as can be ascertained from the official statistics, it appears that up to the end of 1918, 12 tons of scheelite, valued at £1,340, have been exported from the State, whilst up to the same date there have been reported to the Mines Department 10·53 tons of wolfram, valued at £1,295, which represents the total production of Western Australia.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

WEST KIMBERLEY.—Tungsten ores have been worked near Federal Downs in West Kimberley, during the years 1909 and 1910, during which period 27 tons of wolfram were raised and exported.

The ore occurs in compact quartz veins which are in all probability acid pegmatites. The veins are small more or less elongated lenses, occurring in a belt of considerable horizontal extent, and with a maximum width of from 20 to 50 feet. The wolfram is associated with tin ore; a sample of concentrates assayed in the Survey Laboratory gave 18·69 per cent. of tin and 32·46 of tungstic oxide.

PILBARA.—Scheelite has been met with in a gold-bearing quartz reef on the Ard Patrick mine (G.M.L. 143) at Mosquito Creek, a mining centre about 24 miles due east of Nullagine, upon the headwaters of the Nullagine River. The district is made up of schist associated with sedimentary rocks, which everywhere form the matrices of the auriferous quartz reefs. The Ard Patrick reef which strikes generally north-east and south-west, with an underlay to the north-west of about 65 to 70 degrees, has been opened out by a vertical shaft 260 feet in depth. The reef, which is of quartz, carries a little pyrites and is stained with oxide of iron, varies in thickness from 6 to 36 inches; it often contains a considerable quantity of scheelite, usually in close association with the gold. The scheelite has been found to be of most frequent occurrence near the western end of the lease. Two samples assayed in the Geological Survey Laboratory gave the following results:—50·93 and 45·01 per cent. of tungstic acid; with, in the latter, 1dwt. 15grs. of gold per ton. In both these samples the comparatively low percentage of tungstic acid is due to the admixture of a good deal of quartz with the scheelite, which could be readily saved by concentration.

WEST PILBARA.—At Black Gin Point, near Station Peak in West Pilbara, a copper lode containing ores of tungsten has been worked to a limited extent. The ore occurs partly as wolfram but mainly as scheelite. An assay of a sample of this ore, made in the Geological Survey Laboratory, gave a return of:—tungstic oxide 61·73, and copper 1·97 per cent.; together with 14dwts. 4grs. of silver and 1dwt. 8grs. of gold per ton.

MURCHISON.—Wolfram and scheelite occur at Callie Soak about 25 miles north-west of Cue. The staple rock in the district

is granite, which is often porphyritic and traversed by pegmatite and quartz veins. Some of these veins, occurring near the summit of a bold bare porphyritic granite, have been worked for their wolfram contents. The wolfram, with which a little scheelite and molybdenite is associated, occurs as bunches in these quartz and pegmatite veins.

A sample of ore from this locality gave, on partial analysis in the Geological Survey Laboratory, the following results:—

Tungsten Trioxide WO_3	65·09 per cent.
Ferrous Oxide, FeO	10·10 "
Manganous Oxide, MnO	3·07 "

Another sample of the ore from Callie Soak, submitted to the Department under the Public Assay Regulations, consisted of an admixture of molybdenite and scheelite together with some wolfram in a matrix of quartz, mica, and kaolin. An assay of the ore showed it to contain 2·02 per cent. of molybdenite and 9·07 per cent. of tungstic oxide. The approximate mineral composition of the ore was determined as being in parts per hundred as follows:—Scheelite 10, wolfram 1·5, molybdenite 2, and gangue 86·5.

The mining centre of Callie Soak has returned, up to the end of 1918, 8·41 tons of wolfram, valued at £1,148, of which 6·11 tons, valued at £877, was raised from a lease, The Socialist, M.L. 11, which lies about two and a half miles to the westward of Callie Soak. It may in this connection be noted that in Table XXI, page 75 of the Mining Statistics for the year 1917, the above quantity of 6·11 tons is credited to the mining centre of Cuddingwarra in lieu of Callie Soak.

YANDANHOO.—Some small wolfram lodes have been worked in the vicinity of Yandanhoo Hill, which lies to the south of Mount Singleton (Ninghan) on the Yalgoo Goldfield. The tungsten deposits lie adjacent to the series of sedimentary rocks (grits, andalusite slates, etc.) associated with the auriferous conglomerates of Bonnie Venture; these sedimentary rocks are invaded by granite and acid dykes. The tungsten ore (wolfram) occurs in scattered and irregular patches, principally in quartz veins, though occasionally in the adjacent more or less decomposed country rock. The thickness of these tungsten-bearing quartz veins varies from about an inch up to one foot or eighteen inches in thickness. None of the wolfram-bearing quartz reefs have been opened up to any extent, and it is at present impossible to even approximately estimate the ore contents of any of them.

On the property known as the Wolfram King Mine, M.L. 43, two tunnels have been driven in a northerly direction, along the course of a wolfram quartz vein, which in some places attained a thickness of about twelve inches. The lower tunnel has been connected by a rise, with the upper one, 45 feet above it at a point about 33 feet from the mouth; both tunnels have been carried in for a horizontal distance of somewhere about 100 feet. Official assays show the wolfram to be of very high grade, and to be quite free from all deleterious associates.

On the Yandanhoo King, M.L. 31, at an altitude of about 80 to 90 feet above the level of the mouth of the wolfram lode, on M.L. 36, is a wolfram-bearing quartz reef 6 inches thick, and which has been opened out for a length of 35 feet. Another parallel wolfram-bearing quartz reef, about 3 or 4 inches in thickness occurs about 30 feet to the south of this. A very small quantity of ore has been raised from these two veins.

Some little distance to the north-east of the Wolfram King there are a series of irregular veins of quartz, carrying wolfram of the type common to the district; these are situated on what is known as the Wolfram Queen mine, M.L. 44; not much effective work had been done upon them, however. In 1915 a small parcel of a little over 4 cwt. of wolfram from near Mount Singleton assayed in the Geological Survey Laboratory, gave 51·75 per cent. of tungstic acid.

The wolfram-bearing quartz veins of the Yandanhoo neighbourhood are genetically connected with that large mass of granite lying to the south and east, and which penetrates the rocks in the vicinity.

YALGOO.—Scheelite occurs in association with bismuth ores near Yalgoo.

Some concentrates from the Santa Claus Mine, M.L. 29, assayed in the Geological Survey Laboratory; bismuth 61.6; lead 2.2; and tungstic oxide 7.8 parts per hundred. The minerals present in the concentrates consisted of bismuth (bismuth oxide), bismutite (hydrated bismuth carbonate), a little wulfenite (lead molybdate), scheelite (tungstate of lime), turgite (hydrated oxide of iron) and a very little quartz. Other samples from the same locality assayed (a) bismuth 44.94, tungstic oxide 19.29 per cent.; and (b) bismuth 69.30, tungstic oxide 4.34 per cent.

A sample of scheelite from Melville, near Yalgoo, gave on assay in the Geological Survey Laboratory 72.14 per cent. of tungstic acid; but no particulars are available as to the nature of the deposit, or the mode of occurrence of the mineral.

COMET VALE.—Scheelite has been found occurring in association with the gold ores at Comet Vale, a mining centre in the North Coolgardie Goldfield. Accumulated parcels of ore from this mining centre are* awaiting treatment at the State plant at Coolgardie.

Scheelite has been found in the Old Bayley Reef to the north-north-west of the main shaft of the Sand Prince mine.

The quartz reefs occurring on the Lake View lease, G.M.L. 5410Z, contain quantities of scheelite; at a depth of 40 feet below the surface a good body of scheelite, 3 feet in thickness, was met with. The scheelite has been met with in two totally distinct rocks on the Lake View lease, viz., a coarse-grained actinolite rock and a white granitic rock, of which there are several occurring in a narrow belt trending north-west and south-east. The mineral is also known in the adjoining lease on the east, the Lake View Extended, G.M.L. 4739E, as well as P.A. 952Z on the west, formerly known as the Comet, G.M.L. 4650Z.

A sample of scheelite ore, from the Lake View Extended, assayed in the Geological Survey Laboratory, 1.78 per cent. of tungsten trioxide and 7dwts. 10grs. of gold per ton.

Tungsten ores have a fairly wide distribution in the Yilgarn Goldfield.

SOUTHERN CROSS.—The Frazer's lode at Southern Cross contains, in addition to the gold, scheelite in quantities which may become of industrial importance. The lode is of considerable length and often attains a width of 50 feet; it outcrops at intervals in the form of lenses, enclosed in a shear zone of amphibolite and its derivatives. The ore body itself is made up of a number of more or less overlapping lenses of white quartz and is often intersected by dykes of pegmatite granite. The ore body contains massive scheelite in pieces several pounds in weight as well as veins of varying dimensions. The scheelite is often in association with the ore which is richest in gold. A lens-shaped mass of scheelite, about 5 feet in width, was met with on the footwall of the lode in No. 5 stope at the 365 feet level; whilst higher up in the zone of oxidation, boulders of scheelite occurred in the centre of the lode, in association with ore carrying about 30dwts of gold per ton.

WESTONIA.—The gold-bearing pegmatites of the Edna May group of mines, contain both scheelite and wolfram, the former at times being in considerable abundance. Masses of scheelite, several inches in diameter, have been met with in a coarsely crystallised pegmatite vein, at a depth of 550 feet below the surface; the mineral, which is a primary constituent of the rock, encloses grains of biotite and wolfram.

*April, 1919.

Wolfram in crystalline masses up to two pounds in weight occurs in association with quartz and pyrites in some of the pegmatite dykes. If occurring in sufficient quantity, these tungsten ores might be worth concentrating.

COOLGARDIE.—The gold-bearing deposits of Lindsay's mine at Coolgardie contained masses of scheelite carrying fairly coarse gold. The mineral also occurred in the alluvial and detrital sand of which Fly Flat was made up. It does not appear, however, that the scheelite appeared in sufficient quantity to be of economic importance; its chief value lay in its being indicative of the occurrence of the mineral in quartz reefs, stringers, etc., in the vicinity.

HIGGINSVILLE.—Scheelite occurs as fairly large masses in considerable quantity at Higginsville, a mining centre near the southern boundary of the Coolgardie Goldfield, about 20 miles south of Widgiemooltha. In the Sons of Erin Mine, G.M.L. 4184, at Higginsville, where the ore chiefly occurs, there are veins of quartz traversing the scheelite, which indicates a later date of deposition. There is no record of the actual quantity of scheelite raised from this deposit, which has also produced, up to the end of 1918, 15,334.25 ozs. of gold from 21,782.04 tons of ore.

NORSEMAN.—Some fairly high-grade scheelite has been met with in the Norseman area, but there is no record of any quantity of ore having been raised. The mineral has been found in association with the gold-bearing quartz reefs of Norseman, but only in those localities which are traversed by those acid dykes which form the apophyses of the large granite batholith, to the east of the main mineral belt. On the Hill End Mine, G.M.L. 1215, the ore body contains scheelite; a sample of the reef assayed in the Geological Survey Laboratory was found to contain 67.95 per cent. of the mineral, equal to 54.72 per cent. of tungstic acid. The tungsten-bearing quartz reef lies immediately to the south of the Valkyrie Consolidated mine, G.M.L. 1016 (late 936), where there is a large development of acidic dykes (Fig. 7, Bulletin 21). The tungsten-bearing quartz reef is probably one of those east and west veins (the Ophir) which lie to the south of the Valkyrie. Further to the north and about one mile south-west from Trig. Hill B. 23 is another scheelite-bearing auriferous quartz reef, also associated with the belt of acidic dykes. Up to the present, however, it has not been a producer of tungsten ores on a commercial scale.

PHILLIPS RIVER.—An auriferous deposit carrying scheelite occurs at what is known as Dallinson's Reward mine, situated about 10 miles west of Kundip, on the Phillips River Goldfield. Nothing, however, is known of the nature or mode of occurrence of the deposits. A small trial parcel treated at the Floater Battery gave a return of 5ozs. 6dwts. of gold and 22 cwt. of concentrates, which on being assayed yielded 66.2 per cent. of tungstic acid; another parcel crushed at the Gilbert Battery was concentrated after the gold had been extracted and 17 bags of scheelite obtained, which assayed 75 per cent. of tungstic acid. There is no official record of the actual quantity of scheelite obtained from this locality.

BROOKTON.—At Brookton, 118 miles from Perth, a wolfram-bearing deposit occurs on Loc. 5868, five official assays from which gave from 21.19 to 64.72 per cent. of tungstic acid. The ore consisted of an admixture of quartz and wolfram which occurred in a lode, probably an acid dyke, trending north-east and underlying at a high angle to the east. Practically no work has been done upon the deposit and no ore has been raised.

GRASS VALLEY.—Wolfram has been met with on Loc. 2809, situated about three miles due north of Grass Valley, 76 miles from Perth on the Great Eastern Railway. The country rock in the vicinity consists of granite intersected by dolerite dykes. Numerous fragments of wolfram have been picked up on the slope of a hill; one of the fragments had a piece of granitic matrix adhering.

Rutile :
Felspar Deposits.

By

A. Gibb Maitland.

Extract from
The Mining Handbook.

Geol. Surv. Memoir No. 1.
Chapter II, Economic Geology.
1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

Rutile: Felspar Deposits

By
A. Gibb Maitland.

Part II.—Section 7.—RUTILE.

GENERAL STATEMENT.

Rutile, oxide of titanium, is about the only one of the titanium-bearing minerals that has been employed in the arts as a source of titanium, its chief value being its use in the production of titanium-iron alloys.

GEOGRAPHICAL DISTRIBUTION.

Rutile has a fairly wide distribution in the older crystalline rocks of the State. The only locality where the mineral in other than a minute accessory constituent of the rocks occurs is at Yulgering, in the Avon District, about 40 miles north of Toodyay, though not in sufficient quantity to be of economic importance. The country rock in the vicinity of Yulgering consists of granite, associated with hornblende and other gneisses, invaded by dykes of pegmatite and basic rocks. The rutile occurs in the detritus forming the bed of the open shallow valley, Yulgering Gully. The detritus consists of quartz and felspar in which angular fragments of rutile, some of which are as much as $1\frac{1}{2}$ inches in length, occur. The mineral is the black ferruginous variety, Nigrine, which, on analysis in the Survey Laboratory, was found to contain 94.97 per cent. of titanium oxide, indicating a high grade ore. No lode has

been noticed in the neighbourhood, though there are good grounds for believing the source of the rutile to be the pegmatite dykes which occur in the neighbourhood. One of the vughs, about half an inch in length, occurring in the Yulgering granite, was found to contain goethite, which probably resulted from the oxidation of iron pyrites.

Rutile is widely distributed in the form of minute grains and crystals in the rocks of the Kalgoorlie Goldfield; it appears, however, to be far more common in the altered diabases than in the lodes themselves; in the latter the titaniferous mineral being either ilmenite or leucoxene.

At Meekatharra, on the Murchison Goldfield, rutile is of common occurrence microscopically as an alteration product of ilmenite in many of the metasomatic rocks of the gold-bearing area. A highly micaceous schist in the Queen of the Hills Gold Mine carries as much as 2.5 per cent. of rutile.

Rutile is a fairly common constituent in some of the tin wash at Greenbushes. It is also met with in the sillimanite-gneiss at Westonia, on the Yilgarn Goldfield, and also in a granular form in the chromiferous kaolinite of the Edna May Central Gold Mine.

Rutile has also been found at Balbarrup and Karridale, in the South-West Division, but nothing is known as to its mode of occurrence.

The Gold Deposits

of

Western Australia.

by

A. Gibb Maitland.

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Plate III.—A Map of Western Australia, showing the four miles to the inch series of Geological Sketch Maps and other Geological Maps issued since 1896.

Extract from

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THE MINING HANDBOOK OF WESTERN AUSTRALIA.

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The Gold Deposits of Western Australia.

By
A. Gibb Maitland.

PART III.—Section 1.—GOLD.

(With two Maps, Plates II. and III.)

GENERAL STATEMENT.

The gold-bearing deposits of Western Australia have been responsible, up to the end of December, 1918, for the production of 32,306,483.29 ozs. of fine gold, valued at £137,611,513, which figures include the whole of the gold entered for export from the time of the first discovery in 1886, and also that treated at the Perth Mint from its opening in 1899, which has either been exported or used for local purposes.

The figures in the table below set out the quantity of gold from the respective goldfields as reported to the Department of Mines. The discrepancy between the Customs, Mint, and Mines Department figures may, in part, be accounted for by the difficulty experienced in obtaining a record of the alluvial gold, and also by the fact that a good deal of the gold won in the early days was never officially reported to the Department.

Since the first finds were made, the gold yield of the State increased very rapidly; in 1886 an output of 270 ozs. followed the discovery of the Kimberley Goldfield. The gold production gradually increased since that date until the year 1903, when it reached 2,064,801 ozs.; from that time, however, the yield has steadily declined to 876,511 ozs. in 1918.

The alluvial and residual gold won in Western Australia has been, so far as is disclosed by official figures, up to the close of 1918, 274,869 fine ozs.; the yield reached its zenith in 1898, when 668,492 fine ozs. were recorded, whilst in 1918 it only totalled 1,035 fine ozs. Unfortunately, however, the alluvial and residual deposits will in time become exhausted, though it is quite possible that fresh discoveries may be made, and in this way add materially to the gold yield from other sources.

The goldfields are numerous and scattered over a wide stretch of country. Most of them produce other metals besides gold, though in nearly all cases that is by far the most important product.

The total area of the proclaimed goldfields amounts to 329,828 square miles out of the 975,920 which embrace the whole extent of the State. The positions of these goldfields, as legally defined by the authorities, have been shown on the maps of Western Australia which form Plates I., II., and III. The legal boundaries of the goldfields, however, as may be seen by the geological sketch map of the State, Chapter I, bear no relation whatever to the geological boundaries. The map which forms Plate II. shows the location of the principal areas in Western Australia from which gold has been mined.

The southwest corner of the State, from Israelite Bay to Cape Leeuwin, and as far north as latitude 25° S., is a more or less broken tableland from which rise isolated hills and ridges of metamorphic and crystalline rocks, to which a Proterozoic and Archeozoic (Pre-Cambrian) Age has been provisionally assigned. This plateau forms the chief gold-bearing region of Western Australia. Isolated patches of variable extent of these ancient crystalline rocks rise from beneath the newer overlying strata in the North-West and Kimberley Divisions, and are, from the point of view of their mineral occurrences, quite as important, despite their relatively small area, as those in the southwestern portion. Erosion has worn-down the plateau to a considerable extent to an almost level plain, and for this reason what now remain of the gold-bearing deposits represent the lower or deep-seated portions thereof; or, in other words, the

roots. Whilst this is undoubtedly the case there are no scientific reasons for believing that the ore-bodies of the State have, even at the greatest depth yet attained (over 3,470 feet), by any means reached the limits of ore deposition, or that the lodes will not prove productive in depth.

Geologically the Pre-Cambrian Plateau, as shown in Chapter I. under the heading of Archeozoic and Proterozoic, is characterised by a more or less complicated structure; it forms one general geological province in which the nature and mode of occurrence of the gold-bearing deposits are, when viewed broadly, more or less identical throughout.

The interdependence of the gold-bearing areas on the geological structure is exceptionally well marked in all parts of the Pre-Cambrian areas of the State.

The rocks of the plateau are of very different types; many of them are in a crystalline condition and form coarse crystalline schists and gneiss as well as basic rocks, which have been more less crushed, foliated, and completely converted into greenstone schists. The basic rocks can be seen in some localities to gradually pass into hornblende schists and allied rocks. Some of the older rocks of the gold-bearing regions are obviously of undoubted sedimentary origin, and are practically unaltered; others are quartz and mica schists; in certain localities there are cleaved conglomerates. Some of these Pre-Cambrian conglomerates contain vein quartz, the occurrence of which points to the existence of still more ancient gold-bearing reefs. The relatively less altered members of these ancient sediments consist of a great variety of types of indurated slates, quartzites, and conglomerates, together with igneous rocks which probably represent lavas and ashes. The rocks of the gold-bearing plateau have been invaded by batholiths and veins of granite and allied rocks which in many parts of the State occupy very large areas. Much of the granite has been rendered more or less gneissoid as the result of deformation and recrystallisation. The granite is traversed by dykes of basic and acidic rocks of later date. The granite rocks are also traversed by many large ice-like quartz reefs which sometimes rise like walls to considerable altitudes above the surface. For dyke rocks of this type, *i.e.*, those made up of pure or almost pure silica, the term *silexite* has been suggested. The mode of occurrence, etc., of these large quartz masses, which are sometimes mineral bearing, point to their being of igneous origin and representing the final product of the differentiation of a granite magma—its ultra-acid portion. These pegmatitic or highly acid off-shoots do not in all cases come from the granite direct; but probably emanate from what may be called its mother magma lying at considerable depths below the surface. A quartz vein of this character may be seen cutting across an auriferous quartz reef in one of the mines of the Peak Hill Goldfield, and an analogous instance is to be seen in the Nellie May mine at Norseman on the Dundas Field. These granitic rocks are of considerable importance by reason of the fact that they form the matrices of the tin and allied deposits of Western Australia.

The geological formations in which the gold deposits of the State occur are amongst the most ancient in Western Australia, and possibly among the oldest of all the formations of the Australian Continent.

The gold-bearing deposits of Western Australia occur in areas generally as more or less parallel belts of relatively narrow lateral dimensions, though in certain localities they occur as small isolated areas or patches. These narrow, well-defined belts have a general northwest and southeast direction with occasional divergencies of several degrees on either side.

This characteristic zonal arrangement attracted the attention of the earliest geological observers, Messrs. Woodward and Göczel, and found expression in their maps and reports. Much more detailed investigation, and with much better maps than were then available, has enabled considerable additions to be made to our knowledge of the structure of these belts.

The zonal arrangement of the major portion of the gold-bearing deposits, the belts of which have an almost identical trend, coincide with that of the main structural features (tectonic lines) which make up the fundamental complex of the plateau of the interior. The individual gold deposits in these belts or zones, owing to the results of dynamo-metamorphic processes, do not outcrop in long lines but are cut up into relatively short lenticles arranged more or less *en echelon*.

The general trend of the gold deposits bears an intimate relationship to the dominant structural features of the enclosing rocks, which result from the action of compressive forces operating over very wide areas. The auriferous ores are to be found in elongated belts in shatter zones, cleavage planes, joints, faults, and thrust planes occurring along lines of crushing, brecciation, and shearing. These major structural features constitute the controlling feature which governs the general distribution of the gold deposits, whilst minor deformation, such as results from a buckling, etc., of the schistose rocks, in a large measure determines the localisation of many important ore-bodies. The search, therefore, for gold deposits should invariably be made in the direction of the longer axes of the dominant structural features of the rocks; these have been shown to have in Western Australia a general northwesterly trend.

The occurrence of quartz veins, which coincide with the general strike of the foliation, or other planes (?) of the schists, etc., and in fissured zones of metamorphic sedimentary rocks, does not in any way indicate the absence of fissure veins or point to a want of permanency in depth, for the schist belts are, from their mode of origin, likely to be continuous in depth.

Wherever the auriferous deposits have been examined it has been invariably found that granite or rocks allied thereto are of frequent occurrence, either immediately contiguous to the ore-bodies or sufficiently near to have exercised some influence on the genesis of the gold; in some fields the auriferous veins are closely associated with, and appear to pass gradually into, pegmatite dykes or rocks of a similar character. The association of acid intrusives and the gold deposits along the above-mentioned zones are merely expressions of related phenomena, both structural and genetic.

Gold has been found in Western Australia to occur under several different conditions, viz.:—

1. Free gold,
2. Compounds with tellurium and other elements, and
3. Intimate intergrowths with other minerals.

Free gold has been recognised in several different varieties, the names by which they are known being generally descriptive of their outward appearance—thus, crystalline gold, dendritic gold, rough gold, flake gold, mustard gold, and sponge gold.

Compounds of gold with tellurium and other elements occur at Kalgoorlie (Boulder) and other centres, but the latter have not so far been of much importance, being chiefly bismuthic compounds. Tellurides of gold, however, are of more importance and occur at Kalgoorlie, Ora Banda, and Mulgabbie, and at the former place—Boulder—more freely and in larger masses than in other known occurrences. The most frequently occurring mineral is calaverite, whilst petzite, sylvanite, krennerite, and nagyagite are also met with in varying quantities. All the gold ores, more especially the tellurides, contain more or less silver, which, however, is only a by-product.

Of the metallic minerals which are found to accompany gold in Western Australia by far the most important is iron pyrites, which, with its concomitant oxides of iron, is found in every ore-body from Kimberley to Dundas. Not only does this mineral occur in close con-

junction with free gold, but in many instances—such as at Red Hill (Coolgardie Goldfield)—is itself found to carry a considerable amount of gold imperceptible to the naked eye. As a rule the pyrites does not constitute more than four or five per cent. of the gangue, but at some mines in Menzies and Mt. Ida, amongst other places, it forms one-half or more of the latter.

Next in order of importance after pyrites is galena; it occurs in the gold reefs of Hall's Creek, Brockman's, and all the other Kimberley centres; but it is found that the richer the stone in galena the poorer the gold. Galena also occurs in conjunction with gold at Tambourah and Horse-Shoe. Vanadinite has been detected with gold at Coolgardie and Pinyalling. Arsenopyrite accompanies gold at Ruby Creek, Niagara, Coolgardie, Youanme, and Randells. Some beautiful specimens of arsenopyrite have been found in the Bayley's United Mine at Coolgardie; they consisted of veined arsenopyrite traversed in every direction by a network of veins of gold varying in width from one-twentieth of an inch down to a microscopic thickness. Zinc blende is an indication of rich ore at Yandicoogina, Coolgardie, and Lawlers; in each instance, however, it forms only a very small proportion of the total gangue. Native bismuth and bismutite are found in auriferous quartz at Burbanks, Dundas, Yalgoo, and Lawlers. At Burbanks the native bismuth is alloyed with gold to the extent of about one per cent. The bismuth at Lawlers is also in all probability alloyed with gold, since the surrounding scales of bismutite are thick with fine scales of native gold. Pyrrhotite occurs in the quartz reefs of Southern Cross, Westonia, Ora Banda, Menzies, Coolgardie, and Burbanks; in no instance, however, has it proved to be nickeliferous. Chalcopyrites and copper carbonates occur in association with gold at Phillips River, Coolgardie, Sir Samuel, Tambourah, Hall's Creek, Gorge Creek, and many of the Murchison and other centres. Bourbonite is said to accompany gold at Wiluna, at which centre the most characteristic mineral associated with the gold is stibnite. Native copper is reported from Coolgardie, Mt. Sir Samuel, and Rockbourne. Crocoite (chromate of lead) occurs associated with gold at Comet Vale, Ora Banda, etc. Scheelite occurs in auriferous reefs at Westonia, Southern Cross, Higginsville, Comet Vale, and at Mosquito Creek. Of the earthy secondary minerals which accompany gold in Western Australia, quartz is the most important here as elsewhere. Gold occurs in veins of calcite, more or less magnesian, at Mary River, Panton River, Kalgoorlie, Kanowna, and Red Hill. Chalcedony occurs in many quartz veins and is characteristic of the better ore at Donnybrook. Gold has been found in gypsum at the Island, Lake Austin, and is of frequent occurrence at water level at Kalgoorlie. Of the earthy minerals of the lode formations the most important is sericite. Actinolite, chlorite, and other minerals derived from the enclosing rock mass are found in many quartz reefs, but there seem reasons for believing them to owe their origin to agencies other than those which caused the deposition of the gold, and for that reason are of little interest.

When viewed in the light of their geological relationships, the gold-bearing deposits of Western Australia are divisible into three distinct classes, viz.:—

- (a) Veins, lodes, stockworks, dykes, lode formations, etc.,
- (b) Alluvial deposits, and
- (c) Residual deposits.

Group (a), which includes the shallow impregnations of surface material and all those other deposits in which the gold concentration has been subsequent to the formation of the enclosing rock. They are of chief importance, having been responsible for 30,794,486 ozs. of the State's total gold production up to the end of 1918.

The gold deposits of Western Australia occurring in group (a) may, according to the mineral present, be divided into the following six classes, viz.:—

1. *Pyrites-gold-quartz type*, in which iron pyrites is the principal sulphide.
2. *Arsenopyrite-gold-quartz type*, containing a preponderance of arsenical pyrites.

3. *Antimony-gold-quartz type*, in which stibnite, antimony sulphide, is the preponderating sulphide.
4. *Chalcopyrite-gold-quartz type*, in which copper pyrites and its derivatives form the principal sulphide.
5. *Gold-telluride veins*, which are characterised by the presence of tellurides of gold and silver.
6. *Calcite-gold type*, in which calcite is the principal gangue mineral.

On the other hand the gold deposits of group (a) may be broadly classified, according to their shape or form, into the following:—

- I. *Simple or fissure veins*, in which the quartz or ore usually extends for considerable distances both vertically and horizontally, and are often bounded by smooth striated walls.
- II. *Composite veins or lodes*, which are made up of a number of more or less parallel lenticular veins, disposed over a considerable width, and separated by country rock or its alteration products.
- III. *Sheeted zones, i.e.*, a series of closely spaced and parallel veins, generally of small dimensions.
- IV. *Stockwork*, an irregular network of small quartz veins.
- V. *Shear zones, i.e.*, bands of schistose rocks, impregnated with various sulphides, iron pyrites often predominating, and containing little or no quartz.

So far as any observations have yet been made in Western Australia, it has been found impossible to adopt a classification of the gold-bearing deposits based on geological age, despite the fact that there has possibly been gold deposition at different periods.

In addition to the gold derived from quartz reefs, lode formations, etc., the conglomerates at the base of the Nullagine System have been mined in two localities, Nullagine and Just-in-Time, on the Pilbara Goldfield. The auriferous bands occur throughout a thickness of 300 feet of grits, sandstones, and conglomerates, which form the lower portion of the rock series. Those portions of the strata which have proved to be gold-bearing are those largely impregnated with oxides and sulphides of iron. Mining operations have up to the present been confined exclusively to the oxidised zone and over limited and shallow depths.

Gold-bearing conglomerates have been worked near Yandanhoo Hill, on the Yalgoo Goldfield, to the south of Ninghan (Mt. Singleton). These, which are interbedded with an ancient series of folded andalusite-slates, grits, and conglomerates, bear a marked lithological resemblance to those occurring in certain of the goldfields of South Africa.

The deposits included under groups (b) and (c) are of less importance, and from their derivation and mode of origin, in most cases the result of decomposition of gold-bearing rocks *in situ*, are of less permanence.

The alluvial deposits (b) consist of beds of gold-bearing sand and gravel, both ancient and modern, in addition to other detrital deposits, soil and decomposed rock which has been transported by rain wash and the action of gravity from higher levels.

These deposits naturally bear an intimate relation to the veins, lodes, etc. The valleys of the more important watercourses, trending generally with or across the gold-bearing zones, are, as is the case at Kanowna and Kunanalling, filled with water-worn gravel which is sometimes cemented into solid rock and overlain by sands, clays, ironstone, gravel, etc. The gold is not exclusively in the form of grains, scales, etc., but is found occurring in the quartz pebbles themselves.

The residual deposits of group (c) form a fairly important source of gold in the alluvial and more or less related residual formations. The residual deposits are made up in part of rocks, some of which contain quartz veins and stringers, which are more or less decomposed *in situ*, and in part of laterite. The gold in the residual deposits has been concentrated by the removal of some of

the constituents of the rocks in which it is contained, in this way leaving the gold in greater quantity than was contained in the parent rock. Gold released in this way tends, owing to its high specific gravity, to find its way into fissures and cracks as well as to settle down into the more or less cellular and porous mass of decomposed rock.

In addition to the undoubted residual (or detrital) gold, there is another massive, arborescent, or coarsely crystalline form which occurs filling certain irregular cracks or covering cleavage planes, etc., so as to represent the appearance of painted surfaces. The mode of occurrence, associations, and character of this gold all point to a secondary origin; this secondary gold has been deposited from solution not only in some cases in the alluvium and other superficial and residual deposits, but also in the zone of decomposition of the bed rock.

The gold production from these two sources—largely the result of the operations of dryblowers—is a somewhat ephemeral quantity. The total quantity of gold produced from these alluvial and residual deposits is, so far as can be ascertained from official statistics, up to the end of 1918, 274,869 ozs. There are some reasons for believing this to be considerably under the actual quantity of gold produced, for a good deal of the gold won in the early days was never officially reported.

What may be called the surface gold ores are of relatively high grade and as a whole present few if any difficulties in regard to treatment.

Many of the mines in the State have produced large quantities of gold, the details of which are to be found set out in the volumes of mining statistics published annually by the Department of Mines. Over 54 per cent. of the total gold production of the State has been obtained from the East Coolgardie Goldfield, which contains the important mining centre of Kalgoorlie (Boulder).

The deepest gold mines in Western Australia are now more than 3,470 feet below the surface and show little diminution in the size of the lodes.

The following table, which has been compiled from the available official figures, is the nearest possible approach to a statement of the total gold production from the different classes of deposits on each of the separate goldfields of the State.

Table showing the Total Yield of the Two Types of Gold-bearing Deposits occurring in Western Australia up to the end of 1918.

Goldfield.	Alluvial Gold.	Ore Treated.	Gold therefrom.	Total Gold.
	fine ozs.	tons (2,240lbs.)	fine ozs.	fine ozs.
Kimberley ...	3,742.37	17,597.50	14,127.25	17,869.62
Pilbara ...	18,103.77	110,933.92	183,164.83	201,268.60
West Pilbara ...	5,650.50	18,890.71	22,036.27	27,586.83
Ashburton ...	8,667.60	...	315.64	8,883.24
Gaseoyne ...	320.20	356.70	356.34	676.54
Peak Hill ...	1,937.81	484,959.26	249,789.39	251,727.20
East Murchison ...	7,164.53	3,292,720.57	1,715,874.87	1,723,039.40
Murchison ...	15,324.52	4,101,944.26	2,890,943.71	2,906,268.23
Yalgoo ...	1,451.29	172,485.64	115,335.81	116,787.10
Mt. Margaret ...	7,674.30	5,330,790.59	2,812,968.00	2,820,642.30
North Coolgardie... 3 774.58	2,515,362.85	1,938,856.38	1,942,630.96	
Broad Arrow ...	19,175.44	799,296.50	448,679.53	467,854.97
N.E. Coolgardie ...	116,366.64	930,644.64	597,401.15	713,767.79
East Coolgardie ...	53,616.46	26,616,787.78	17,046,531.93	17,100,148.39
Coolgardie ...	9,362.05	1,763,374.71	1,166,597.54	1,175,959.59
Yilgarn ...	89.88	1,959,219.79	906,887.19	906,977.07
Dundas ...	2,027.12	862,933.70	592,795.98	594,823.10
Phillips River ...	472.20	87,773.22	83,469.67	83,941.87
Donnybrook ...	23.24	1,653.30	818.52	841.76
State generally ...	124.89	27.00	7,535.81	7,660.70
Total ...	274,869.45	49,067,732.64	30,794,485.81*	31,069,355.28

* Includes 201,545.55ozs. of dolled gold from different goldfields and mining districts.

The gold ores have a very wide distribution in Western Australia instead of, with certain notable exceptions, being concentrated into very rich deposits; whilst this is so, the results obtained by geological exploration, prospecting, and mining operations indicate that the gold mining industry will be progressive. An increase in the gold production of the State can, however, only take place by the discovery of new finds, or fresh deposits on existing fields, in addition to its being possible to profitably handle ore of a decreasing average grade. The future of gold mining in Western Australia must in a great measure depend upon the exploitation of its low-grade deposits, of which there are very many.

There is a larger area of auriferous country exposed in Western Australia than in any other portion of the Commonwealth, and probably no State can show a greater diversity in geological resources. Since the relations which the gold-bearing deposits (one of the main factors in the State's prosperity) bear to the broader geological features naturally take a prominent place in any account dealing in a comprehensive way with its mineral deposits, the method adopted has been to embody a brief *aperçu* of the salient features of the goldfields into which the auriferous areas of Western Australia have for convenience of administration been divided, followed by a succinct account of the typical gold occurrences in each of the different belts or districts. The information available, however, is in one or two cases more fragmentary than could be wished. It has been found most convenient to adhere to a strictly geographical order in description, beginning with the field at the northern extremity of the State.

GEOGRAPHICAL DISTRIBUTION OF THE DEPOSITS.

KIMBERLEY GOLDFIELD.

The Kimberley Goldfield, the most northerly in the State, and discovered in 1882, is of historical importance, though it has not been a very notable gold producer. The gold belt of Kimberley—a succession of crystalline schists, metamorphic sediments, and allied rocks of remarkable persistence—has been proved to extend from Denham River to Mount Dockrell, also in the Mueller Range, from whence it strikes northwestward along the foot of the King Leopold Range to King Sound. This belt of crystalline rocks, micaceous and talcose schists, gneiss and granite, varies in width from 10 to 30 miles, and has a horizontal extent of at least 120 miles. The crystalline schists have been folded in a northwest and southeast direction, with a secondary folding in a direction approximately at right angles to this.

There are numerous quartz reefs, many of large size and with well defined walls, traversing these rocks generally along the strike, often for considerable distances. In addition there are quartz reefs of distinctly local origin, bearing some relation to the acid dykes which, in certain localities, are fairly numerous.

The quartz reefs contain small quantities of iron and arsenical pyrites, oxides, carbonates, and sulphides of copper, in addition to, in several cases, a large quantity of galena.

The river valleys and flats are, in many parts of Kimberley, covered with extensive deposits of quartz gravel and drift, which owes its origin to the disintegration of the reefs. These alluvial deposits, when prospected, have been found to contain gold, even in some of those cases in which they were at a considerable distance from any known quartz reefs and ladders. The alluvial deposits of the different river systems, which extend over hundreds of miles in length, present favourable conditions for the development of gold dredging as an important industry; with an average rainfall of 21 inches, which the district possesses, the engineering difficulties should not be, by any means, insuperable.

Mining and prospecting operations have been confined, however, to six more or less isolated centres. These, up to the end of 1918, have only produced 17,869.62 ozs. of fine gold, of which 3,742.37 ozs was alluvial gold. There are sound reasons for be-

lieving that a far greater quantity of alluvial gold than this has been obtained from Kimberley, but which was never officially reported. The export and Mint returns, however, show the total gold production of Kimberley to be 28,870.33 fine ozs.

The following table shows the total gold yield of Kimberley so far as such can be ascertained from official data.

Synoptical Table showing the Gold Yield of the various Mining Centres of the Kimberley Goldfield up to the end of 1918.

Mining Centre.	Ore crushed. tons (2,240 lbs.).	Gold therefrom. Fine ozs.
Ruby Creek	12,784.50	9,562.41
The Brockman	3,814.75	3,224.73
Half's Creek	517.55	540.44
The Mary	399.00	210.03
Mount Dockrell	44.00	435.93
The Pantan	37.70	153.71
Total from reefs	17,597.50	14,127.25
Alluvial gold ... ..	...	3,742.37
Total gold ... ..	...	17,869.62

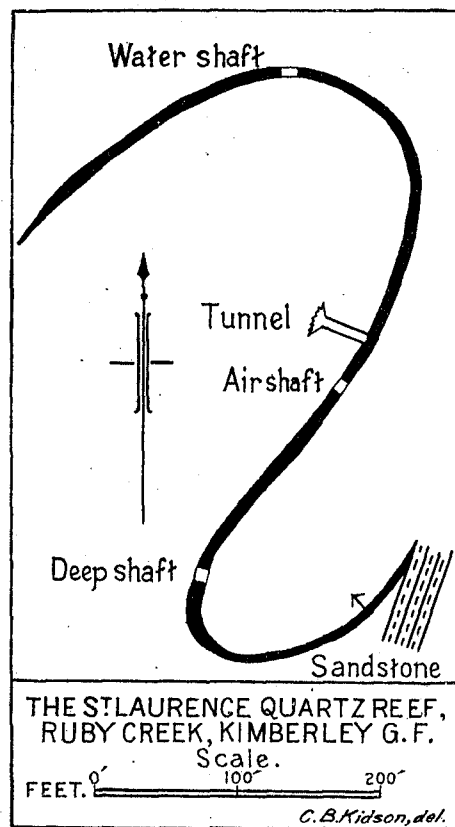


Fig. 1.

Ruby Creek.—The mining centre of Ruby Creek, which has produced the largest quantity of gold from any of the localities in Kimberley, is situated in the vicinity of the divide, which separates the waters flowing into the Ord and Fitzroy Rivers, respectively.

The country rock consists chiefly of slates, schists, quartzites, and allied rocks, standing up in bold parallel ridges with a general northeast and southwest strike; these are traversed by several large quartz reefs which conform in strike to that of the enclosing country rock.

A felsite dyke rises prominently on the crown of a well-marked succession of ranges trending generally north-northeast. The geological situation of this felsite dyke seems to be closely connected with the fracturing of the rock and to have some intimate connection with the gold deposition, for it is often closely associated with the gold-bearing quartz reefs. The quartz reefs are made up of a dull, yellowish-grey cellular and vuggy quartz, which contains varying quantities of black and other oxides of iron as well as casts and occasional crystals of iron pyrites.

The Saint Lawrence quartz reef, which contained some very rich ore, has a remarkably irregular strike, as shown in Fig. 1. The slates, which form the casing of the reef, have also participated in the folding which the reef has undergone. The reef, which is about three feet thick, has been worked to a depth of over 100 feet, vertically, below the surface. The quartz, which is of a dark blue colour, contained very little accessory minerals; it is said to have been richest where it was smallest, especially in the apex of the smaller horse-shoe bend. The fact that the rich shoots of ore are known to occur in intimate connection with the apices of folds in other important quartz reefing districts ought to be borne in mind. The important structural feature of this ore-body is the saddle reef nature of the quartz veins, from which it differs only in the fact that the legs are practically horizontal.

The Ruby Creek Centre is about three miles in length, most of the areas having been taken up in a continuous line.

The Brockman. The Brockman mining centre is situated about 10 miles to the southeastward of Hall's Creek on Butcher's Gully, which is one of the tributaries of the Black Elvira. The rocks consist of alternating beds of metamorphic sandstones and shales, which are very micaceous, highly inclined, and strike generally north-northeast. The main feature at the Brockman is the large quartz reef, which forms the axis of the principal hill ridge, and attains an elevation of about 300 feet above the general level of the surrounding country. It is upon this that most of the principal mines are situated. The belt of rich gold-bearing country is narrow, though it extends for a distance of some three or four miles.

The alluvial deposits were much richer and more widely distributed than in any other portion of the Kimberley Goldfield.

Most of the gold-bearing quartz reefs were discovered by tracing up their connection with the neighbouring auriferous gravels.

Many of the quartz reefs have a regular strike parallel to that of the enclosing metamorphic sediments; one of them—the Mount Bradley reef—reached thicknesses varying from 10 to 15 feet.

The Lady Margaret line of reefs, situated on a low ridge to the westward of the main group of reefs, consists of some cross stringers of quartz intersecting a basic dyke; this, which is 10 feet thick, penetrates the sandstones and schists along the strike and indurates the strata. In one locality the dyke has a quartz reef in direct contact with it and the adjoining sediments.

Hall's Creek. The mining centre of Hall's Creek, the official centre of the Kimberley Goldfield, is about 212 miles by the telegraph line from Wyndham, and 304 miles from Derby. The country is made up of highly inclined greenish micaceous sandstones and shales, forming continuous outcrops on the sides of the prominent ranges, which trend generally north-northeast and underlie eastwards. Some of the shales exhibit a slaty cleavage parallel to the

direction of the strike, and others pass gradually into micaceous schist. Large felsite dykes, conforming both in strike and dip to the surrounding country rock, make very prominent features in the district. These, together with the dominant strike of the hill ranges, that of the sediments and schists, and the direction of the schistosity as exhibited by the layers of mica, all point to the fact that the main tectonic lines or fissuring of the country trends generally north-northeast and marks that of the gold-bearing belts. The felsite dykes also contain innumerable ramifying quartz veins, but they contain no gold. The gold belt of Hall's Creek, which proved so rich in places, is included within a narrow belt of country lying to the west of the township. The gold-bearing reefs proved to be very small, though occasionally they swelled out into very large bunches. The quartz as a whole contains a very large proportion of galena, and in places smaller quantities of iron pyrites, copper pyrites, malachite, and hematite. The alluvial gold of the gullies has been directly derived from the quartz leaders and veins. Hall's Creek has not, as may be seen by the table of statistics, been a large gold producer.

The Mary River Mining Centre lies about 16 miles southwest of Ruby Creek and on the headwaters of the Fitzroy River. Some of the largest deposits of alluvial gold obtained anywhere in the district have been met with at this centre. The strata of the Mary River consist of highly inclined somewhat micaceous hornblende schist, slates, etc., containing numerous quartz reefs. Such mining operations as have been carried out have been on somewhat poorly mineralised quartz associated with a series of small parallel veins of calcite. The calcite contains free gold in places; in one case a prospecting shaft has been sunk upon a thin vein of calcite. The Mary River district, however, has not been a notable gold producer despite its inherent potentialities.

Mount Dockrell is one of the outlying portions of the Kimberley Goldfield, being situated close to the edge of the so-called Great Desert and on the headwaters of one of the principal tributaries of the Mary River. The geological formation of the gold-bearing area consists of highly inclined metamorphic sandstones, shales, and mica schists with basic dykes or sills striking generally north-northeast. The ancient sediments are highly micaceous and the quartz veins also contain fair quantities of mica; an association which suggests an affinity with veins of pegmatite. Some very rich deposits of gold were found in the deep gullies which lie some three or four miles to the southwest of Mount Dockrell; the working of these alluvial deposits resulted in the discovery of several quartz reefs, upon which some more or less desultory prospecting has been carried on. In one quartz reef—McNeill's—40 tons of ore, obtained from within 15 feet of the surface, gave a yield of 352 ozs. of gold; at a depth of about 50 or 60 feet the reef consisted largely of galena in which free gold was visible. The adjacent reef—the Victoria—about 12 inches thick, yielded 123 ozs. of gold from 4 tons of ore.

The Mining Centre of the Panton is situated at the extreme north end of the known gold-bearing belt of Kimberley and about 42 miles northeast of Hall's Creek. The country in the vicinity consists of a more or less level plain covered with a considerable thickness of black soil. A fairly rich patch of gold-bearing alluvium was discovered along Grant's Gully and Dead Finish Creek; close to these patches several small rich reefs have been met with and opened up. The rocks in the neighbourhood consist of sandstones, clay slates, etc., traversed by a huge razor-backed felsite dyke which forms the Mackintosh Hills. There are two series of quartz reefs. The first, trending generally northeast and southwest, are of small size, though they can be traced for considerable distances. One of these reefs which outcrops on a small rise about 10 feet above the plain can be traced for about a mile. The second series of reefs are large bunchy masses of quartz, striking east and west, and

cutting obliquely across the veins of the first series; they are not, however, very persistent, and cannot be traced for any distance. A vein of this type—The Perseverance—has been proved to be auriferous. Some of the reefs of the first series contain considerable quantities of copper pyrites in addition to iron pyrites as well as occasional large quantities of galena. In The Lone Hand, however, the reef at a depth of 60 feet was found to be made up almost wholly of galena, which, on assay, was found to contain 26 ozs. 12 dwts. of silver per ton. The Lone Hand reef is stated to have produced 260 ozs. of gold between the surface and a depth of 16 feet from a quartz vein 14 inches thick. This yield has not been included in the table of statistics. The Panton reefs are often accompanied by veins of massive calcite, agreeing in this respect with those of the Mary River, to which reference has already been made.

PILBARA GOLDFIELD.

The Pilbara Goldfield is situated in latitude 21° S., and is, with the exception of Kimberley and Yilgarn, the oldest and in some respects amongst the least known of any of the mining fields of Western Australia. By far the major portion of the Pilbara field is drained by the De Grey River and its numerous tributaries. The field contains several gold- and tin-bearing belts scattered over different portions of the district. Economically the auriferous deposits have proved to be the most important. The area of the field as defined by the legal authorities embraces 32,696 square miles. Prospecting has been carried out in the Pilbara district since the year 1877. The gold yield from the Pilbara Goldfield as reported to the Mines Department up to the end of 1918 has been 201,268.60 fine ozs., of which 18,103.77 fine ozs. have been obtained from alluvial deposits; the quantity of gold bullion entered for export and received at the Perth branch of the Royal Mint amounts, however, to 277,541.55 fine ozs.

The geology of the gold-bearing portions of the Pilbara Goldfield shows that the oldest rocks, designated the Warrawoona Series, consist of an assemblage of sedimentary rocks, quartzites, conglomerates, etc., many of which have been converted into quartz, mica schist, etc., by dynamic agencies. Associated with these undoubted sedimentary strata are a series of basic igneous rocks which have been rendered more or less schistose by the same causes. Some of the basic igneous rocks are fairly massive, and all contain more or less hornblende and its alteration products—chlorite, etc. These beds have been highly plicated, overthrust, and faulted, and are now found almost invariably dipping at very high angles. Full details of these beds are given *in extenso* in Chapter I., pp. 16 and 17. The Warrawoona Beds occupy a fairly large area in the centre of the Pilbara field and are the principal home of the auriferous ore-bodies. The ore-bodies in nearly all cases are found to be parallel to the planes of stratification (foliation (?)) in part of the metamorphic rocks, and may perhaps on that account be termed bedded veins. The Warrawoona Beds have been invaded by batholiths and veins of granite and allied rocks which occupy a very large area in the Pilbara field. The gold-bearing reefs of Pilbara are chiefly confined to the mutual margin of the granite and adjacent rocks, and are concentrated chiefly in important mineralised belts or zones in what is really a metamorphic aureole of which the mass embracing the Moolyella tin field (*vide* pp. 3 and 4, Chapter II., Part III., Section III.) is the most typical. The strike of the adjacent rocks conforms to that of the margin of the batholiths, and they almost invariably dip away from the granite on all sides; in other words, these batholiths arch the strata by which they are surrounded.

The granite mass covers a wide expanse of territory extending over an area of about 900 square miles in the country lying to the east of the Coongan River, to the west of Nullagine, and to the south

of what may be called the Marble Bar-Yandicoogina mineral zone. The central portions of this granite batholith are traversed by several north and south quartz reefs and innumerable pegmatite veins, both of which are tin bearing. Round the peripheral portions of this granite batholith are grouped the auriferous reefs of Bamboo, Talga Talga, Marble Bar, Warrawoona, and Yandicoogina, which have produced 91,051.24 ozs. of fine gold.

The geographical positions of the various gold mining centres of Pilbara show a zonal arrangement of the auriferous deposits. From the results of the field operations carried out during several field seasons it appears that the auriferous deposits of Pilbara may be conveniently divided into six main and distinct groups: (a) Lalla Rookh; (b) North Pole, Talga Talga, Bamboo; (c) Marble Bar, Warrawoona, Yandicoogina, Mount Elsie, Boodalyerri; (d) Nullagine, Twenty-Mile Sandy, Mosquito Creek; (e) Tambourah, Western Shaw; and (f) North Shaw.

The length of the Lalla Rookh belt has not yet been defined, but it does not appear to be less than 30 or 40 miles. The North Pole, Talga Talga, and Bamboo Belt is 50 miles in length. The Marble Bar, Warrawoona, Yandicoogina, Mount Elsie, and Boodalyerri belt has a proved extent of about 80 miles. The Nullagine, Middle and Sandy Creek Zone is known to extend for a distance of at least 40 miles, and there are strong geological reasons for the belief that it continues much farther to the east and may possibly cross the upper reaches of the Oakover River. The Tambourah and Western Shaw belt does not appear to be less than 30 miles in length, whilst that of the North Shaw has only been proved to extend for a few miles.

The general direction of these gold-bearing belts almost everywhere coincides with the strike of the schists and their associates, which, as has already been pointed out, also conforms in general to that of the margin of the granite masses. The width of the gold-bearing belts naturally varies, and in three of the most northerly zones the full width cannot be defined owing to the fact that one of the boundaries is invariably marked by a powerful fault.

Quartz reefs occur in great abundance all through the belts as well as to a more limited extent in the areas occupied by the granitic rocks. The quartz reefs of Pilbara when viewed broadly are of two distinct types, viz., white quartz reefs and laminated quartz and jasper veins allied to, if not actually identified with, the hematite-bearing quartzites (?) which invariably form such a conspicuous feature in most of the goldfields of the State. The quartz reefs of what may be called the massive type occur plentifully in both the schists and the granites; they are not as a rule long, and occasionally swell out into large lenticular masses. Some of the reefs have been traced along the outcrop for over 2,000 feet and occasionally have been found swelling out to masses measuring about 15 feet across.

In addition to the gold derived from the quartz reefs interest attaches to the gold occurrence in sedimentary rocks which bear a close resemblance to the auriferous conglomerates of the Rand (South Africa), better known as the Banket Deposits. Gold-bearing conglomerates have been mined at Pilbara in two localities—Nullagine and Just-in-Time. These conglomerates have only proved to be gold-bearing where they rest upon that portion of the underlying formation which carries auriferous quartz reefs.

The following synoptical table shows the gold yield of the different mining centres of the Pilbara Goldfield up to the close of 1918. The grouping of the centres has been governed by geological considerations, the significance of which will be apparent by an inspection of the geological sketch map of the Pilbara Goldfield which forms the Frontispiece of Bulletin 40.

Synoptical Table showing the Gold Yield of the various Mining Centres of the Pilbara Goldfield up to the end of 1918.

Mining Centre.	Alluvial Gold.	Ore treated.	Gold Th e- from.	Total Gold.
	Fine ozs.	Tons(2240lbs)	* Fine ozs.	Fine ozs.
Bamboo Creek ...	...	19,016-60	31,683-36	31,683-36
Talga Talga ...	50-26	779-15	1,649-05	1,699-31
Marble Bar ...	38-68	24,071-59	30,661-96	30,700-64
Warrawoona ...	44-30	11,199-84	20,680-07	20,724-37
Yandicoogina ...	...	2,836-95	6,323-68	6,323-68
Boodalyerrie ...	...	120-25	887-07	887-09
Breen's Find ...	...	14-00	66-82	66-82
Elsie ...	...	620-50	1,723-20	1,723-20
Lalla Rookh ...	...	7,132-50	8,993-37	8,993-37
North Pole ...	...	524-50	410-31	410-31
North Shaw ...	7-53	351-45	674-72	682-25
Sharks ...	145-08	24-50	112-51	257-59
Shaw River ...	...	101-00	49-63	49-63
Tambourah ...	...	2,077-75	2,616-17	2,616-17
Western Shaw ...	12-52	1,222-50	1,025-27	1,037-79
Wynnan's Well ...	93	810-90	1,488-98	1,489-91
Eastern Creek ...	...	4,285-50	7,979-17	7,979-17
McPhee's Creek... ..	...	113-00	137-92	137-92
Mosquito Creek... ..	1-07	9,488-74	15,580-77	15,581-84
Middle Creek ...	...	6,497-90	8,842-50	8,842-50
Nullagine ...	104-70	11,438-00	20,818-25	20,922-95
Twenty Mile Sandy ...	33-10	5,437-85	9,600-90	9,634-00
Sundry parcels treated at Doherty's Works...	...	...	1,172-32	1,172-32
Fremantle Trading Company's Works... ..	...	...	8-29	8-29
State Battery—Twenty Mile Sandy ...	...	62-00	1,744-32	1,744-32
Various Works ...	...	50-50	2,641-67	2,641-67
Reported by Banks and Gold Dealers ...	6,191-35	...	35-54	6,226-89
Total ...	6,629-52	108,277-47	177,607-84	184,237-36

* Includes dotted gold and specimens.

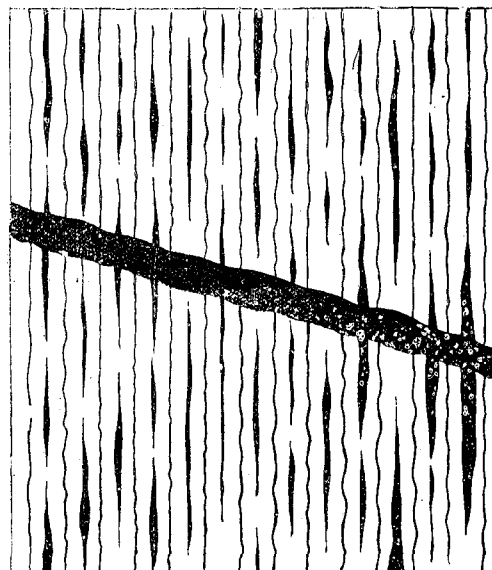
The following is a brief *aperçu* of the salient economic geological features of the different belts, beginning with those surrounding the Moolyella batholith.

Yandicoogina.—The mining centre of Yandicoogina is situated about 35 miles southeast of Marble Bar. The various formations occurring at Yandicoogina consist of schists and allied rocks, and granite, together with a newer series of sandstones and conglomerates with associated volcanic rocks. There are two distinct types of ore deposits at Yandicoogina, viz., the white quartz reefs, and the banded quartz (chert?) veins; the latter, however, stand up in the form of long, low serrated ridges. The bulk of the gold, however, has been derived from what may be called the normal quartz reefs. With one exception, the gold-bearing reefs are everywhere confined to the area occupied by the schists, etc., which, however, do not occupy any very large area of country. The quartz contains iron pyrites, galena, together with small quantities of green and blue carbonates of copper, and occasionally some zinc blende. What is known as the Granite Reef occurs in the granite a mile or two north from its junction with the metamorphic rocks. The granite is traversed by vertical joints, and the reef, which is not a foot thick, occurs along a line of fault underlying from 40 to 45 degrees to the north. An adjacent quartz reef, 15 inches thick, occurring also in the granite, contains galena, arranged in bands through the stone, together with a little zinc blende in addition to free gold.

Warrawoona.—The Warrawoona mining centre lies about 15 miles from Marble Bar and embraces the western extension of the Yandicoogina belt of auriferous rocks. The rocks of Warrawoona are quartz and mica schists of sedimentary origin, associated with a series of basic igneous rocks and their schistose derivatives, in addition to two distinct series of basic dykes. Intrusive granite and dykes of felspar porphyry make an important feature in the district. The whole area has been profoundly affected by earth movements of varying degrees of intensity after the intrusion of the granite

took place. There is a large development of banded quartz (chert) veins; one conspicuous band traverses the whole length of the district, viz., six miles, and forms the centre of the main gold-bearing zone, which is of considerable longitudinal extent, though averaging only about 20 or 30 chains in width. In addition to the banded quartz veins there is another type of fracture developed on the field, which makes itself manifest in two well-defined bands, trending, approximately, parallel to them. These bands are represented by a "sheeting" or "zoning" of the country rock. Lenticules or "eyes" of quartz, parallel to the planes of foliation, occur in these bands. Figure 2 shows a section across one of these compression

Fig. 2.

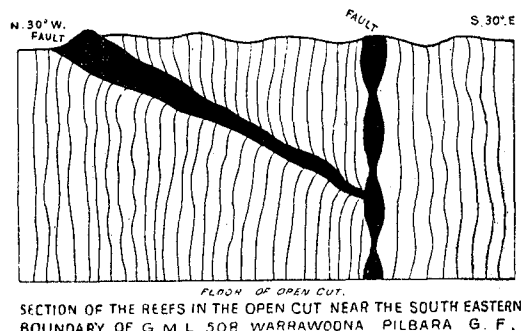


SECTION ACROSS A COMPRESSION FRACTURE TRAVERSED BY A QUARTZ REEF, WARRAWOONA.
PILBARA G. F.

fractures with the characteristic quartz lenses of very much newer formation. The auriferous deposits of Warrawoona are quartz reefs which outcrop over a belt about 6 miles in length and about a quarter of a mile wide. In addition to the gold-bearing belt of Warrawoona, there are several minor outlying virtually isolated reefs, which have been worked in a more or less desultory fashion. There are no alluvial deposits of any extent within the limits of Warrawoona, and only 44.30 ozs. of alluvial gold have been reported from them. The gold-bearing reefs of the Warrawoona belt exhibit, when viewed as a whole, a general parallelism to the trend of the main structural features of the district. The reefs may be divided into two totally different types, which are sharply differentiated from each other. The first type may, for convenience, be called the normal or fissure vein type, whilst the "kidney" shaped, lenticular quartz reefs are locally spoken of as the "leader"; both types have been more or less opened up and their relative importance as gold producers well established, though, of course, the normal quartz reefs have been most extensively worked. The "leader" type of reef at Warrawoona, which forms a continuous band of about two and a half miles in length, occurs along a line of rupture, scored with slickensided surfaces, which are exhibited almost everywhere underground, and which are often coated with fine films of gold. The "reef" or "leader" is represented by kidney or damper-shaped lenses of quartz, which vary from a few inches in width and a foot or two in length as measured along the length of the

vein; the interval between each lens of quartz fluctuates within wide limits. In some sections the "easing" of the lens is quartz of a somewhat different type and points to the quartz lenses being portions of a pre-existing quartz reef, which has been shifted in segments along a vertical line of dislocation. The reefs of the "leader" type are of later formation than those of the fissure veins. Fig. 3 shows a section of a fissure vein abruptly cut off by the "leader." From the very nature of the "leader" type of vein they are naturally somewhat difficult to work, as the slopes must be kept within the nar-

Fig. 3.



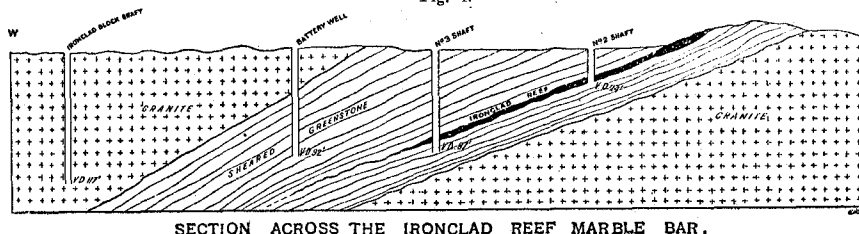
rowest possible limits and merely the auriferous quartz lenses extracted. A feature of many of the normal reefs is the folding and faulting to which they have been subjected. The Horseshoe vein of the Bow Bells lease is a typical example of a folded reef. Other reefs have been faulted; the high inclination of the majority of the quartz reefs is such as might permit of a considerable displacement

without any marked effect on the outcrop, hence many faults, unless disclosed during the course of mining operations, might easily escape detection. In addition to the normal vertical faults, there are also reverse faults or thrust planes, which are either horizontal or are inclined at relatively low angles to the horizon. Typical instances of these are to be found in the workings on the Gauntlet and the Klondyke Boulder leases, particulars of which are to be found set out at length in Bulletin 40. The reefs of both types are composed of a hard, translucent and crystalline quartz, which, in addition to the gold, contains pyrites, chalcopryite, limonite, malachite, ferruginous wad, and a chromiferous mica. Cases have been observed of the occurrence of enleite, carrying a trace of gold.

Marble Bar.—Marble Bar, the official centre of the Pilbara Goldfield, derives its name from the picturesque "bar" of jasper which crosses the Coongan River, about two and a half miles to the southwest of the township. The mining centre forms the western extension of the Warrawoona-Yandicoogina gold-bearing belt, with which it can be geologically linked. The auriferous reefs, which have produced 30,661.96 ozs. of gold, are embraced within a comparatively narrow belt of greenstone schist, running north and south, and extend over a length of a little over three miles, adjacent to the granite. The district has been subjected to a considerable amount of faulting. Most of the water courses in the district are occupied by a variable width of alluvium, but in no case do these deposits attain a great thickness, nor are they of any economic importance, having produced only 38.68 ozs. of gold.

The Augusta Reef makes a bold outcrop on the slopes of a fairly conspicuous though low hill, and is traceable all round the northeast, east, and southeast sides. The quartz reef, which averages about 3 feet in thickness, occurs in lens shaped bodies of quartz succeeding each other closely along the strike of the lode. The quartz is of a dark colour and contains small quantities of the sulphides of iron, copper and lead. The ore body dips at an angle of about

Fig. 4.



SECTION ACROSS THE IRONCLAD REEF MARBLE BAR.

20 to 25 degrees to the westward, and has been intersected by faults. A good deal of work has been done upon it and the workings expose two parallel lenses of quartz separated by about 3 feet of fine-grained greenstone. The ore deposits of the Ironclad consist of five well defined reefs, which occur within a belt of schisted greenstone lying between the normal granite, as shown in Fig. 4. Mining operations, however, have been carried out on what may be called the main reef, which outcrops boldly along a low ridge near the eastern boundary of the lease. The main reef is of quartz with some very ferruginous patches resulting from the decomposition of pyrites.

Talga Talga.—The mining centre of Talga Talga lies about 15 miles north of Marble Bar and three miles distant from the Talga Talga River. The country rocks are identical with those of Marble Bar, and consist of schists of various types intersected by granite. The quartz reefs often contain bands of greenish quartz, the colouring matter of which is due to minute scales of either chrome chlorite or chrome mica. Some of the reefs contain a little galena; one sample assayed 1 dwt. 11 grains of gold, 8 ozs. 11 dwts. 8 grains of silver per ton, and 33.76 per cent. of lead.

Bamboo.—The mining centre of Bamboo lies about 40 miles to the northeast of Marble Bar, and is situated on Bamboo Creek—one of the tributaries of the De Grey River. The gold-bearing belt of Bamboo is contained within a series of greenstone schists and allied rocks, which occupy a width of about three miles in a northwest and southeast direction. The schists are vertical or inclined at high angles and have been intersected by granite, which sends out tongues and bosses into them. Mining operations have shown that the gold-bearing reefs are confined to a narrow strip of schistose rocks, not exceeding half a mile in width, which has become involved in the faulting to which the overlying sedimentary and volcanic rocks of the Nullagine System have been subjected. The schists are traversed by several persistent belts of cherts (?), one of which was about 30 feet in width.

The Bulletin Reef is worked by the deepest shaft (about 400 feet) on the Pilbara Goldfield, and is said to contain the longest continuous shoot of ore worked on the field. The reef itself is of quartz which at the 160 feet level is two feet wide, and from it many small veins and stringers of quartz emanate. Some of the ore was very rich in gold and contained a good deal of sulphide of

antimony. Some of the lenses of ore in the mine have reached a thickness of as much as five feet. There have been several rich crushings (over 20ozs. per ton) from several of the Bamboo reefs.

Lalla Rookh.—The mining centre of Lalla Rookh is situated about 45 miles west of Marble Bar, at the foot of what may be called the main range, which presents a steep face to the coast and extends northwest and southeast for considerable distances. The rocks of the field consist of greenstone schists and allied rocks, diabase, laminated ferruginous jaspers, and granite, together with a series of sedimentary rocks. Shallow alluvial deposits form a wide strip along the banks of Lalla Rookh Creek, but they have yielded very little gold. The greenstone schists and their allies are vertical or are inclined at high angles in a series of folds the trend of which has been modified by the faulting to which all the beds have been subjected. The quartz reefs have also been subject to the same faulting as the schists. It is amongst these rocks that the most important auriferous reefs yet opened up occur. The schists have been invaded by granite which is also traversed by some of the reefs. The quartz of which the gold-bearing reefs of Lalla Rookh is made up is generally of a milk-white colour, and with one exception contains very little iron pyrites. The gold production of this centre has been up to the end of 1918 8,993.37ozs. of fine gold, which is virtually that of one mine, the Lalla Rookh Leases, and may be followed without a break for about 6,000 feet; at its northernmost extremity this passes into a very banded form identical with some of those laminated quartz veins which form such conspicuous features in most of the goldfields of Western Australia. None of the workings is extensive, nor have they been carried down to any depth.

Western Shaw.—The Western Shaw mining centre lies about five miles to the southeast of Tambourah and somewhat further to the east of the boundary of the intrusive granite. The geological formations are represented by a series of greenstones and their schistose representatives. These are succeeded on the east by silky acidie schists, grits, quartzites, and fine conglomerates, which latter have been subjected to considerable dynamic alteration. Most of the water-courses are occupied by a variable width of alluvium of no great thickness. Some portions of these have been extensively worked and a large amount of alluvial gold is believed to have been won soon after the first rush in 1891. There are several well-defined quartz reefs conforming in dip and strike to the foliation of the enclosing schists. The longest reef has a continuous outcrop of about 1,200 feet, whilst another to the east is represented by four well-marked veins connected by thin threads of quartz making an ore channel of about 2,500 feet long. The quartz is of a milk-white colour and is occasionally very much honey-combed as the result of the decomposition of iron pyrites. None of the workings is of any depth, nor of any extent.

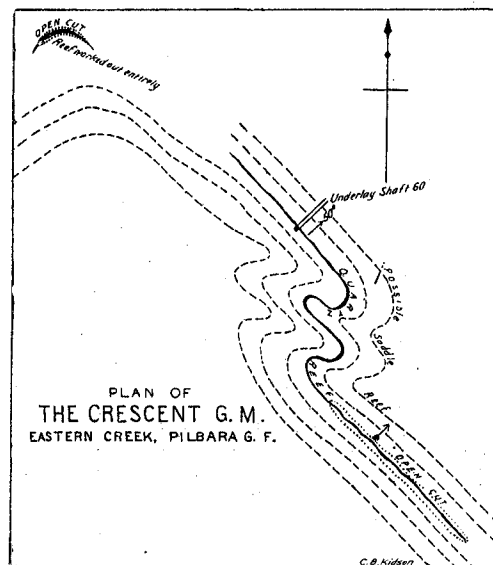
Tambourah.—The mining centre of Tambourah is situated about 75 miles southwest of Marble Bar upon the headwaters of the creek from which it takes its name and which forms one of the most important branches of the Shaw River. In its geological structure the neighbourhood of Tambourah consists practically only of two formations, viz., granite and its derivatives together with greenstone and its transmuted varieties. The granite is intrusive and sends out veins into the greenstone in addition to containing masses of the latter, more especially along its margin. The mining centre lies just to the west of the junction of the greenstone with the granite. The auriferous belt extends for about two miles south at an average distance of about a quarter of a mile east of the granite junction. The quartz reefs are very numerous and occur both in the granite and the basic rocks. The quartz of most of the reefs is of a white or amber colour and in cases is heavily mineralised with iron pyrites, arsenical pyrites, galena, and some copper pyrites. The reefs form a group of parallel veins, parallel with the lamination of the enclosing country rocks, viz., north and south. The reefs vary in size and are all vertical or inclined at high angles to the eastward. The reef which has the greatest linear persistence is that traversing the Western Chief.

Mosquito, Sandy, and Middle Creeks.—The mining centres of Mosquito, Sandy, and Middle Creeks are embraced within a mineral belt which extends from Nullagine to Mosquito, a distance of about 24 miles. Numerous quartz reefs outcrop over a belt of about a couple of miles in width. Many of them have been opened up at one time or another and worked, though naturally they vary in their dimensions and richness in different portions. The staple geological formation consists of highly inclined schistose rocks, associated with a series of sedimentary rocks, from which however they cannot be satisfactorily separated. These rocks are intersected by granite and pegmatite veins which latter traverse the granite also; in addition an approximately parallel series of quartz reefs, which may merely represent another phase of the pegmatite intrusions, occurs in the granite. Near the township of Mosquito the beds have been invaded by a conspicuous boss of granodiorite with a length of about 90 and a maximum width of 40 chains.

Quartz reefs occur in great abundance in the country to the westward of the Nullagine River; they outcrop over a belt about four miles in length which emerges from beneath the beds of the Nullagine System. The productive area consists of a belt about a mile wide which has a general strike of northeast and southwest. The reefs invariably occur along the bedding planes of the enclosing rocks; few attain any very great horizontal extent, nor are they very thick. The reefs, which have been worked to a very shallow depth, are of white quartz containing little if any pyrites.

The gold-bearing reefs of Eastern Creek, a tributary of the Nullagine, lie within a geological area which connects it with the Mosquito Creek belt. The reefs are of quartz, which contains haematite and its oxidation products in addition to large crystals of iron pyrites. The Eastern Creek reefs are situated in a strip of country about half a mile wide, made up of highly inclined quartzites, metamorphic sandstones, etc., some beds of which have been twisted, folded, and faulted in all directions. The quartz reefs are

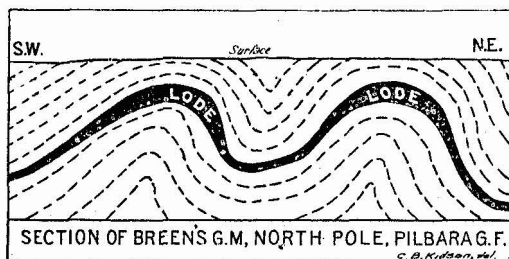
Fig. 5.



numerous and outcrop along the sides of the hills; they vary in thickness from a few inches up to as much as four feet. Some of the quartz has been deposited in the corrugations of the strata, producing what are really saddle reefs, several good instances of which are to be seen in the outcrops, and of which the Crescent Gold Mine at Eastern Creek is a typical instance (Fig. 5).

At what is known as Breen's Gold Mine at the mining centre of North Pole is a gold deposit of a type somewhat unusual in the North-West. The lode is formed in the folds of the country rock (Fig. 6), but the vein filling is not quartz but "a layer of the

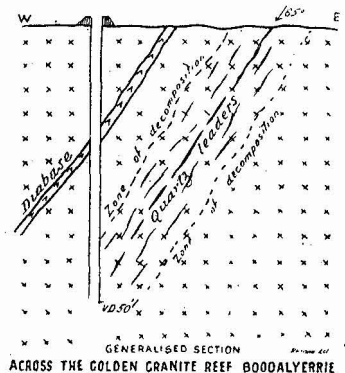
Fig. 6.



country rock impregnated with gold contents from circulating solutions in which silica, etc., have been absent . . . " in which case it may be looked upon as an impregnation. The lode has a general strike of northeast and southwest with an underlay to the southwest at a low angle.

Boodalyerri.—The rich gold deposits of Boodalyerri, situated about six miles east of Mount Elsie, occur in granite country within the marginal zone of the batholith, adjacent to the basic and micaceous schists into which the granite is clearly seen to be intrusive. The ore deposit in the Golden Granite Mine (Fig. 7) con-

Fig. 7.



sists of a network of small quartz veins occurring in proximity to a basic dyke. The granite adjacent to the quartz veins has been altered into a greenish yellow rock, from which chemical analysis indicates that the lime, soda, and magnesia have been to a large extent removed, and the potash considerably increased. The altered rock has no defined boundaries, but passes almost insensibly into the normal granite of the neighbourhood. The somewhat exceptional occurrence of the auriferous reefs in the granite at Boodalyerri may in all probability be ascribed to the fact that the surface at this locality is not very far from the roof of the batholith.

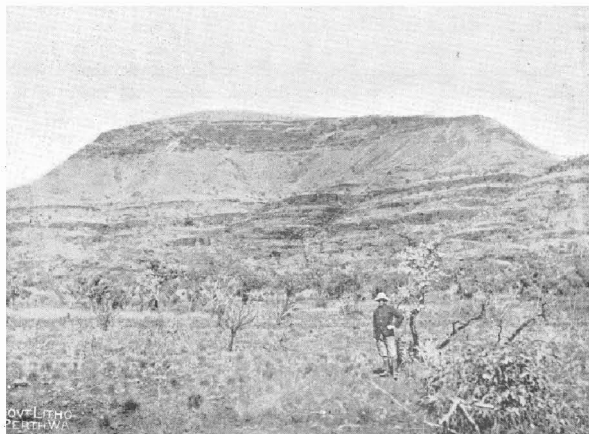
Gold-bearing Conglomerates.—In addition to the gold derived from quartz reefs, etc., of the Pilbara field, the conglomerates at the base of the Nullagine Formation have been mined in two localities, viz., Nullagine and Just in Time. It is noteworthy that the base of the formation has only proved to be auriferous in those

places where it lies upon that portion of the underlying beds which carries gold-bearing quartz reefs.

Nullagine.—The mining centre of Nullagine is situated about 55 miles to the northnorthwest of Marble Bar upon the Nullagine River about 90 miles above its junction with the Oakover River. Interest attaches to the district on account of the marked resemblance which the gold-bearing conglomerates of Nullagine bear to those of the Rand (South Africa), better known as the Banket deposits. The Nullagine auriferous conglomerates, which seem to form lenticular masses, occur in the basal members of the formation as developed in the ranges to the northwest of the township of Nullagine. (Fig. 8.)

The formation, which presents a plateau-like appearance, exhibits a bold escarpment when viewed from the southeast, and certain of the harder beds stand out in bold relief, presenting mural faces at different levels. (Fig. 9.)

Fig. 9.



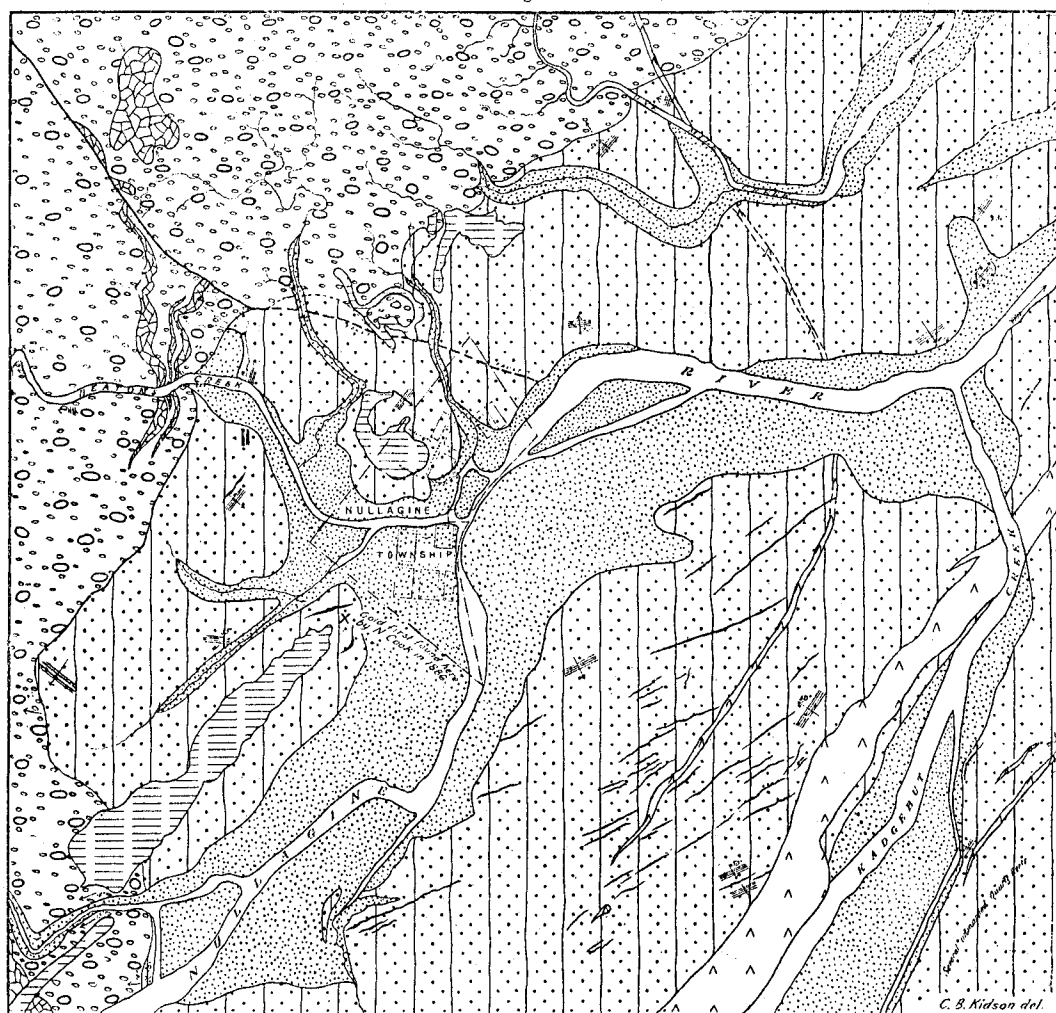
Mt. Margaret, looking East, Hamersley Range.

The first discovery of gold was made at Nullagine in the year 1886 and a reward of £250 was made to the finder—Mr. N. W. Cook. The spot at which the original find was made lies just to the east of the escarpment of the Nullagine Formation, and from the disintegration of which the gold was probably derived.

The auriferous strata of the formation occur through a thickness of about 300 feet of grits, sandstones, and conglomerates, forming the lowest portion of the rock series, which dip at a low angle to the west. The basal conglomerate is made up of rounded, ellipsoidal or sub-angular fragments of the rocks forming the underlying series (Mosquito Creek Beds). These often include pieces which reach a length of 3 or 4 feet, though the bands containing the larger fragments are merely local. Fig. 10 shows a portion of this conglomerate at the entrance to one of the mine workings. The conglomerate consists chiefly of fragments of the pre-existing conglomerates, cherts, grits, and shales; reef quartz, identical in character with that forming the auriferous deposits in the underlying strata, being a very common constituent. The pebbles and boulders are embedded in a matrix which is principally sandy though sometimes aluminous.

Careful analyses have been made in the Geological Survey Laboratory of both the oxidised and the sulphide varieties of the conglomerates by Dr. E. S. Simpson, and the results of its mineral composition are set out below.

Fig. 8.



CHAINS. 0 20 40 60 80

Scale.

LEGEND.

Alluvial Deposits.....		Laterite.....	
Nullagine Beds { Conglomerates &c.....		Mosquito Creek Beds.....	
{ Lavas & Ashes.....		Dolerite.....	
Quartz Reefs.....		Dip & Strike of Strata.....	

GEOLOGICAL MAP OF
NULLAGINE
PILBARA G.F.

Mineral Constituents of the Nullagine Conglomerate.

	Oxidised.	Sulphide.
Quartz (vitreous and chalcedonic)	about 49	about 45
Goethite	" 17	Nil
Iron pyrites	Nil	" 34.5
Jarosite	11	Nil
Albite	" 5	" Nil
Kaolin	"	" (?)
Talc	"	"
Ilmenite	"	"
Chlorite	Nil	"
Orthoclase	Nil	"
Arsenopyrite	Nil	"
Apatite	Nil	"
Gold, ozs. per ton	1.144	0.500
Silver, ozs. per ton	0.162	0.350

* Indicates the presence of the mineral, but in undetermined quantities.

The conglomerates or consolidated shingles are of sedimentary origin, and owe their occurrence to the disintegration of pre-existing strata.

The gold-bearing strata are largely impregnated with the oxides and sulphides of iron, and which lie between the fault, north of Beaton's Creek and the basic dyke (possibly along a fault line also), crossing the One-Mile Creek in the vicinity of Mineral Lease 51. The workings can all be included within a quadrilateral area, comprising about 160 acres. Mining operations have been confined exclusively to the outcrop of the conglomerates, and to very limited and shallow depths. Certain portions of the conglomerate are marked by the presence of abundant pyrites and its oxidation products; it is, however, in the oxidised zone of the conglomerate that mining operations have been chiefly carried on. In the unoxidised portions, the pyrites occurs both as crystals, grains, and rounded or pebble-like forms; a photograph of some of the characteristic forms forms Fig. 11. Some of the pyrites nodules are nearly an inch in diameter, and from the size of some of the hematite pebbles, there must be some considerably larger. A radiate fibrous structure can be detected in some of the oxidised conglomerates, where the hematite pebbles exhibit fractured surfaces. In some portions of the conglomerate these hematite fragments make up fully one-half of the rock.

Considerable interest attaches to the occurrence of the rounded pebbles and pellets of hematite and pyrites, in that they have been held to owe their form to attrition and to be of detrital origin. It

Fig. 10.

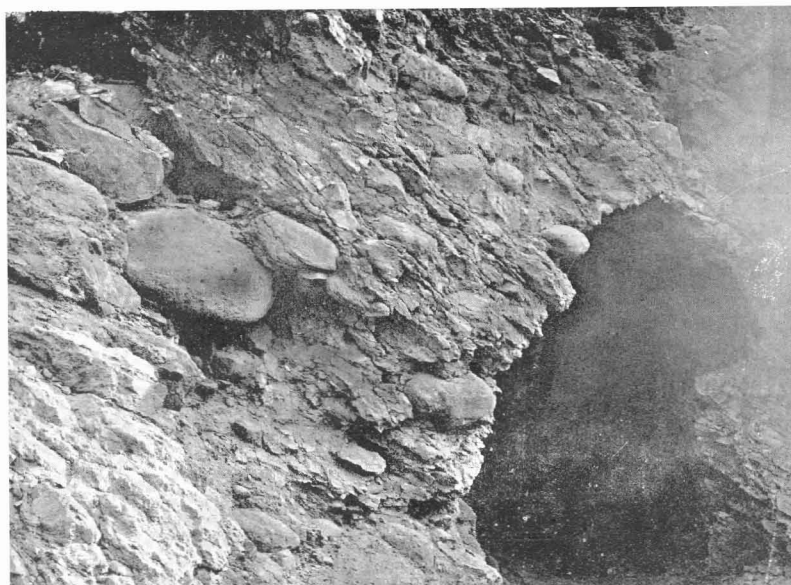


Photo: S. J. Beeher.

A portion of the Auriferous Conglomerate, Nullagine.

is, however, more than likely that they are merely replacements of some varieties of the pebbles of which the conglomerates are constituted.

The gold occurring in the conglomerates is nugget and crystalline, and invariably occurs in or lining the sides of the cavities which have been left by the oxidation of the pyrites. The gold is, however, very unevenly distributed throughout the mass of the conglomerate, and from its characteristics is of secondary origin, having been introduced together with the pyrites by solutions percolating down the most porous portions of the rock; a condition faci-

tated by the downward inclination of the bedrock and, possibly, accentuated in part by the folding which the strata have undergone.

The intrusion of the acidic dyke into the lower portion of the conglomerate and the volcanic phenomena of which it formed a part may, possibly, have resulted in the formation and circulation of the mineralising solutions and tended towards the deposition of the gold.

Several of the gold-bearing bands of the basal conglomerate have been opened out at about a dozen places at different elevations, and from these several crushings have been taken out and recorded.

The gold yield of the conglomerate is small, not amounting to more than 3,299.71 fine ozs., derived from the milling of 5,185.50 tons of ore, or at the rate of .63 oz. per ton. Individual crushings show

as high as 1.92 ozs. per ton down to 2.4 dwts., the latter being the average figure for 777 tons crushed from the workings on Grant's Hill (Fig. 12), a return which seems to indicate

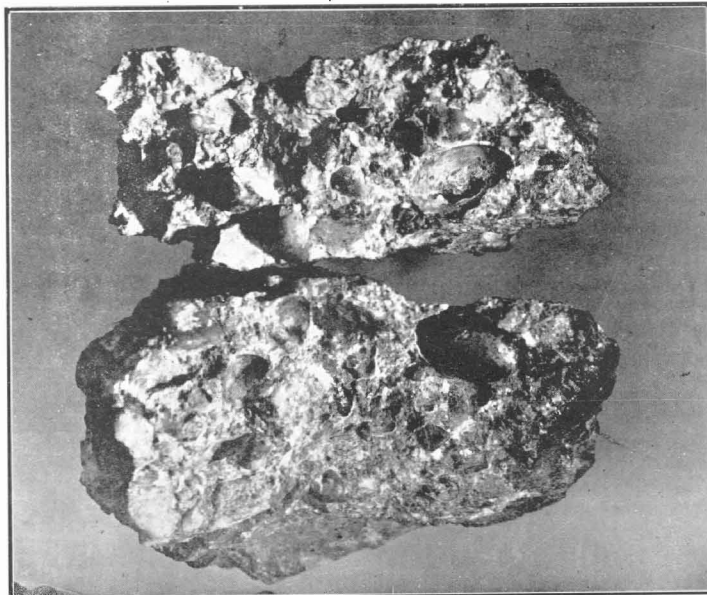


Fig. 11.—Pyritic Conglomerate, Nullagine.

an uneven distribution of values in the conglomerate, rather than a general decrease in the grade of the ore. The average, however, of the crushings recorded from the con-

glomerates cannot be regarded as an index of the value of the whole deposit if worked upon a large scale; such would probably prove to be of very low grade, calling for much more favourable economic

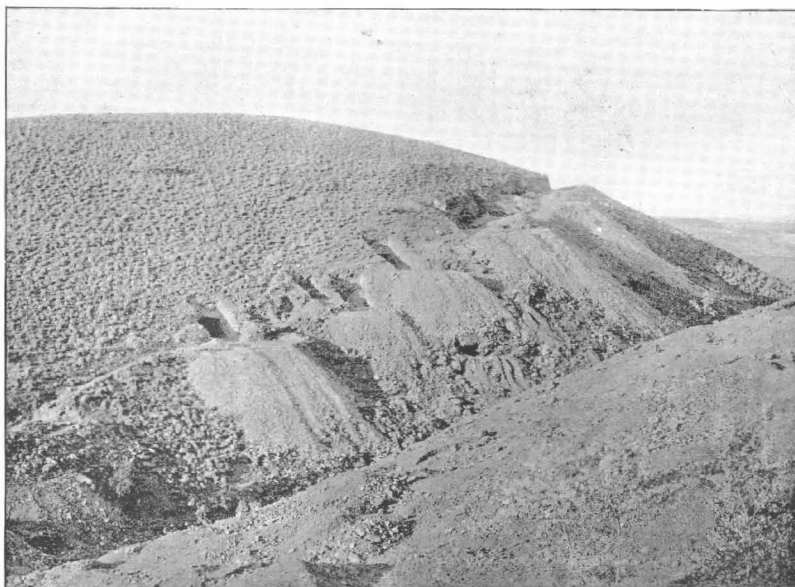


Photo: S. J. Becher.

Fig. 12.—Workings on the Grant's Hill Conglomerate, Nullagine.

conditions than at present prevail, when it might be possible to successfully mine and treat an undoubtedly large tonnage of gold-bearing conglomerate. The mining operations which have hitherto been carried out in the basal conglomerate are by no means sufficient to thoroughly test the capabilities of the deposits; so far the workings are relatively of small extent by comparison with the area over

which the gold-bearing portions of the conglomerate have been proved to extend.

A large sluicing plant was erected at Nullagine for the purpose of extracting the gold from the boulder-strewn flats formed of the *débris* of the conglomerate (Fig. 13).

Fig. 13.

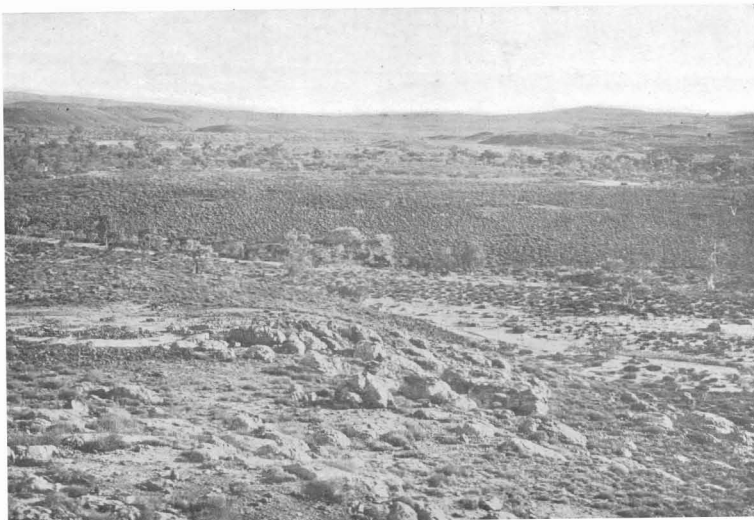


Photo: T. Blatchford.

General view of the Nullagine Conglomerates.

Neg. 868.

The returns show that from these dredging areas, 37,300 cubic yards of gravel yielded 912.26 ozs. of gold.

It is noteworthy that over that portion of the formation from which the conglomerate crushings have been obtained, numerous dry-blowers have been at work for a number of years and have obtained a considerable quantity of gold, of which the published figures afford no clue, for much of it in the early days was never officially reported to the Government. Probably fully one-half of the alluvial gold from Nullagine, shown in the official statistics as amounting to 6,330.22 ozs., may be legitimately claimed as having been derived from the escarpment of the conglomerate.

Just in Time.—The mining centre of Just in Time, which was the scene of the great gold-rush in 1892, is situated about eight miles south of Marble Bar, on one of the tributaries of the Coongan River. Although the gold yield of this centre has been small, considerable interest attaches to the locality by reason of the fact that another gold-bearing conglomerate at the base of the Nullagine Formation has been worked to a limited extent. It resembles in many important respects the gold-bearing conglomerates of Nullagine. The locality upon which operations have been principally centred is upon the slopes and summits of a relatively narrow, though conspicuous, ridge, which trends generally northwest and southeast, where the Nullagine Formation is represented by about 350 feet of grits, quartzites, sandy shales, and conglomerates, together with a great thickness of bedded lavas. At the base of the formation, and resting with a violent unconformity on the older rocks, is a very ferruginous conglomerate, which varies in thickness from an inch up to 5 feet 6 inches (Fig. 14). The conglomerate is mainly made up of boulders and rounded and sub-angular fragments of the underlying rocks, together with occasional pebbles of a pre-existing conglomerate. The matrix of the gold-bearing conglomerate is very hard and siliceous from the presence of secondary silica, and certain

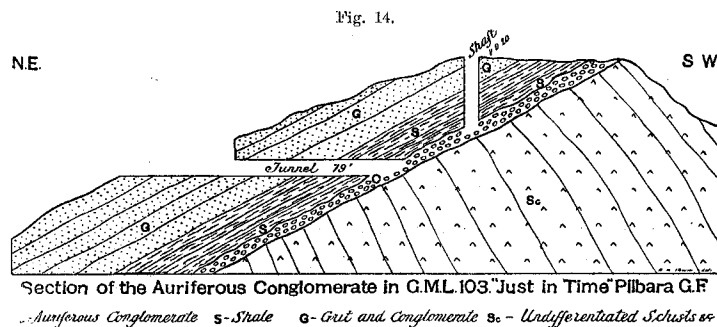
portions of it contain a sufficient quantity of hematite and limonite to give a distinctive character to the rock. The iron ore is virtually confined to the thin lenticular bed at the base of the formation, though a small quantity occurs in the stratum on a higher horizon at the mouth of the tunnel. The best of the gold is stated to have been found near the footwall, where "the lode 'freezes' very lightly on to the walls. . . . The gold occurs as water-worn particles and grains sometimes attaining as much as several ounces in weight." The iron ore also occurs in more or less rounded forms, and there seem sound grounds for the belief that the rounding of the iron ore and the gold is due to other causes than attrition. It is possible, however, from its nature and mode of formation, that a certain quantity of detrital gold and iron ore may occur in the conglomerate, but the bulk of it is of secondary origin. The gold-bearing conglomerate is not of any great horizontal extent, nor does it appear to penetrate to any considerable depth. It was deposited on a very uneven bottom, and occurs in a more or less local depression in the underlying rocks. There have been only 60 tons of conglomerate ore crushed, which produced 47.30 ozs. of gold, or at the rate of .78 ozs. per ton milled.

As has been the case at Nullagine the sloping ground at the foot of the escarpment has yielded considerable quantities of gold to the dry-blowers, of which no record is obtainable. Most of this owed its origin to the weathering of the conglomerate and the liberation of its mechanically carried gold and its concentration in the detritus.

General.—The known occurrence of such an extensive rock series as the Nullagine Formation has been proved by geological mapping to be, and the fact that it has been shown to contain considerable quantities of gold in localities where the requisite and qualifying conditions for gold deposition obtain, would seem to encourage efforts in the direction of carefully prospecting other

parts of the basal members of the group. Such prospecting should be a relatively easy task, as the gold-bearing portions of the conglomerate have invariably proved to be those which are the most

ferruginous; hence the search for iron-stained conglomerates near the base of the formation would seem to be the lines upon which such efforts should tend.



WEST PILBARA GOLDFIELD.

The West Pilbara Goldfield is of some historical interest in that it contains one of the oldest mining centres in the State. The gold-mining history of the field opened with the discovery of auriferous quartz reefs in 1877, since which date West Pilbara has turned out 27,586.83 ozs. of fine gold, of which 5,550.56 ozs. have been reported as having been obtained from the alluvial deposits. A very large quantity of alluvial gold is known to have been obtained from the field, of which no record has been kept; the difference between the returns of the Mines Department and those of the Mint and Customs Office—which amounts up to the close of 1918 to 12,689 ozs.—in all probability represents some, at any rate, of the unreported alluvial gold. Even this figure is probably far below the actual quantity of alluvial gold obtained.

The following table gives the gold production of the various mining centres on the West Pilbara field.

Synoptical Table showing the Gold Yield of the various Mining Centres of the West Pilbara Goldfield up to the end of 1918.

Mining Centre.	Alluvial Gold.	Ore Crushed.	Gold therefrom.	Total Gold.
	fine ozs.	tons (2,240lbs.)	fine ozs.	fine ozs.
Croydon ... ..	...	8.00	5.44	5.44
Hong Kong	21.40	340.00	445.62	467.02
Lower Nicol	10.44	663.20	417.54	427.98
Mallina ... ..	...	141.60	128.44	128.44
Nicol ... ..	...	30.00	11.47	11.47
Pilbara	1.11	220.00	534.68	535.69
Rochbourne ... ..	...	221.96	669.89	669.89
Station Peak	177.74	10,793.50	11,387.90	11,565.64
Towranna ... ..	...	3,965.80	5,190.13	5,190.13
Upper Nicol ... ..	...	6.50	2.57	2.57
Weiriana ... ..	...	2,500.15	3,142.71	3,142.71
From Goldfield generally reported by Banks and Gold Dealers ...	5,339.87	...	99.98	5,439.85
Total	5,550.56	18,890.71	22,036.27	27,586.83

The area of the West Pilbara Goldfield, as legally defined for purposes of mining administration, embraces 10,843 square miles of which, however, only about 1,500 are occupied by mineral-bearing formations, for, as may be seen by reference to the geological map of the field (Plate I, Bull. 41), by far the largest portion of the field is covered by almost horizontal sedimentary and igneous rocks of the Nullagine Formation, which effectually conceals the older rocks beneath.

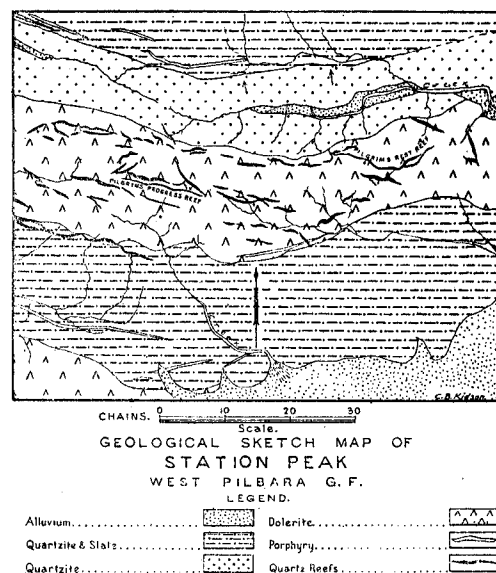
The remaining portions of the field consist of granite and gneiss, together with a series of metamorphic rocks of sedimentary origin and some basic dykes of pre-Nullagine age. The valuable gold

deposits of West Pilbara are confined to the northern and eastern portions of the field.

Gold has been produced at twelve different centres, of which the most important is Station Peak (Youlingoorina), situated on the headwaters of the Peeawah River. The first find of gold was made in 1897, when about 20 ozs. of alluvial gold was found in one of the gullies, though it was not until 1901 that the first gold-mining lease was applied for. A fairly lofty east and west ridge traverses the area and carries numerous quartz reefs.

Station Peak in its geological structure is comparatively simple, consisting of a highly inclined series of sedimentary rocks invaded by basic and acidic dykes, upon which rests an isolated patch of the Nullagine Formation (Fig. 15). The basal beds of the highly in-

Fig. 15.

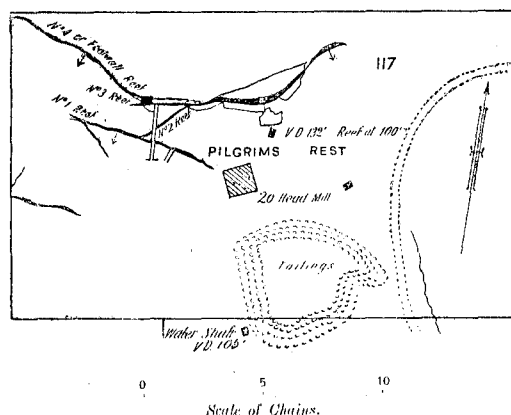


clined sediments consist of quartzites, slates, and arkose. The sediments are traversed by a dyke of quartz dolerite which varies from 800 to 1,200 feet in width.

A large number of acid porphyry dykes occur in the vicinity of the mines and invade not only the sediments but the dolerite dyke also. The main dolerite dyke is of considerable economic importance owing to its forming the matrix of the auriferous quartz reefs. Portions of the dolerite have undergone a certain amount of dynamical alteration, resulting in the formation of a rock with a more or less marked foliation, but in which the original structure has not been entirely obliterated. These zones of altered rock are narrow and of no great length, and the quartz reefs are almost everywhere confined to them. The reefs have more or less parallelism, which is roughly approximate to the general trend of the dolerite dyke in which the majority of them lie.

The main Pilgrims' Rest Reef, from which 9,382 ozs. of gold have been crushed, has a length of about 4,000 feet; it is, however, only at its eastern extremity that the reef has been worked, in that portion which is contained within the boundaries of G.M.L. 117, Pilgrims' Rest (Fig. 16). The thickness of the reefs varies

Fig. 16.



from an eighth of an inch to as much as 20 feet; they are not everywhere confined to the dolerite, for isolated cases occur in which they traverse the sedimentary beds and intersect the porphyry dykes. As a whole the quartz is of a bluish white colour, sometimes discoloured with oxide of iron, and at others containing copper and arsenical pyrites. The fact that some of the quartz reefs intersect the acid dykes indicates that the fissuring and subsequent mineralisation followed the injection of the porphyry.

These acid dykes do not rise to the level of and pierce the overlying Nullagine Formation, hence it is quite clear that whatever may be the exact position of that group in the geological time scale, the age of the Station Peak reefs is pre-Nullagine. The intrusion of the great granite batholith, of which the acid dykes form the apophyses, seem to have been the culminating effect of intense earth movements tending to produce fractures and fissures, which, through mineralising agents, formed the lodes of the district. Station Peak is essentially a one-mine township, which depends for its prosperity upon the Pilgrims' Rest Mine, which has yielded up to the end of 1918 9,382 ozs. of fine gold, or 43.11 per cent. of the total production of the West Pilbara field.

The mining centre of Pilbara, which lies about 10 miles west of the Yule River along the western margin of that large granite batholith which occupies such a large area of country in this portion of the State, appears to have been discovered in 1888 and to have been one of the first alluvial fields in the North-West. The country rock of Pilbara, however, consists of metamorphic quartzites and schists, some of which appear to have affinities with rock of igneous origin; these beds are overlaid by the Nullagine Formation. The

schists and metamorphic sediments are traversed by quartz reefs, and here and there by acidic dykes which form the apophyses of the granite. The Pilbara field is situated in a narrow belt of schists about six miles in length and a mile in width. There are three distinct zones in this belt. The first may be called the cupriferous, owing to the fact that along it a series of copper-stained schists occurs, with here and there copper-bearing quartz veins. The second, or middle, is the auriferous zone, from the fact that it contains the principal gold deposits, and is intersected by numerous large though somewhat irregular quartz veins. The third, or tin-bearing zone, is situated along the edge of the granite, the gullies traversing which have yielded considerable quantities of stream tin. The gullies and flats have been extensively worked for the detrital gold they contained, and they have yielded some thousands of ounces, chiefly slugs, nuggets, and coarse gold, much of which in all probability has never been officially reported to the Government. It is stated that some of the finest specimen stone found anywhere in the North-West was taken from the quartz veins of Pilbara. The Pilbara centre is one which has always enjoyed a good reputation amongst prospectors, in that many of them return there after prospecting in the outside districts and claim to be able to more than make a reasonable livelihood.

The Hong Kong centre lies about six miles north of Pilbara, and is made up of a series of schistose rocks which are traversed by small, rich, though not very persistent quartz veins, some of which contain both iron and copper pyrites.

The mining centre of Egina is situated on the eastern side of the Peewah River about 40 miles from Balla Balla, 80 miles from Roebourne, and eight or nine north of Hong Kong. Egina is a locality which has been well known as an alluvial field and where very many rich patches have been worked and where a certain amount of gold can always be obtained by dry-blowing. The detrital gold which has hitherto been won was obtained from the gullies and along the watercourses on the flats, and from the sides and crowns of the numerous low hills in the vicinity. The country rock of the Egina field consists of clay slates, some bands of which are highly ferruginous, in addition to beds of indurated slate and schist. The strata, which are either vertical or are inclined at high angles, have a general east and west strike.

On the caps of some of the low hills a little conglomerate is occasionally found, possibly representing the base of the Nullagine Formation which occurs a little distance to the south and forms the tableland dividing Egina from Hong Kong. Many of the dry-blown patches have been worked right up to the conglomerate, which suggests the possibility of the gold having been derived from the basal beds of the formation, as at Nullagine and Just in Time.

Nearly all the alluvial gold from Egina was of the uniform size and shape of small melon seeds. Many of the slates on being split open contained particles of ironstone of the same melon seed-like shape. A good deal of alluvial gold from Egina is stated to have had particles of ironstone adhering—a circumstance which suggests the possibility of the original source of the gold being from impregnation in the slates.

The Towranna Mining Centre, which is situated about twelve miles south of Mallina and half-way between Croydon and Whim Well, is the second largest gold producer in West Pilbara. A very important geological feature is the occurrence of a belt of porphyry trending nearly north and south. The quartz reefs occur both in the porphyry and the schists; those in the porphyry, however, are more persistent and apparently richer than the others. The reefs are of bluish-white vitreous quartz which contains the decomposition products of iron pyrites and galena. Very little alluvial gold appears to have been found in the district. A good deal of work has been done on the two principal reefs, the Yellow Aster and the Towranna, which have yielded 997.15 and 1,075.95 ozs. of gold respectively.

ASHBURTON GOLDFIELD.

The Ashburton Goldfield, which is situated on the Ashburton River and extends from a point 150 miles from its mouth for about 150 miles inland, was first proclaimed a goldfield in the year 1890. The area of the goldfield, as defined by the authorities for purposes of administration, embraces 14,230 square miles.

The gold yield from the Ashburton Goldfield, as reported to the Department of Mines from its institution in 1894, amounts up to the end of December, 1918, to 8,883.24 fine ozs., all of which, except 315.64 ozs., being the product of alluvial mining. Prior to that date however, there have been recorded up to the end of 1890, 10,000 ozs. of alluvial gold from the Top Camp; 1,500 ozs. from Soldier's Secret; and from the Dead Finish 1,000 ozs., making 12,500 ozs. to be added to the figures of the Mines Department, and thus bringing the total gold yield of the Ashburton up to at least 21,133.24 ounces.

By far the larger area of the goldfield is made up of representatives of the Nullagine Formation, which constitutes the high plateau breached by the Ashburton River. The field contains minor gold-bearing areas scattered over widely separated localities. The gold-bearing zone of the Ashburton field is defined by the escarpment of the Nullagine Formation which flanks both walls of the river valley and has been estimated at about 7,000 square miles. The primary gold deposits are contained in a highly inclined series of sedimentary rocks, quartzites, grits, and slates, having an average strike of 222 degrees and which unconformably underlie the Nullagine Formation. The strata of the older rock series—the Ashburton Beds—are traversed by quartz reefs of varying dimensions and interrupted continuity; the rocks are disposed in a series of more or less acute folds, and the quartz reefs, which occur on the flanks of the arches, may possibly represent the legs of saddle reefs more or less modified by denudation. The quartz of which the reefs are made up is usually highly ferruginous, containing in places a large quantity of goethite (?) due to the decomposition of iron pyrites which will probably be found below water level. Some of the quartz contains small quantities of oxide of manganese, and others in addition have veinlets of chaledony traversing the brown iron ore. A little galena has also been met with in the gold-bearing reefs. The Top Camp Diggings, which forms the uppermost mining centre of the Ashburton Goldfield, was the scene of the first gold find, and up to the year 1890 it is stated that over 10,000 ozs. of alluvial gold have been obtained, one nugget weighing 87 ozs. The official returns as supplied to the Mines Department are obviously far below the actual amount of gold won. The district is made up of clay slates, etc., of the Ashburton Beds, capped by the almost horizontal basal dolomitic limestones of the Nullagine Formation. The slates, etc., are intersected by several small quartz reefs and leaders, many of which are highly ferruginous.

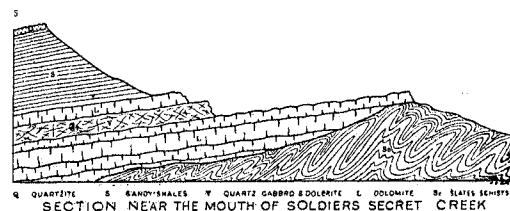
Higher up the Ashburton River, near the head of Turee Creek, one of its important tributaries but outside the limits of the proclaimed boundaries of the goldfield, a large quantity (some thousands of ounces) of alluvial and detrital gold is stated to have been obtained. Little, however, is known of the detailed geology of the district in question.

At Mount Bresnahan, on the boundary between the Ashburton and Peak Hill Goldfields, the Nullagine Formation rests upon the upturned edges of the Ashburton Beds; the country is well worth prospecting, as there appears to be some likelihood of alluvial gold being obtained in the vicinity.

The *Soldier's Secret Diggings*, sometimes known as Middle Camp, is situated about 14 miles south of the junction of the Ashburton with Wandary Creek. The gold-bearing deposits of Soldier's Secret are situated in the group of steep hills about two miles to the north of the escarpment of the Nullagine (Bangemall) Formation, a section of which is to be seen near the mouth of the creek in a hill about 550 feet above the level of the surrounding country (Fig. 17). On the eastern bank of the creek near the old well, several very thick vertical quartz reefs outcrop; these continue

across country for considerable distances on a general bearing of 111 degrees. The veins are enclosed in beds of slate which are almost vertical, and to the strike of which the reefs conform. The quartz reefs in several instances form the crests of prominent ridges and stand out in bold relief like walls of masonry. In one case a

Fig. 17



prominent quartz reef is seen to be intersected by a basic dyke, which may be connected with the volcanic plateau dividing the Lyons and the Ashburton Rivers. It is doubtless from these quartz reefs that the gold occurring in the gullies at Soldier's Secret has been derived. About 1,500 ozs. of alluvial gold is stated to have been obtained from this centre up to the end of 1890, and that the largest piece found weighed about an ounce.

The *Dead Finish Diggings* are situated on the north side of the Ashburton River. The neighbourhood is made up of sandstones, quartzites, and conglomerate which are disposed in a series of more or less acute folds. The quartzites are traversed by quartz reefs, parallel to both the dip and strike of the beds. The reefs appear to occur on the flanks of the arches into which they have been thrown. It is estimated that at the end of 1890 about 1,000 ozs. of alluvial gold, besides a small amount of reef gold, had been obtained from the Dead Finish; the detrital gold was mostly shotty in character, the largest piece recorded weighing about eight ounces.

The *Mount Mortimer Diggings* are situated about six miles south of the Ashburton River, and about 10 miles southeast of Mount Dawson or Mount Mortimer proper. The country rock consists of highly inclined sandstones and grits of the Ashburton Beds. These, which are occasionally faulted, are traversed by quartz veins and leaders. About 1,000 ozs. of alluvial gold has been reported from this centre up to the end of 1890, including a nugget of 56 ozs. Some of the quartz reefs have been worked and portions of them proved to be very rich. One of the most prominent of the quartz reefs contained small patches of galena, one sample of which assayed 59.60 per cent. of lead, 1dwt. 2 grains of gold, in addition to 18ozs. 7dwts. of silver per ton.

GASCOYNE GOLDFIELD.

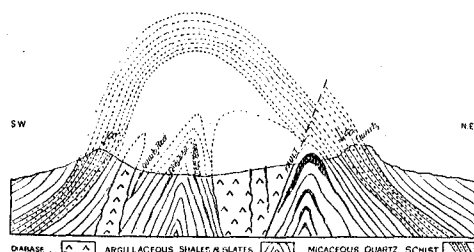
The Gascoyne Goldfield, which embraces an area of 5,313 square miles, was discovered in 1896 and officially proclaimed in 1897. Since that date it has produced 676.54ozs. of gold, of which 337ozs. are the results of the crushing of 356.70 tons of ore. Prospecting and mining operations have been chiefly confined to the neighbourhood of Bangemall.

The *Bangemall Gold Mining Centre* is situated about 270 miles from Carnarvon on one of the tributaries of the Lyons River and about 30 miles west of Mount Augustus, one of the highest mountains in the State. When viewed broadly the geological structure of the area is fairly simple, and the rocks exposed few in number. The rocks consist of slates, limestones, quartzites, and igneous rocks. The productive area of Bangemall lies between two bands of micaceous quartz schist which trend generally northwest; these two bands form the legs of a denuded anticlinal fold which pitches to the southeast, and they trend across country for considerable distances and,

about 12 miles northwest from Bangemall, are also associated with gold-bearing quartz veins. The alluvium in the bottoms of many of the valleys has been worked for its gold contents. The alluvium in Prospectors Creek is the most extensive and that upon which most work has been done; so far as operations have been carried the thickness of the alluvial deposit attains a maximum of from 8 to 10 feet.

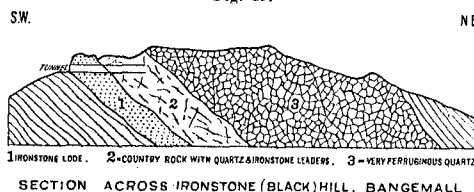
The quartz reefs of Bangemall are very numerous and are all confined to a belt about 60 chains in width exhibiting a marked parallelism in a northwest direction. They vary very much in thickness—from that of a thin sheet of paper up to 120 feet. It is only, however, upon six of them that any mining work has been done. The most important feature of the Bangemall field is the saddle-reef nature of the auriferous quartz veins, of which the one outcropping at the head of Black Hill Gully is the most typical. The vein has a maximum width of 120 feet, in one or two places it rises to a considerable height above the surface, and has a length of at least 6,000 feet. Where the vein is crossed by one of the creeks, both walls of the quartz dip at a fairly steep angle to the northeast and southwest respectively. The reef as followed along the outcrop to the southeastward varies greatly in size and form, and diminishes to mere threads of quartz. The reef forks and the two extremities are in one place about 500 feet apart and represent the legs of a saddle reef which has been laid bare by denudation. (Fig. 18.)

Fig. 18.



Black or Ironstone Hill (Fig. 19) is made up of a series of quartz reefs which trend northwest and southeast. The reefs show all gradations from a pure white quartz reef to a brecciated quartz cemented by oxides of iron, which graduates into a

Fig. 19.



dense limonite with fragments of white and glassy quartz, and finally into a frothy cellular limonite containing a little hematite. Some of the ironstone contains free gold; one small fragment dollied about 60z. of gold, and some contain kernels of solid pyrites. A good deal of chalcidony has been deposited in most of the quartz reefs, and some contain pyrites.

PEAK HILL GOLDFIELD.

The Peak Hill Goldfield, which comprises an area of 23,650 square miles, was established by proclamation and gazetted in 1897. By far the larger portion of the goldfield consists of undulating

country situated on the relatively high plateau drained by the headwaters of the Ashburton, the Gascoyne and Murchison Rivers.

The gold yield from the Peak Hill field as reported to the Mines Department up to the end of 1918 has been 249,889.33 fine oz., of which 1,937.81 ozs. have been obtained from alluvial deposits. The quantity of gold bullion entered for export and received at the Perth branch of the Royal Mint amounts, however, to 208,893.84 fine ounces.

The following synoptical table gives details as to the gold production from the various centres on the Peak Hill Goldfield.

Synoptical Table showing the Gold Yield of the various Mining Centres of the Peak Hill Goldfield up to the end of 1918.

Min g Centre.	Alluvial gold.	Ore crushed.	Gold therefrom.*	Total gold.
	Fine ozs.	Tons (2,240 lbs.)	Fine ozs.	Fine ozs.
Egerton ... ..	...	5,266.00	2,402.58	2,402.58
Horseshoe ... ..	...	744.43	4,001.93	4,001.93
Mt. Fraser ... ..	...	469.50	376.37	376.37
Peak Hill ... ..	...	473,485.38	236,141.30	236,141.30
Ravelstone ... ..	...	4,773.45	3,502.49	3,502.49
Wilgeona ... ..	...	128.50	170.33	170.33
Wildhorpe ... ..	...	47.00	20.93	20.93
From Goldfields generally—				
Sundry parcels treated at Purcell's Works	...	...	294.58	294.58
Sundry parcels treated at State Battery, Egerton	...	...	294.87	294.87
Sundry parcels treated at State Battery, Ravelstone	...	15.00	1,318.87	1,318.87
Sundry parcels treated at Various Works	...	30.00	319.97	319.97
Reported by Banks and Gold Dealers	1,937.81	...	345.17	2,282.98
Total	1,937.81	484,959.26	249,789.39	251,727.20

* Includes 3,951.53 ozs. dollied gold.

Geologically the Peak Hill Goldfield is made up of greenstone schists, phyllites, quartz and mica schists invaded by diabase dykes and intrusive granite, probably of Archaean Age. Representatives of the Ashburton Beds cover a very large area of country and are overlaid by almost horizontal strata belonging to the Nullagine Formation. The most northerly centre where mining operations have been carried on is at Mount Egerton, which lies about eight miles on the north side of the Gascoyne River and about 10 miles south of the Trig. Station erected on Mount Egerton. The mining centre is by no means a new one as it was worked for alluvial gold as far back as the early nineties, though no record exists as to the quantity of gold obtained from it. Serious attention, however, was not paid to the quartz reefs and lodes until the year 1909. The rocks which comprise the gold-bearing zone consist of highly inclined quartz-hornblende-mica schists merging into, on the one hand, ferruginous quartz schists, and on the other, micaceous slates or phyllites. These have been invaded by dykes and veins of hornblende granite and granodiorite, which lies within a belt about 25 chains wide. The quartzites conglomerates and sandstones dip at an angle of 19 degrees to the north on the north side of the belt and at the same angle to the south at the south side, demonstrating the presence of an anticlinal axis along the gold-bearing belt. There are some sound geological reasons for believing this auriferous belt to extend as far westward as Bangemall on the Gascoyne Goldfield where the gold deposits are also laid bare along the axial line of a similar fold (q.v.). The Mount Egerton gold deposits, which have been proved to extend continuously over a

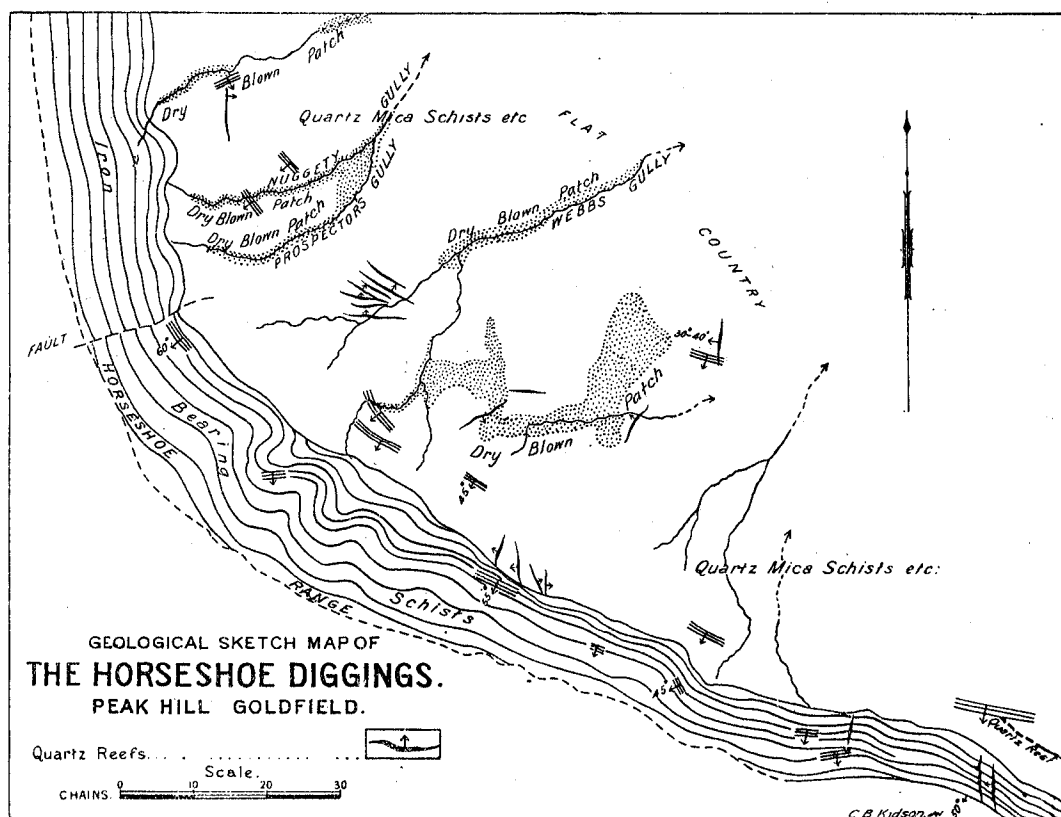
length of about 2 miles, consist of short lenticular lenses of quartz at the northern end of the field and "formations" (auriferous shear zones) on the southern. In order to assist in development a State battery was erected at Mount Egerton in 1912, and up to the end of 1918 there were crushed 7,582 tons of ore, which gave a result of 4,018 ozs. of gold, being at the rate of about half an ounce of gold per ton of ore crushed.

The most productive centre on the field is that of *Peak Hill*, which is situated about 67 miles northeast of Meekatharra, and was discovered in 1892. Peak Hill is a small cone-shaped hill standing on a plateau on the top of the Robinson Range, which divides the waters of the Gascoyne from those of the Murchison River. The townsite of Peak Hill is said to be about 1,930 feet above sea level. The country rock of Peak Hill consists of banded, and, in places, granular quartzites (with secondary silica), iron-bearing

schists, micas, and chlorite schists, all of which are very distinctly and usually regularly foliated. The quartzites and iron-bearing schists generally appear as fairly conspicuous ridges, whilst the more micaceous beds, owing to their feeble resistance to denuding agencies, form the flat or gently undulating portions of the ground. Some of the beds have become highly crystalline by metamorphism, and others resemble very closely the basic (greenstone) schists, which make such prominent features in the geological structure of the more southerly fields.

Garnetiferous amphibolite and biotite-carbonate schist have been met with in the Peak Hill Mine and its vicinity. An important feature in the structural geology of Peak Hill is the presence of almost vertical masses, veins, and dykes of pure silica, which cross the strike of the strata at all angles. In one of the mines a vein of this character is seen cutting across an auriferous quartz reef.

Fig. 20.



They probably represent a pegmatitic phase or the ultra acid portion of a granitic magma. Somewhat similar in their mode of occurrence to these veins are those large masses and dykes of hydrated oxide of iron which make such conspicuous features in some portions of the Peak Hill Goldfield. The gold-bearing ore deposits of Peak Hill consist of a mass of country rock traversed by a net-work of inter-lacing veins of auriferous quartz. The country rock weathers in the direction of kaolin, and possesses, unless in exceptional cases, no sharply defined limits, whilst the gold is not confined to the reefs or veins, but is disseminated through the country rock. The ore-body in the Peak Hill Mine itself trends generally between north and

south and northnortheast and southsouthwest, dipping westward at an angle of about 30 degrees. The lode occurs along a strike fault which coincides with the stratification of the enclosing rocks. The matrix of the lode is largely made up of quartz with fine sealy (sericitic) kaolin, which in the lower levels is more or less chloritic, representing the weathered product of a biotite-carbonate schist. Large ragged pieces of gold as well as rich bunches of ore have been of frequent occurrence in the main vein of the Peak Hill Mine. A variable thickness of superficial deposits rests upon the underlying rocks of the field; these surface deposits consist of loose gravel or loam, from which the gold was obtained by dry-blowing.

This gravel reposes directly upon an irregular surface of iron-stained cement, about 6 to 8 feet thick, which rests upon an old eroded watercourse and fills up the inequalities in the latter, which, however, are of no great depth. In some cases erosion has succeeded in cutting down the cement to bed rock and exposing the underlying schists. Lithologically the cement is an ordinary conglomerate formed by the mechanical action of water; its pebbles being derived from the disintegration and subsequent deposition of the pre-existing rocks. The pebbles are embedded in a matrix of sand formed of the comminuted remains of the underlying rocks. The component parts of the cement are in every way identical with those of the rocks at present outcropping, whilst the quartz pebbles are similar in character to the quartz forming those reefs by which the country rock is traversed. The gold in the cement is not exclusively in grains, scales, or nuggets, but is also found attached to its original quartz matrix. The amount of gold won from the cement, as shown by the official figures, has been considerable. Up to the end of 1897, 1,964 tons of cement crushed yielded 2,105 ozs. 7 dwts., or at the rate of 1 oz. 10 grs. per ton. The official data afford no clue as to whether the 3,349 ozs. of gold returned from the unspecified tonnage of quartz in 1895 has been obtained from the cement or from the superincumbent gravel. It is quite possible that this cement may be a relic of the Nullagine Formation, which occurs in great force some distance to the north and which was probably continuous over the whole of the Peak Hill Goldfield, as what are believed to be representatives of the formation have been met with as far south as the neighbourhood of Meekatharra.

The mining centre of *Horseshoe* is situated on the northeast flank of a sigmoidal-shaped range, which rises very abruptly from the surrounding plains and of which Mount Beasley forms the highest summit. The range has a general north and south trend, and is virtually continuous with that low line of hills which extends as far as the township of Peak Hill, from which it is distant about 16 miles. The range stands up from about 300 to 400 feet above the general level of the surrounding country and is much cut into by several gullies, of which the most important are Nuggetty, Prospector's, and Webb's. The range is made up of metamorphic rocks, hard slates, schists and quartzites, some of which carry such large quantities of hematite as to give a distinctive character to the beds. The outcrop of the iron-bearing bands (Fig. 20) forms the most conspicuous feature of the range and is visible for very great distances; individual beds are in places very minutely pucker and contorted. The slates are underlain by micaceous schists, which never form any conspicuous feature in the landscape. The ore-bodies of Horseshoe consist of small rich "specimen" gold-bearing reefs, the gold in which is stated to be usually found at the intersection of two sets of quartz veins. No reefs of any size have been found at Horseshoe, though some abnormally high returns have been obtained from some of the ore-bodies already worked. The only extensive ore-body worked is the so-called "sandstone lode" met with in a tunnel put through the range by the Horseshoe (Peak Hill) Goldfield Company. The lode, which was from 3 to 6 feet wide, consisted of iron-stained clayey matter with siliceous grit and blocks of decomposed felspathic rock, the whole being traversed by numerous irregular veins of iron-stained quartz which occasionally contained some gold.

Some of the quartz of the Horseshoe reefs contains fair bunches of galena, though in no case in sufficient quantity to be worth saving. A considerable quantity of alluvial gold has been obtained from the gravels at the foot of the range, and £16,000 worth is stated to have been taken by the dry-blowers from Nuggetty Gully.

MURCHISON GOLDFIELD.

The Murchison is of some historical interest in that in the year 1855, when the economic value of the district as regards its mineral resources was entirely prospective, it was officially set forth in a report to the Government that the country to the east of the Murchison

River had every appearance of being one of the finest goldfields in the world. While it cannot be said that the goldfield, which embraces an area of 25,474 square miles, and which constitutes one of the most important auriferous regions of the State, has come up to the high expectations then formed of it, still the Murchison does possess what is believed to be one of the largest solid quartz reefs mined anywhere—the Great Fingall Reef at Day Dawn, in addition to the phenomenally large and rich iron-ore deposits of the Wilgie Mia in the Weld Range.

The Murchison rose from the position of a pastoral district in the year 1891, when the first gold find of any real importance took place at Nannine. Gold was, however, discovered in 1888 a few miles to the north of Cuddingwarra, though the find attracted but little attention at the time.

Since the first discovery of gold, operations, despite the many causes which stood in the way of mining development, have been carried out on the Murchison Goldfield which has been responsible for 2,906,268.23 ounces of the State's total output of gold at the close of the year 1918. Of this amount 15,324.52 ozs. have been derived from alluvial deposits.

Synoptical Table showing the Gold Yield of the various Mining Centres of the Murchison Goldfield up to the end of 1918.

Mining Centre.	Alluvial gold.	Ore treated.	Gold therefrom.*	Total gold.
		Tons.		
	Fine ozs.	(2,240 lbs.)	Fine ozs.*	Fine ozs.
Barrambie ...	...	16,974.42	14,396.82	14,396.82
Cuddingwarra ...	10.59	60,188.65	49,202.77	49,213.36
Cue ...	55.67	278,883.21	209,279.31	209,334.98
Erola ...	...	1,510.65	2,484.71	2,484.71
Erol's ...	...	14,325.50	9,015.35	9,015.35
Mindoolah ...	3.07	8,939.50	5,906.91	5,909.98
Roedy's Find ...	164.88	1,246.80	3,887.03	4,051.91
Tuckabianna ...	23.44	2,652.00	3,786.71	3,810.15
Tuckanarra ...	66.59	20,598.80	29,332.68	29,399.27
Abbot's ...	...	35,240.20	37,232.83	37,232.83
Burnakura ...	12.51	38,617.95	34,011.44	34,023.95
Chesterfield ...	29.02	7,184.86	8,365.63	8,394.65
Gabanintha ...	1.33	22,981.50	14,241.30	14,242.63
Garden Gully ...	26.36	30,092.16	21,833.61	21,859.97
Gum Creek ...	25.27	3,977.08	3,726.04	3,751.31
Holden's Find ...	...	7,244.25	3,008.40	3,008.40
Jillawarra ...	169.02	1,523.05	4,132.97	4,301.99
Meekla Pools ...	...	323.30	269.94	269.94
Meekatharra ...	185.71	837,609.61	560,053.68	560,239.39
Munara Gully ...	...	13,247.75	6,541.29	6,541.29
Nannine ...	41.65	94,175.82	69,958.25	69,999.90
Quinn's ...	9.55	20,548.66	12,087.37	12,096.92
Ruby Well ...	...	7,704.00	4,338.50	4,338.50
Stake Well ...	...	21,528.00	9,959.98	9,959.98
Star of the East ...	...	27,371.62	20,400.37	20,400.37
Yaloginda ...	10.89	27,722.19	16,078.84	16,089.73
Day Dawn ...	126.30	1,908,013.47	1,213,967.49	1,214,093.79
Jasper Hill ...	4.90	15,495.75	10,835.87	10,840.77
Lake Austin ...	608.26	30,256.01	47,494.24	48,102.56
Mainland ...	3.65	7,349.58	25,998.20	26,001.85
Lennonville ...	7.11	141,758.90	127,695.64	127,702.75
Mt. Magnet ...	28.28	378,138.77	225,054.18	225,082.46
Mt. Magnet East ...	63.29	5,736.78	3,757.60	3,820.89
Moyagee ...	...	3,123.38	4,474.01	4,474.01
Paynesville ...	...	47.50	756.41	756.41
Youanme ...	...	33.00	44.58	44.58
From Districts generally	...	8,679.59	77,290.89	77,290.89
Reported from Banks and Dealers	13,647.18	...	41.77	13,688.95
Total ...	15,324.52	4,101,944.26	2,890,943.61	2,906,268.13

*Includes 35,577.29 dollied and specimens.

The Export and Mint figures, however, give the gold yield of the Murchison field to be 3,129,884.03 fine ounces. The mines of the Murchison yield almost entirely gold, though there are a few locali-

ties from which small quantities of copper and tin have been obtained, but so far they have not proved to be of any importance and have been described under the respective headings of copper and tin.

The geological structure of the Murchison mineral belt is remarkable for its uniformity. It may be described as a series of more or less persistent zones of schists and allied metamorphic rocks (in part sedimentary) forming a more or less distinct lithological province. The schists and their associated rocks are notable by reason of their persistent strike and horizontal extent, one belt alone having been proved to be continuous for at least 30 miles. These zones of schists are everywhere surrounded by granite, which seems to be of two distinct geological ages, viz., an older, which has undergone the same dynamic alteration to which the schists owe their origin, and a much newer, which penetrates the older granite as well as the schists. The schists are associated with diabase (dolerite), pyroxenite, and allied rocks and there are sound reasons for believing that some at any rate of the schists merely represent crushed or plated out varieties of the basic rocks. Portions of the field are traversed by belts of laminated quartzites which appear to be quartz reefs of a specialised type. These laminated quartzites are intersected by numerous faults which are of economic importance by reason of the fact that it is along them that rich shoots of gold often occur.

Meekatharra.—One of the principal mining centres along the belt is Meekatharra, which is one of the most northerly of the Murchison mineral bearing belt.

The mining centre of Meekatharra, for many years regarded as the "bright spot" of the Murchison Goldfield, is situated on the great central plateau of Western Australia, at an altitude of about 1,700 feet above sea-level, and on the divide which separates the areas of exterior and interior drainage. The principal streams belonging to the system of exterior drainage all discharge into the Murchison River, which flows westward into the Indian Ocean, whilst those of the interior drainage system flow southwards into the inland basin of Lake Anneau.

The average rainfall of the district is low, viz., 10 inches, and being very irregular there is no surface water except at very rare intervals.

The geological constitution of Meekatharra consists in the main of a complex of crystalline rocks comprising granitic, doleritic, and peridotitic types.

Upon this ancient complex of crystalline rocks, a series of bedded deposits, chiefly arkose, conglomerate and indurated black slate, was laid down; to this succeeded the great outburst of granite and allied acid igneous rocks which, just to the north of Meekatharra, enclosed, compressed and otherwise altered the sediments to such an extent that it is not now readily possible to differentiate them from the rocks upon which they were originally deposited.

The granitic rocks occupy the western portion of the Meekatharra area, and form a band of about two or three miles in width with a general north-easterly strike. The granite is intrusive into the older crystalline complex and sends out veins into the basic rocks, in addition to containing masses of the latter along its eastern margin. Of the granite two lithological types have been recognised, viz. (a) a hornblende granite (or quartz-diorite) in which the feldspars are often represented by epidote, and (b) a biotite-microcline granite. There are also gradational types which point to an intimate relationship between the two varieties; the two granites, however, form part of one and the same mass.

An important feature in the area is the number of acidic dykes which intersect the older rocks of Meekatharra; these, in all probability, form the apophyses of the large granite mass to the west of the ore-bearing belt. The acid dykes, which weather into a white kaolin, are often sealed with quartz veins, a typical example of which occurs in the 300 feet level in the Ingliston Extended Gold

Mine (Fig. 21). These are often closely associated with auriferous veins and formations, though the acid dykes were introduced somewhat earlier than the deposition of the gold.

Fig. 21.



Photo.: E. de C. Clarke.

Neg. 1420.

Weathered Porphyry in 300ft. level, Ingliston Extd. G.M.
Quartz veins more evident than in fresher rock.

The largest and by far the most important part of the field is made up of a congeries of basic rocks, having a considerable petrological range, though linked together by ties of affinity, and comprise two main groups, viz.:—

- (a) The comparatively fresh greenstones which include dolerite, norite, amphibolite, epidiorite, and serpentine; and
- (b) much altered chloritic, carbonated and talcose rocks, in which the individuality and geological identity appear to have been almost entirely lost, due perhaps in part to the thermal metamorphism of the granite.

The relation of the various rock types to one another is not in all cases quite clear.

The serpentines have a general parallelism to the prevailing strike of the schists, and from the mode of occurrence of that associated with the ore-bearing belt, it may, perhaps, represent an intrusion sill-like in character.

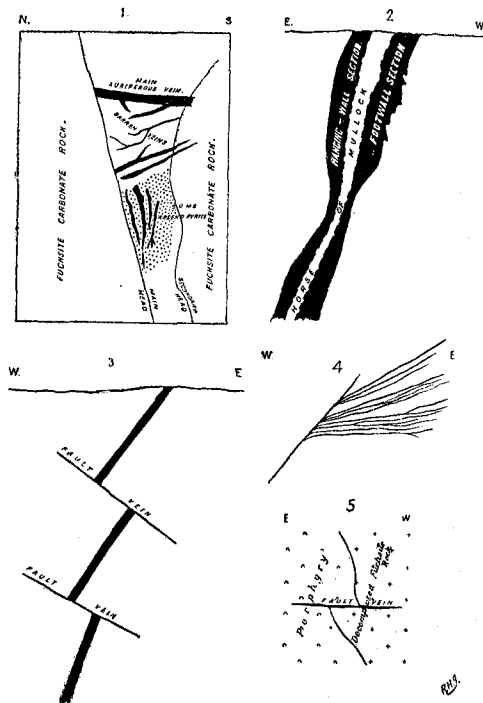
Unaltered dolerite dykes occur in several localities; they probably represent one of the latest, if not the last, phase of eruptive activity in this portion of the Murchison field. These dolerite dykes are found in some of the mine workings of the main auriferous belt; they are younger than the ore and are in no way genetically connected therewith.

A series of volcanic beds in the form of flows of basalt and andesite, together with breccias and tuffs which are in a fresh state of preservation, is associated with these basic rocks. They occur just to the east of the Meekatharra gold-bearing belt of Paddy's Flat.

Highly inclined sedimentary rocks, in the form of arkoses, grits, and conglomerates, occur a short distance to the northeast of Meekatharra, adjoining the southeastern edge of the granite; these occasionally contain small quartz veins, indicating that they were formed prior to the mineralisation of the district; they owe their present position to tectonic disturbances.

The underground water-level in the district is usually below 100 feet in depth, and it is only very rarely that any large quantity of meteoric water reaches the supply already stored in the rocks.

Fig. 22.



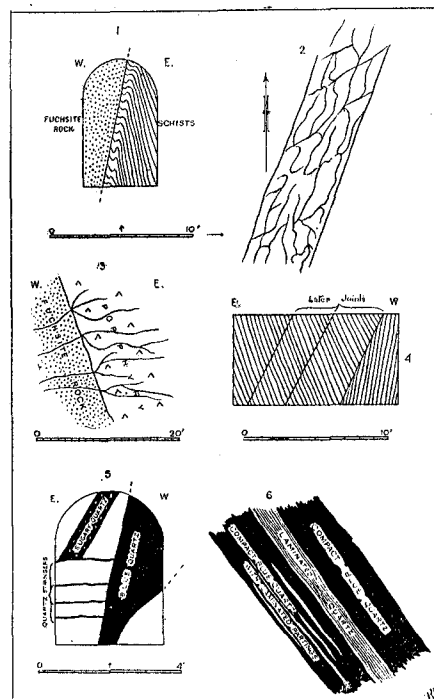
Sections illustrating Features in Workings near Meekatharra.

1. Globe G.M.: Relation of veins and fuchsite rock. Scale: 8ft. = 1in.
2. Macquarie G.M.: Diagrammatic cross-section of lode.
3. Globe G.M.: Supposed structure of ore body (Diagram.)
4. Gwalia Extended G.M.L.: Shaft F—three groups of quartz stringers united to form a rich vein. (Diagram.)
5. Gwalia Extended G.M.L.: Shaft H—relation between flat vein, porphyry, and fuchsite rock. Scale: 8ft. = 1in.

The underground waters, of which several samples have been analysed, prove to be of one general type, and in all probability owe the concentration of the contained salts in part to residual oceanic waters, to rain, and to local weathering of rocks and lodes. The waters would not, however, appear to have played any part in

ore deposition, and it has been found that the circulation of water underground in Paddy's Flat is slow and restricted, even in the direction of the prevailing foliation, so that at right angles to this it must be almost negligible. To what extent the composition of the underground waters has been influenced by residual magmatic water there is no evidence at present available. A very conspicuous feature in the field is that complex set of structures now represented by bands of jaspilite often having a ribbon-like structure.

Fig. 23.



Geological Features in Workings near Meekatharra.

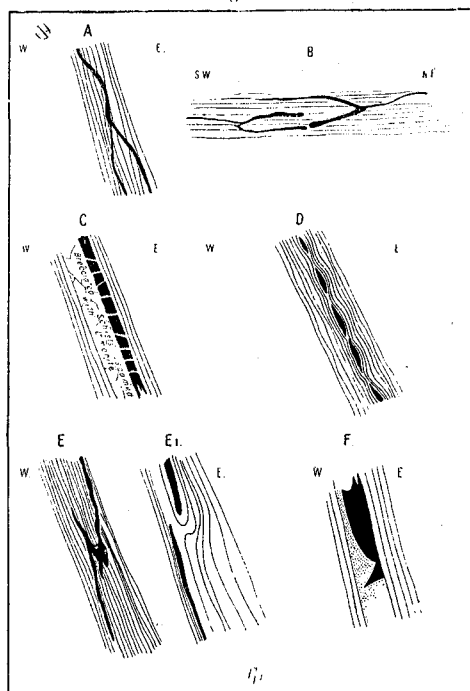
1. Ingliston Consols Extd. G.M., 174ft. level (section).
2. Ingliston Consols Extd. G.M.—Arrangement of quartz veinlets in lode (diagrammatic plan).
3. Marmont G.M., 196ft. level—Quartz veins are auriferous at contact of fuchsite rock and porphyry (section).
4. Ingliston Extd. G.M., 300ft. level—Shear planes of schists displaced by later joints (section).
5. Pioneer Group, Shaft 7—A "sugary" quartz vein cut off by stringers from main vein (section).
6. Pioneer Group, Shaft 11—Section showing structure of vein. Scale: 4ft. = 1in.

These bands, which have a general strike of north-northeast, owe their origin to compression and intense shearing, and a subsequent metasomatic replacement of the fine-grained chloritic schists through the action of carbonated waters.

The ore deposits of Meekatharra are almost entirely restricted to the eastern portion of the field and are principally confined to the marginal zone of the granite and its metamorphic aureole. They have a more or less definite strike, parallel to that of the main tectonic lines of the field. There are two distinct directions—one north and south and the other east and west—in which fault and shear planes run. The north and south shear planes are the most

important geological feature, since, with several minor exceptions, such have determined the lines of the gold-bearing deposits, and it is noteworthy that these rocks, which have not in some measure yielded to the shearing stresses, are destitute of auriferous lodes. When viewed broadly, the ore deposits consist of veins and lodes. The veins are principally quartz, some of which are probably but an ultra-acid phase of the porphyry dykes, whilst the lodes consist of—(a) deposits which owe their origin to metalliferous solutions, emanating from the acid magma, which constituted the primary source of the granite and (b) silicious impregnations of zones of sheared country rock. The types of ore deposits in some of the workings near Meekatharra are shown in Figs. 22 and 23. The Yaloginda belt, at the south end of Meekatharra, is made up of almost vertical sheared rocks, in which the ore bodies are formed of lenticular quartz veins, which lie parallel to the shear planes and represent a replacement of the country rock. The quartz veins are

Fig. 24.



Typical Sections of Yaloginda Veins.

Scale: 12ft. = 1in.

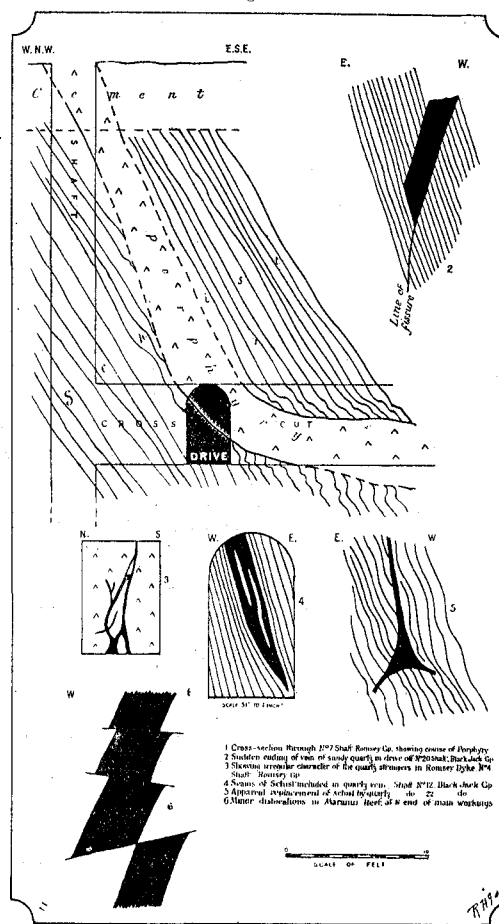
- A. Yaloginda Belt, Shaft 6—Branching vein—section.
- B. Yaloginda Belt, Shaft 22—Branching vein—plan.
- C. Yaloginda Belt, Shaft 43—North Revenue Vein—section.
- D. Yaloginda Belt, Shaft 65—Eerin Vein—section.
- E. & E1. Yaloginda Belt—Sections of Rocklee Vein in 73ft. level and below 45ft. level.
- F. Yaloginda Belt, Shaft 85—Relation between compact and "sugary" quartz.

very often in the form of kidney-shaped masses, not more than two feet in thickness. Some typical sections of these occurrences are shown in Figs. 24 and 25. The ore deposits contain but a small number of minerals other than the gold contents, the quartz and allied veins are usually destitute of minerals, whilst the metasomatic

auriferous bodies contain arsenopyrite as the most important metallic mineral, though pyrites occurs in smaller quantities.

Of the geological age of the auriferous deposits, there is, at the present time, no direct evidence, although everything points to the Pre-Cambrian as being the most probable; but though this may be the case, it does not follow that the fissuring and mineralisation were necessarily contemporaneous. The deposits would appear to have closely followed the intrusion of the Meekatharra granite, which is,

Fig. 25.



Types of Veins and Lodes near Yaloginda.

perhaps, from the economic point of view, the most important geological event at this period. The returns, which furnish as complete a record of the yield of the various deposits as possible, show that, up to the end of 1916, the total output from the Meekatharra Centre amounted to 499,509 ozs. of fine gold, together with 2,460.40 ozs. of fine silver, derived from the milling of 740,732 tons of ore, in addition to 1,757 ozs. of specimen and detrital gold. The abandoned workings on the field, however, do not of necessity imply that the deposits have been exhausted, for it is possible that many may be re-opened and possibly worked under more favourable conditions than at present prevail.

The underground mapping of the lodes and fissures and their presentation on a uniform scale as in Bulletin 68, *q.v.*, should tend to materially facilitate future exploration work.

Cue and Day Dawn.—The mining centre of Cue, the official headquarters of the Murchison Goldfield, is situated at an altitude of 1,485 feet above sea level on the western edge of the granite plateau, which extends for a considerable distance to the eastward, and which is drained by creeks falling into Lake Austin on the south. The first gold was found at Cue in the year 1891, though it was not until the year 1893 that the reefs were opened up. The country in the vicinity of Cue is made up of granite and schistose rocks, intersected by dykes and masses of both basic and acid rocks. By far the larger portion of the country to the north and west of Cue is made up of granodiorite, which is intrusive and sends out dykes into the basic schists, etc. The granodiorite, which has a granitic habit, forms the matrix of the numerous productive quartz reefs, and upon its surface those large areas of gold-bearing residual deposits have been discovered which have proved such rich dry-blowing patches. The gold-bearing reefs occurring in the granodiorite are of two diverse types, viz.: (a) those which are more or less parallel to the boundary between the granodiorite and the amphibolites and which have a northerly underlie, and (b) those which radiate from the contact area and underlie generally westwards.

A certain number of quartz reefs occur in the amphibolite and other basic rocks; these have been estimated to constitute about one-tenth of the auriferous reefs in the vicinity of Cue, and have yielded about one-twentieth of the total gold production of the vicinity. The reefs of this class exhibit a general parallelism with that of the boundary which divides the granodiorite from the basic rocks, though they have not the same linear continuity as the reefs in the granodiorite. There are no gold-bearing alluvia in the Cue district, though there are extensive patches of residual deposits, from which a considerable quantity of gold was obtained in the early days of the field, but of which no authentic record is available. The two main areas of residual deposits are known as the Patch and the Pearling Ground. The gold in the Patch occurred in a very quartzose surface formation about 12 inches in thickness; the gold was generally ragged and flaky and was found at times adhering to the quartz. Later it was discovered that the Patch was underlain by a series of more or less horizontal payable gold-bearing quartz reefs, to the disintegration of which the residuals in the area were due. The gold in the Pearling Ground was large and rough and was often found adhering to and contained in fragments and lumps of quartz, which resulted directly from the disintegration *in situ* of quartz veins of considerable richness.

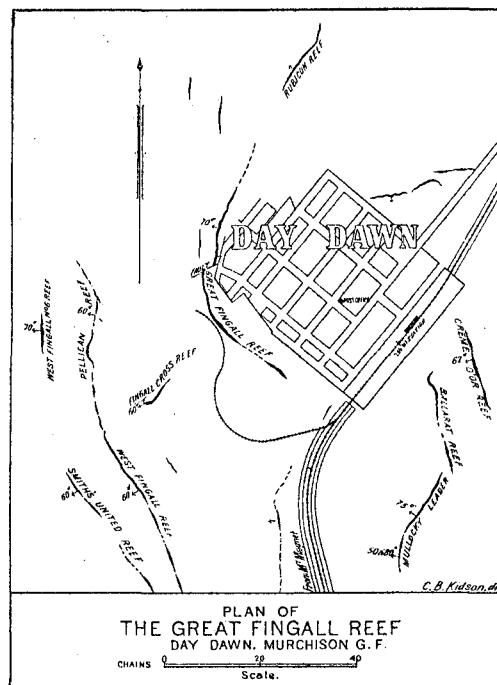
The belt of basic rocks of Cue—epidiorite and amphibolite—continues southwards to the mining centre of Day Dawn, where they cover extensive areas of country. Day Dawn was discovered in 1891, when what is now known as the Great Fingall Reef was found.

Very little alluvial or detrital gold has ever been found at Day Dawn and such relatively small patches as have been worked occurred not far from the outcrops of quartz reefs, to which their enrichment could be readily traced.

The principal mine at Day Dawn is The Great Fingall, the ore body in which constitutes one of the largest solid quartz reefs mined anywhere. The reef (Fig. 26), which has a boomerang-shaped outcrop of about 30 chains in length, has produced up to the end of 1918, 1,181,197.48 ozs. of fine gold and 169,210.20 ozs. of silver from the milling of 1,861,947.01 tons of ore. The average underlay of the Great Fingall Reef is about 60 degrees to the southwest, and its maximum thickness 40 feet. The reef pinches, however, at either end to mere stringers and threads of quartz. The ore-shoot was of considerable size, separated by zones of poor or barren ground, and did not follow the fissure plane down its full dip but traversed it diagonally. The main shoot varied from 6 to 40 feet in thickness, with an average length of about 600 feet. The lowest vertical depth at which the reef has been mined is 2,500 feet. The Great Fingall Reef is more or less transverse to the general trend

of the main tectonic lines of the field, which constitute the general trend of the reefs in the ore-bearing zone; it occupies a relatively narrow zone of schistose amphibolite, which is traversed by basaltic dolerite and acid porphyry dykes. The quartz below water level contains small quantities of pyrites, pyrrhotite, mis-pickel, zinc blende, galena, and a little copper pyrites.

Fig. 26.



Mount Magnet and Lennonville.—The mineral zone which traverses the northern portion of the Murchison Goldfield is continuous through the Mainland and Lake Austin as far south as Mount Magnet and Lennonville. The fundamental rocks of the southern belt consist of a series of amphibolites, epidiorites, the pyroxenites and their sheared and altered forms, into which granite is intrusive. There are, in addition, several acid dykes, felsite, and quartz-porphry, some of which carry small gold-bearing quartz veins. The granite forms a relatively narrow belt on the eastern side of the gold-bearing area between Mount Magnet and Lennonville, whilst on the west it covers an extensive tract of country. The ore deposits of the belt are divisible into: (a) quartz reefs, (b) banded quartzite (?) lodes of which there are two types: the hematite and the non-hematite-bearing, and (c) what may best be described as fault lodes.

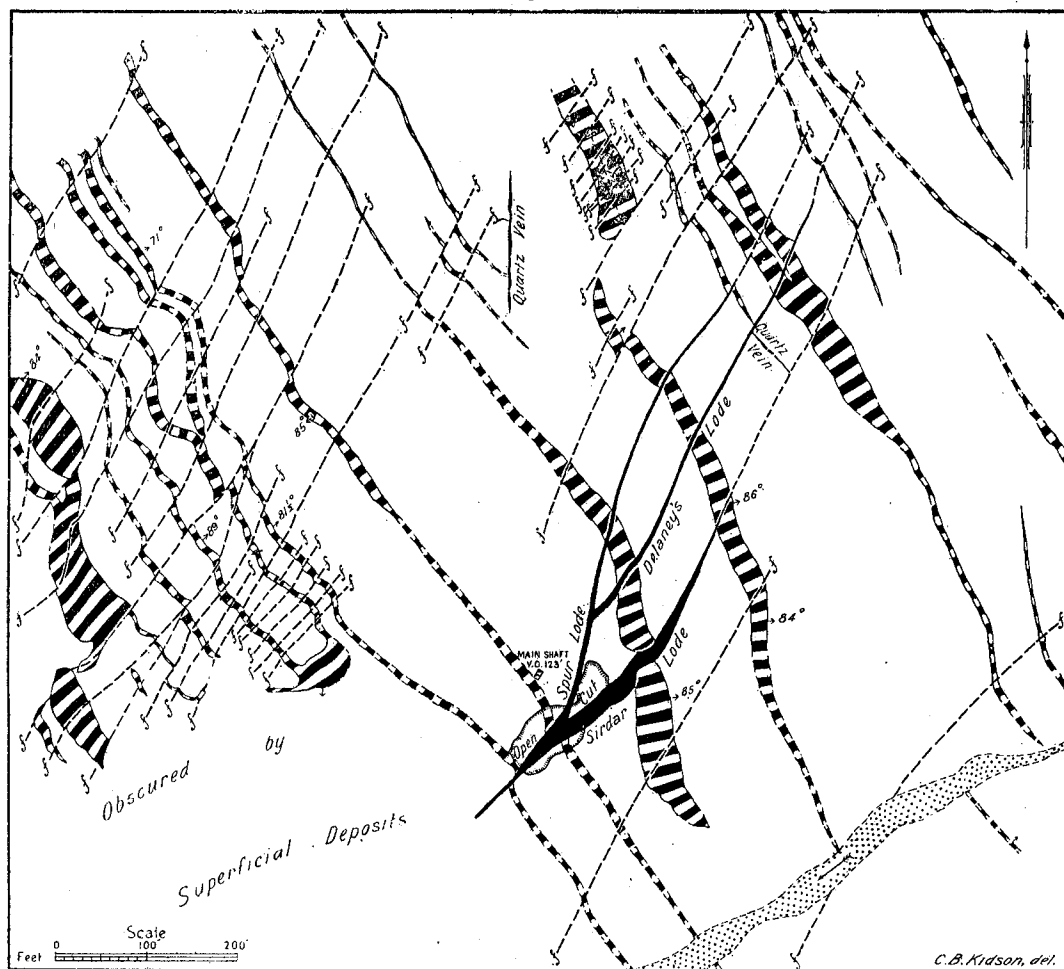
The quartz reefs occur both in the granite and the greenstones, though it is only in the latter that they have been proved to be auriferous. When viewed as a whole they exhibit a general parallelism which coincides more or less with the boundary which separates the granite from the greenstones. Some of the more well-defined lodes and reefs occupy what appear to be fault fissures, whilst others occur in fissures between the foliation planes of the schists and other small cross-fractures. The reefs have been found to differ greatly in thickness, varying from a few inches to as much as 15 feet, whilst some are of considerable longitudinal extent. The Long Reef at Lennonville has been followed along the strike for a distance of

about 1,500 feet, and the New Chum Reef at Mount Magnet for about 1,000 feet. The reefs in the district have been proved to be gold-bearing to the greatest depth yet mined, viz., about 500 feet. The quartz of which the reefs are made up contains pyrites as the commonest accessory mineral; ores of antimony and manganese also occur, though in relatively small quantities.

The banded quartzite lodes are thick masses of more or less altered greenstones, which trend in long and almost vertical bands in

a general north and south direction. They vary greatly in width, sometimes attaining 15 chains, with a length of as much as 240 chains. The more iron-bearing varieties are made up of thin alternating layers of quartz and iron oxides (magnetite and hematite), some of which have been found to contain as much as 50 per cent. of metallic iron. Deposits of this type characterise the Boogardie neighbourhood, whilst the quartzose or jaspery type form the prevalent variety in the vicinity of Lemonville. These quartzite (?) lodes

Fig. 27.



THE SIRDAR LODE. BOOGARDIE, MURCHISON GOLDFIELD.

Greenstone. Jasperite. Alluvium. Faults.

are associated with very thin veins of quartz when they are gold-bearing. The greatest depth at which lodes of this type have been met with is in the Saint George Mine at Mount Magnet, where mining operations ceased at a vertical depth of 300 feet below the surface, at which depth the ore-body was partly quartzose and

partly graphitic and contained some iron pyrites. The gold in this quartzitic type is generally free and very fine.

The fault lodes are, as their name implies, bands of lode stuff lying between fault planes which generally cut across the iron-bearing quartzites almost at right angles to their general trend; these struc-

tural features are of considerable importance from a mining point of view, in that it is along these lines that many of the rich shoots of gold, for which the district is famous, occur. The fault planes vary in width from that of mere threads up to as much as 15 feet, and are at times filled with soft decomposed earthy rock which occasionally exhibits shearing parallel to the boundaries, and, at others, with brecciated fragments of the enclosing quartzites embedded in a cement of iron and chaledonic quartz. Quartz stringers are often met with in the fault planes, and these have been found to be very highly auriferous. It is of importance to note that the geological mapping of the district has shown that quartz reefs often form the continuation of these fault lines. In the Boogardie district there are a great number of these quartzite and jasper lodes, which are traversed by these fault planes in considerable numbers.

These breaks, of which one of the most typical instances occurs in the Sirdar Mine at Boogardie, have proved at times to be extremely rich in gold (Fig. 27). The Sirdar lode and its two branches have alone produced, up to the end of 1918, 6,225.14 ozs. of gold from the milling of 17,852.85 tons of ore.

Quinn's.—The mining centre of Quinn's lies somewhat to the eastward of what may be called the Meekatharra-Magnet belt, at about 22½ miles southeast of Nannine and 35 miles northeast of Tuckanara.

As a gold producer, Quinn's has not added any very large amount to the yield of the Murchison field; it possesses, however, some peculiarities in geological structure, which are of more than local importance.

The larger portion of Quinn's is made up of epidiorite, which surrounds areas of metamorphic rocks, now represented by quartz-chlorite, quartz andalusite, and chlorite tale rocks, believed to be of sedimentary origin. The contact between the two rock series is marked by a circular belt of jasper (Fig. 28). The quartz reefs of Quinn's are divisible into (a) the large non-auriferous "buck" reefs, probably an ultra-acid phase of the pegmatite dykes, and (b) the gold-bearing quartz reefs and veins. The reefs are arranged in two directions, roughly, at right angles to each other, viz., east-northeast and northwest, whilst the veins in each group are approximately parallel to each other. The gold-bearing reefs in the epidiorites have been found to contain some very rich patches of gold where, as at Boogardie, they intersect the jasper bars, whilst those in the metamorphic sediments (?) are the most persistent besides being of very great length. The Three Sisters Reef has been proved to extend for over a mile in length. The reefs naturally vary very much in width, some being mere threads of quartz and others measuring five feet from wall to wall. The reefs are of white or bluish laminated and jointed quartz, in which the gold is somewhat erratic in its occurrence. None of the workings at Quinn's has been carried down below 200 feet vertically below the surface.

YILGARN GOLDFIELD.

The Yilgarn Goldfield, which embraces an area of 17,700 square miles, was discovered in 1887, and established by proclamation, gazetted in 1888.

The first authentic gold find on the Yilgarn Goldfield was made at Ennuin in 1887; this was shortly afterwards followed by the discovery of the Pioneer Mine, Fraser's, at Southern Cross, which has been more or less continuously worked for over a quarter of a century.

Mining operations on the Yalgoo Goldfield have been confined to 16 more or less widely separated centres. The field has since its discovery produced 906,977.07 ozs. of fine gold, of which the Fraser's lode alone has yielded 174,813.49 ozs. of fine gold.

The following synoptical table gives details as to the gold production from the different centres on the Yilgarn Goldfield:—

Synoptical Table showing Gold Yield of the Yilgarn Gold field up to the end of 1918.

District or Mining Centre	Alluvial gold.	Ore treated	Gold therefrom.	Total Gold Yield.
	Fine ozs.	Tons. (2,240lbs.)	Fine ozs.*	Fine ozs.
Blackbourne ...	...	1,282.50	341.37	341.37
Bullfinch ...	...	335,613.49	146,363.22	146,363.22
Corinthian ...	...	134,581.50	29,398.12	29,398.12
Ennuin ...	...	251.56	433.46	433.46
Forrestonia ...	...	77.00	58.26	58.26
Golden Valley ...	...	8,914.46	9,990.28	9,990.28
Greenmount ...	45.99	113,961.50	28,981.06	29,027.05
Hope's Hill ...	...	131,837.55	35,930.63	35,930.63
Kennyville ...	...	25,427.35	13,470.66	13,470.66
Koolyanobbing ...	...	363.00	127.98	127.98
Marvel Loch ...	7.72	347,619.25	108,096.88	108,104.60
Mt. Jackson ...	4.42	38,667.78	28,879.31	28,883.73
Mt. Rankin ...	3.84	666.00	181.75	185.59
Parker's Range ...	...	30,280.50	15,385.20	15,385.20
Southern Cross ...	5.86	436,385.30	213,268.35	213,274.21
Weston's ...	...	333,164.77	235,708.85	325,708.85
From Districts generally	...	126.28	40,268.28	40,268.28
From Banks and Gold Dealers	22.05	...	3.53	25.58
Total ...	89.88	1,959,219.79	906,887.19	906,977.07

*Includes 1,394.70 ozs. Dolled and Specimens.

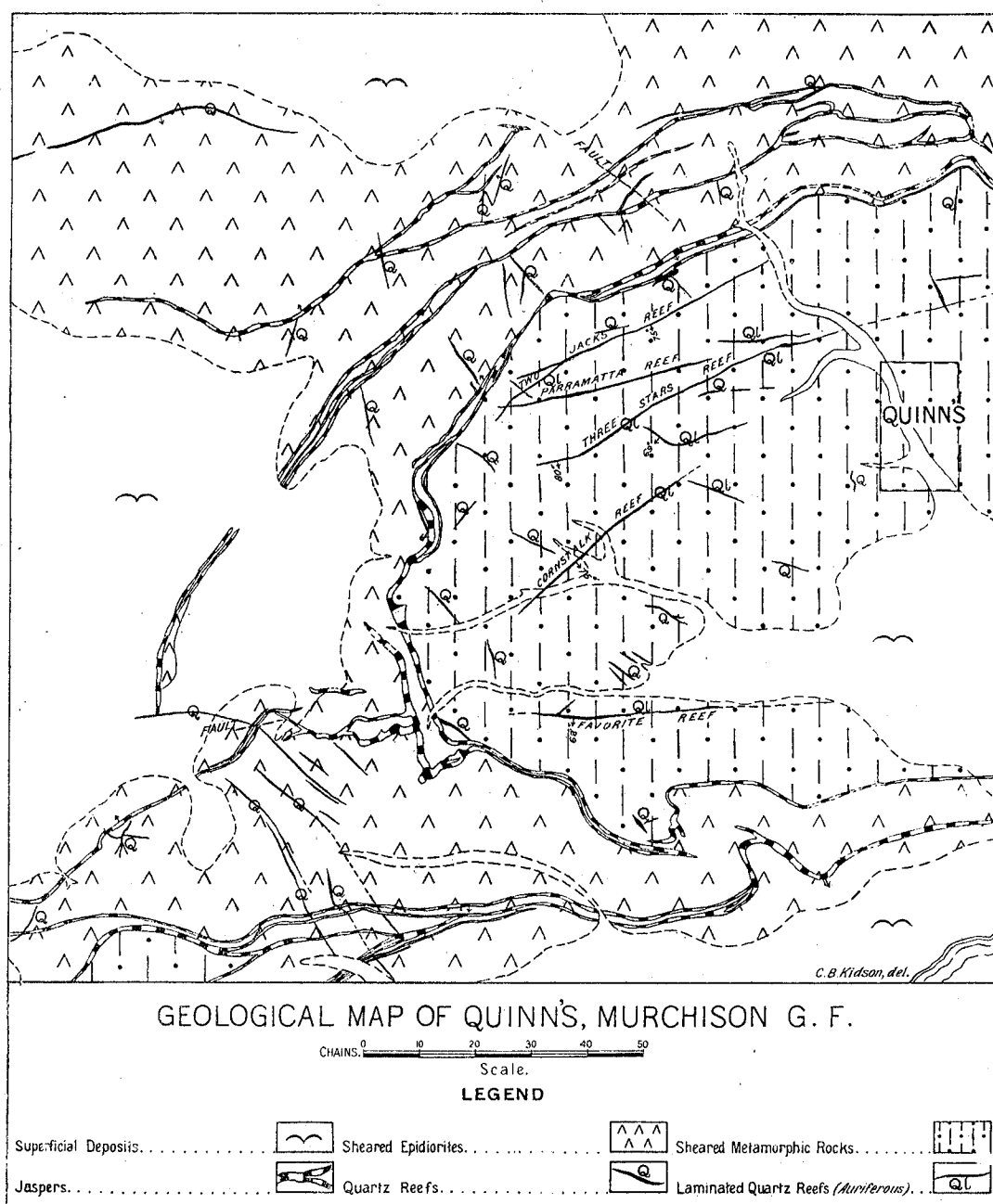
The figures in the above table have been compiled from the data furnished by the Statistical branch of the Mines Department. It is more than likely that these figures do not accurately represent the production of the Yilgarn Goldfield, for in the early days of the field a great deal of the gold won was probably never officially reported to the Government. No silver has been mined in the Yilgarn Goldfield, its occurrence being incidental to the output of gold. The total amount of silver produced up to the end of 1918 is only 23,795.60 fine ozs.; it occurs, however, at nearly every centre, though in most cases the amount is so small as to be almost negligible.

A high-grade deposit of iron ore occurs in the Koolyanobbing Range, near Lake Seabrook; the ore, which is fully described in the section dealing with the iron deposits, consists of micaceous haematite, associated with the ferruginous jaspilites which form the backbone of the range. The ore is one of the purest yet found in Western Australia.

The Yilgarn Goldfield, as one of the important gold-bearing areas, comprises in its geology and mineral resources much that is typical of the Interior Plateau, and exhibits a considerable diversity in geological constitution. The chief interest in the field centres in the gold-bearing deposits which, when viewed broadly, form three more or less distinct belts rather than the more general problems of geology, of which it, however, presents very many calling for much detailed research. The rocks of the Yilgarn Goldfield may be divided into three classes, viz., granite and its allies, those that are of undoubted sedimentary and those that are of igneous origin. By far the larger area of the goldfield is made up of granite, which is of distinctly later origin than the greenstones, as these are invaded by dykes of pegmatite and veins of granitic quartz. There is a very large area of rhyolite porphyry showing flow structure at the edge of the granite lying to the north of Mt. Jackson, of which it may possibly represent a fine grained marginal zone, though it has been described as a true acid lava.

The mineral zone which traverses the Murchison Goldfield seems to be, more or less, continuous southward, through the Yilgarn Goldfield.

Fig. 28.



The gold-bearing belts of the field may be designated for convenience of description:—

(a) The Yilgarn Gold Belt: This, which has a length of over 100 miles, enters the goldfield on its southern boundary, near Mt. Ironcap, and passes through Mount Holland, Cheriton's, Parker's

Range, Marvel Loch, Southern Cross, Corinthian, Bullfinch, Golden Valley, and terminates near Eneuin.

(b) The Mount Jackson and Bungalbin Belt is the most northerly of the gold-bearing areas; it has a longitudinal extent of a little over 30 miles and a general trend of northwest and southeast.

(c) The Westonia Belt, which is a more or less isolated area, lying about 35 miles to the west of the main or Yilgarn Gold Belt. It includes Boodalin, and its length, so far as is known, does not exceed 25 miles, whilst its width is about 5 miles.

Yilgarn Gold Belt.—The oldest rocks of the Yilgarn Gold Belt are of sedimentary origin; they extend from a point southwest of Cheriton's northwards, past the Great Victoria Mine to Marvel Loch, and continue further northwards, occupying part of the country near Bullfinch and Golden Valley, where they appear to terminate. South of Southern Cross there are five closely related areas of sediments, the largest of which is directly in contact with the granite on its western margin. Near Bullfinch the sedimentary rocks occur in two belts, one about four miles long and about 25 chains wide, the second 13 miles long and about 60 chains wide, near Golden Valley. The beds are made up of sericite, graphite, andalusite and mica phyllites, with siliceous and ferruginous quartzites, together with conglomerates, in which the pebbles, varying in size from that of a pea up to 4 or 5 inches long, have been drawn out or otherwise more or less deformed by intense pressure. Some of the more highly siliceous sedimentary rocks are only distinguishable with difficulty from vein quartz. Many of these sedimentary rocks present all the phenomena resulting from contact metamorphism.

Along the eastern margin of the belt to the south of Southern Cross the strata are almost vertical, and on the southwest they dip at angles varying from 40 to 50 degrees to the west, whilst near the northern end of the belt they dip eastward at angles alternating from 80 to 85 degrees. There are strong geological reasons for believing the beds to have been highly folded, the axis of which trends from northwest to north five degrees east. Near Golden Valley the quartz reefs dip both to the east and the west, conforming in this respect to the dominant structural features of the district. It has not been found possible to obtain a reliable basis with which to enable an estimate to be made as to the thickness of these ancient sediments, though it appears to be considerable.

After the deposition of the sediments they appear to have been invaded by great masses of basic igneous rocks, and erosion has been carried on over a sufficiently long geological period to expose the intrusive granite and its associated differentiates. The basic rocks consist of amphibolite, hornblende, epidiorite, and dolerite; some of the greenstones exhibit a pronounced schistose structure, and it may be that some are of sedimentary origin. The greenstone schists are of considerable economic importance in that they form the matrices of many of the gold-bearing ore bodies of the belt. The coarse grained greenstones, later in age than the finer foliated variety, are seldom if ever found carrying gold-bearing reefs or lodes. The granite and rocks genetically related thereto, which flank both sides of the Yilgarn Gold Belt, are younger than the ancient sediments. There is a marked degree of schistosity exhibited by the granite in certain localities, which may be held to indicate solidification prior to the cessation of those earth movements preceding the deposition of the much newer rocks, which in other districts repose directly upon it. Small dolerite dykes injected at a later geological period than the consolidation of the massive granite are also met with, but these do not appear to have exerted any influence on the ore deposits. There is no evidence whatever as to the geological period at which the granite was intruded. In nearly all cases the boundary of the granite is approximately parallel to the planes of bedding and foliation of the rocks adjacent thereto. Dykes of pegmatite granite are very plentiful in the belt; in some cases there are very pronounced pegmatitic segregations in the mass of granite itself; these gave no defined walls but merge insensibly into the enclosing rock. The pegmatite dykes traverse the greenstones; they also intersect many of the gold-bearing lodes and reefs and occasionally act as carriers of the rarer minerals, in addition to andalusite, garnet, tourmaline, and molybdenite.

From the point of view of economic geology, the metamorphic sedimentary rocks are of considerable importance in that along

their contact with igneous rocks the prominent ironstone lodes occur. The most noteworthy of these is what may be called the Caudan (King's Cairn)—Grand National Lode, which extends northward from Dingo Tank (Reserve 13208) to Great Victoria for a distance of rather more than eighty miles.

The gold-bearing ore deposits of the Yilgarn Gold Belt consist of a line or chain of interrupted and overlapping lenses which traverse the area from end to end, the position of the deposits being governed by the general character of the rocks they traverse.

The auriferous deposits are, when viewed broadly, divisible into three main groups, viz. (a) quartz reefs; (b) laminated haematite-bearing quartz lodes, and (c) lode formations, *i.e.*, crush or shear zones.

(a) The Quartz Reefs.—The quartz reefs of the belt may be subdivided into four distinct types, viz. (1) white massive more or less non-auriferous quartz veins, probably of pegmatitic origin, which represent the final product of the differentiation of a granitic magma. The quartz of this type occasionally contains a little mica and scattered crystals of felspar. These pegmatitic quartzes occur both in the granite and the adjacent greenstones. At times they are found to occupy the junction between the two types of rocks; typical instances being the Hope's Hill and the Leviathan Reefs, near Southern Cross. Several large and more or less conspicuous outcrops of pegmatitic quartz occur in the vicinity of Kennyville, to the east and northeast, and others are known in the neighbourhood of Bullfinch, to the north of Southern Cross. There are no known instances in which quartz reefs of this type have proved to be of value as gold carriers, though they have been found to contain molybdenite.

(2) Quartz reefs occurring in the Belt of Greenstones.—This type of quartz reef is economically the most important in the belt, inasmuch as it forms the chief source from which the gold has been won. The quartz is usually massive, generally very much iron-stained where weathering has removed the pyrites, etc. The reefs, when viewed broadly, exhibit a more or less parallelism, conforming in this respect to the chief tectonic lines of the belt, and generally occur as lenses of short length and variable thickness, in which payable gold shoots occur. The quartz reefs appear to have been formed after the development of the schistosity of the greenstones, and in all probability represent a replacement of the country rock along shear zones. The main quartz reefs of the Corinthian Mine form a typical example of this class of deposit.

(3) Quartz Reefs occurring in and forming an integral part of the laminated haematite quartz lodes.—These quartz reefs, which usually occur as stringers in the lenses of jaspillites, are composed of ferruginous glassy quartz, lying along the planes of foliation of the enclosing rocks. Typical examples of this class occur in the Haddon, Lord Cardigan, and Wimera leases at Southern Cross.

(4) Small Quartz Veins or Laterals.—These quartz veins, which are frequently disposed almost at right angles to the strike of the other quartz reefs, owe their origin to later earth movements than those which produced the main fissuring of the belt. Quartz of this type may readily be seen in many of the workings on the ore bodies of the belt. There seem reasons for believing the phase of lode alteration, by which these laterals were produced, brought about the deposition of the gold in the main ore deposits, hence on that account they are of some importance as "indicators."

(b) Laminated haematite quartz lodes.—The haematite quartz lodes are restricted in the vicinity of Southern Cross to the greenstone areas and more especially to the epidiorites. Three more or less distinct types of these lodes are met with in the belt, viz.:—Quartz with thin seams of oxide of iron, chiefly haematite; a variety in which the iron and silica are in about equal proportions; and the third in which the iron predominates, at times to the exclusion of the silica. It has been found that these three types occur along parallel lines which coincide more or less with that of the granite boundary, and that the most siliceous variety lies nearest to the granite, whilst the most highly ferruginous is furthest removed from the junction.

The *Great Victoria Lode*, near Jacoletti's, belongs to this type; it consists at the outcrop of a mass of laminated brown haematite and quartz, which trends generally northwest and southeast. The outer lode has a length of at least 15 chains and is of considerable width. The thickness of the lode at 285 feet below the surface varies from 100 to 150 feet. It rapidly passes into dense iron sulphides, which, in turn, give place to highly coloured jaspilites. The gold contents of the lode are fairly regular in their distribution. So far as can be ascertained from the official figures, it appears that the Great Victoria lode has produced, up to the end of 1913, 11,899.85 ozs. of fine gold from 97,870.26 tons of ore.

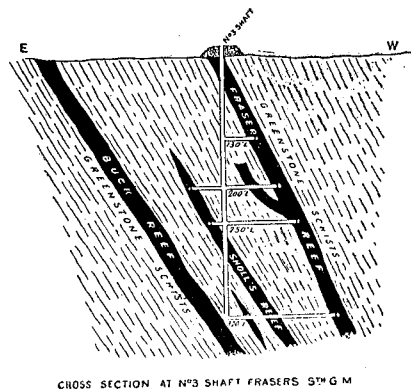
The *Bullfinch Mine* is a typical instance of payable gold in the quartz-haematite schists and their equivalents. The ore bodies of the Bullfinch occur in the form of elongated lenses, which, in all probability, represent catch zones in the greenstone schists. These ore lenses vary greatly in width, reaching as much as 90 feet in places: they have been followed along the strike for considerable distances. The Bullfinch deposits vary from a type in which haematite predominates to one consisting largely of silica with only a small percentage of iron, arranged in more or less parallel bands, which are separated by ferruginous, clayey schists. Some portions of these ore bodies, owing to leaching, are represented by almost pure sintering quartz, somewhat resembling pumice, which contains more or less free gold. The quartz veins in the oxidised portions frequently contain carbonates of copper and, in isolated cases, native silver, in addition to high gold values; in the unoxidised zone there are iron pyrites, marcasite, pyrrhotite and galena. In what has been designated the Northern Series of the Bullfinch lodes, the ore body at a depth of about 120 feet to 130 feet, changes from a siliceous deposit to one of a dolomitic nature, of which the chief constituents are dolomite (bitter spar), about 55.2 per cent., calcite 14.3 per cent., and actinolite 25 per cent., together with small amounts of pyrrhotite, and in all probability serpentine, albite, and quartz. This lode is possibly a replacement of an epidiorite or a rock allied thereto. The deposits on the Bullfinch Mine have produced, up to the end of 1918, 134,978.39 ozs. of fine gold, and 19,351.17 ozs. of silver from 354,188.42 tons of ore. The first 1,027.52 tons crushed produced 1,095.88 ozs. of fine gold, showing the extent of the surface enrichment. The abnormally high values of the lodes probably resulted from local enrichment along fault planes, etc., due in part to the removal by solution or otherwise of more or less valueless material.

(e) *Lode formations.*—A very typical instance of these lode formations is the Fraser's Lode at Southern Cross. This ore body occupies a shear or shatter zone of very considerable length, situated not far from the junction of the granite and amphibolite and its derivatives, and is conformable to the foliation. The lode trends generally northnorthwest and underlies west at an angle of about 70 degrees. It has a length of at least a mile. The large quartz reefs at Ilope's Hill to the north and the Peronea lease to the south are probably along the same shear zone. The Fraser's lode varies very much in thickness, ranging from 10 to 50 feet, which latter is the greatest width of ore yet stoped in any part of the workings. The ore body consists of several lenses of bluish-white quartz encased in amphibolite (Fig. 29). Some of the quartz probably owes its origin to a resilicification along the line of the pre-existing quartz veins by the addition of silica derived from the adjacent granite batholith. The shear zone contains iron pyrites and its oxidation products, and it has been found that the gold contents bear an intimate relation to the extent of the mineralisation. The lode below the oxidised zone passes into schist with pyrites and thin seams of magnetite as well as some pyrrhotite. The deposits also contain galena and scheelite; one mass of scheelite was about five feet thick. This mineral also occurs in the form of boulders in the oxidised zone, and usually carries about 30 dwts. of gold per ton; in some places it is thickly studded with it.

The Fraser's lode is intersected, in a direction at right angles to its general trend, by dykes of pegmatitic quartz, containing much

white mica, and where this occurs there is a slight impoverishment in the gold contents at the points of contact. The lode channel has been proved by boring operations to depths of from 700 to 1,000 feet below the surface. The results of the deep boring showed the lode to be very persistent and to have maintained its position at the different depths at which it was cut in the six bore holes. The

Fig. 29.



values, however, as disclosed by the boring, were in no case very high; one from a depth of between 734 and 738 feet in No. 6 bore hole being 6 dwts. 13 grs. of gold per ton—a result probably quite as good as might be expected from holes put down more or less at random with the object of defining position rather than snatching for ore shoots in such a long and large low-grade ore body as the Fraser's lode. So far as can be ascertained from official data, the Fraser's lode has produced 174,813.49 ozs. of fine gold from the milling of 336,041.00 tons of ore, or an average of .52 oz. per ton.

Superficial (Detrital) Deposits.—A classification of the detrital gold deposits occurring in the Yilgarn Gold Belt is possible in the light of their origin; they may be divided into two classes, viz., those of alluvial origin and those which owe their occurrence to the weathering *in situ* of rocks carrying gold-bearing quartz veins and leaders.

The residual deposits are found occurring on the rock masses, to the decay of which they owe their origin, whilst their gold contents have resulted from a natural concentration following the removal, by solution or otherwise, of some of the constituents of the parent rock mass. In no case have these alluvial and residual deposits occurring in the Yilgarn Gold Belt been found to attain any great thickness. Their economic importance is comparatively insignificant, there having been produced only 63.41 ozs. of fine gold, or .011 per cent. of the total yield of the area.

The total gold production of the Yilgarn Gold Belt up to the close of 1918 has been 552,256.51 fine ozs., which has been derived from the milling of 1,587,024.24 tons of ore.

Mount Jackson-Bungalbin Belt.—The Mount Jackson-Bungalbin Belt is made up of greenstones and sedimentary rocks surrounded on all sides by granite and gneiss. The granitic gneiss, which is well seen at the Native Well on the Mount Jackson-Southern Cross road, may probably be the foundation upon which the schistose rocks were laid down. It is, however, quite clear that there is a younger granite which penetrates not only the gneissic rocks, but the schistose and associated rocks also; the intrusive nature of this granite is well exposed around the Koolyanobbing Ranges. Here the main reef in Clark's Syndicate Mine occurs along the contact of the intrusive granite and the basic schists. The greenstones consist of dolerite, gabbro, and amphibolite of varying textures, in addition to a de-

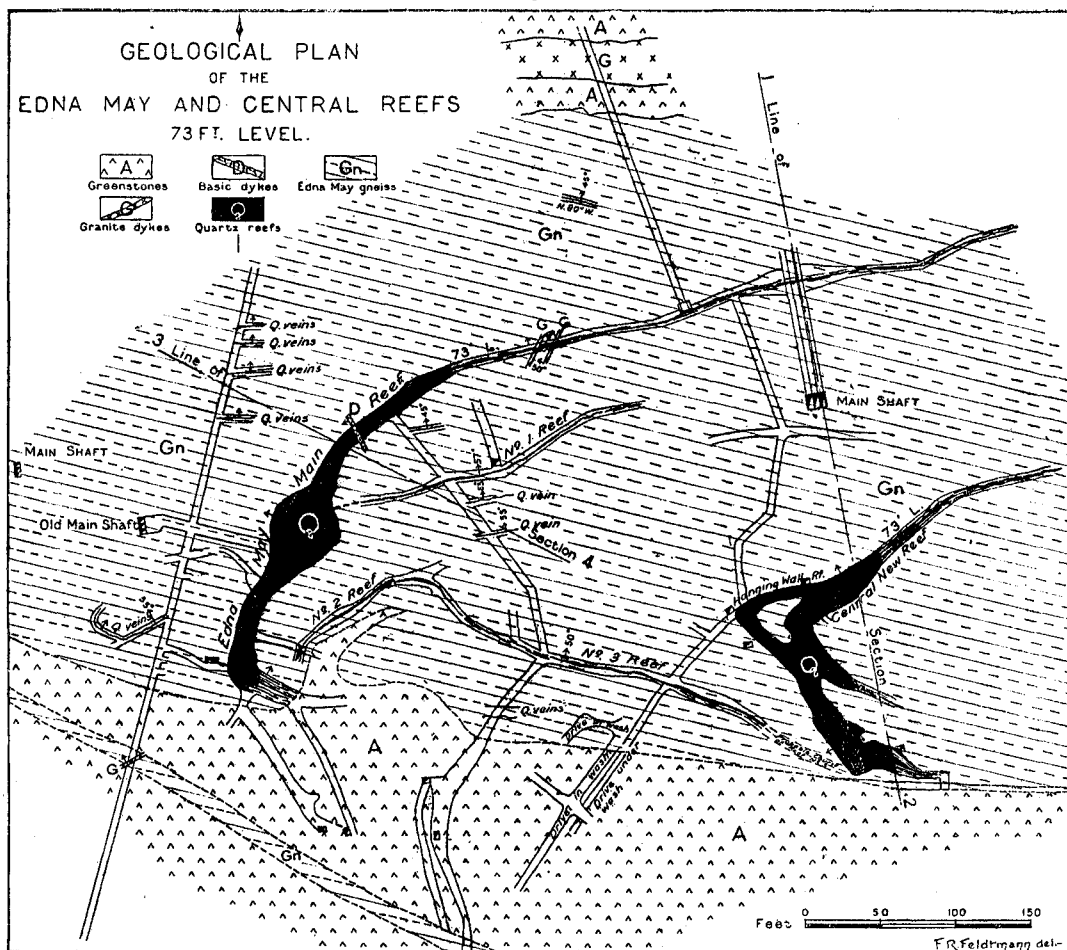
velopment of acid volcanic (?) rocks. The greenstones are traversed by jasperites which extend over a considerable area. Resting upon the greenstone are a series of slates, quartzites, and conglomerates which contain pebbles of the underlying jasperites.

The ore deposits of the belt consist of: (a) quartz reefs, and (b) ferruginous quartz lodes (jasperites). The quartz reefs possess all the characteristics of deposits of this nature and vary in thickness from that of a sheet of paper up to as much as five feet. They have

been responsible for most of the gold obtained from the belt. The most common minerals occurring in the quartz reefs, in addition to the gold, are galena and zincblende together with some arsenical and copper pyrites.

The ferruginous jasperites are traversed by numerous veinlets of quartz, and, as the gold in these deposits is stated to occur almost exclusively in the quartz, it follows from its sporadic distribution that they are not very valuable. Typical examples of these jasperite

Fig. 30.



ore deposits occur on the Mount Bacon and Burgoose leases. The Mount Jackson-Bungallin Belt has produced 29,011.71 ozs. of fine gold from the treatment of 39,030.78 tons of ore.

Westonia Belt.—The Westonia Belt is about six miles to the north of Carrabin Railway Station; it extends southeastward to Boodalin on the railway line, from which point it continues some distance further to the south. Compared with the other two, it is the smallest of the auriferous belts on the Yilgarn Goldfield. Gold appears to have been first found in the Westonia Belt some time during the year 1910. Since that date it has produced, up to the end of 1918, 325,708.85 ozs. of fine gold from 333,164.77 tons of ore; of this amount 161,807.75 ozs. have been obtained from the Edna

May mine alone. The Westonia Belt is made up of a series of ancient sedimentary rocks, together with a group of acidic and basic igneous rocks, the whole being surrounded by granite on all sides.

The oldest rocks of the belt appear to be the metamorphic sediments, though they are but poorly represented, having only been noticed in the neighbourhood of Boodalin, not far to the north of the railway line, where graphitic and andalusite shales have been recognised. The sedimentary rocks, however, are of but little economic importance inasmuch as they are not auriferous except in rare instances where they are in direct contact with the greenstones.

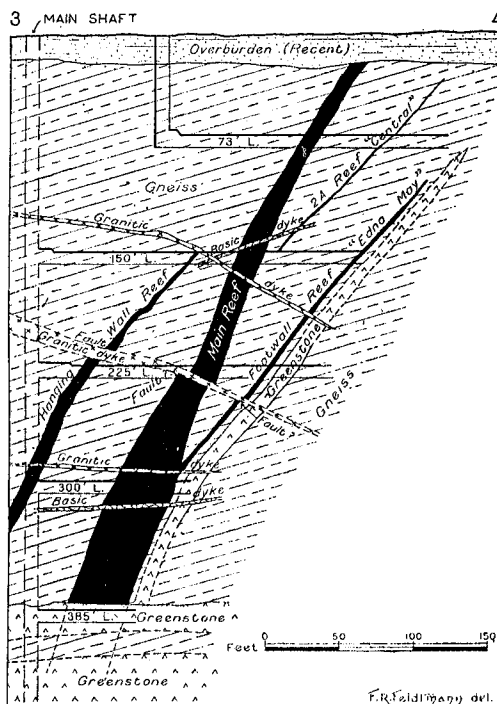
The greenstones consist of hornblendite, amphibolite and quartz diorite, forming a narrow belt which extends from Boodalin Siding,

past Westonina, and some distance northwest of Boodalin Soak. These basic rocks are of some importance inasmuch as they form the matrices of gold-bearing leaders.

Of the gneissic rocks what is known as the Edna May gneiss is the most important of all the rocks at Westonina, as it contains the chief gold-bearing deposits of the belt. The gneiss forms an elongated lens, about 60 chains in length, in a general northwest direction, with a maximum width of about 410 feet, the whole being completely surrounded with basic rocks. The gneiss consists of a foliated quartz-mica-hornblende-felspar rock which appears to owe its origin to the transmutation of a granodiorite. The foliation planes of the gneiss are approximately east and west with a prevailing dip to the northeast at varying angles. The gneiss is traversed by several quartz veins which vary in thickness from mere threads up to as much as 40 feet in places; of the quartz veins two classes may be recognised, viz. (a) those occurring in fissures transverse to the foliation planes, and (b) small more or less irregular veins, lying along the planes of foliation. The quartz, which contains rows of fluid inclusions and is associated with felspar, both of which solidified at the same time, is of granitic origin and represents the highly acid phase of a quartz-felspar-pegmatite. The gold occurs in these pegmatite veins, which are seen to pass on the one hand into granite and on the other into quartz. Pyrites, marcasite, galena, biotite,

Fig. 31.

CROSS SECTION OF THE EDNA MAY REEF



wolfram and molybdenite are the principal minerals occurring in association with the gold. Gold has also been found in a gabbro-pegmatite at Boodalin.

The Edna May group of lodes comprises two principal ore bodies, viz., the Edna May and the Central Reefs, lying approximately parallel to one another and which, in the upper levels, are

almost boomerang, horse-shoe, or hook-like in shape (Fig. 30). This resemblance, however, gradually disappears as the reefs are followed down. The two main ore bodies are connected by a quartz vein 12 inches wide, known in different parts of its course as the No. 2 Edna May and No. 3 Central Reef.

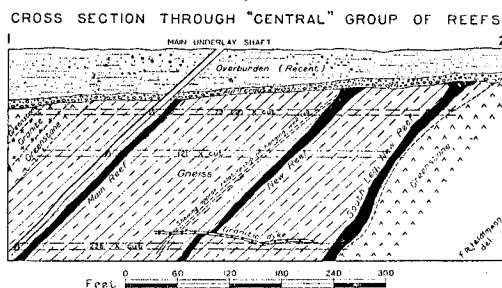
In the Edna May Mine there is one main quartz reef and several smaller ones, the relative positions of which are shown in the section which forms Fig. 31. The main lode is quartz containing fluid inclusions in addition to more or less kaolinised felspar; at times, however, the ore body is found passing into a rock which closely resembles a granite. All the available evidence points to the fact that the lode is in reality the acid phase of a quartz-felspar pegmatite. The gold occurs finely disseminated throughout the quartz, there being very little coarse gold present; it has also been found embedded in the felspar crystals as well as in the wolfram. The ore body also contains small quantities of pyrites and marcasite, in addition to grains, crystals, and bunches of galena, as well as scheelite, wolfram, molybdenite, wulfenite, and some eroseosite.

The lodes are traversed almost at right angles by granite dykes which vary in thickness from 2 inches up to as much as 20 feet and over. Some of these, as may be seen in section (Fig. 31), appear to be along fault lines. There are also basic dykes which intersect the ore bodies.

The principal ore body in the Central Mine is of pegmatitic quartz in every way identical with that of the Edna May Main reef; it contains, however, a small quantity of iron sulphides and galena. The Central Reef has, as may be seen in the plan (Fig. 30), a remarkable hook-like form, and it is stated that the gold values proved to be higher in the apex of the bend than in other parts of the ore body. Like the Edna May, the Central Reef has been faulted and is likewise traversed by granitic dykes, which, in some instances, are probably continuous with those in the Edna May Mine. One basic dyke was met with in the mine workings. The section across the Central Mine (Fig. 32) shows the relative positions of the Edna May and the Central main lodes and the granitic dyke. In both mines the workings have been carried down to a depth of about 300 feet.

Superficial Deposits.—The superficial deposits cover a fairly extensive portion of the Westonina belt; they consist chiefly of sand, loam, "cement," and ferruginous and siliceous laterite. Little is known as to the thickness of these deposits. Though the superficial deposits are rarely auriferous, still gold does occur in the buried alluvial wash, which traverses the Edna May Central Lease (Fig. 32), at a depth of about 50 feet below the surface. The wash, which

Fig. 32.



varies from about 4 feet 6 inches to about 8 feet in thickness, is made up of clay, in which subangular pebbles of quartz, closely resembling that forming the main reef, are embedded. The gold occurs as coatings to the pebbles in addition to filling in cracks by which they are traversed; it is also found in the argillaceous cementing medium. The richest portions of the wash are those in which the quartz pebbles occur in the greatest quantities. Like some of the

gold at the deep lead at Kanowna, it is secondary and owes its origin to deposition from solution either during the formation of the old watercourse or subsequent to its burial. There is no official record of the quantity of gold obtained from the buried alluvium of the Edna May Central Lease.

YALGOO GOLDFIELD.

The Yalgoo Goldfield, which embraces an area of 23,230 square miles, was discovered in 1890, and officially declared a goldfield by proclamation in 1895. The goldfield is situated on the high ground drained by the Sanford and Greenough Rivers and all those southerly streams which discharge themselves into Lakes Moore and Monger.

The Yalgoo Goldfield has long been of scientific and commercial interest on account of the variety of its mineral deposits, viz., gold, iron, copper, wolfram, molybdenite, bismuth, corundum, etc.

It appears that gold was first found on the Yalgoo Field early in the year 1890 in a large copper-stained quartz reef, occurring in the Nancarrong Hills, a few miles to the east of Yunin Station.

The rocks in the vicinity are quartzite and mica slate, penetrated by granite dykes and associated with ironstone lodes of the type common to other fields in the State.

The gold deposits of the Yalgoo Field are found in portions of a belt of country of considerable width, which extends from the neighbourhood of Mount Gibson on the south to Mount Barloweerie on the north. The auriferous areas occur as narrow, though well-defined belts lying within the limits of the country referred to. The rocks of the Yalgoo Goldfield comprise granite and allied acid rocks and metamorphic rocks of both sedimentary and igneous origin. There are also areas of basic rocks, gabbros and dolerites, in addition to a much newer series of quartz dolerite dykes, which intersect the granite and porphyry veins.

By far the larger area of the field is made up of granite, which is of later date than the majority of the rocks; along the marginal zone of the granite, lenses of the older greenstones are found enclosed in the acid rocks.

The surface of the granite is often covered with a capping of siliceous laterite. The present surface of the granite areas appears to approximately coincide with the original roof of the granite masses. Remnants of the pre-existing rocks, which formed the roof over the granitic intrusions, occur in many parts of the field, and have all undergone more or less metamorphism; they contain a number of ore-bearing channels.

The eastern flanks of the Yeo Hills show very clearly the intrusive nature of the granite; tongues and dykes penetrate the metamorphic rocks; there are also pegmatite dykes and veins.

Mount Barloweerie is made up of highly inclined sedimentary rocks, intersected by granite, pegmatite, and quartz veins, which in all probability represent an ultra-acid phase of the granite. In the neighbourhood of Mount Kenneth there is a belt of sheared quartz-cyanite rock, entirely surrounded by granite; the rock is believed to have been originally of sedimentary origin.

The bulk of the gold of the Yalgoo Field has been derived from ore bodies lying in the more or less schistose marginal zones of the granite batholiths, which make such conspicuous features and cover such large areas. There is a rude parallelism in the general direction of these schistose belts.

The condition of gold-mining on the Yalgoo Field may, in a measure, be gauged by the fact that at the end of 1918 there were 32 gold-mining leases in force, totalling 484 acres. The total number of gold-mining centres on the field amounts to 19, from which, up to the end of 1918, there have been returned 116,787.10 ozs. of fine gold, of which 113,591.75 ozs. are the result of the crushing of 172,484.04 tons of ore, whilst 1,451.29 fine ounces were derived from alluvial sources, and the remaining 1,744.06 ozs. being

dollied gold and specimens. The five mining centres which have yielded the largest quantities of gold are, in the order of the amount of their production, Field's Find, Goodingnow, Yunin, Gullewa, and Yalgoo. The following table gives in detail the ascertainable gold production from the 19 different centres on the Yalgoo Goldfield.

Synoptical Table showing Gold Yield from Centres in the Yalgoo Goldfield up to the end of 1918.

Mining Centre or District.	Alluvial Gold.	Ore treated.	Gold therefrom.	Total Gold.
	Fine ozs.	Tons. (2,240 lbs.)	Fine ozs.*	Fine ozs.
Adavale ... ..	...	10.00	12.56	12.56
Bilberatha ... ..	...	554.00	202.97	202.97
Carlaminda ... ..	...	1,061.32	596.68	596.68
Field's Find	5.77	36,480.05	27,503.50	27,509.27
Goodingnow	294.70	20,510.81	22,479.64	22,774.34
Gullewa ... ..	...	23,344.00	15,404.87	15,404.87
Kirkalucka ... ..	...	8.80	4.01	4.01
Messenger's Patch	463.12	1,025.75	1,210.70	1,073.82
Mt. Farmer ... ..	...	69.00	46.41	46.41
Mt. Gibson ... ..	...	5.00	17.67	17.67
Ninghan ... ..	...	31.00	413.81	413.81
Noongal	11.55	3,373.45	2,127.13	2,138.68
Nyounda ... ..	...	434.00	427.49	427.49
Pinyalling ... ..	...	2,442.10	1,038.55	1,038.55
Rothessay ... ..	...	8,971.00	3,331.15	3,331.15
Waddingarra ... ..	...	613.11	639.12	639.12
Warriedar ... ..	...	10,382.25	3,800.17	3,800.17
Yalgoo ... ..	...	7,145.00	10,487.90	10,487.90
Yuin ... ..	...	55,348.00	22,449.57	22,449.57
From District generally	9.42	677.00	3,141.91	3,151.33
From Banks and Dealers	666.73	...	...	666.73
Total	1,451.29	172,485.64	115,335.81	116,787.10

* Includes 1,744.06 ozs. of dollied and specimens.

Field's Find.—The mining centre of Field's Find has been the most productive of all the gold-mining areas on the Yalgoo Goldfield. Up to the end of 1918 it has yielded 27,509.27 ozs. of fine gold, obtained from the milling of 36,480.05 tons of ore.

No geological survey having yet been made of Field's Find not very much is known in regard to the geological constitution, structure, and relationships of its gold-bearing deposits. The neighbourhood of Field's Find has a large development of hematite-jaspilite with bands of blood-red jasper, and occasionally the pale-green variety—greenalite. The jaspilites are highly brecciated in places and are traversed by a network of quartz veins disposed at all angles and trending in all directions. To the west of the township of Field's Find is a low though rugged and conspicuous hill of a fine-grained greenstone, on the eastern flanks of which the mines are situated. A well-defined ore-channel occurs on the western slopes of a persistent band of jaspilite, which is stated to carry rich ore shoals.

Goodingnow (Payne's Find).—The gold-mining centre of Goodingnow (Payne's Find) is situated some distance to the east of what may be called the main belt of the Yalgoo Field, about eight miles north of Goodingnow Station.

Gold appears to have been first recorded from this centre in 1911, and since that date it has produced, up to the end of 1918, 22,198.62 ozs. of fine gold, derived from the milling of 20,510.80 tons of ore; it has also yielded 575.72 ozs. of alluvial, dollied, and specimen gold.

The mining centre is situated on the eastern slopes of some rising ground made up of a relatively small lens of more or less basic rocks entirely surrounded by granite. The rise is flanked by two creeks which carry their drainage southward into the northern arm of Lake Moore.

The rocks of Goodingnow consist of epidiorite and hornblende schist, serpentine and foliated quartz-porphyrries, in addition to hornblende-biotite gneiss, which forms the matrix of the chief ore bodies of the field. The greenstones and the serpentine have been subject to dynamical alteration, producing sheared varieties in which there are occasionally quartz veins along the foliation planes. Gold-bearing quartz veins are met with to a limited extent in the epidiorite and hornblende-schists, though very rarely in the serpentine. No mine has yet been worked on a vein wholly in serpentine. The highly sheared porphyries which occur as dyke-like masses both in the greenstone and in the serpentine contain some low-grade gold-bearing quartz veins, of which the Rose Group in the southwestern corner of the field is a typical example.

Economically the hornblende-biotite gneiss is the most important of all the rocks of Goodingnow, inasmuch as it forms the matrix of those quartz reefs which have been responsible for the major portion of the gold output from the mining centre. The gneiss covers a considerable area and lies to the east of the greenstone belt. Two lithological types are recognisable; one characterised by a predominance of biotite with quartz parallel to the foliation planes, and the other in which the mica is entirely subordinate to the hornblende. Lithologically the gneissoid rocks resemble those of Westonia, on the Yilgarn Goldfield, and, like them, appear to be genetically related to granodiorite. The gneisses of Goodingnow are traversed by a large number of narrow dykes of pegmatite, which have a more or less northwesterly trend; they also occur in the greenstone, but not, however, in such large numbers. The pegmatites, which are traceable for considerable distances, cut through and at times displace the gold-bearing quartz veins, and are therefore of younger formation.

The gold-bearing quartz reefs occur mainly in the gneiss, and with a few exceptions they lie parallel to the planes of foliation. These ore bodies are at times of considerable length, the lens forming the Carnation-Blue Bell line having been proved for 1,200 feet. The veins vary greatly in thickness—from mere threads up to as much as 9 feet.

The gold deposits consist of lenticular or elliptical masses of quartz, the longer dimensions of which appear to correspond to the structure of the rock they replace and to the foliation of which they conform (Fig. 33). Some of the ore-bodies have been followed in the workings to the greatest depths to which they have been carried, viz., 300 feet. The quartz lenses dip generally to the west-south-west and pitch south. The shoots in the quartz veins, which have yielded most of the gold, are generally very narrow, greatly elongated vertically, and may be described as pipes.

The mineralogy of the gold ores of Goodingnow is on the whole fairly simple. Quartz is the dominant gangue mineral, which, in addition to the gold, contains iron pyrites with some galena and zinc blende, as well as siderite and chalcoppyrite.

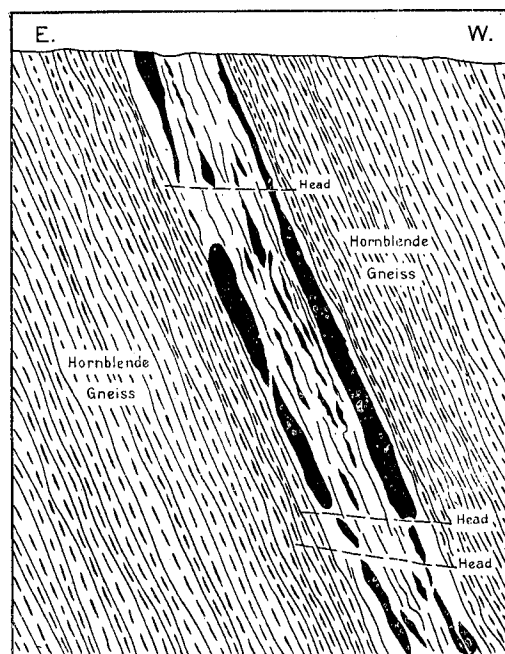
Yuin.—Yuin, one of the principal mining centres on the field, is situated about 50 miles to the northwest of Yalgoo, and is essentially a one-mine township, which depended for its prosperity upon the success of the Royal Standard Mine, from which, up to the end of 1918, 20,095.08 ozs. of fine gold were obtained from 48,028.50 tons of ore. The total gold yield of the Yuin Centre for the same period amounted to 22,449.57 fine ozs. from 55,348.00 tons of ore.

The rocks of the more immediate vicinity of Yuin consist chiefly of granite and greenstone, associated with dykes of pegmatitic granite and a group of silicified rocks, to which, for want of a better, the term "quartzite" has been applied, though they appear to owe their origin to a silicification of bands of more or less foliated greenstone.

The greenstones are usually dense fine-grained rocks which occasionally pass into hornblende schists and allied foliated rocks. The granite, which occupies most of the country in the vicinity, is generally coarse in grain, and is of the microcline-biotite variety.

The rock is intrusive into the greenstones, and the intrusion took place prior to the foliation. Fine-grained acid dykes, made up of quartz, felspar, and mica, intersect the greenstones at all angles, though at times they lie along and parallel to the planes of foliation. The dykes vary from three inches to as much as sixty-six feet in thickness; they are seen to intersect the quartz reefs near the

Fig. 33



SECTION OF
THE MARIGOLD LODGE IN SHAFT 17. G.M.L. 660.
GOODINGNOW (PAYNES FIND). YALGOO G.F.

Feet. 0 1 2 3 4 5 6
Scale.

township of Yuin. About half-way between the Old Station at Yuin and the Royal Standard Mine is a large ice-like quartz reef trending generally northeast and southwest, which is probably genetically related to the acid dykes. The newest rock on the field is the dolerite which intersects but does not displace the Royal Standard ore-body (Fig. 34).

Quartz reefs occur both in the granite and the greenstone; those, however, in the granite are somewhat irregular in their occurrence, and do not appear to be gold-bearing.

The principal ore-body worked at Yuin is that in the Royal Standard group of leases (Fig. 34). The ore-body consists of parallel quartz reefs lying along the foliation planes of the greenstone which constitutes the country rock. The quartz reef upon which mining operations have been chiefly centred is a well-defined solid body which has been followed more or less continuously along the outcrop for a distance of over 2,500 feet. The general strike of the reef is east and west with an underlie to the north of 70 degrees; its thickness varies from 18 inches to as much as 9 feet, and it has been followed to a depth of 300 feet from the surface, at which point it and the greenstone matrix are abruptly truncated by coarse-grained granite. The junction is marked by an almost

flat plane along which the rocks have been broken and crushed over a width of from one to six inches.

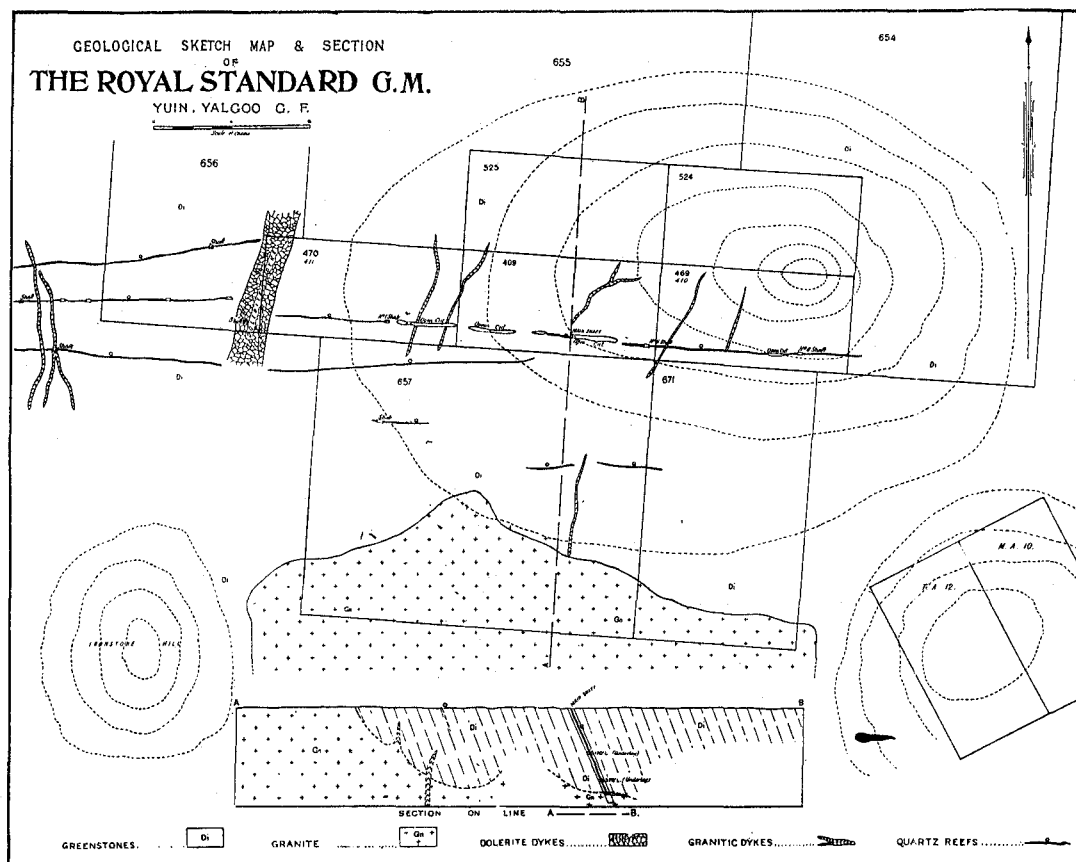
The junction plane probably marks a line of fault (? over-thrust) which has had the effect of displacing the reef, for at the granite contact the quartz vein is 6 feet wide and the junction is sharply defined without any indication of a gradual petering out of the quartz.

The quartz of the Royal Standard reef is coarse and granular and of a bluish tint. The gold is fine in grain, and the shoots pitch to the east as do also the longer axes of the quartz lenses.

Gullewa.—Of the geological structure of the Gullewa mining centre, which has produced 22,774.34 ounces of gold, practically nothing is known, for up to the present time no geological survey has been made of that locality. There are, however, a series of small gold-bearing reefs, some of which proved to be very rich, though on the whole very small; of the mode of occurrence of these deposits there are no data available.

Yalgoo.—The gold-mining centre of Yalgoo, which has yielded, up to the close of the year 1918, 10,487.90 ozs. of fine gold, lies in

Fig. 34.



a broad valley flanked on either side by low ranges made up of greenstone and their metamorphic derivatives. The valley is drained by a small creek which carries all the waters southwards. The broad expanse of the valley is covered with a variable thickness of superficial deposits, some of which have been partially cemented into solid rock.

The most important ore deposit in the more immediate vicinity of the Yalgoo township is that which was opened up in the Emerald Reward Mine. The deposit consisted of a boat-shaped mass of quartz about 100 feet long, ten feet wide, and ten feet deep, from which over 4,000 ozs. of gold were obtained.

A fairly well-defined fissure extends along what may be called the outcrop of the reef, which has a trend of northeast and south-

west. The Emerald Reward Reef is hemmed in between two comparatively barren belts of foliated greenstone, separated by either a line of fault or joint, which is fairly persistent to the northeast and southwest. The deposit is neither more nor less than a network of irregular veins embraced within certain well-defined limits, parallel to the general strike of the reef.

Several other small rich lenticular veins of quartz also occur in the greenstone country, but little or no work has been done upon them.

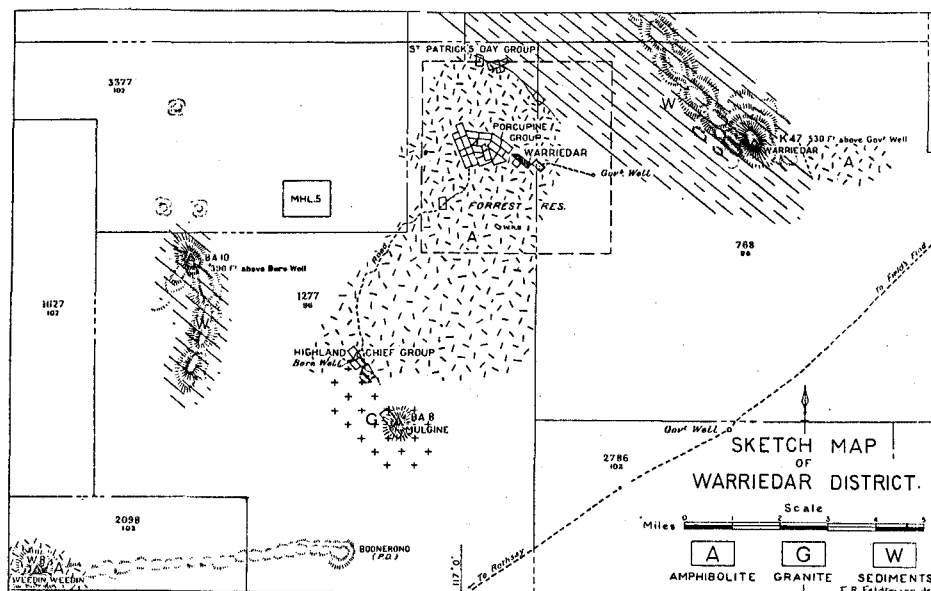
The quartz reefs have an average underlay to the west of from 50 to 70 degrees.

Warriedar.—The gold-mining centre of Warriedar is situated about 70 miles by road from Yalgoo and five miles west of Mount

Warriedar, K.47, an important hill rising to an altitude of about 600 feet above the general level of the surrounding country. The vicinity of Warriedar is made up of massive amphibolite (derived from a gabbro), granite, and allied rocks in intimate association with a series of shales, quartzites, and conglomerates, which may be designated the "Warriedar Beds." The strata have an average strike of N.50°W. and dip at about 80 degrees to the southwest.

The greenstones are traversed by more or less parallel jaspilites which trend generally east and west. Dykes of basaltic dolerite are found in many places intruding the granite. The granite is seen to be intrusive into the amphibolite and many dykes of quartz-porphry and pegmatite, in addition to veins of pegmatitic quartz, emanate from the granite and penetrate the greenstone for distances varying from 10 to 20 chains. (Fig. 35.)

Fig. 35.



Finely banded lenses of jasper, which bear a marked resemblance to those of the greenstones, are also met with in the Warriedar Beds, in which they trend generally north and south. These sedimentary beds have undergone a certain amount of laterisation.

The ore deposits of Warriedar are almost exclusively confined to the basic rocks, amphibolites, hornblendites, and epidiorites, which are traversed by a number of more or less parallel shear zones. A certain amount of faulting of later date than the production of the shear zones has affected the district, and in all probability this bears some genetic relationship to the uprise of the granite magma.

The gold production of Warriedar as disclosed by the official statistics amounts, up to the end of 1918, to 3,798.37 fine ozs. derived from the milling of 10,382.25 tons of ore, most of which has been obtained from the lodes.

The ore deposits of Warriedar are divisible into four classes, viz. (a) jaspers, (b) lodes, (c) quartz reefs, and (d) detrital deposits.

The jaspers occur in four main lines, which trend generally north 79 degrees west, and are usually very highly inclined. They consist of alternating laminae of iron ore and flinty quartz; below the zone of oxidation they are represented by sheared and more or less altered rock, often very highly impregnated with sulphides. Analysis of a typical sample from the Ironclad Mine, G.M.L. 699, gave SiO_2 , 43.13; Fe_2O_3 , 53.25; and FeO , 1.28 per cent., equal to 38.27 per cent. of metallic iron.

The lodes are distributed in four main lines, the average strike of which is northnorthwest, and the dip about 68 degrees to the eastsoutheast; as a rule, they are of no great length, the average

being about 1,000 feet. Like the deposits of Boogardie, on the Murchison (pp. supra), they lie along fault lines generally at right angles to the strike of the jaspers. The lodes appear to be chiefly masses of dense iron ore, occurring in bands of sheared and kaolinised country rock. They have been found to contain ores of manganese, bismuth, and arsenical pyrites, in addition to chloropal and chrysotile asbestos. Some of the lodes below the zone of oxidation, viz., those of the Aurum and Ironclad leases, were found to be represented by chloritised and micaceous epidiorite, intersected by irregular lenses and stringers of quartz, together with patches of dense pyrites. The mineralogical composition of the Warriedar lodes is of such a nature as to have an appreciable effect upon the treatment of the ore. The lode in the bottom of the Ironclad Main Shaft contained arseno-pyrite, actinolite, magnetite, wolfram, psilomelane, and quartz; in addition, a sample yielded, on assay, 3 ozs. 7 dwts. 17 grains of gold, and 6 dwts. 3 grains of silver per ton. A sample of sulphide ore from the Golden Bar Extended Lode, G.M.L. 863, was found to contain 36.3 parts per hundred of arseno-pyrite, 23.6 of marcasite, and 35.6 of quartz, in addition to gold at the rate of 5ozs. 0dwts. 19 grains per ton, and of silver 1oz. 1dwt. 14 grains.

The quartz reefs occur both in the gabbro derivatives and the granitic rocks; in neither group, however, have they proved to be very rich in gold. The reefs vary from mere threads of quartz up to as much as 12 feet in thickness and are not of any great length. There are a great number of quartz reefs in the granitic rocks of the vicinity of the Highland Chief Mine; they are arranged in two distinct series—one trending generally north, 20 to 25 degrees west, and a second northeast. Both series are roughly parallel to the boundaries of the intrusive granite. Small quantities of molybdenite and some bismuth carbonate have been met with in a few of the reefs. The

valleys along many of the watercourses carry a fair depth of alluvium in some places, but they do not appear to have yielded much, if any, gold.

Noongal (Melville).—The mining centre of Noongal lies about 12 miles to the north of Yalgoo. Gold appears to have been first recorded from this centre in the year 1894, since which date it has been responsible, up to the end of 1918, for 2,046.30 ozs. of fine gold, derived from the milling of 3,373.45 tons of ore, in addition to 92.38 ozs. of alluvial, dolled, and specimen gold.

The oldest rocks of Noongal consist of metamorphosed dolerite, gabbro, pyroxenite, and peridotite, which, from recent researches, appear to be merely the differentiation products of one parent rock mass. These basic rocks have undergone a certain amount of shearing. To the west of the greenstone belt is a large area of intrusive granite, from which numerous acid dykes emanate and penetrate the basic rocks for considerable distances, in addition to engulfing large masses, sometimes acres in extent, which are completely surrounded by the acid intrusions. Cases occur in which it appears that basic rocks have been partially assimilated by the granitic magma. The acid dykes consist of granite-porphry, biotite-microcline granite, and pegmatite, which form a complicated network of veins ramifying in all directions. The gold-bearing deposits of Noongal are all situated at the foot of a belt of hills trending generally northeast and more or less continuous from Yalgoo.

The ore deposits occur along the contact zone, between the basic and the acidic rocks. The gold-bearing deposits are quartz reefs, which, when viewed from the point of view of their occurrence, are divisible into two groups, *i.e.*, those occurring in or intimately associated with acid dykes, and those in the greenstones. The quartz veins occurring in the acid rocks, though extremely irregular in their occurrence, vary greatly not only in width, but also in strike, and occasionally carry patches of very high grade ore. The quartz reefs of the greenstones are more consistent in their behaviour; they at times are of some thickness, are traceable for considerable distances along the strike, and have been followed to fair depths, vertically, below the surface. From the deposits of this class, a few hundred tons of fair grade ore have been obtained.

The gold-bearing quartz veins appear to be merely off-shoots from the acid dykes. The acid dykes and associated quartz veins form the matrices of a number of valuable minerals—scheelite, molybdenite, corundum, ilmeno-rutile, and various compounds of bismuth. From 1915 up to November, 1918, 1,932½ lbs. of bismuth ore, valued at £472, was raised from the deposits of Melville.

Rothsay. The mining centre of Rothsay is situated in the southwestern portion of the Yalgoo Goldfield about 19 miles southwest of Warriedar. Gold was first discovered at this centre in 1894, since which date it has only produced, up to the end of 1918, 3,298.02 ozs. of gold, obtained from the milling of 8,966 tons of ore.

Rothsay lies near the southern extremity of a line of low hills, trending generally north-northwest, of which the most prominent summit is Weed-in-Weedin (W. 8), made up of greenstones, the highly sheared zones of which form the belts along which the gold deposits are situated. The greenstones consist of epidiorite and hornblende schists, together with hornblendites, tremolite rocks, and serpentines, which are in all probability derived by differentiation from one parent magma. Several small pegmatite dykes occur on the field, as well as veins of basaltic dolerite, one of which is seen in the workings of the British Queen Mine to cut across the quartz reef.

The gold at Rothsay is found in quartz veins which strike generally northwest—a direction parallel to the shear planes by which the greenstones are traversed. The outstanding feature in the structural geology of the field is the length and parallelism of

the quartz veins. The reefs, which dip to the northeast at angles varying from 50 to 70 degrees, trend generally northwest; they are lenticular or kidney shaped and differ greatly in thickness, sometimes reaching as much as 6 feet from wall to wall.

Six lines of quartz reefs have been recognised, of which one, worked in the Woodley's Reward Mine, is traceable for at least a mile.

Bonnie Venture (Yandanhoo Hill). Gold-bearing conglomerates were discovered on the Yalgoo Field in the year 1912 in a belt of rugged country of which Yandanhoo Hill forms the highest summit. The strata constitute the main axis of the hill, which rises somewhat abruptly to an elevation of about 300 feet above the general level of the low ground which surrounds it upon three sides.

The find is situated about five or six miles to the south of Mount Singleton (Ninghan) at a locality known as the Bonnie Venture. The strata consist of quartzites, grits, and conglomerates. Interstratified with the beds is a narrow band of fine-grained black andalusite slate; the rock in all probability owes its origin to the alteration induced by the granite batholith which does not reach the surface in the immediate neighbourhood but which outcrops about a mile to the south and is intrusive. The sedimentary rocks have a prevailing red colour resulting from the presence of small quantities of iron oxide. These highly inclined sediments appear to be on the same stratigraphical horizon as those of Mount Warriedar, K. 47, which lies some distance to the north. Lithologically the Warriedar Beds differ from those of the Bonnie Venture in that they are purely siliceous and not ferruginous. The sediments are invaded by granite of the ordinary type prevailing on the Yalgoo Field, as well as by acid dykes which in all probability form its apophyses. The gold-bearing conglomerate and the geological formation in which it is contained bear a close lithological resemblance to certain of the South African rock systems in which some of the conglomerates have been worked for their gold contents, which, however, are of low grade.

The conglomerates and associates of the Bonnie Venture outcrop over a length of a mile; the beds are vertical and strike generally north and south. The two beds upon which mining operations have been concentrated occupy the centre of the area (Fig. 36). The westernmost conglomerate outcrops over a length of about 800 feet and has been opened out by five shafts put down to varying depths; the easternmost lies about 4 claims distant, and one shaft has been sunk upon it. There seem sound reasons for believing the conglomerates to be merely the exposed limbs of an acute anticlinal fold, which is not of any great horizontal extent, but which has been somewhat modified by faulting.

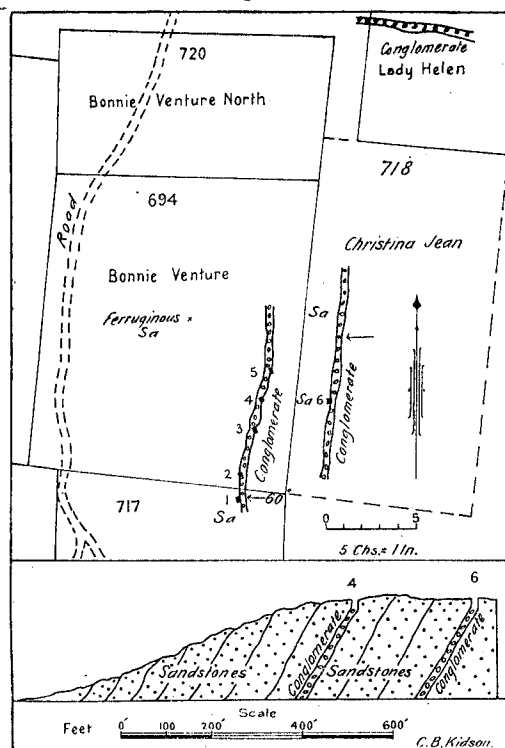
What may for convenience be called the lodes consist of ferruginous sandstones, which contain in places rounded and sub-angular pebbles of quartz, granite (?), and banded cherts (jasperites), and are occasionally traversed by veins of oxide of iron. The westernmost, or main, ore-body varies in thickness, the maximum width having been proved to be 12 feet.

The walls of the sandstone underlying the conglomerate occasionally show slickensided faces which are inclined to the northwards at angles of about 35 degrees. Fractures are seen to traverse the ore-body obliquely and are coated with an inch or two of white clay. The general appearance of the beds underground indicates that there has been a certain amount of faulting, and the fractures produced in this way may possibly have been the channels up which the gold-bearing solutions travelled.

An analysis (4135E) of a typical sample of the gold-bearing conglomerate showed its mineral composition to be quartz (about 85), kaolin (?), sericite (about 5), goethite (about 2) per cent., together with small amounts of ilmenite, magnetite, apatite, rutile, zircon, actinolite, a little halite, and a variety of jarosite.

Several assays of the gold-bearing conglomerate have been made at different times in the Geological Survey Laboratory, and results varying from traces up to 2 ozs. 16 dwts. of gold per ton obtained. The gold occurs as flakes and grains in the sandy matrix as well as in the heart of the quartz pebbles of which the conglomerate is constituted; as a rule the gold occurs as very minute particles showing no sign whatever of abrasion such as might have been expected had it been of detrital origin, and deposited at the same period as that of the sediments. Its characteristics, etc., all point to the fact that the gold is of secondary origin and not an original constituent of the conglomerate.

Fig. 36.



PLAN & SECTION OF THE GOLD BEARING CONGLOMERATES,
BONNIE VENTURE MINE.
YALGOO GOLDFIELD.

When viewed as a whole the deposit is of low grade; a trial crushing of 10 tons of the conglomerate gave a total gold yield of only 1.41 ozs. The importance, however, of the occurrence of these auriferous conglomerates lies in the fact that they point to the possibility of there being other areas of the belt of ancient sediments traversing the Yalgoo Goldfield which may also be gold-bearing.

PHILLIPS RIVER GOLDFIELD.

The Phillip's River field, which embraces an area of 5,078 square miles, was discovered in the year 1892 and established as a goldfield by proclamation gazetted in 1900. The history of this, one of the smallest of the declared goldfields, virtually commenced in 1892 with the discovery of small quantities of gold in association with copper and iron pyrites. It was not, however, until 1899 that

auriferous quartz reefs were discovered, on the western edge of what is now the mining belt of Phillips River. This was shortly afterwards followed by the finding of the copper lodes of Ravenshorpe, to which reference is made in the section dealing with the copper deposits.

Gold-mining operations on Phillips River have been restricted to five separate centres as set out in the table:—

Synoptical Table showing Gold Yield from Centres in the Phillip's River Goldfield up to the end of 1918.

District or Centre.	Alluvial Gold.	Ore treated.	Gold therefrom, *	Total Gold.
	fine ozs.	tons (2,240lbs.)	fine ozs.	fine ozs.
Kundip	192.33	63,522.32	52,185.90	52,378.23
Mt. Desmond ... ..	...	9.00	3,917.44	3,917.44
Mt. Purohas ... ..	...	350.80	302.19	302.19
Ravensthorpe	157.82	23,891.10	26,420.29	26,578.11
West River ... ..	...	...	13.29	13.29
Various Works ... ..	...	...	630.56	630.56
Banks and Dealers	122.05	...	...	122.05
Total	472.20	87,773.22	83,469.67	83,941.87

* Includes 775.33 ozs. of dolted gold and specimens.

The field since its discovery has produced, up to the end of 1918, 83,469.67 ozs. of fine gold, derived from the milling of 87,773.22 tons of ore, in addition to 472.20 ozs. of alluvial gold.

The fundamental rocks of the Phillips River Goldfield are both of igneous and sedimentary origin, which have in part lost not only their individuality but their geological identity. The ore-bearing portion of the field is made up of ancient metamorphic sediments associated with a series of crystalline rocks of igneous origin, into which a large dome-shaped mass or batholith of soda-granite has been intruded; in addition there are dykes of diabase, quartz-diorite, and their derivatives, as well as veins of soda-porphry and pegmatite. The basic dykes, which appear to emanate from the large mass of greenstone lying to the west of Ravenshorpe and draining the waters of Annabelle Creek, traverse the granite, in which they occur in great numbers.

The gold-bearing deposits are all restricted to or occur near the margin of the granite, and their distribution is largely controlled by the system of fracturing to which the district has been subjected. The mines are situated on the western fall of the Ravenshorpe Range at the head of the drainage areas of the Steere and Phillips Rivers.

The lodes may be divided into two classes—(a) those of which copper is of the greater intrinsic value, and (b) those in which gold is the more important mineral constituent, as is the case in the mining centre of Kundip, from which the bulk of the gold is derived.

There are two types of quartz reefs on the field—(a) large reefs of milky-white quartz, which contain little if any gold and probably represent an ultra-acid phase of the apophyses of the intrusive granite, and (b) clear glassy quartz reefs, usually heavily charged with oxides of iron and containing fairly high gold and silver values.

The gold-bearing belt of the Phillips River is approximately parallel to that of the Yalgoo Field, and possibly in more or less general alignment with that of Yalgoo.

EAST MURCHISON GOLDFIELD.

The East Murchison Goldfield, which embraces an area of 28,746 square miles, was originally established as a goldfield by proclamation in 1895, and has been divided for purposes of administration into three districts, viz., Lawlers, Wiluna, and Black Range.

The field has produced up to the end of 1918, 1,715,869.66 ozs. of fine gold, derived from the treatment of 3,292,711.52 tons of ore, in addition to 7,164.53 ozs. of alluvial gold. This quantity of gold has been obtained from about 19 different centres, indicated in the table.

Synoptical Table showing the Gold Yield of the East Murchison Goldfield up to the end of 1918.

Centre or District.	Alluvial Gold.	Ore treated.	Gold therefrom.*	Total Gold.
	Fine ozs.	Tons. (2,240lbs.)	Fine ozs.	Fine ozs.
LAWLERS.				
Bronzeving ...	...	468.00	318.03	318.03
Cork Tree ...	...	3,780.00	3,357.59	3,357.59
Kathleen Valley ...	...	75,425.00	46,723.87	46,723.87
Lake Darlot ...	1.16	68,950.94	56,717.22	56,718.38
Lawlers ...	14.81	1,260,172.70	485,242.25	485,257.06
New England ...	...	2,520.50	1,657.07	1,657.07
Sr Samuel ...	...	269,142.00	141,283.46	141,283.46
Wiluna ...	92.89	470,510.97	203,425.45	203,518.34
WILUNA.				
Collavilla ...	...	1,548.00	517.75	517.75
Mt. Keith ...	...	8,056.00	6,675.22	6,675.22
BLACK RANGE.				
Barrambie ...	...	575.50	1,966.46	1,966.46
Bellehambers ...	...	45.00	36.62	36.62
Berrigin ...	...	12,702.06	16,479.29	16,479.29
Curran's Find ...	...	6,573.00	2,565.20	2,565.20
Errol's ...	20.70	291.50	1,215.05	1,235.75
Hancock's ...	...	27,993.75	34,502.00	34,502.00
Manning Marley ...	...	60,001.25	47,969.87	47,969.87
Montagu ...	...	9,927.90	7,835.28	7,835.28
Nungarra ...	72.61	15,550.65	13,351.52	13,424.13
Sandstone ...	28.76	688,779.27	446,190.30	446,219.06
Younanne ...	36	306,907.95	141,975.45	141,975.81
Various Works and Districts generally	...	2,789.00	55,782.68	55,782.68
Banks and Dealers	6,933.24	...	81.50	7,014.74
Total ...	7,164.53	3,292,711.52	1,715,869.13	1,723,033.66

*Includes 12,517.77ozs. of dilled gold and specimens.

By far the larger area of the East Murchison field is made up of granite, which outcrops in the form of bare flat rocks, low hills, and numerous breakaways. Throughout the whole area, it has been found that the granite is of one lithological type, with, however, local variations; in some cases there are sheared and foliated forms, along the planes of foliation of which numerous lenticular quartz veins occur. The granite and its derivatives, aplite, pegmatite, and other acid dykes, is clearly younger than those basic rocks into which it intrudes. Sometimes these apophyses penetrate the adjacent rocks for as much as ten chains from the parent granite; usually they form narrow tortuous dykes, and there are gradual passages from pegmatitic granite to quartz veins. The intrusion of the granite was followed by the formation of the main gold-bearing reefs occurring on the East Murchison field.

The basic rocks are disposed in several fairly well-defined belts, made up of quartzose amphibolite, epidiorite, hornblendite, and serpentine, in addition to a newer series of dolerites which occur as quite fresh dyke rocks traversing the older series. The gold-bearing lodes and reefs are found chiefly in the quartzose amphibolites.

The older crystalline rocks of the East Murchison field are unconformably overlaid by a series of coarse conglomerates, quasi-vitreous sandstones, shales, with occasional limestones, some of which are dolomitic. These beds, which are usually disposed at gentle angles, though occasionally faulting and some local folding is observable. These sedimentary beds, which rest upon an irregular floor of granite, form part of the Nullagine Formation, which in this area is exposed only in the watershed of West Creek, which flows into Lake Way.

The geographical situation of the various gold-mining centres exhibits a marked zonal development of the auriferous deposits. As a result of the geological surveys which have already been carried out, it appears that the auriferous deposits of the East Murchison Goldfield may be divided into three main and distinct groups, which for convenience of description are designated:—

(A) Kimberley Range, Wiluna and Lawlers Belt. This belt, which extends from Thaduna Hill, on the headwaters of the Gascoyne, through Wiluna and Sir Samuel to the vicinity of Lawlers, has a horizontal extent of about 150 miles. Its continuity is to a certain extent interrupted by the Nullagine sedimentaries of the Kimberley Range and the rocks of the Barr-Smith Range to the north of Sir Samuel.

(B) Barlow's Belt, the northern extremity of which is situated in lat. 26° 18' south, and long. 120° 36' east, and the southern, near Leonora, in the Mount Margaret Goldfield, thus having a length within the proclaimed area of the East Murchison Goldfield of about 130 miles.

(C) Mount Ereka Belt, which is the most easterly of any of those on the field. The northernmost limits of the belt are situated in lat. 26° 23' south, and (approximately) long. 121° 30', whilst the southern is in the vicinity of Mount Blackburn, to the north of Lake Darlot, its length thus being about 90 miles.

To the westward of the three main belts there are other more or less isolated areas, which include the mining centres of Errol's, Barrambi, Montague, Sandstone and Younane.

(A) KIMBERLEY RANGE, WILUNA, and LAWLERS BELT.—This belt, which has a length of about 150 miles, presents a general uniformity in its geological constitution and structure. At the extreme northern end, however, in what may be called the Kimberley Range belt proper, the red soil plains strewn with rubble made up of quartz and ironstone effectually conceal the underlying rocks; wherever the rocks are exposed they are found to be extremely weathered. Several low ridges, rising like islands from the red soil plains, in which the underlying rocks are exposed, are made up of more or less altered quartz-dolerites. The western edge of the belt is made up of weathered basic (?) schists, which are traversed by numerous quartz reefs lying parallel to the strike of the enclosing rocks. A considerable amount of quartz rubble is to be found strewn all over the surface of some of the flats. The geological constitution of the area warrants attention being paid to it by prospectors.

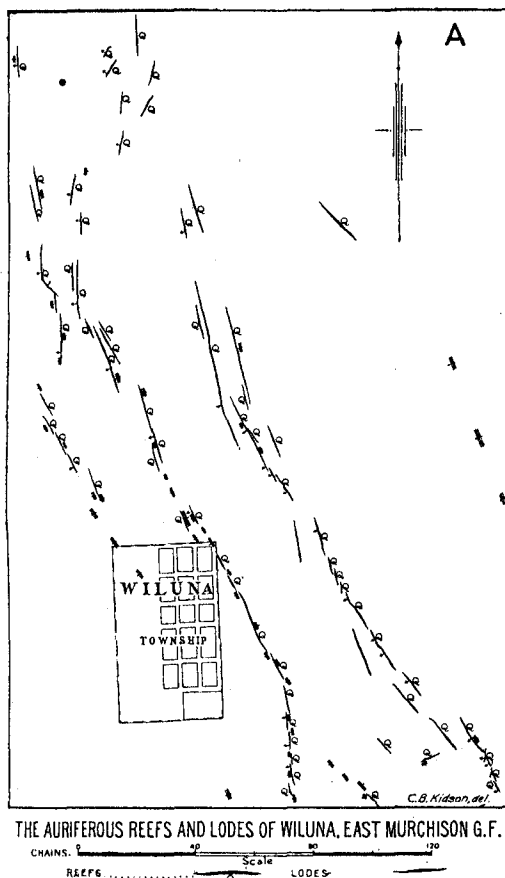
The belt extends in a general southsoutheasterly direction and disappears beneath the sedimentary rocks of which the Finlayson Range is constituted. Emerging from the southern extremity of the tableland it can be followed without interruption through Wiluna to the Barr-Smith Range.

The belt is made up of a complex series of metamorphosed igneous rocks, which there is some reason to believe were originally dolerites. The massive greenstones are traversed by belts of schists, which in places represent crush zones along lines which have undergone more or less intense dynamic metamorphism. The gold-bearing reefs and lodes occur as well-defined zones in the schists, trending generally parallel to the dominant strike of the enclosing rocks, which dip steeply to the west. The belt includes the mining centre of Wiluna, from which over 140,000 ozs. of fine gold have been obtained in addition to about 71,000 ozs. from the more immediately surrounding districts. The principal mining centre in the belt is Wiluna, situated about 92 miles north of Mount Sir Samuel and 120 miles northeast of Nannine. The centre was discovered in the early part of the year 1896, when numerous leases were pegged out on lines of reef, the outcrops in many cases showing coarse gold, which at times proved rich enough for the prospector to dolly profitably. Following these discoveries some very rich deposits of detrital gold were found in the vicinity of Lake Violet; a slug of highly ferruginous quartz, weighing 466 ozs. 16 dwts. and containing 248 ozs. 18 dwts. of gold, which occurred in the form of a large thin sheet, was unearthed.

Two low parallel ridges, on which the gold-bearing deposits occur, running generally north and south through the centre of the field, and rising to a height of about 100 feet above the general level of the country, form the principal topographical feature of Wiluna. These hills are divided by a watercourse, which has cut a fairly deep channel between them, and which serves to carry the drainage southward into Lake Way.

In its geological constitution Wiluna is made up of a complex mass of fairly fine-grained quartz-dolerite and its derivatives, associated with hornblende; traversing the main mass of greenstone, which is encased in granite, there are several well-defined belts of schists, which vary from a few feet up to several chains in width. These schists, as exposed on the surface, have undergone a secondary silicification to such an extent as to simulate the appearance of quartz and mica-schists. These belts of schists mark main shear or crush zones, along which the principal quartz reefs and lodes, often arranged *en echelon*, occur.

Fig. 37.

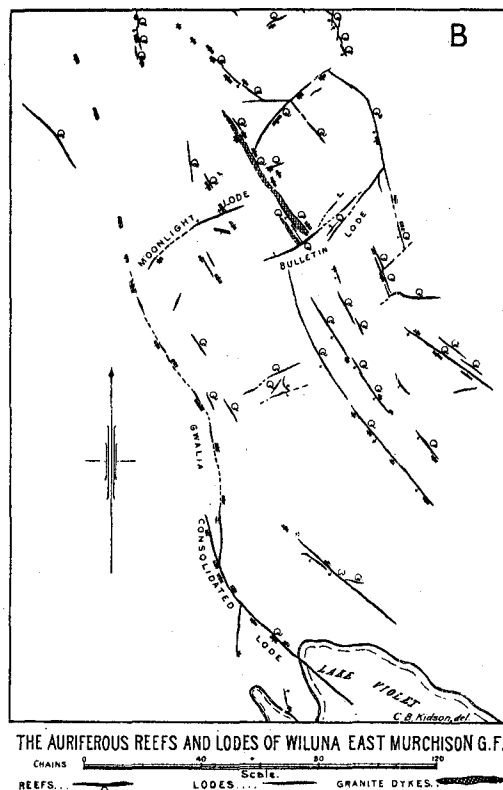


The ore deposits of Wiluna fall naturally into two main and clearly differentiated groups, viz., (a) Quartz Reefs and (b) Lode Formations.

The Quartz Reefs, when viewed broadly, exhibit a marked parallelism (Figs. 37 and 38) and fall naturally into two main groups, a northwesterly and northeasterly; they all occur within

well-defined and more or less narrow belts of schist. Individual reefs often attain a great size, at times reaching as much as twenty feet in thickness, and are continuous along the strike for a distance of fully a mile; they at times rise as conspicuous hills of quartz to heights of as much as from 40 to 50 feet above the general level of the surrounding country. The reefs are occasionally represented by a series of lenticular lenses of quartz of varying width arranged

Fig. 38.



en echelon; the horizontal distance between the respective quartz bodies varies from 33 to 66 feet. In many cases the quartz lenses owe their displacement to cross faults, which are often marked by the presence of small quartz veins.

Some of the auriferous quartz reefs of Wiluna have been found to carry masses of stibiconite (antimony ochre), cervantite (oxide of antimony), and stibnite (antimony sulphide). Some of the antimonial gold ores have assayed from 56 to 58.5 per cent. of antimony and .65 to .32 oz. of gold per ton, in addition to .25 to .50 oz. of silver.

The Darlington Main Reef, north of the Wiluna Township, is of hard white quartz, three or four feet in thickness, and contains more or less antimony. The Weelana Reef, which is a lens-shaped quartz vein, forming part of the long line of reefs, arranged *en echelon* over a length of about two miles, and extending southwards from the Highland Mary, contains the sulphantimonate of lead and copper in addition to some carbonate of copper. The Lone Hand Reef, which lies about half a mile to the south, is about 1,200 feet in length and from 4 to 6 feet thick, contains in

addition to the gold a good deal of stibnite and stibiconite. The Moonlight Reef trends about at right angles to the general strike of the main ore bodies of Wiluna, and is traceable for about 40 chains in an east-northeast direction. The deposit contains cervantite and stibnite, some of which assayed as much as 4 ozs. of gold per ton.

The Lode Formations occur principally at the southern end of the field (Fig. 38), where they run in a general northeasterly direction, almost at right angles to the general trend of the quartz reefs. The lodes range from wide mineralised belts of schist to fairly distinct and wide ore bodies with well-marked walls; they, in all probability, represent old fault or shear lines, along the cleavage (?) planes and cracks of which gold-bearing solutions have had more or less free access. It has been found that where these cracks and cleavage (?) planes are most numerous the gold values are higher than in those portions which have offered greater resistance to crushing and fracturing. The lodes carry varying quantities of massive stibnite, some of which is very high in gold, assays of as much as 17 ozs. of gold having been obtained. The best known and most typical of the lode formations are the Gwalia Consolidated, the Moonlight, and the Bulletin.

The Gwalia Consolidated Lode (Fig. 38), which is one of the largest at Wiluna, and situated in the low-lying country near Lake Violet (Way), has a total length of about 1,800 feet, is made up of a belt of crushed and shattered greenstone which varies in width from 50 to 100 feet, and is full of veins of quartz, in addition to being heavily charged with pyrites below water level. The lode, which has been extensively worked, is associated with a quartz reef carrying some stibnite and its oxidation product stibiconite. A very large massive quartz reef occurs near the centre of the lode; the reef, which trends generally northwest and southeast, faults the Gwalia Consolidated ore body, the two dislocated portions being known as the north and south lodes respectively. A parallel foliation of the country rock occurs along the line of the quartz reef. The heave of the fault is a large one, the distance along the fault between the ore bodies being quite 800 feet. The Moonlight Lode (Fig. 38), which has a length of at least half a mile, trends generally east-northeast with a high underlay to the northward, consists of a belt of crushed and foliated greenstone of variable width, represented in part by iron-stained clayey and siliceous rubbly matter, with smooth and distinct walls.

The place of the lode is often taken by solid reef quartz, containing large bunches of stibnite, which, near the surface, is represented by cervantite and stibiconite. The gold values are not solely confined to the lode itself but have been met with outside the walls of the defined ore body, for as much as 50 feet.

The Bulletin Lode (Fig. 38) is made up of sheared and shattered greenstones, trending generally northeast, and with a very steep underlay to the northwest. The lode does not appear to have any defined walls; it consists of a narrow zone of crushed rock, which has been more or less impregnated with gold-bearing solutions. Smooth walls are of frequent occurrence, though they do not everywhere mark the limits of the values, for the impregnation has been found to occasionally extend into the uncrushed country rock, though naturally the values are highest and most concentrated where the crushing has been the most intense.

A fair amount of work has been done on the Bulletin Lode.

A few patches of residual and detrital gold have been obtained at the southern end of the Wiluna belt, within a few inches of the surface; but though several fair-sized pieces were unearthed no very large quantity of gold has been recorded from this source.

The auriferous rocks of Wiluna extend southwards in a fairly well-defined belt, and some gold discoveries have been made at a point about 11 miles from the township, at a locality now known as *Cole's Find*.

The rocks in the vicinity are very much weathered greenstone schists, which are traversed by lenses and reefs of quartz. The schists have, in places, been hardened by the deposition of iron and silica; the deposits produced by this cause occur as more or less parallel bands which present the appearance of quartzose, and gossany lodes, of a nature warranting more or less careful and systematic prospecting, as it is possible that they represent the caps of lodes which may ultimately develop into mines.

The extension of the greenstone schists of the Wiluna Belt has been exploited at Kingston, or what is known as Cork Tree Flat, about 30 miles to the south. The rocks consist of basic schists inter-laminated with large quartz reefs, associated with which is a pronounced lode of brown iron ore. Two reefs, the Enterprise and the Kingston, have been worked to some extent. The former, said to have attained a maximum thickness of about six feet, has yielded 2,709 ozs. of gold from 2,880 tons of ore. The Kingston reef, which varies from 2 to 6 feet in thickness, has been proved for a length of over 200 feet along the strike north 10 degrees west. The reef lies along the foliation planes of the schists, which dip westerly at a high angle. The total gold yield, however, of the Kingston mining centre has been 3,302 ozs., derived from the milling of 3,780 tons of ore.

The favourable greenstone country continues southward to the neighbourhood of Mount Keith, which lies about 45 miles southeast of Wiluna and about 25 miles north of Kathleen Valley, from which it is separated by a belt of granite. In the neighbourhood of Mount Keith a series of quartz reefs occurring on a ridge trending generally northwest and southeast have been worked; these have up to the end of 1918 yielded 6,588 ozs. of gold from 8,066 tons of ore. The belt is about two miles distant from the large mass of intrusive granite, which has engulfed several bands of ferruginous quartz schist. The ore bodies at Mount Keith consist of parallel quartz lenses, never more than about 3 feet apart; the lenses vary in thickness from a few inches to as much as 6 feet. The reefs are enclosed in the foliation planes of the greenstone schist, which represents a line of shearing (?) having a proved length of at least 3 miles. The continuity of the Wiluna Belt to Lawlers is interrupted near Kathleen Valley by a stretch of granite 12 miles in width. The belt continues southward through Sir Samuel and Lawlers, where it is contained in a very large fragment 55 miles long by 20 miles wide made up of basic igneous rocks, which are in contact with granite on all sides.

The mass is composed chiefly of fine-grained epidiorites and allied rocks, intersected by acid dykes, some of which are quartz-porphyrines, and others granite of the type common to the mass by which the basic rocks are surrounded.

The auriferous deposits in the vicinity of Sir Samuel, which have produced 141,283 ozs. of gold from 269,142 tons of ore, are chiefly normal quartz reefs, which with one or two exceptions are small and of no great horizontal extent. The general strike of the reefs is north and south, which coincides with that of the foliation of the schists which everywhere constitute the matrix.

Most of the reefs contain copper pyrites, at times in considerable quantity.

There are only two reefs of any size at Sir Samuel, viz., the Bellevue and the Vanguard. The Bellevue Reef, which trends north and south, has been followed along the surface for over 1,700 feet and worked to a depth of over 400 feet. It has an underlay to the west of about 60 degrees, and has yielded 129,860 fine ozs. of gold, and 10,225 of silver, from the milling of 248,549 tons of ore. The ore body consists of a somewhat laminated quartz, varying considerably in size; it occurs as lenticular masses, some of which reach as much as 30 feet in width, the average, however, being somewhere about 5 feet. The reef is chiefly solid quartz, which contains varying quantities of copper-bearing pyrites; it is found that below the zone of oxidation nearly all the gold is carried by the pyrites.

As a rule the lode has no very sharply defined walls, the schists passing by almost imperceptible gradations into fine-grained epidiorite.

The Vanguard Reef, which has yielded 3,967 ozs. of gold from the milling of 9,941 tons of ore, makes a boomerang-shaped outcrop of at least 500 feet in length. As seen near the surface the lode consists of a crush zone of fine-grained slightly foliated greenstone, containing seams and masses of quartz, together with some oxide of iron, which often passes into bodies of ore made up entirely of quartz. The lode varies considerably in size, reaching as much as 12 feet wide; in the workings below the zone of oxidation (60 feet in vertical depth) it is heavily charged with pyrites containing very little copper.

Above the 60 feet level the ore is highly oxidised and contains a considerable quantity of fine flaky gold, which probably owes its origin to secondary decomposition during oxidation of the outcrop.

Some distance to the southward is the mining centre of Lawlers, which lies about 80 miles northwest of Leonora, the present terminus of the railway line from Kalgoorlie. The mining centre of Lawlers lies on a plain, surrounded on three sides by some low rough hills, which rise to heights varying from 100 to 300 feet above the general level of the surrounding country. The hills are drained by two fair sized creeks, which trend generally southwesterly.

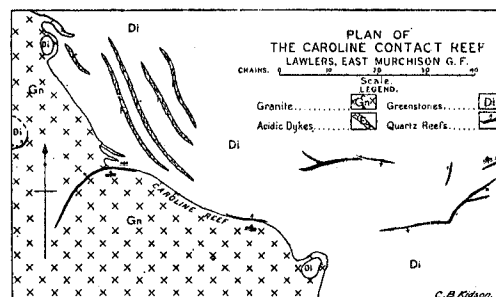
The rocks of the Lawlers district are, when viewed broadly, divisible into two sharply differentiated classes, viz., granite and basic rocks (*i.e.*, greenstones), of which the latter are of the greatest economic importance. The granites and greenstones are traversed by a number of acid dykes, which vary in their lithological character from coarse-grained granite through aplites and quartz-porphyrries to fine-grained compact felsitic rocks, some varieties of which simulate quartzite in appearance. The dykes, most of which are merely offshoots from the main mass of granite, vary in width from one foot up to as much as two to three chains; in some cases they can be traced across the surface for over a mile. The granite is intrusive and sends out long irregular arms and offshoots, which intersect the greenstones in all areas. There are, in addition, several much newer dolerite dykes. The country occupied by the Lawlers greenstones has a width of about 15 miles and is continuous in a northerly direction as far as Sir Samuel. The greenstones are both massive and foliated; some of the schistosity, however, owes its origin to pressure exerted in the rocks, as a result of expansion from weathering. A very large portion of the district is covered with a varying thickness of recent superficial deposits made up principally of loose sandy soil; there are, in addition, subordinate areas of laterite, which are, however, very limited in extent.

The gold-bearing deposits of the vicinity are scattered over a belt of country, which extends about two miles south of Lawlers to about eight miles north of it, and about six miles in width. The ore deposits of Lawlers are, for the most part, quartz reefs, though "lodes," *i.e.*, belts of crushed and foliated country rock permeated with seams and veins of quartz lying along the foliation planes, occur, and have been worked.

The quartz reefs occur both in the granite and the basic rock, though those present in the granitic area have, with one exception, been of a too low grade to be an important source of gold. The reefs have no prevailing direction. Some of the reefs, however, are to be found on the contact between the granite and the greenstones; contact reefs of this type are usually found to be made up of strongly laminated white glassy quartz of lenticular habit. A good example of this type is the Caroline Reef (G.M.L. 916) which at 100 feet below the surface proved to be 20 feet wide, the hanging wall being greenstone and the footwall granite (Fig. 39). The total quantity of gold raised from the reefs of the Lawlers neighbourhood amounts to 485,242.25 fine ozs. obtained from the milling of 1,260,172.70 tons of ore. A fairly large quantity of alluvial and detrital gold has been raised from the Lawlers district, though most of it, however, appears to have been obtained from

the hilly country to the north of Lawlers township and at Waroonga. No separate record appears to have been kept of this, for in the official statistics there is recorded only 14.81 ozs. of alluvial gold up to the end of 1918. The Vivien is a type of quartz reef characteristic of those occurring in the greenstone areas. The mine is situated about 7½ miles north-northeast from Lawlers. The ore body, a pure quartz reef, of great size and length, and of

Fig. 39.



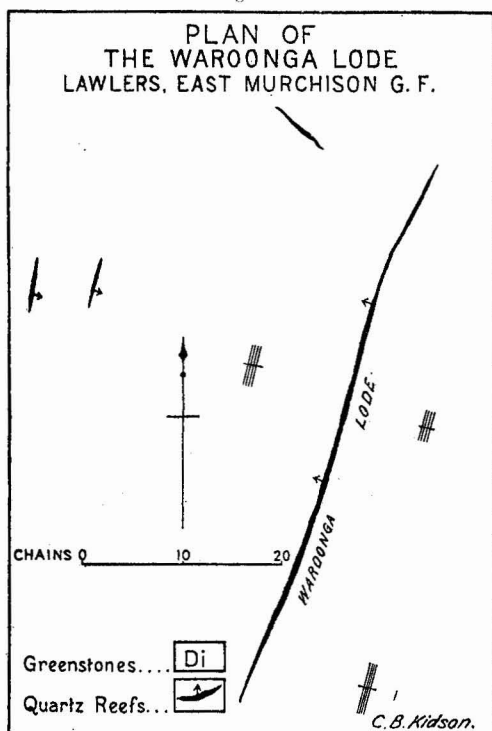
a somewhat lenticular habit, has an underlay to the southeast of about 45 degrees. The reef averages about from 5 to 6 feet in width, though in places it measures as much as 25 feet from wall to wall, and has been opened for about 1,500 feet in length, and to a depth of over 400 feet. The quartz is mostly strongly laminated and in the upper levels contains many vugs and is much iron-stained; below the No. 3 level, which marks the limits of oxidation, the quartz is highly charged with iron, pyrites, pyrrhotite and arsenical pyrites. The country rock frequently shows slickensided faces. The Vivien Reef has been a large producer of gold, having crushed to the end of December, 1918, 209,520.18 tons of ore for 76,795.19 ozs. of fine gold, and 1,697.88 ozs. of fine silver. The Waroonga (Fig. 40) is a type of the lode formations of which there are one or two in the neighbourhood. The lode has been opened out by levels for over 2,700 feet in length, and to a depth of over 500 feet from the surface is proved to be from 60 to 30 feet wide, though in places it attains a thickness of at least 120 feet. The ore body, which appears to have been formed along lines of shearing, shattering and faulting, consists of broken up and crushed kaolinised country rock, containing as one of the results of metasomatic processes, silica and metallic sulphides. Near the surface the lode has been changed by weathering into a mass of ironstained clay, with ramifying quartz veins, this clay passes gradually in depth into actinolite chlorite and similar silicates, and the whole of the lodestuff being more or less heavily impregnated with sulphides. The foliation of the enclosing country rock which is a marked and characteristic feature in the upper levels gradually disappears in depth and gives place to a hard fine-grained massive greenstone. The Waroonga lode has a general strike of northeast, with an underlay to the west of about 60 degrees; there is no regular footwall, for the lode passes gradually into the schistose country, the limits of the ore body being defined by the decrease in the value of the gold contents. Many parts of the lode are almost entirely quartz, some of which forms large lenses of from six to eight feet in thickness. The gold values appear to be usually concentrated in the quartz veins, though where there is little quartz the values are mainly in the sulphides and their oxidation products. There has been considerable secondary deposition of gold in the superficial portions of the lode.

The Waroonga Lode has produced up to the end of September, 1920, 325,539.33 ozs. of fine gold, and 11,817.68 ozs. of silver from the milling of 965,156.00 tons of ore.

The Waroonga ore channel in all probability continues in a southwesterly direction for about 60 chains where what is known as the New Woman Lode has been worked. A small quartz reef has been opened out to a shallow depth along the outcrop for a length of 300 feet upon what is in all probability the southern extension of the Waroonga Lode. This ore body may be traced to what was known as the New Woman South Lease (858) where it has been worked along the outcrop for over 600 feet in length; it proved to be two feet wide and contained fairly rich ore. About 66 feet east of the main shaft there is a wide belt of shattered country, highly impregnated with ironstone and quartz said to be carrying a little gold. The recorded output from the New Woman ore body is 1,495.65 tons of ore with a yield of 1,657.64 ozs. of fine gold.

The two gold-bearing belts to the eastward—Barlows and Mount Eureka—possess the structural and other features which make up the main area previously described, and in addition to bearing a somewhat similar relation to the surface configuration, they represent features favourable to the formation of gold-bearing deposits and on that account warrant more or less systematic prospecting, carried out on judicious lines.

Fig. 40.



(B) THE BARLOW'S BELT, the northern extremity of which is in south latitude 26 degrees, about 30 miles northeast of Wiluna, has a length of about 130 miles in the East Murchison Goldfield. The rocks of the Barlow's Belt consist of amphibolite, hornblende, epidiorite and jaspers of the type so common in the portions of the State occupied by the Archean Rocks.

A certain amount of prospecting has been done within the limits of the belt, the position of which has been defined on the

geological sketch map which forms the frontispiece of Bulletin 83. Mining operations also have been carried out at Collavilla, Barlow's, and Bronzewing, which are often referred to as the Bronzewing District.

At Bronzewing, which lies on a low hill rising above the general level of the surrounding country, operations were principally centred upon a quartz reef, from ten to twelve feet wide, which trends generally north and south, and has been traced for over 22 chains along the outcrop. A small gold-bearing quartz reef, about 18 inches to 3 feet wide, occurs to the westward, and had been opened up to a shallow depth; this reef proved to carry gold con-

Fig. 41.



Photo.: E. de C. Clarke;

Neg. 1188.

Outcrop of a Jasper Bar.

This bar, about one mile south of the Black Range Mine, forms a prominent, almost continuous ridge for about three miles.

tinuously along the outcrop for about 30 chains. The walls of the reef were smooth and distinct, and the quartz was contained within the foliation planes of the greenstone schists. The Bronzewing ore-body disappears beneath the surface soil on the south, but owing to the thickness of the cover its extension has not been traced. Other parallel gold-bearing reefs are known in the neighbourhood, which, however, has only produced 468 tons of ore yielding 318 ozs. of fine gold. Some of the quartz reefs in the neighbourhood carry iron oxide, green and blue carbonates of copper, in addition to a little copper pyrites, though not in such quantities as will have any serious effect upon cyaniding operations.

(C) THE MOUNT EUREKA BELT, which is the most easterly on the East Murchison Goldfield, has a length of about 90 miles. The rocks consist of amphibolite, altered dolerite, and epidiorite, with a fairly large development of jaspers which attain their greatest development in the vicinity of Stirling Peaks. The neighbourhood

of Mount Eureka, at the northern end of the belt, is the only locality at which prospecting operations appear to have been carried out. Two shafts had been sunk from which a considerable quantity of ferruginous quartz was raised; the rocks in the immediate vicinity of the mine consist of weathered greenstone schist, associated with lateritic ironstone. Though no ore has been crushed from the belt, its geological structure and constitution warrant systematic prospecting.

The westernmost portion of the East Murchison Goldfield includes five mining centres—Sandstone, Youanme, Montague, Bar-rambi, and Errols—which up to the end of 1918 have produced 599,232.36 ozs. of fine gold.

Sandstone is the principal township in the Black Range Mining District, and is connected by rail with Geraldton, which lies about 309 miles to the westward. The locality first came into prominence in the early part of 1903 as an alluvial centre, after which gold-bearing reefs were discovered, some subsequently developing into mines of considerable importance.

The gold-bearing area of the vicinity of Sandstone is fairly extensive; it has, as may be seen by a reference to the geological sketch map (Plate i., Chapter I., and the frontispiece to Part ii.

of Bulletin 31) an area which is triangular in shape, the apex of which lies about nine miles north of Sandstone. The area opens southwards to a width of about 20 miles and includes the mining centres of Bellehambers and Maninga Marley. The southernmost extremity of the area, which has a maximum width of about 25 miles, does not extend far to the south of either of the two localities previously mentioned.

The rocks comprising the gold-bearing area are of metamorphic origin and are nearly all basic compounds, both massive and schistose, which investigation seems to indicate were originally derived from a quartz-dolerite. The metamorphic rocks are intersected by masses and dykes of granite and allied acid rocks, whilst the whole gold-bearing area is entirely surrounded by granite. The basic rocks are traversed by a large number of jasper bars which in this area appear to owe their origin to the transmutation of basic rocks as a result of excessive and possibly long-continued shearing. These jasper bars (Fig. 41) traverse the area in a general east and west direction; they consist of highly laminated quartz, often red and black in colour, with occasional thin laminae of hematite and magnetite, and are lithologically less ferruginous than those of the type prevailing on the Murchison Field. When seen below ground in the mine workings (Fig. 42) the jasper

Fig. 42.

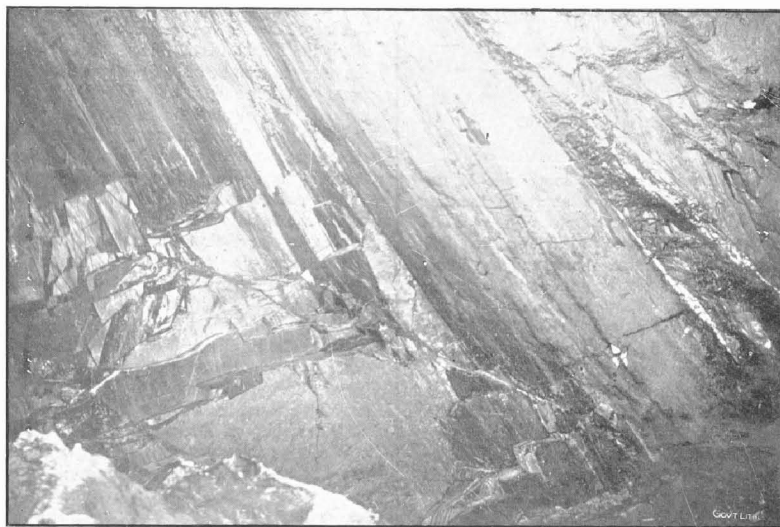


Photo.: E. de C. Clarke.

Neg. 1189.

Graphite Schists of the Jasper Bar in Lower Level, Black Range West Mine.

bars are found to pass by imperceptible gradations into graphite schists, which when examined microscopically exhibit evidence of having been subject to considerable dynamic alteration; in some cases the carbon content diminishes in depth and the rock is represented by chlorite schists. These form the zones along which very marked shearing of the massive quartz-dolerite took place and are contemporaneous with the fissures in which the auriferous quartz was deposited.

The most important gold-bearing deposits in the belt are the reefs, which usually consist of clean compact quartz, of a white or bluish colour, enclosed between smooth and well-defined walls. The quartz on the hanging wall is often slickensided, the stone breaking clean away from it, in contradistinction to that on the footwall, where

the ore merges gradually into the adjacent country rock. The quartz reefs are not, as a rule, highly mineralised; iron pyrites is the commonest accessory mineral, whilst copper pyrites, with its decomposition products, arsenical pyrites, and zinc blende, together with a little zircon, occur to a lesser degree. Calcite is known to be present in two of the ore-bodies, viz., the Sandstone and the Black Range reefs. The principal reefs of the Sandstone belt trend generally north and south, and have an underlay to the westward at angles averaging about 35 degrees. A large number of the smaller and less important reefs trend northwest and southwest, with an underlay to the northeast. The Wanderie Reef, to the west of Sandstone, has an east and west outcrop, with a dip sometimes to the north and at others south.

The most important ore-body is the Sandstone Reef, which was so named on account of the friable and granulated nature of the quartz, some portions of which in the upper levels, being so sandy as to crumble readily between the fingers into a coarse grit and sand. The reef has an outcrop of about 50 chains in length, in a north and south direction, enclosed in an amphibolised quartz-dolerite; at its southern extremity the reef abuts against the long east and west jasper bar, which has been proved to be continuous for about 200 chains. There is no very clear evidence that the bar exercises any definite enriching or impoverishing effect on the gold-bearing quartz reef. The Sandstone Reef underlays west at angles varying from 30 to 40 degrees, and has an average thickness of about four feet, though, in places, its width reaches as much as ten feet. The Sandstone reef has produced 175,921.45 ozs. of fine gold from 311,226 tons of ore. A fine-grained basaltic-dolerite-dyke is associated with the reef, and has been followed for over 3,000 feet horizontally, and to 460 feet vertically. The dyke occasionally breaks across the reef (Fig. 43), and displaces it, though does not appear to have exerted any appreciable influence on the gold values.

Fig. 43.

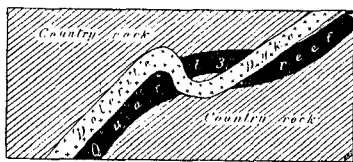


Diagram illustrating one type of fracture of the Sandstone Reef by the Dolerite Dyke.

About a mile to the westward and on the south side of the jasper bar, against which the Sandstone reef abuts, is another parallel ore-body, known as the Black Range Reef. The reef lies between two conspicuous and parallel bars, which are about 800 to 900 feet apart; they consist of laminated quartz and ironstone, which, in depth, give place to highly schistose greenstone, carrying seams of ironstone and a little quartz. These bars represent shear zones, which carry no appreciable gold values. The Black Range Reef has an average thickness of about 5 feet, and in places exhibits a strong, bold outcrop; it underlays to the west at from 30 to 40 degrees. The reef, which is of considerable length, has been worked to a vertical depth of 900 feet. The deposit resembles in all its essential characteristics that of the Sandstone Reef, the quartz occurring in large lenses up to about 8 feet in width. The reef has been an important gold producer, having yielded 159,278 ozs. of fine gold from 227,485 tons of quartz.

The Youanme Belt, which has produced 141,975 ozs. of fine gold, lies in the extreme southwest corner of the field. The existence of the belt has been known for a number of years, a good deal of prospecting having been carried out during the years 1895-6. The gold-bearing belt is about 10 miles in width and 30 in length; it has its northern limits some miles north of Trig. Station N.B. 47 and continues to the southeast in the direction of the western arm of Lake Barlee. The rocks of the belt consist of massive and schistose basic rocks, traversed in places by bands of jasper and numerous lenticular quartz reefs. The schistose rocks carry a number of small quartz and ironstone veins, lying parallel to the foliation planes; veins of this type are never very thick, nor do they reach any great length. These veins sometimes carry gold; some of the schists also carry a certain amount of fine gold, which occurs chiefly on the cleavage or foliation planes. The principal mining centre in the belt is at Youanme (Coorang), where active operations have been chiefly centred upon the ore-body in the property of the Youanmi Gold Mines, Ltd. The mining area of Youanmi is on the margin of, and in part in a granite mass, the bound-

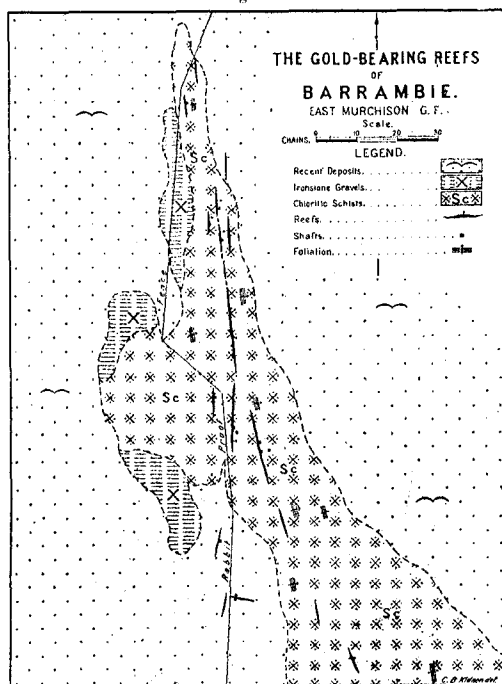
dary of which is very irregular, and to a large extent obscured by superficial deposits. The auriferous area of Youanmi occurs in a belt of basic rocks, epidiorite, amphibolite and their derivatives, chlorite-sericite schist, invaded by dykes of granite, which mineralogically is identical with that of the main mass. The gold deposits of Youanmi are situated in a belt of schistose rocks, about one and a quarter miles wide, which occur adjacent to the margin of the granite constituting the eastern boundary of the basic complex; it is, however, only in the southern portion of the belt that the lodes have proved payable. The continuity of the lodes and ore shoots has been interfered with by the presence of the tongues of granite, as well as the occurrence of a series of shear zones and fault planes of apparently different ages. The effect of these dislocations has been to cut up the ore shoots into a series of lenses of very variable dimensions. The width of the lodes varies within very wide limits. The ore bodies contain fairly large quantities of pyrites in a finely granular form, together with some arsenopyrite and stibnite. Large quantities of magnetite occur in the rocks of the Youanmi mine, outside the lode channels. The principal ore body on the field is the Youanmi lode which has been worked down to a depth of 778 feet below the surface; from such investigations as have recently been made by the Geological Survey there are sound scientific reasons for the belief that payable ore bodies occur below those depths to which the lode has hitherto been worked.

The westernmost gold-bearing belt of the East Murchison field is that of Barrambie and Errol's, situated near the 284-Mile peg, along the Rabbit-proof Fence. The gold-bearing deposits occur on the western slopes of the Barrambie Ranges, which consist of a range of fairly rugged hills, trending generally northwest and rising to a height of about 200 feet above the general level of the surrounding country. The gold-bearing area extends from Errol's, about 9 miles northwest from Barrambie, to a point about four or five miles from it, having a total length of about 12 to 15 miles, and an approximate maximum width of about three miles. The rocks, of which the belt is made up, are somewhat chloritic schists, which appear to owe their origin to the transmutation of a highly hornblende granite or granodiorite; these are enclosed in granite of the type prevailing over large areas in the interior of Western Australia. The general strike of the foliation of the schists is in a northerly direction, with a steep dip to the east. Well-defined shear or fault planes occur along the strike of the schists; these fault fissures carry quartz veins, which are at times of considerable length, though not usually very thick. At Errol's, the quartz reefs are of the usual lenticular type, so common in schistose rocks, whilst at Barrambie, on the other hand, the reefs, though small (Fig. 44), can be followed for a considerable length along the outcrop; one of them can be followed for a distance of 34 chains, without a break. The Barrambie-Errol's belt has yielded about 3,202 ozs. of fine gold.

The Montague Gold Belt lies to the west of Barrambie and north of Sandstone, and is of considerable extent; it includes within its boundaries the mining centres of Birrigrin (Babba Walya) and Montague. The gold-bearing zone is about 50 miles in length and 15 wide. The rock formations consist of greenstone schists and several bands of laminated hematite quartzites, the whole being intersected by acid dykes, probably emanating from the main mass of granite by which the belt is everywhere surrounded. The basic rocks are much crushed and foliated for several chains from the junction of the granite and the metamorphic rocks, whilst the granitic dykes lie, as a rule, parallel to the boundary between the two rock masses. The acid dykes have not any very great horizontal extent, and occur within a quarter of a mile from the main granite mass. The ore deposits appear to occur in two principal forms, viz., quartz reefs, and impregnations in the schists associated with veins and lenses of quartz. The quartz reefs are fairly numerous and are to be found along the junction of the granite and the greenstone, and occasionally adjacent to the granitic dykes. At other times they

occur along the foliation planes of the schists, though cases do occur in which they intersect them at small angles. As a rule, these reefs trend generally north and south; they are usually vertical or inclined at very high angles. In the case of the impregnations, how-

Fig. 44.



ever, it has been found that the principal values are met with in the small quartz veins. The minerals found in the reefs and veins are limonite, haematite, iron pyrites, together with a little copper ore. The gold-bearing zone has not been a large producer though, it has yielded 7,835.28 ozs. of gold.

MOUNT MARGARET GOLDFIELD.

The Mount Margaret Goldfield has been an important gold producer, having turned out 2,820,624.30 ozs. of fine gold up to the end of 1918; thus from the point of view of its gold yield ranking third of the known fields in the State. The goldfield, which was previously included in that of North Coolgardie, was established by proclamation in the year 1897; its boundaries were amended, however, in 1917 so as to embrace an area of 57,230 square miles.

The Mount Margaret Goldfield is situated in South latitude 28 degrees, and East longitude 123 degrees. It is traversed by that system of so-called lakes, Carey and Raeside, in reality constituting the beginnings of river channels in that extensive system which, during Cretaceous-Tertiary times, drained the portion of the country now occupied by the strata of the Eucla Tableland or Nullabor Plains.

Mining operations on the Mount Margaret Goldfield have been confined to the more or less widely separated centres, situated in the three districts, Mount Malcolm, Mount Morgans and Mount Margaret, into which the field has been divided for purposes of administration. The following synoptical table gives details as to the gold production from the different centres on the Mount Margaret Goldfield.

Synoptical Table showing the Gold Yield of the Mount Margaret Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dollied, and Specimens.	Ore treated.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	Tons (2,240lbs.)	Fine ozs.	Fine ozs.
MOUNT MALCOLM.				
Cardinia ...	1,568.29	1,628.24	3,550.42	5,118.71
Diorite King ...	948.72	36,925.83	34,393.18	35,341.90
Dodger's Well ...	61.27	2,085.55	2,572.89	2,634.16
Leonora ...	2,043.40	2,701,944.75	1,304,838.31	1,306,881.80
Malcolm ...	55.95	65,283.68	49,511.39	49,567.34
Mertondale ...	55.24	89,715.46	62,328.59	62,383.83
Mt. Clifford ...	1,838.79	4,686.96	15,322.64	17,161.43
Pig Well ...	34.61	16,068.72	15,740.95	15,775.56
Randwick ...	417.24	9,342.79	9,577.73	9,994.97
Webster's Find ...	82.40	23,157.80	14,909.75	14,992.15
Wilson's Creek ...	4.24	338.50	187.31	191.55
Wilson's Patch ...	100.88	27,006.10	13,490.59	13,591.47
District generally ...	2,524.51	407.00	17,521.48	20,045.99
	*9,735.63	2,978,651.38	1,543,945.23	1,553,680.86

*Includes 228.03ozs. of dollied and specimens.

MOUNT MARGARET.				
Burtville ...	468.50	68,899.32	103,908.62	104,377.12
Duketon ...	2,743.15	31,681.42	22,452.71	25,195.86
Eagle's Nest ...	343.09	401.00	1,261.43	1,604.52
Erlistoun ...	1,307.90	29,133.05	20,298.45	21,606.35
Euro ...	111.66	91,815.75	37,699.58	37,811.24
Laverton ...	3,494.68	1,225,546.83	555,091.13	558,585.81
Mt. Barnicoat ...	...	675.00	382.49	382.49
Quartz Hill ...	...	10.00	3.86	3.86
Red Hill ...	...	27.00	13.76	13.76
District generally ...	1,997.17	228.50	11,412.45	13,409.62
	*10,466.15	1,448,417.87	752,524.48	762,990.63

*Includes 595.61ozs. of dollied and specimens.

MOUNT MORGANS.				
Australia ...	2,305.41	16,712.94	25,378.38	27,683.79
Eucalyptus ...	3,232.27	1,724.85	3,407.90	6,640.17
Federation Well ...	...	1,356.57	1,847.39	1,847.39
Korong ...	125.15	3,001.28	3,706.34	3,831.49
Linden ...	673.61	28,976.70	30,511.66	31,185.27
Mt. Margaret ...	61.01	6,618.50	4,471.57	4,532.58
Mt. Morgans ...	165.83	740,495.25	352,315.29	352,321.12
Murrin Murrin ...	387.84	128,211.47	101,459.20	101,847.04
Redcastle ...	544.61	2,648.95	2,332.64	2,877.25
Yundamindera ...	165.69	72,927.35	49,337.16	49,502.85
Mt. Howe ...	...	5.00	11.13	11.13
Mt. Celia ...	...	14.00	5.29	5.29
District generally ...	4,071.57	100,013.23	80,642.28	84,713.85
	*11,672.99	1,102,706.09	655,426.23	667,099.22

*Includes 35.92ozs. of dollied and specimens.

Grand Total ...	*31,874.77	5,529,775.34	2,951,895.94	2,983,770.71
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*Includes 859.56ozs. dollied and specimens.

A very large portion of the proclaimed limits of the Mount Margaret Goldfield has never yet been examined by any member of the Geological staff, hence our knowledge of its features are not as complete as is desired. Detailed geological observations, however, have been carried out at several of the more important mining centres in addition to reconnaissance surveys of fairly wide areas. The combined results of these investigations have enabled a fair idea being obtained as to the limits of the gold-bearing zones by which the Mount Margaret field is traversed.

The western half of the Mount Margaret Goldfield contains all the gold-bearing deposits so far known. This portion of the field consists of relatively low-lying salt-pan country, occupied by the very long and narrow channels, Lakes Carey and Raeside, into which all the drainage of the area flows. The western portion of the field is made up, geologically, of a series of metamorphic sedimentary

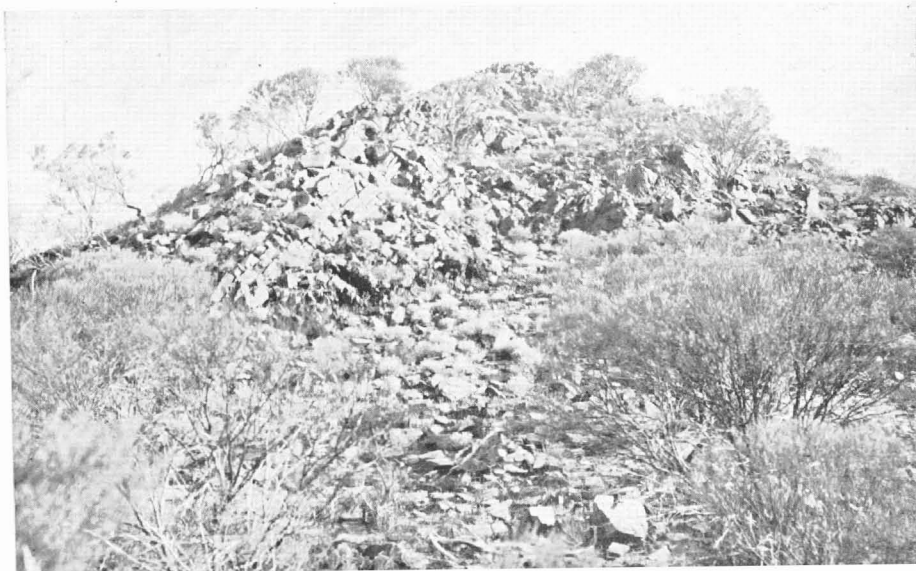
rocks, together with some of igneous origin, and a large development of crystalline rocks, the derivatives of dolerites and gabbros, such as epidiorites, amphibolites, or chlorite-carbonate rocks ("greenstones"). The greenstones are associated with some contemporaneous acid igneous rocks, which vary from andesites to quartz-porphyrates. Intersecting these are many dykes and masses of granite, porphyrite and quartz-porphyrates, which have, in common with most of the other rocks, undergone more or less dynamical alteration. The gold-bearing deposits, *i.e.*, quartz veins, some of which contained rich pockets of gold, have often been found to lie parallel to the schistosity of the rocks, with which they coincide in both dip and strike, generally north-northwest.

The northern part of the known portion of the field, which includes Lakes Carnegie and Wells, forms a plateau region containing many more or less isolated flat-topped tablelands and hills, made up chiefly of the rocks of the Nullagine Formation. In this locality the formation consists of conglomerates, grits, sandstones, quartzites, shales and limestones, occurring, as a rule, in the form of broad shallow folds in which the dip amounts to about five or six degrees. There are also some dolerite sills, etc., associated with the strata.

The southeastern portion of the field is occupied by a series of almost horizontally-bedded slightly compacted sandstones, claystones, and boulder beds, tentatively designated the Wilkinson Range Beds. The base of this series is seen at Dunge's Hill and forms the Virginia Range. Outliers of these rocks, which cover an extensive area in the Mount Margaret field, occur in the Princess and Carelew Ranges, and at Mount Draper, on the western side of the northern portion of Lake Wells. These beds, which are believed to be of Late Tertiary or Mesozoic Age, tend from their very nature to conceal the older metamorphic auriferous horizons. The northernmost area in which these later sediments have been found is at Mount Hooley, South latitude 26 degrees, north of the eastern end of Lake Carey, just on the northern boundary of the Goldfield. The mapping of the areas occupied by these beds, and those belonging to the Nullagine Formation, would delimit the extent of the possible mineral-bearing country in the Mount Margaret Goldfield.

Mount Malcolm District.—The most extensive and important area in the Mount Margaret Goldfield is that of the Mount Malcolm District, which has produced, up to the end of 1918, 1,553,680.86 ozs. of fine gold, or more than one half of the total yield of the whole

Fig. 45.



Mount Leonora.—Outcrop of Metamorphic Sediments; Dip, 55 degrees East.

field. Of the whole amount of gold obtained from the district, 1,154,609.08 ozs. have been produced from the Sons of Gwalia ore body, near Leonora, which is the most important deposit and the one upon which the prosperity of Leonora largely depended.

The district is comprised of a complex of metamorphic rocks, covered to a variable depth by superficial deposits (sand, soil, cement, etc.) which effectively conceal important geological boundaries in critical localities.

The metamorphic rocks are made up of a series of crystalline schists, both basic and acidic in composition and of both igneous and sedimentary origin.

The oldest rocks of the district are those metamorphosed sediments which are exposed at Mount Leonora (Ermi) (Fig. 45), a prominent hill near the township of Leonora, rising to a level of about 25 feet above the general level of the surrounding country.

The beds are well exposed on the flanks of the hill, and also to the south of the mount where they have been extensively quarried for road making, etc. The strata, which dip eastwards at angles of from 56 to 55 degrees, consist chiefly of quartz and andalusite schist, the average mineral composition of which, as deduced from the chemical analyses of two samples from widely separated localities, is, in parts per hundred—andalusite, 20.8 to 30.7; quartz, 69.5 to 74.43; mica, 1.6 to 2.26, together with a little albite and some rutile. These sedimentary schists extend without any interruption northwards as far as Mount George. In the neighbourhood of the old Bannockburn Mine these metamorphosed sediments are very fine in grain; they trend generally north and south and are arranged in the form of an anticlinal fold. The numerous quartz reefs occurring in the neighbourhood are merely lenses along the bedding planes, to which they conform both in dip and strike.

A considerable development of hematite-bearing quartz bands forms a notable feature of these metamorphic sediments. Bands of this nature can be followed more or less continuously along the ridge which extends from Leonora northwards in the direction of Mount George and thence to Lake Raeside; they consist of bands or lenses of quartz, from 10 to 50 chains long, and from 12 inches to 100 feet in thickness. The rocks often project above the surface for several feet and make very prominent features in the landscape. These quartz lenses everywhere conform both in dip and strike to those of the schists in which they are enclosed.

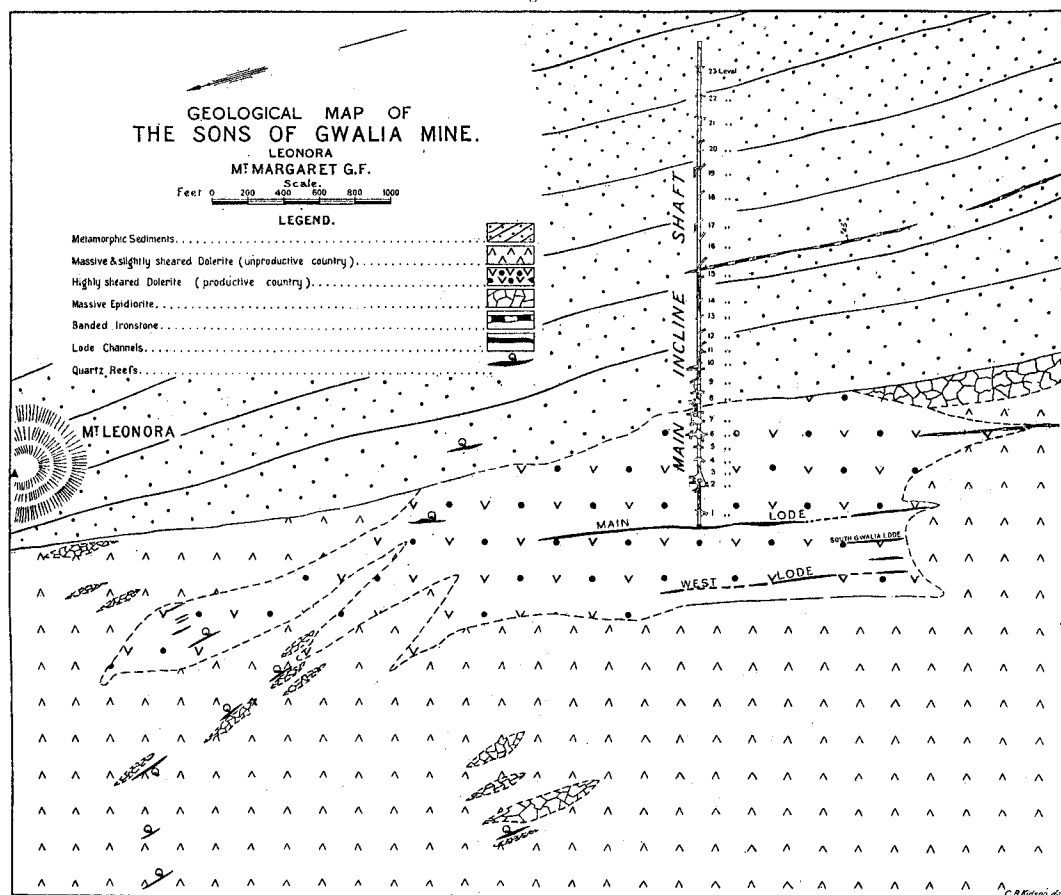
The basic rocks, which comprise the main auriferous series, are made up principally of a complex of chlorite and talc chlorite

schists (derivatives of dolerite or gabbro and pyroxenite), which are largely developed along the outer margin of the main belt, whilst the centre portion is occupied by more or less massive rocks. There seems good reason for believing that the schists are merely portions of one and the same mass which have undergone dynamical metamorphism, possibly modified by chemical action.

The greenstones and basic rocks have been invaded by granite and allied rocks which cover a very wide area; acid dykes may be seen traversing the greenstones in the vicinity of the Leonora Gold Blocks Mine.

The massive greenstones contain crush lines which in many cases carry quartz veins, some of them having proved to be gold-bearing.

Fig. 46.



All the important ore deposits occur in the basic rocks and their derivatives, which have yielded fully 90 per cent. of the total output of the district.

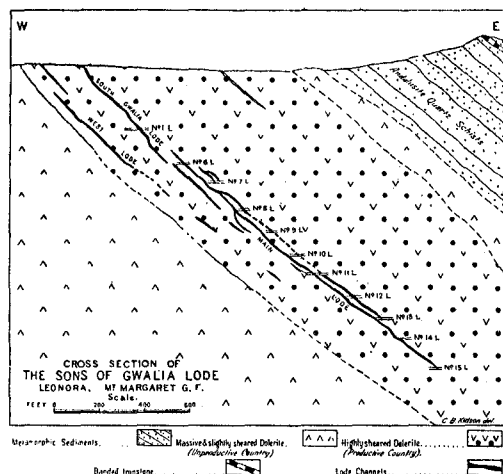
The gold-bearing rocks of Leonora are arranged in two belts, the westernmost being that along the contact between the granite and the schists, which includes the Tower Hill, the Main Reef, and the Trump Groups, whilst the most easterly embraces what may be called the Gwalia gold-bearing zone. The quartz veins in the first belt are usually lens-shaped and separated from each other by bands of broken and slickensided quartz; some of the quartz lenses contain ferri-ferous dolomite and a little copper carbonate.

The Sons of Gwalia Lode (Fig. 46) is by far the most important in the district, and illustrates the occurrence of an important type of gold-bearing deposit.

The lode, which occurs entirely in greenstone schist—a highly sheared quartz dolerite—has a general strike of about north 16 degrees east and a length of over 2,000 feet; it virtually comprises three ore bodies designated the Main, the South Gwalia, and the West lodes respectively, the mutual relations of which are indicated in the cross section (Fig. 47). The ore body is made up of several composite mineralised lenticular quartz veins which vary greatly in size and are separated by areas of more or less unproductive ground; the

general mode of occurrence of the quartz veins is exemplified by those in the 300 feet level, the plan of which is reproduced as Fig. 48. The quartz veins have been developed over a width of somewhere about 100 to 150 feet. The lode itself underlays to the west at an

Fig. 47.



average angle of about 45 degrees and has been opened out along the dip by means of twenty-three levels driven roughly at intervals of 100 feet. The ore often separates along foliation (?) planes (simulating quartzite or quartz-schist), in which there is occasionally

a considerable development of chlorite showing thin flakes of gold on the surfaces. The principal gangue mineral is quartz with pyrites, and calcite, chlorite, muscovite, and acicular tourmaline.

A somewhat similar belt of auriferous country to that which constitutes the matrix of the Sons of Gwalia lode may be followed in a northerly direction as far as the Harbour Lights Mine, some miles from Leonora.

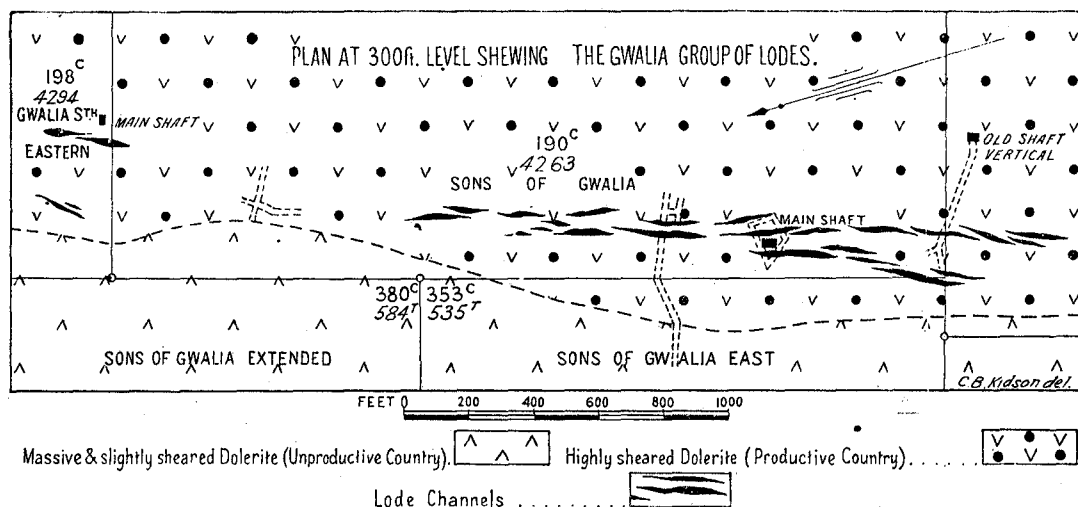
Mount Morgans District.—The Mount Morgans district has produced 503,970.81ozs. of fine gold, of which over 350,000ozs. have been obtained from Mount Morgans, the centre from which the district derives its name. Another important centre is Murrin Murrin, which has been responsible for over 101,000ozs., whilst the balance of the production has been derived from about nine other more or less isolated centres, of which details are given in the previous synoptical table.

The Mount Morgans district is made up of belts of ferruginous cherts or quartzites (jaspilites) which have a general northwesterly trend. The main belt first makes its appearance in the southern portion of the district on the shores of Lake Roeside to the south of Mount Millicent, ultimately disappearing where it enters Lake Carey to the eastward of Yundamindera. These jaspilites, which present all the usual gradations from pure quartz, through ribbon jaspers to haematite quartzite, are arranged in a series of steeply inclined anticlinal folds, the trend of which is parallel to that of the sedimentary series of the Yilgarn belt to the west. It is associated with a jaspilite band of this type, lying further to the northwest, that the ore-body of the Westralia Mount Morgans occurs.

Some of the greenstones with which the jaspilites are associated exhibit a marked bedded structure, and are believed to be basic lava flows.

Bands of serpentine and dolomite occur in parallel belts which coincide in strike with the jaspilites and their associates.

Fig. 48.



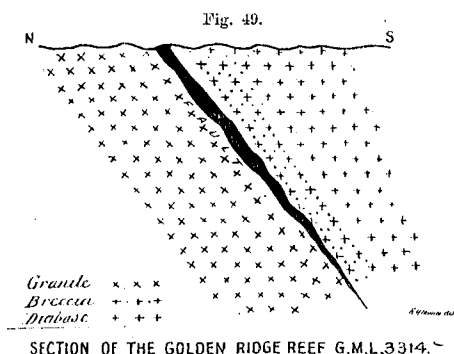
A very large area of the district is made up of granite and rocks genetically allied thereto. The main granite belt extends without interruption northward from the neighbourhood of Mount Percy as far as the northern boundary of the Mount Morgans District to the westward of Mount Zephyr. In many localities along the marginal contact with the surrounding greenstones there is a marked

increase in basicity, resulting in the formation of rocks containing large quantities of hornblende. Fragments of greenstone are frequently to be seen caught up in the main mass of the granite along the contact aureole. In many localities the granite has undergone more or less dynamic deformation resulting in the production of granitic gneiss.

The mining centres, in nearly all cases, bear a more or less intimate relation to the boundary of the granitic rocks, and in areas which have undergone considerable dynamic disturbance are represented by shearing and faulting.

The quartz reefs range from veinlets a fraction of an inch in width to solid veins sometimes as much as 30 feet thick; they dip at steep angles, and as a general rule conform closely both in dip and strike to the structural planes at the enclosing rocks.

The mining centre of Linden lies about eight or nine miles east of the Edjudina-Camelback Soak belt of haematite quartzite. The country rock in the vicinity consists of greenstone traversed by belts of peridotite and invaded by granite and allied acid rocks. The productive centre lies adjacent to the junction of the greenstones and the allied rocks with the granite. The ore bodies consist of quartz reefs and veins which at times lie along the shear zones, traversing the fine-grained greenstones, though in the case of the Golden Ridge (Federal) the quartz reef, which has been worked, occurs along the junction of the granite and greenstone. The granite footwall (Fig. 49) shows well-marked slickensided faces trending in the direction of the underlay of the reef. The deepest mine at Linden, the Democrat, is about 400 feet, and the ore-body is an irregular quartz



reef occurring in a very much contorted basic schist, which latter carries a little gold, though the bulk of it occurs in the quartz reef and leaders. The shoot of gold, which has been proved to be from 60 to 100 feet long, has been worked to a depth of 370 feet, and is associated with an acid dyke of which kidney-shaped lenses are to be found occurring in the schists.

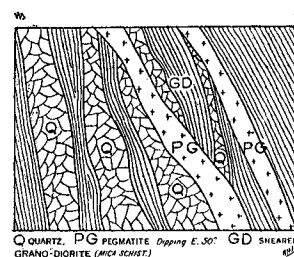
The mining centre of Eucalyptus lies some distance to the northwest of Linden. The productive area of the field is embraced within very narrow limits. A fairly extensive deposit of detrital gold shed from a series of quartz reefs, trending northwest, arranged *en echelon*, occurs in a horseshoe-shaped mass of gabbro penetrating the greenstone which makes up the staple formation of the district. The residual superficial deposits do not appear to exceed six or eight feet in thickness and occur on both sides of the outcrops of the quartz reefs, which have been worked for rich patches of stone. A good deal of dry-blowing has been carried out in these superficial deposits and from what can be seen in some of the workings, costans, etc., it appears that the greenstone is intersected by a network of quartz veins, constituting an auriferous stockwork, to the decomposition of which some of the rich dry-blown patches may be ascribed. The richness of the superficial deposits, as well as the high gold content of the quartz leaders and reefs, would seem to afford good grounds for more judicious and systematic prospecting than has been the case in the past. No separate record appears to have been kept of the quantity of alluvial gold won from Eucalyptus, but it is stated to have been over 2,000 ozs. The drainage from Eucalyptus flows northeast into Lake Carey along several well-defined watercourses. The rich residual deposits have led to prospect-

ing in these valleys for deep leads, but so far nothing but a thin cover of wash resting upon decomposed rock has been met with. The fall between Eucalyptus and Lake Carey is very slight and hardly sufficient to warrant the inference that the country is likely to develop an extensive system of deep leads.

The mining centre of Yundamindera (The Granites) is situated in an area made up chiefly of granite and grano-diorite, which extends from Yundamindera to Mount Kildare. A mass of granite about 140 chains long and 40 chains wide occurs at Yundamindera and its longer axis trends generally northwest; the granite gradually merges into the grano-diorite on all sides. The gold-bearing reefs of Yundamindera occur along the eastern margin of and are enclosed in the granite. Some portions of the granite have a rude foliation, and contain lenticular patches of micaceous schist.

Some of the quartz reefs, from their highly laminated nature, appear to have undergone a certain amount of crushing since their formation. Pegmatite dykes are of frequent occurrence at Yundamindera, and were injected after the formation of the quartz reefs, which they intrude; typical examples are to be found in the Little Wonder Mine (Fig. 50). In the Queen of the May Mine,

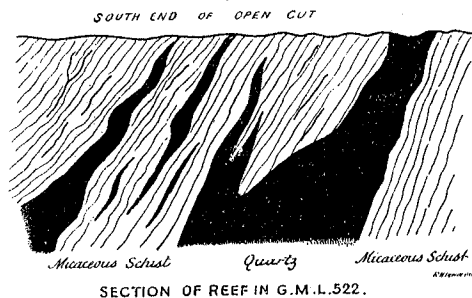
Fig. 50.



Sketch of section in workings, south of the Little Wonder G.M., Yundamindera, looking North.

where the ore-body consists of thin veins of quartz occurring parallel to the planes of the micaceous schist (? sheared granite), there are numerous flat dykes of granite and pegmatite. The quartz reef occurring in the Little Wonder (Woomera) Mine is enclosed in micaceous schist (Fig. 51), resulting from the transmutation of the granite.

Fig. 51.



Lying further to the north is the belt in which the Westralia Mount Morgans Mine is situated and which has produced 319,816 ozs. of gold from the milling of 681,963 tons of ore. The ore-bodies of Mount Morgans are situated along one of the razor-backed ridges, which extends northwest for about five miles and forms a prominent feature in the local landscape, known as the Morgans Line.

The prevailing rocks of the Mount Morgans neighbourhood are made up of a complex of basic and acidie rocks. The basic rocks are essentially hornblendic, of which there are several varieties; some of them have been converted into schists, which are chiefly developed along the junction with the acidie rocks. The latter, which occupy the greater portion of the country to the east of the Morgan line, are

chiefly quartz and felspar porphyry, which in places have been converted into granitic schists.

The more important ore deposits are to be found at or near the junction of the two groups of rocks, or in the vicinity of the numerous acid dykes by which the greenstones to the east are traversed. The gold-bearing deposits of Mount Morgans are geo-

Fig. 52.



Photo.: C. F. V. Jackson.

Outerop in the Morgans Line of Lodes.

logically divisible into two more or less distinct groups, viz. (a) banded quartz reefs and lodes, and (b) normal quartz fissure veins.

The normal gold-bearing quartz veins are almost entirely confined to the smaller areas of basic rocks to the east of the main ridge. The banded quartz veins form a series of bold outerops (Fig. 52) on the summit of the main Morgans ridge, and have been traced across country for a distance of about four miles (Fig. 53), along a powerful line or lines of weakness, which have formed channels for the more or less free circulation of mineral-bearing solutions. What may be called the main line of weakness does not consist of one continuous vein, but of a number of lenticular masses of quartz arranged more or less *en echelon* in a general northwesterly direction. The quartz varies from pure white quartz, through banded and highly siliceous rocks lithologically simulating quartzites in appearance to normal jaspillites. The quartz often carries considerable quantities of iron pyrites, small quantities of chlorite, and some calcite. The ore-bodies have been intersected by porphyry dykes of which a typical example occurs in the 75 feet level in the Sons O'Gowrie Mine (Fig. 54).

The Westralia Mount Morgans lode, the only payable deposit on this belt, consists of a number of parallel quartz lenses embraced within a breadth of about 80 to 100 feet (Fig. 55). The lenses attained their maximum development at about 200 feet below the surface. The ore shoots have a general southerly trend, and are contained in a lens-shaped pipe, the main axis of which dips to the south at an average angle of about 45 degrees. The vertical section

of the lode (Fig. 56) shows that it is contained almost entirely in the intrusive porphyry.

Mount Margaret District.—The Mount Margaret District is the largest of the three administrative divisions of the Mount Margaret Goldfield; it comprises 39,893 square miles, or more than one-half of the proclaimed area of the field.

The district has produced 762,900.63 ozs. of fine gold, of which 558,585.81 ozs. have been obtained from Laverton, the balance having been derived from nine other fairly widely separated mining centres, of which details are given in the synoptical table, to be found on a previous page.

A very considerable area of the north-eastern portion of the field is quite unknown geologically and geographically. The south-western half of the district contains the gold-bearing deposits.

The district presents, in its physical features, many marked differences, which are merely the outward expression of its geological features. The northern portion is chiefly made up of sedimentary rocks, forming mesas and buttes, separated by fairly extensive plains. This type of country is drained by several well-defined creeks, which discharge their drainage into that extensive salt lake system known in different parts of its course as Lakes Rudall, Carnegie and Wells. The southern portion of the district is occupied by granite, in which there are belts of greenstone and allied rocks. The only elevations in the granitic areas are low "breakaways," and more or less isolated rocky islands. In the green-

Fig. 53.

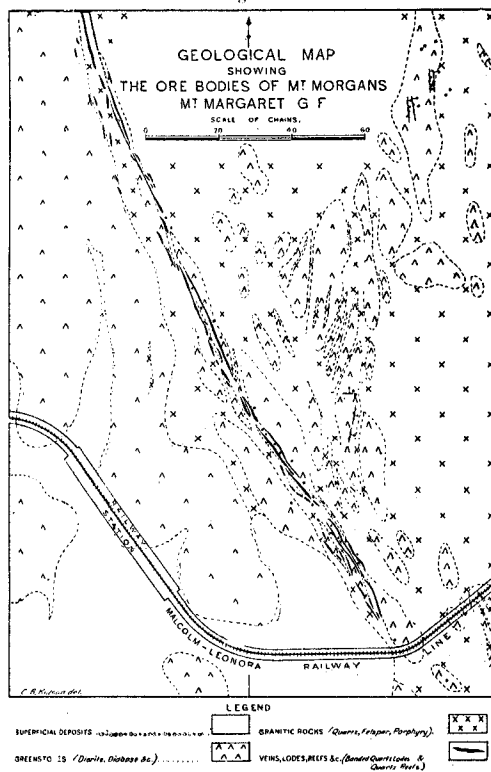
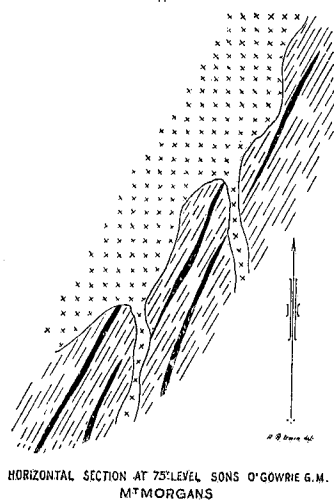
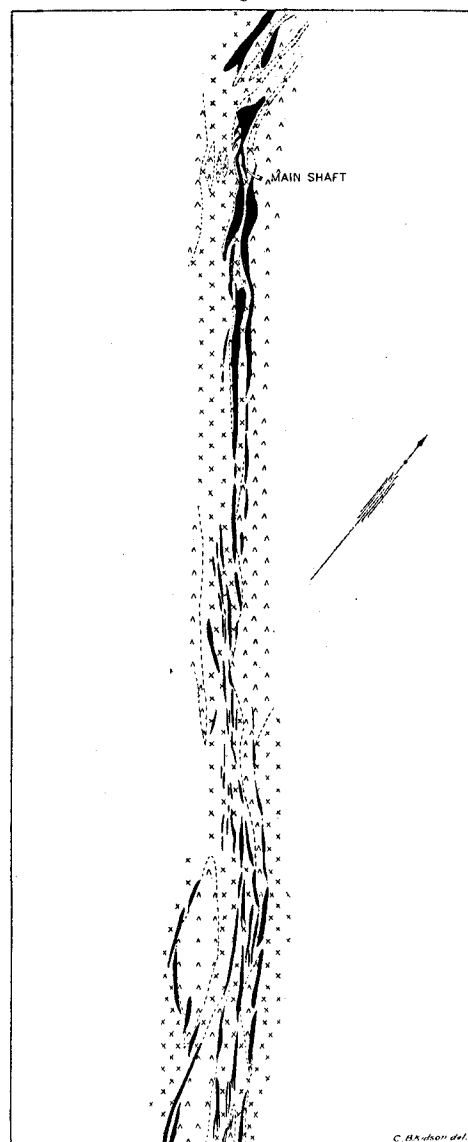


Fig. 54.



stone belts, there are low rounded hills and ranges, which protrude above the level of the surrounding country. Few creeks exist in this, the southern portion of the district; those which do occur, however, lose themselves in the sandy flats, within a few miles of the higher country in which they take their rise.

Fig. 55.



The known northern portion of the Mount Margaret District is a plateau-like region, made up of beds of the Nullagine Formation, which, in this portion of the State, ranges from coarse conglomerates to shales, with occasional limestones, associated with bands of ver-

million-coloured opal. These beds rest with a violent unconformity on all the other formations in the district, with the exception of the Mesozoic rocks, which are so largely developed in the southeastern area.

The beds of the Nullagine Formation appear to have been but little affected by earth movements; it is seldom that any pronounced dip can be observed, though generally the beds are disposed in a series of broad, shallow folds, with dips varying from 5 to 6 degrees. The formation carries no gold-bearing deposits and on that account is of no economic value.

A very large area of the southeastern portion of the district is made up of horizontally bedded sandstones and claystones, with a basal conglomerate containing ice-scratched boulders embedded in a bluish-green mudstone. These, the representatives of the Wilkinson Range Beds, appear to have been formed in a shallow sea. It is unlikely that any gold-bearing alluvial deposits will be met with beneath the boulder bed.

The oldest rocks in the district are the greenstones, which vary considerably in their lithological characters; they consist of epidiorites, amphibolites, and chlorite-carbonate rocks, which were

gold deposits. The basic rocks are traversed by shear zones which have a general northnorthwesterly trend, though there are occasional departures from this, such as at Windarra Hills, near Laver-ton, and other localities, where the shear planes and associated quartz veins are seen trending more or less at right angles to the dominant structural feature of the area.

The gold-bearing deposits are almost everywhere found in those areas in which the shearing has been most pronounced and the shear zones most persistent. The gold deposits of the Ida H. and the Lancefield bear an intimate relationship to the shear zones, which are in part represented by jaspilites.

The greater part of the Mount Margaret District is made up of biotite-microcline granite which is overlain by coarse red sand. The granite is younger than the basic rocks; there are tongues, dykes, and veins penetrating the greenstones, and in some cases lenses of the basic rocks have been caught up in and entirely surrounded by granite. None of the granite areas give much promise of containing gold-bearing deposits, though traversed by many barren pegmatitic quartz reefs.

The greenstones occur in well-defined zones of which the Duketon-Laverton-Pinjin belt is the most important. It has a length of about 200 miles and constitutes the matrix of the more important gold deposits of the Mount Margaret District.

The Duketon-Laverton belt when viewed broadly consists in the main of a congeries of metamorphosed basic igneous rocks bounded by granite. The rocks of the belt include epidiorite, amphibolite and their derivatives, chlorite-carbonate rocks, the whole varying within very wide limits, not only in composition, texture and grain, but also in the extent of the alteration they have undergone.

The biotite-microcline granitic rocks, which bound the belt on all sides, are much more uniform in character than is the case with the greenstones: they vary in grain from fine to coarse, some are markedly porphyritic, and have in places, generally near the contact with the basic rocks, been subjected to dynamic strain resulting in strong shearing and granulation.

The greenstones of the belt have been invaded by numerous acid rocks which have also undergone a certain amount of dynamic metamorphism.

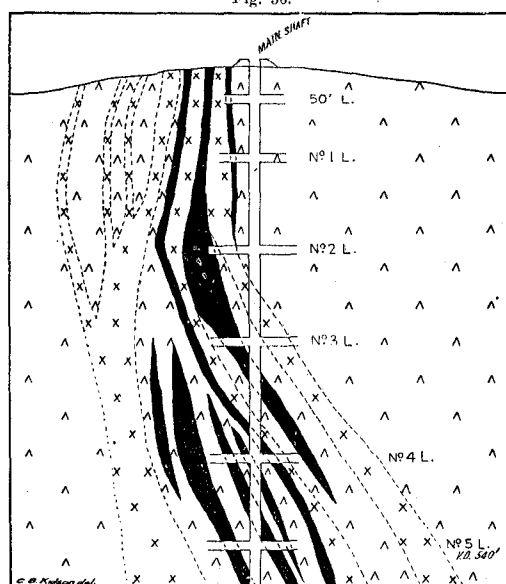
Later dykes, having a lithological range from basaltic dolerite to camptonites and totally unaffected by shearing, are occasionally found traversing both the acid and basic rocks. These later dykes having been intruded subsequent to the era of gold deposition, are of no economic value, except in so far as they may break through and displace any gold-bearing formations, in which case their presence would tend to increase the cost of mining operations.

The chlorite-carbonate rocks and their metamorphosed equivalents form the matrices of most of the important gold deposits of the belt. No gold deposits have been found in the granitic rocks except along and adjacent to the boundary between them and the basic rocks, where the most favourable localities for the development of gold-bearing ore bodies exist, of which the Ida H., the Lancefield, and the Augusta may be cited as instances.

The most important mining centre in the belt is that of Laver-ton, which has produced over half a million ounces of gold since its discovery in the early nineties. The mining centre is situated on the eastern slope and near the northern edge of a series of low irregular ridges of hills, trending generally north and south. This ridge of hills is made up chiefly of greenstones of both the massive and foliated varieties, all of which are very much decomposed and weathered.

The foliated basic rocks of Laverton are traversed by several parallel shear planes (Fig. 57) represented by banded haematite quartz lodes in the form of a series of bold serrated outcrops traceable across the surface for considerable distances; they vary in width from one to three chains. All gradations from pure banded quartz to practically unaltered schist may be seen. These deposits

Fig. 56.



GEOLOGICAL SECTION
SHOWING
THE ORE BODIES OF MOUNT MORGANS
MOUNT MARGARET G.F.

Feet 0 80 160 240
Scale.

LEGEND.

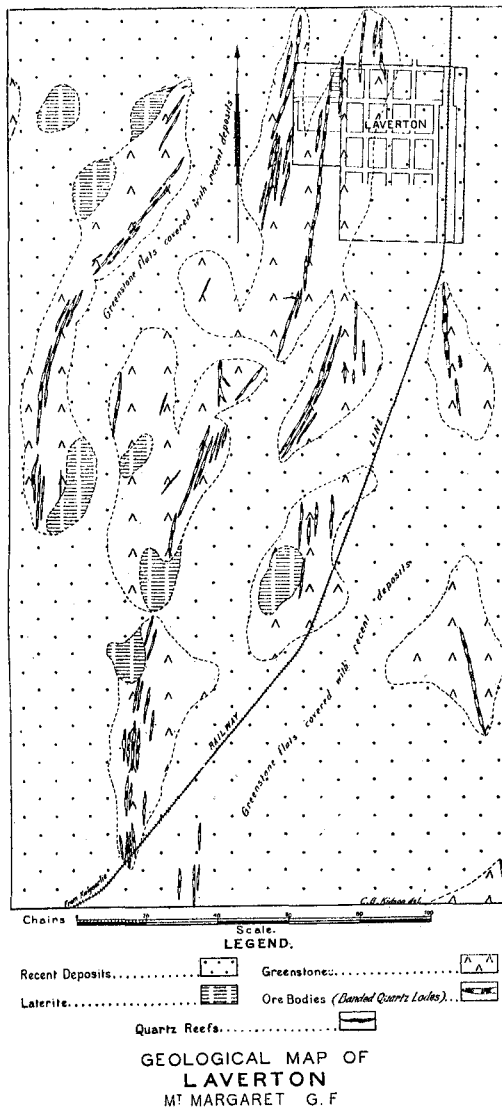
GREENSTONE (Dolerite, Diabase, etc.) GRANITIC ROCKS (Quartz, Schist, Amphibolite, etc.)
BANDIED QUARTZ LODES & QUARTZ REEFS

originally dolerites. The rocks naturally vary not only in grain, texture, and composition, but also in the degree of dynamic and possibly thermal metamorphism to which they have been subjected. These chlorite-carbonate rocks occur in bands which seldom exceed 10 chains in width, and are to be seen passing gradually into the normal greenstones. They constitute the country rock of the more important ore deposits, whilst the finer-grained amphibolites are occasionally traversed by several rich though somewhat erratic

are usually more or less lenticular. Individual lenses vary in length from a few chains up to half a mile with an average width of from 20 to 100 feet. Quartz reefs are at times associated with these haematite quartzites; they are, however, of later date, for they often cut them obliquely, and at times run longitudinally through them. These haematite quartz deposits are all more or less auriferous, and have occasionally been worked for their gold contents.

Quartz reefs of the normal fissure vein type are of frequent occurrence, generally in the massive greenstones, and have been worked to a somewhat limited extent. Reefs of this type are of fair size

Fig. 57.

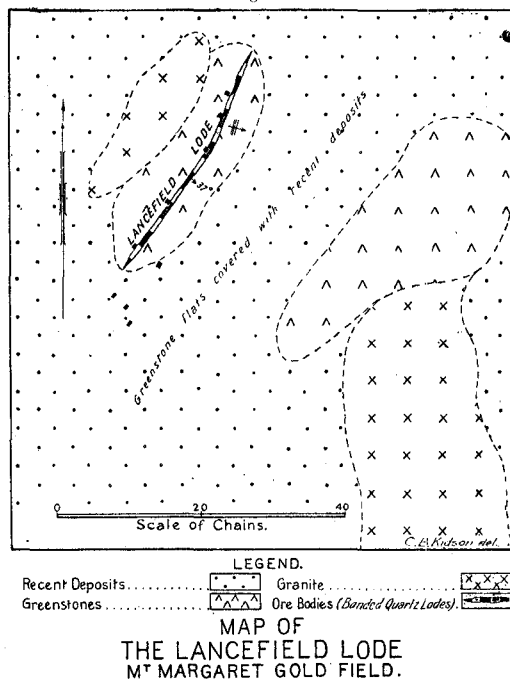


and are traceable for considerable distances. Several small quartz leaders may be seen running into these reefs, and it has been found that at the intersection of the two good "dollying" stone has been obtained.

There are, in addition to the previously mentioned type, a fair number of large-sized quartz reefs at the contact of the granites with the greenstones. The reefs of this type have proved for the most part to be short and somewhat irregular in their mode of occurrence, as well as low in gold contents.

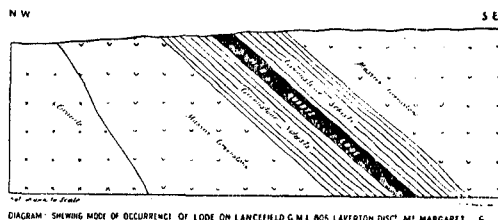
The largest and most important mine in the vicinity of Laverton is the Lancefield, which may be regarded as typical of the class of deposit constituting the ore body, which has produced 271,736.14

Fig. 58.



ozs. of fine gold from the milling of 711,429.78 tons of ore. The ore body consists of a large banded hematite-quartz lode, trending northeast and underlying to the southeast at an average angle of about 40 degrees (Fig. 58). The lode near the surface in the upper levels of the mine simulates the appearance of a normal laminated

Fig. 59.



quartz reef with well-defined walls (Fig. 59), contained in a belt of about 30 feet of greenstone schists. The ore body has an average thickness of about 17 feet, though it has been seen to vary from 3 to 25 feet in places. A band of graphitic schist of somewhat limited extent is occasionally found on the wall of the lode. The shoot of ore has been proved to extend for over 1,000 feet in length,

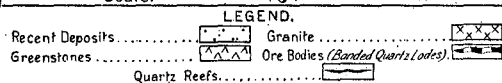
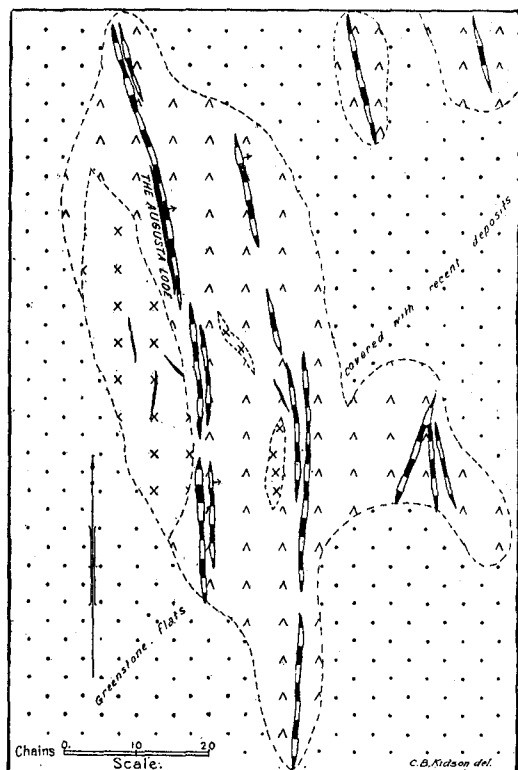
whilst the gold values are stated to have been fairly uniform. The limits of the zone of oxidation are about 200 feet below the ground level.

A large percentage of arsenical pyrites is met with below the zone of oxidation, occurring in band approximately parallel to that of the quartz in the lode.

The reef near the southern end of the workings is intersected by a granitic dyke which in all probability is an offshoot from the main mass of granite, lying about 10 chains to the northwest, and to the boundary of which the general strike of the Lancefield lode conforms.

The *Augusta Reef* is an important ore body situated about four miles to the west of Laverton, having produced 33,307.51 tons with a total gold yield of 26,376.89 ozs. The deposit is a normal

Fig. 60.



MAP OF
THE AUGUSTA LODGE
MT MARGARET GOLD FIELD.

quartz reef, lying alongside and through a belt of altered greenstone schist (Fig. 60), which in places has the appearance of a hematite-bearing quartz lode. This, at 300 feet below the surface, is a hard schist impregnated with hematite and quartz along the planes of foliation. The schist passes gradually into massive greenstone, made up

of hornblende, triclinal felspar, and a little magnetite (Fig. 61). The reef varies in thickness from that of a sheet of paper up to as much as six feet; it has no very defined walls, and has an easterly underlay of about 45 degrees. The quartz is clean and white, and occasionally shows coarse gold fairly freely. The ore contains thin films of the

Fig. 61.

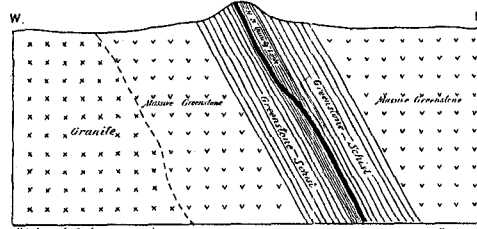
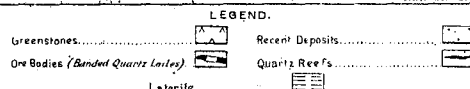
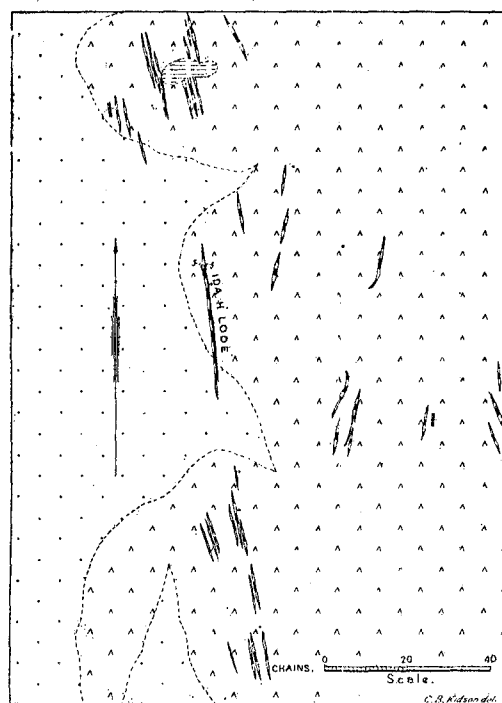


DIAGRAM SHOWING MODE OF OCCURRENCE OF REEF ON AUGUSTA, G.M.L. 371 LAVERTON
MT MARGARET G. F.

telluride of lead, Altaite. The Augusta lode, like the Lancefield, lies adjacent to the main mass of the granite batholith, which occurs some little distance to the west.

The *Ida H. Reef* is one of the most important in the Laverton-Duketon gold belt (Fig. 62), it lies about seven miles to the southeast of Laverton. The mine has produced 225,596.88 tons of ore from

Fig. 62.



GEOLOGICAL MAP OF
THE IDA H LODGE
MT MARGARET G. F.

which 106,911.00 ozs. of fine gold have been obtained. The ore body is an irregular quartz reef occurring in and parallel to a belt of basic schists of variable width. Small leaders of gold-bearing quartz are also met with in the schists, invariably occurring along the planes of foliation.

The main quartz reef is of pure white quartz, reaching as much as six feet in width, but tapering out gradually into the schist. The reef has been followed along the surface for about 1,600 feet in a general north and south direction, and underlays to the eastward at an angle of about 60 degrees. The gold contents are not uniform over the entire length of the reef. In the lower levels of the mine the quartz carries only a small quantity of sulphides of which zinc blende forms a part. The enclosing schists have at the surface been partly transmuted into a solid haematite-quartz lode, which alteration does not extend below 100 feet from the surface, although there are occasional seams of ironstone running through them. Several bands of solid massive pyrites up to three feet in thickness occur in the schists at the 300 feet level parallel to the main reef. The sulphide ore bodies represent metamorphic replacements of the schists and are the downward extension of the seams of ironstone exposed in the upper levels. They carry an appreciable though not an exploitable quantity of gold. Several vertical dolerite dykes, up to 20 feet in width, intersect the reef without in any way disturbing its continuity.

The Burtville Mining Centre is about 24 miles southeast of Laverton. It has produced 104,377.12 ozs. of gold, and is of importance in that it is within the granitic rocks that most of the payable gold-bearing reefs occur (Fig. 63). The rocks of the district consist of both granite and greenstones, which latter are traversed by small belts of haematite-bearing quartz, none of which are of any great length or exhibit much continuity.

The granite is intrusive into the greenstones; an important area of it is that which is situated to the east of Burtville and occupying a circular area of about a mile in diameter. Most of it, however, is concealed beneath a cover of superficial deposits of variable thickness. The granite is intersected by dolerite dykes, which are met with in some of the mine workings. The auriferous quartz reefs of the granite are generally small, being from 6 to 18 inches in thickness, though of considerable horizontal extent. These reefs at times continue into the greenstones without any change in either dip or strike. The quartz reefs are usually of a white or bluish colour, and are often of exceptional richness in gold; some crushings from these veins have averaged a little over 5 ounces to the ton.

Near the northern end of the belt, at Duketon, an extensive system of regular quartz reefs forms the most important geological feature. These reefs may be followed for a distance of about five miles in a general north and south direction at the contact between the granitic and the greenstone schists, which constitute the rocks in this portion of the belt. In addition to what may be called the main line, there are other small quartz reefs in the schists. These Duketon reefs have produced, up to the end of 1918, 25,195.86 ozs. of fine gold from 22,452.71 tons of quartz.

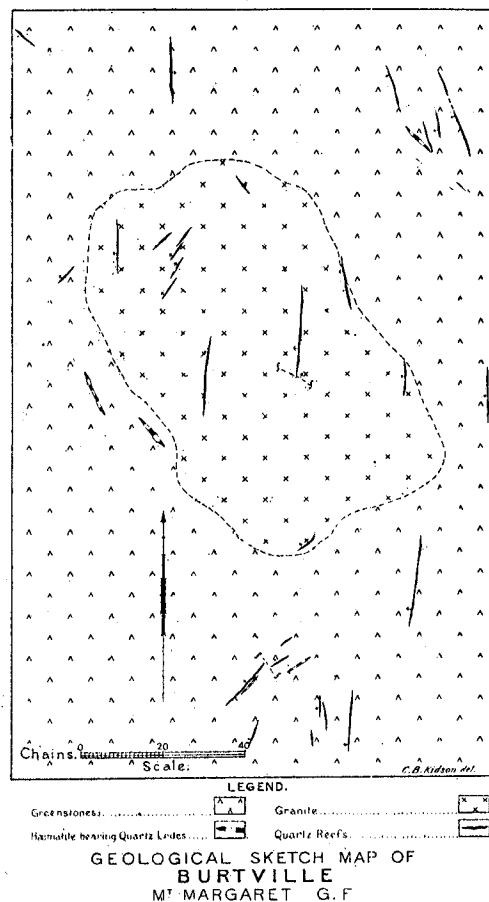
There are in addition seven other known belts, viz.: the Ulrich Range, the Mount Cumming, Mount Gill, Truscott Hill, Mount Shenton, Point Salvation, and the Cosmo Newberry Belt.

The Ulrich Range (or Gregory Hills) Belt, which lies about 43 miles east-northeast of Duketon, is lenticular in shape, being about five miles long and one and a-quarter miles wide. It is made up of epidiorite entirely surrounded and intruded by an immense number of acid dykes. The greenstones are traversed by several quartz reefs and leaders lying parallel to the foliation of the country rock. There is one fairly well-defined line of reef which is traceable north and south for about 700 feet, though intersected by dykes of granite. The ore body is in reality a series of lenses of quartz, the largest continuous length being 60 feet. The quartz is white and glassy and contains considerable quantities of carbonate of copper, with some small pockets of galena.

On one reef a shaft had been put down to a depth of 35 feet, and in it a reef about 3 feet 6 inches wide was met with. The belt is characterised by the occurrence of small lenses or leaders of quartz containing short and fairly rich shoots of gold.

A fair amount of alluvial gold has been found in the gullies draining the eastern fall of the Ulrich Range Belt; this has been obtained in wash from a depth of from two to four feet below the

Fig. 63.



surface, and usually where the acid dykes and veins cross the gully, virtually forming natural riffles. Most of the gold is very fine, the largest piece of which there is any record being less than 10 pennyweights. Some of the alluvial gold had small pieces of ironstone attached, indicating ironstone leaders as the parent source.

The Mount Cumming Belt, which is a lenticular area about ten miles in extent, lies about 85 miles northeast of Laverton. It is about seven miles long and has a maximum width of two miles; it is made up of massive epidiorite surrounded by granite and intersected by narrow acid dykes, some of which penetrate as far as 20 chains from the margin. The epidiorite contains small lenses of quartz in addition to several large ice-like quartz reefs in the northern end of the belt not far from the granite.

The Mount Gill Belt is one of the most easterly in this latitude (26 degrees south). It lies about ten miles east of Mount Cumming

and covers an area of approximately ten square miles. The staple country rock is a highly foliated epidiorite capped by sedimentary rocks belonging to the Wilkinson Range Series. The schists resulting from the foliation of the epidiorite trend generally northnorthwest and are in places traversed by jaspilites. Some quartz reefs of lenticular habit cut the schists at varying angles oblique to the dominant strike; some of these quartz lenses contain oxide of iron. There are also large pegmatitic quartz reefs of the Mount Cumming type, destitute of mineral.

The Truseott Hill Belt, which is situated about four miles south of the Mount Cumming area, is only about five miles in extent. The rocks of the belt are hornblendites and epidiorites of varying degrees of schistosity, traversed by quartz reefs and small bands of jaspilite.

The Mount Shenton Belt is about 24 miles long and about seven wide. It is made up chiefly of foliated epidiorite associated with bands of haematite quartz schist, some of which are over 300 feet thick; though at Mount Venn massive gabbro, the youngest intrusion, makes its appearance. There are in the rocks of this belt bosses, lenses and dykes of acid rocks which vary from fairly coarse pegmatites to compact porphyries, some of which are seen to emanate from the granite by which the belt is everywhere surrounded. The quartz reefs and quartz lenses traverse the belt, often occurring along the contact between the granite and the greenstones.

The Point Salvation Belt has an area of about 48 square miles; it is made up of basic rocks which in places have been converted into greenstone schists, the general trend of which is northwesterly. Small bands of jaspilite traverse the basic rocks which are everywhere covered by large quantities of quartz rubble. There are, however, but few quartz reefs; the quartz is milk-white in colour, and so far as can be seen destitute of mineral.

The Cosmo Newberry Belt, which has an area of about 34 square miles, lies about 60 miles northeast of Laverton, and has been the scene of more or less vigorous prospecting. The belt is made up of a series of low ridges trending generally northnorthwest for a distance of over 10 miles, with a breadth varying from three to five miles. The belt rises from the midst of extensive sand plains, overlying granite, by which it is everywhere surrounded. The rocks forming the belt are massive and foliated greenstones, viz., epidiorites and hornblende schists. They are traversed by several shear zones along which these acid dykes trend, as do also most of the quartz veins and reefs. The acid dykes vary from coarse pegmatites to compact porphyries, which vary in width from a few feet up to one chain. At what is known as Split Rock (Survey Station J.H.R. 162) there is a large mass of intrusive granite covering an area of about one square mile, and entirely surrounded by greenstone. There are at the southern end of the belt several later dolerite dykes which, as they intersect the acid veins, are the youngest igneous rocks in the district.

Numbers of small and irregular lenticular quartz reefs occur in the older greenstones. The trend of the reefs coincides with that of the dominant foliation of the district; the reefs seldom reach any great length, though at times they are of considerable width. The quartz reefs are as a rule not distinguished by bold outcrops, and many are doubtless concealed by the thick cover of cement which overlies most of the rocks in the district. The reef quartz is white and glassy, generally low in gold contents, though some of the smaller leaders have been found to carry good values. Quartz reefs and masses of quartz, sometimes of great thickness and seldom more than two or three chains in length, occur in intimate association with the acid dykes of which they are doubtless the ultra-acid phase; their gold content, however, is so small as to be entirely negligible.

A good deal of work has been done, and shafts sunk on several of the quartz reefs; and a fair tonnage of ore has been raised and is still lying in the old dumps.

On what was known as the Cosmo (G.M.L. 1624T) a quartz reef trending northwest and underlying at 35 degrees to the eastward has been opened up by a shallow shaft and worked for some distance along the outcrop. The reef, which varies in thickness from three to eighteen inches, forms a contact vein the footwall of which is greenstone and the hanging wall a siliceous rock ("quartzite"?). A trial parcel of eight tons of ore from the shaft and the open cut, on being treated in a battery, gave a return of 29 ounces of gold, or an average of 3ozs. 12dwts. 12 grains per ton by amalgamation, whilst the sands assayed 3dwts. per ton.

The Wanda (G.M.L. 1795T, a northwesterly quartz reef, underlying west at 75 to 80 degrees, occurring beneath the cover of cement, has also been worked. The reef in places reaches a thickness of 24 inches. A crushing of six tons is stated to have yielded by battery amalgamation an average of 16dwts. of gold per ton, and the sands to have assayed 2½ dwts. of gold per ton.

At what was known as the Constancee, G.M.L. 1779T, a reef about 10 inches thick trending northwest and inclined to the southeast at 45 degrees, has been opened out on the underlay. A trial crushing of eight and a half tons of this yielded 29ozs. 3dwts. 6 grains of gold per ton by battery amalgamation, or an average of 3ozs. 8dwts. 9 grains per ton, with an assay value of 12dwts. per ton in the sands. From another vein of quartz about two feet thick, 18 tons were treated by battery amalgamation, with a total yield of 17.21 ozs. of fine gold.

The more or less desultory work so far carried out on the reefs occurring in the Cosmo Newberry Belt, though not to be in any way regarded as a thorough test of their value, still the results of the treatment of the small trial parcels may be regarded as encouraging. So far as can be judged it appears that the Cosmo Newberry belt holds out a fair promise of giving good results in return for systematic and judicious prospecting and development.

NORTH COOLGARDIE GOLDFIELD.

The North Coolgardie Goldfield which originally formed part of Coolgardie and which covers an area of 13,746 square miles, was first established as a goldfield by proclamation in 1895; latterly it has been divided for purposes of administration into the four districts designated Menzies, Ullaring, Niagara and Yerrilla.

The goldfield has produced, up to the end of 1918, 1,844,990.02 ozs. of fine gold, obtained from the milling of 2,415,349.62 tons of ore, in addition to 12,927.40 ozs. of alluvial gold, in which figure is included the small quantity of 1,356.48 ozs. of dollied and specimens, thus bringing up the total gold yield of the North Coolgardie Goldfield to 1,857,917.42 fine ozs. This quantity of gold has been obtained from 19 widely distributed mining centres, of which details are given in the synoptical table.

Synoptical Table showing the Gold Yield of the North Coolgardie Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial Dollied and Specimens.	Ore treated.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	Tons (2,240lbs.)	Fine ozs.	Fine ozs.
MENZIES.				
Comet Vale ...	441.61	216,279.43	169,077.62	169,519.23
Goongarrie ...	1,000.47	28,033.04	17,770.43	18,770.90
Menzies ...	1,460.83	805,154.96	658,805.73	660,266.56
Mt. Ida ...	101.38	60,166.87	69,541.13	69,642.51
District generally ...	1,125.56	4,576.05	37,156.97	38,282.53
	* 4,129.85	1,114,210.35	952,351.88	956,481.73

*Includes 198-35ozs. dollied and specimens.

Synoptical Table showing Gold Yield of North Coolgardie Goldfield—contd.

District or Mining Centre.	Alluvial, Dollied, and Specimens.	Ore treated.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	Tons (2,240lbs.)	Fine ozs.	Fine ozs.
ULARRING.				
Davyhurst ...	172-04	159,079-58	125,953-05	126,125-09
Diemel's Find ...	7-37	102-50	119-13	126-50
Mulline ...	309-62	98,674-73	100,285-60	100,595-22
Mulwarrie ...	78-29	20,402-01	27,330-22	27,408-51
Ularring ...	563-34	9,572-60	13,761-12	14,324-46
District generally ...	35-12	1,304-35	18,407-89	18,443-01
	* 1,165-78	289,135-77	285,857-01	287,022-79

*Includes 1,144-32ozs. dollied and specimens.

NIAGARA.				
Desdemona ...	14-72	10,916-95	8,105-58	8,120-30
Kookynie ...	378-06	738,204-66	392,317-02	392,695-08
Niagara ...	188-04	94,271-29	57,879-08	58,067-12
Tampra ...	90-17	52,457-87	24,048-80	24,138-97
District generally ...	2,213-64	1,155-50	15,687-92	17,901-56
	* 2,884-63	897,006-27	498,038-40	500,923-03

*Includes 9-43ozs. dollied and specimens.

YERILLA.				
Edjudina ...	39-70	34,847-70	43,972-39	44,012-09
Mt. Remarkable ...	17-74	528-72	415-09	432-83
Pinjin ...	146-35	18,064-15	12,605-51	12,751-86
Yarri ...	98-60	42,130-35	21,942-04	22,040-73
Verilla ...	3,124-69	18,020-21	13,651-13	16,775-82
Yilgarnie ...	151-50	244-25	341-62	493-12
District generally ...	1,168-47	1,161-85	15,814-95	16,983-42
	* 4,747-14	114,997-23	108,742-73	113,489-87

*Includes 4-38ozs. dollied and specimens.

Grand Total ...	*12,927-40	2,415,349-62	1,844,990-02	1,857,917-42
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*Includes 1,356-48ozs. dollied and specimens.

The goldfield comprises an elevated tableland covered with long and narrow salt lakes (*e.g.*, Lakes Ballard, Barlee, Raeside, etc.) which have a gradual fall towards the Nullabor Plains.

The major portion of the North Coolgardie Goldfield is made up of granite and rocks genetically allied thereto. The granite, though it occupies the largest area of the surface of the field, is not however the oldest rock, for it is seen almost everywhere to intrude all the other main rock masses. The granite in some parts of the field has undergone a certain amount of dynamic deformation, resulting in the production of granitic gneiss and rocks allied thereto. There is a marked increase in basicity in many localities along the marginal contact of the granite with the surrounding greenstone, producing rocks containing large quantities of hornblende.

The remainder of the North Coolgardie Goldfield is composed of more or less metamorphosed sediments in intimate association with lavas and ashes in addition to a complex of basic rocks which consist for the most part of amphibolites and epidiorites (originally dolerites or gabbros) altered in places to hornblende schists and further to chloritic rocks, hornblendites (derivatives of pyroxenite) and serpentines, talc chlorite and carbonate rocks.

The Menzies District covers an area of 6,805 square miles; it has produced 956,481.73 ozs. of gold of which the bulk has been obtained from the mining centre of Menzies. The district is a tableland about 1,400 feet above sea level, which is traversed centrally by the Eastern Goldfields Railway.

The geological features of the Menzies district comprise a complex of basic rocks divisible into epidiorite, hornblendite, ser-

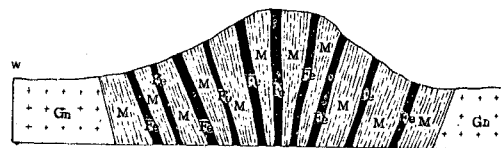
pentine, and their derivatives, quartz-carbonate-chlorite schists. Acid rocks are largely developed in the district; they consist of granite, quartz-porphry and quartz-felspar-porphry and their derivatives, gneiss, mica schist and sericite schist.

Transitions from acid dykes to porphyritic granite have been noticed in some portions of the district.

A belt of highly inclined altered sedimentary rocks forms the low country of Lake Goongarrie; the rocks comprise conglomerates, grits, shales, slates and phyllites. Some of the pebbles in the conglomerate owe their pronounced lenticular shape to the stretching resulting from dynamic metamorphism. The sediments have a dominant strike of a few degrees to the west of north, with a high dip to the west, and a width across the strike of over two miles; the apparently great thickness may in all probability be due to repetition by folding. The bed contains numerous quartz reefs which on the whole conform both in dip and strike to those of the sediments. This bed of sediments in all probability forms the northern extension of the eastern limb of the Kalgoorlie Series, which is exposed between Kanowna and Kalgoorlie.

The northwesterly portion of the Menzies district is what is known as the Brooking Range greenstone belt, which is about 30 miles in length; along the base of the range are highly inclined beds of metamorphic sedimentary rocks (Fig. 61) (mica schist, etc.); the whole belt being surrounded by granite. Quartz is fairly plentiful, though no reefs appear to have been worked.

Fig. 64.



Gn. Granite. M. Metamorphic Rocks. Fe Haemate Quartz Schist.

Section across the North End of the Brooking Range.

About 18 miles to the east is the Mount Ida-Copperfield belt, which is about 50 miles in length and has an average width of six or seven miles. The belt consists geologically of basic rocks and their derivatives, associated with beds of ferruginous quartz schist and jasperoid rocks, trending generally north-northwest; these being invaded by the granite which surrounds the belt on every side.

The Mount Ida-Copperfield belt includes the two established mining centres of Mt. Ida and Copperfield, which have produced 69,642.51 ozs. of fine gold. The gold-bearing deposits occur principally within the zones of foliated rocks, to the trend and dip of which they almost everywhere conform. The ore deposits are for the most part clean quartz reefs occurring occasionally along lines of considerable length, though generally they are small and irregular. Two of the principal lines of reef—the Copperfield and the Timoni—have been proved for about twenty chains along the strike (Fig. 65). The quartz is of lenticular habit, varying in thickness from mere threads up to bunches of considerable size, locally known as kidney reefs; they often consist of a series of lenses of quartz connected by a thin thread of quartz, and often only by the line of the walls of the enclosing schists. The quartz lenses, which are usually of a high grade, are sometimes almost contiguous and at others 50 or 100 feet apart.

The gold-bearing zones are intersected by a series of cross fissures along which secondary quartz veins occur, often very rich in gold; though never exhibiting marked continuity. Examples of this type are to be seen in the Copperfield group of leases (Fig. 65).

of a porphyritic phase of the granite; it is, however, quite possible that others may be metamorphic sediments and form the northern extension of those on the western shores of Lake Goongarrie, to which reference is made further on.

A portion of the northwestern corner of the Menzies centre is traversed by numerous acid dykes, some of which are of very considerable extent.

The ore deposits of Menzies have, when viewed broadly, a more or less approximate parallelism, generally northwesterly, with a fairly high underlay to the west. There are two gold-bearing zones in the more immediate vicinity of Menzies. The main or western zone starts to the northwest of the townsite, at the Saint Alban's group of leases, from which it extends southeasterly for a distance of about 10 miles, passing the township of Woolgar (Yundaga) and terminating near the Barunga Brave lease. This zone is made up of a series of quartz reefs, lying more or less parallel and intersected by barren quartz reefs (cross-courses) occurring along fault lines or thrust planes, which trend generally east and west and underlay to the north. The easternmost zone is the Kensington belt, which strikes generally northeast, and is situated on the western side of Mount Misery. This zone is not nearly so long as the western or main ore channel, nor has its gold yield been very great. The quartz reefs, which are confined to the greenstones, are of various types and of somewhat different characters. Several large banded quartz reefs (simulating quartzite in appearance) occur in certain localities; they are, however, of no extent, nor have they proved of any economic importance. Some very ferruginous lodes, which below water level often pass into pyrites (mostly marseite), are met with and can be traced for considerable distances along a more or less northwest course; they are to a slight extent auriferous.

Most of the gold from Menzies has been obtained from lenticular veins of quartz. One of the longest of these is 1,600 feet, though with the exception of those in the larger mines, reefs of this type do not attain any great longitudinal extent, forming rather a series of small but rich and more or less parallel veins.

The gold in the quartz reefs is associated with iron, copper and arsenical pyrites, galena (which is very abundant) and zinc blende. Free gold invariably occurs in the rocks within the limits of the zone of oxidation.

The gold-bearing area of Comet Vale lies about 17 miles in a southerly direction from the Menzies mineral belt, and is traversed by the Kalgoorlie to Leonora railway line.

The geological constitution of the country in the more immediate vicinity of the townsite is made up of basic and ultra-basic rocks, granite and allied acid dykes, and some rocks which may possibly be metamorphic sediments forming the northern extension of those at Goongarrie.

Recent superficial deposits occur so abundantly as to largely obscure a very large area of the solid rocks. The superficial deposits which overlie several known reefs and probably conceal many others, consist of laterite and its secondary products, sand ridges, silt, salt, and gypsum of the lakes.

The main basic and ultra-basic rock masses of the district consist of epidiorite, amphibolite, hornblende-schists, serpentine, hornblende, peridotite and talc-chlorite schist, of the mutual relationships of all of which there is as yet no very definite evidence. The hornblende schists are associated with the massive amphibolites and epidiorites of which they probably form transmuted varieties.

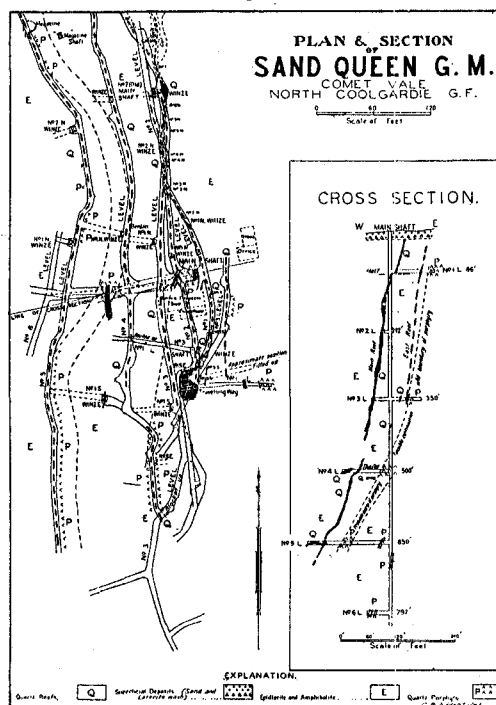
The epidiorites and amphibolites and the bands of chloritic talcose schists form the most important economic rock group of Comet Vale, and it is in this belt that the principal line of lode is situated. The hornblende schists and allied rocks form an important group lying to the west of the township and forming the country rock of the Lady Mary line of lode. A belt of grey serpentine with narrow bands of talc schists lies to the east of the mass of epidiorite;

it is traversed by the Happy Jack lode, which contains crocoite (the chromate of lead). The hornblendites and altered peridotites, with the talc chlorite carbonate rocks derived therefrom, form a belt of rocks lying between the grey serpentine and the western shores of Lake Goongarrie. These are of some economic value, as in them occurs the Tunnel line of reef.

Granite and allied rocks form a fairly extensive belt of country to the west of Comet Vale and in the vicinity of the quarry arm of Lake Goongarrie. The granites and their apophyses, the aplite and porphyry dykes, are younger than the basic rocks. The quartz porphyry dykes are to be found in various parts of the field, ranging from 2 to 20 feet in thickness; the aplite dykes, which vary in width from 12 inches to 66 feet, are younger than the porphyries, which they are seen to intrude in many places.

The gold deposits of Comet Vale comprise two groups, viz., quartz reefs, and lode formations, of which the former make up practically the whole of the deposits occurring at this centre. The

Fig. 67.



quartz reefs occur in three distinct and well defined lines, viz., the Sand Queen-Gladsome, the Tunnel, and the Lady Margaret with its northwesterly extension the Lady Mack, each of which occurs in a different type of rock. The Sand Queen-Gladsome line of reef is the most important in the district, having produced 145,715.56 ozs. of fine gold. This deposit is made up of a series of quartz reefs which have a general northwesterly trend and an underlay to the westward; it occurs in a main though not absolutely continuous fissure about 60 chains in length, traversing fine-grained epidiorite and amphibolite. The outcrop of the Sand Queen-Gladsome ore body, however, is concealed by a variable thickness of sand and ironstone wash. The ore body in the Sand Queen mine has been followed to a vertical depth of over 650 feet from the surface (Fig. 67); its thick-

these reefs have not proved to contain nor have produced very much gold. It is possible that these sediments form the northern extension of that group which makes such a pronounced feature in the vicinity of Kalgoorlie, farther south. The most important, from the economic standpoint, of the recent superficial accumulations are those alluvial deposits occurring in the beds of the different creeks and gullies, and which have been worked for their gold contents. These deposits have produced, so far as is disclosed by the official figures, up to the end of 1918, 1,000 ounces of gold; there are, however, reasons for believing this to be considerably below the quantity actually obtained.

The auriferous deposits of Goongarrie are almost entirely made up of quartz reefs, though gold has occasionally been found in the adjacent decomposed schists. The reefs vary in thickness from an inch up to as much as 14 feet, with length occasionally amounting to several chains. The strike of the quartz reefs varies, though the greatest number have a general north and south direction; there are some, however, which are parallel to, and others which cut across, the trend of the foliation of the schists. There is, however, no definite evidence as to the relative ages of these different groups of veins. Whilst quartz reefs occur in pretty well all the rocks of Goongarrie, they are most numerous in the schists and the sedimentary rocks; the gold-bearing reefs, however, are almost wholly confined to the quartz-carbonate-schists.

So far as observations have been carried, it appears that the gold occurs as fairly rich pockets or small shoots in the main reefs; some of the small quartz leaders have proved to be very rich. Some of the quartz reefs have undergone minute fracturing after their formation, and a certain amount of gold has been introduced subsequently. The quartz reefs contain few accessory minerals, iron pyrites being the most abundant. The effect of the intrusion to which the main mining belt has been subject has been the formation of reefs, which are often short and of irregular habit. The extent to which mining has yet been carried at Goongarrie is too small to enable any very definite conclusions being arrived at as to the effect which depth will have upon the ore bodies, though there is no doubt that many will persist to considerable depths below the surface.

The New Boddington deposit is the principal ore body hitherto worked at Goongarrie; it has produced, up to the end of 1918, 7,024.47 ounces of gold, obtained from the milling of 12,230.70 tons of ore. The ore body is situated on a prominent hill, near the centre of the field, known as Boddington Hill, upon which quartz reefs stand out conspicuously. Two distinct lodes, lying about 60 feet apart, known as Kerman's reef and the Boddington reef, constitute the New Boddington deposit; these two veins have been worked to depths a little over 300 feet vertically below the surface. The Boddington yielded fair returns from the upper levels, in all probability as a result of surface enrichment; whilst Kerman's contained a very rich narrow shoot of gold, occurring in a reef only a few inches thick. The country rock of the lodes, which generally lie parallel to the schistosity, owes its origin to the chemical and dynamical alteration of a quartz-amphibolite. The two ore bodies are parallel quartz reefs which strike generally northwest and underlie to the southwest at a high angle. The thickness of the reef varies; in the case of the Boddington from a few inches up to 12 feet; whilst that of Kerman's is from a few inches up to 6 feet. The Boddington reef has been traced for a considerable distance along the surface, as well as at the 50 feet level; it has been followed to 300 feet below the surface, at which depth it proved to be very thick. Kerman's reef, however, is neither so well defined nor so persistent, although it proved to be continuous down to the 200 feet level. The two reefs are intersected by faults, which have the effect of shifting them horizontally for a few feet; these "breaks" are arranged *en echelon*. The lodes are traversed by quartz veins and reefs, of somewhat later formation; these, however, do not appear to have exerted any appreciable effect of enriching the main reefs at the points of intersection. The walls of the reefs are as a rule smooth

and well defined, though the quartz of the reefs has been traversed by small fractures, into which some at any rate of the gold has been subsequently introduced. The accessory minerals of the quartz, in addition to the gold, are pyrites, calcite (as coarse crystalline veins), selenite, and well-formed crystals of mispickel (arsenical pyrites). The normal level of the underground water, which is extremely salt, is about 130 feet vertically below the surface.

The Niagara District covers an area of 688 square miles, and has produced 500,923.03 ounces of fine gold, most of which has been derived from the deposits of the Kookynie mining centre. The district forms part of a gently undulating tableland, which has an average altitude of from 1,200 to 1,460 feet above sea-level, and is traversed centrally by the railway line from Menzies to Malcolm. So far as geological observations have been carried, the rocks of the Niagara district appear to be almost entirely of igneous origin, many of which have undergone such superficial decomposition as to render it somewhat difficult to differentiate between the various varieties. The rocks of the Niagara district, when viewed broadly, are divisible into four main lithological groups, viz.: (a) basic and intermediate rocks, (b) acid rocks, (c) schistose rocks of uncertain origin, and (d) recent superficial deposits. The mutual relationships between the different groups are not in all cases easily determinable.

The basic and intermediate rocks include amphibolites, epidiorites and allied rocks, which there seem sound reasons for believing to have been derived from gabbros and dolerites. The whole of these basic rocks, which are fairly widespread, are in nearly all cases fine and medium grained in texture. The basic rocks occur in all stages of decomposition, from fairly fresh rocks to ferruginous clays and kaolin.

Some of the coarser grained basic rocks are of later date than those finer textured varieties into which they appear to be intrusive. Certain of the finer grained basic rocks are in all probability old lava flows. The greenstones represent the oldest of the groups occurring in the Niagara district, and are intruded by the granites and its allies. The planes of foliation of the schistose varieties of the basic rocks have a dominant strike of north-northwest. The greenstones carry numerous auriferous lodes, principally at or close to the contact with other rocks, as well as in the schistose belts; the more massive varieties, however, are traversed by a few gold-bearing deposits. The acid rocks occupy the largest area of the Niagara district, and are of considerable economic importance from the fact that several large and payable gold-bearing quartz reefs occur in them. The acid rocks are divisible into three well-marked lithological types—quartz-porphyrries, gneisses, and granites. The quartz-porphyrries form a distinct group which, while containing a few quartz reefs, is not of any great economic importance, though the Grafton reef at Tampa, which has produced over 5,300 ounces of gold from 3,500 tons of ore, occurs in it—not far, however, from its junction with the greenstones. The granite rocks are made up mainly of biotite-granite, and to a less extent of hornblende granite and granodiorite, which latter constitutes a well-defined belt in the biotite granite of Kookynie. The granodiorite is traversed by an important quartz reef, the Altona, from which 13,820 ounces of gold have been reported.

The granite is usually massive, and numerous dykes penetrating the greenstones emanate from the main mass. The muscovite granite dykes may be seen gradually passing into pegmatite and finally into aplite. One of the pegmatites was found to contain pink garnets, ilmenite, zircon, limonite, and the phosphate of yttrium (xenotime). They also contain non-auriferous quartz veins of secondary origin. Several "islands" of greenstone, which vary from a few inches up to several chains in length and breadth, occur and form important features in the granites. The gneisses are almost entirely restricted to the neighbourhood of Niagara, where they occur in bands with a dominant trend of east-northeast; in other parts of the district, however, they are found as fringes on the granite masses. It is prob-

able that the gneisses owe their origin to an alteration of the normal granite, though some of the less acid varieties may have been derived from the quartz-diorites. The gneissic rocks of Niagara are of economic importance by reason of the fact that they form the matrix of many of the gold-bearing reefs at that centre.

The schistose rocks occur as broad bands lying between the granite and the greenstone in the neighbourhood of Niagara. The rocks of which the bands are composed are greatly weathered; they vary in texture from fine-grained shaley rocks to coarse-grained gritty varieties, whilst some are highly micaceous. These schists, in all probability, are merely transmuted varieties of gneisses and greenstones, and the thin quartzose bands represent decomposed pegmatites and allied acid rocks. The schists contain quartz reefs, but most of them are non-auriferous: hence this group of foliated rocks is of little or no economic importance. The recent superficial deposits, which consist of laterite and its associates, stream deposits, together with clays and sandy loams, are fairly wide-spread, though of no great thickness. Only 2,884 ozs. of fine gold have been recorded from these deposits, and this has been chiefly derived from the laterites of secondary origin occurring in the neighbourhood of Tampa.

The gold-bearing deposits of the Niagara district consist of quartz reefs, varying in thickness from veins less than an inch to others which reach as much as from 10 to 15 feet; the average thickness of the reefs of the district, however, not being more than two feet. The reefs are found traversing most of the members of the different rock series, and are at times to be seen passing from one rock to another, pointing to the fact that the lithological character of the matrix plays but a subordinate part in the formation of the veins. The reefs frequently follow the strike of the main trend lines which dominate the district, and their occurrence seems to have been determined by that of the latest of the fracture systems to which the area has been subjected. Minor displacements are to be found in some of the quartz reefs, though, on the whole, there has been very little disturbance since the introduction of the gold-bearing deposits. The auriferous quartz of which the reefs are made up is frequently very white in colour and contains few accessory minerals: Pyrites, galena, calcite, ankerite, and chlorite have been detected, in addition to the following bismuth minerals:—bismuthinite, tetradyomite, bismutite, and bismutospherite. The gold occurring in the reefs is often very coarse in grain, though at times it is in such a fine state of division as to be invisible to the unaided eye. In the reefs in the more immediate vicinity of the mining centre of Niagara the gold is to be found in narrow bands, which vary in thickness from a few inches up to as much as two feet. These gold-bearing bands occur at times on the footwall of the reefs, though instances of the occurrence of the bands in other portions are not unknown.

The principal and typical ore-bodies of the Niagara district which have produced the bulk of the gold have been as follows:—

Gold Production.

Cosmopolitan	265,277.65 fine ozs.
Champion	32,648.38 "
Orion	19,050.70 "
Altona	13,820.31 "

The Cosmopolitan (Englishman) Reef, the most important of the whole district, is a quartz reef, from a few inches up to 12 feet thick, which occurs in a biotite-microcline granite about two and a-half miles east of the boundary of the greenstones. The reef, which trends generally north and south, has an underlay to the east, and has been opened out by 12 levels. The shoot of gold, which has been followed, has a decided pitch to the south.

About a mile and a-half to the eastward is a long parallel line of reef, The Altona (Cosmopolitan No. 2), occurring in granodiorite, of a much less acid type than the rock which forms the matrix of the Cosmopolitan (Englishman) Reef. The Altona is part of a long line of reef, filling a very strong fissure considerably over a

mile in length. The reef, which is of quartz, varies in thickness from a few inches up to as much as four feet, and is enclosed within fairly well-defined walls. The quartz contains abundance of iron pyrites, both coarse and fine; the coarser varieties being in cubes up to an eighth of an inch in size. The coarsely crystalline pyrites carries very little gold, whereas in the finer dense varieties there was much coarse gold.

The Champion Reef occurs in greenstone not far from the junction between it and the granite which adjoins it on the west. The reef, which trends generally northeast and underlays to the east, has been opened out and worked to a depth of about 400 feet below the surface. The quartz of which the reef is made up is as much as 10 feet thick, and is highly mineralised. The reef has been faulted in an east and west direction, the hade of the fault being to the south and the displacement to the west about 40 feet. The gold occurs in horizontal bands in the quartz, forming a series of "floors" separated by barren bands of quartz; the pitch of the ore shoot is to the north.

The Orion Reef constitutes the largest and the deepest mine at Niagara. The gold-bearing deposit of the Orion Mine is a quartz reef which forms part of the main lode channel of the Niagara mining centre. This lode channel has a proved length of not less than 120 chains. The rocks along this lode channel are almost all basic igneous rocks, which have been sheared and foliated parallel to the dominant trend of the mineral zone. The ore channel and the walls are well defined, the hanging wall being particularly smooth and regularly striated. Part of the ore channel traverses a belt of gneissic granite which intrudes the basic rocks. The general strike of the channel is north 80 degrees east, with an average underlay to the south of about 50 degrees. The Orion Reef has been worked down to a level of about 600 feet below the surface; it varies in thickness from a few inches to about eight feet, and the ore shoot from which the bulk of the gold has been derived pitches to the east. In addition to the gold, which is principally confined to a thin band in the reef, the following accessory minerals have been found to occur in subordinate quantities, viz., calcite, ankerite, chlorite, bismuthinite, tetradyomite, and iron pyrites.

The Ularring District covers an area of 3,003 square miles, and has produced 287,922.79 ozs. of fine gold, the bulk of which has been derived from the two mining centres of Davyhurst and Mulline.

The Ularring District is a more or less elevated tableland, consisting of level plains covered with a considerable thickness of superficial deposits, through which rise low rough greenstone hills and ridges, together with some bare outcrops of intrusive granite. Very large areas of the district are, however, not marked by any outcrops, the underlying rocks being completely covered by soils which vary in character according to the nature of the rocks from which they are derived. The disintegration of the granite and its allies usually results in the formation of a red or yellow sandy soil, whilst the basic rocks produce light or dark red soil, containing but little sand. The basic rocks and their associates, which comprise the matrix of the gold-bearing deposits, are arranged in three well-defined belts, the westernmost forming a band which extends from Mount Elvire to the southern boundary of the district between Yeerilgee and Coorara Soak—a distance of about 70 miles, and described as the Yeedie-Bulgar Belt, which owes its name to a prominent hill on the northern shore of Lake Barlee, on the East Murchison Goldfield. The central belt, which adjoins Day's Rock on the east, extends southwards between the arms of Lakes Ballard and Barlee for a distance of over 20 miles in the direction of Hospital Rocks. The eastern and most important is the Davyhurst-Mulline Belt, in which lie the mining centres of Davyhurst, Mulwarrie, Ularring, Mulline, and Riverina, the sources from which practically the whole of the gold in the Ularring district has been raised.

The Yeedie-Bulgar Belt is made up of various types of greenstone schists, associated with bands of ferruginous quartz schist, the whole being traversed by newer greenstone dykes and numerous

quartz reefs; the belt seems to warrant judicious prospecting, though the absence of water in close proximity to what may be called the auriferous areas tends to retard progress in this direction. The belt, which is very narrow, is bounded on both sides by intrusive granite.

The belt lying immediately to the east of Day's Rock (a large mass of bare granite) is made up principally of massive epidiorite, bounded on the west by a belt of ferruginous quartz schist in intimate association with metamorphic sedimentary rocks, forming a zone about a mile in width. Whilst many portions of the belt appear to be devoid of reefs, a considerable quantity of quartz *débris* strews certain portions of its surface and must have been derived from the disintegration of reefs which are not now visible. Some reefs, however, are to be seen outcropping. A well defined quartz vein occurs at Metzke's Find, a locality in the northern extension of the belt, within the limits of the Menzies District. This reef, which outcrops for a distance of about 15 chains, has been opened out and worked by a series of shallow shafts to a depth of 43 feet below the surface.

The Davylhurst-Mulline Belt has a length of about 38 miles, in a general north and south direction, with a maximum width of about 10 miles. The greater portion of the belt is made up of amphibolites (including epidiorites and hornblende schists), which owe their origin to the transmutation of gabbros and dolerites. These greenstones are traversed by some well-defined shear zones, along which the rocks have been altered to hornblende schists, which as a rule form bands only a few feet in width, forming a channel for the gold-bearing solutions. The amphibolites form the country rock of most of the auriferous deposits of the belt, which are generally confined to the hornblende schists. The basic rocks correspond in some respects to the newer greenstones of Kalgoolie, though they have not been so highly sheared, nor subjected to the same carbonation and chloritisation as those of that centre.

The amphibolites are surrounded on all sides by biotite-microcline granite, which is of a later date, though the junction between the two is for the most part hidden by superficial deposits; where, however, it is visible, the basic rocks are found to be highly foliated and at times contorted, the lines of foliation being as a rule parallel to and dip away from the granite boundary. Small patches of foliated greenstone are often found caught up in the granite along its margin. Numerous acid dykes, which vary in width from a few inches up to 60 feet, intruding the greenstones, are often of frequent occurrence in the belt. These dykes are closely allied to and are probably connected with and form offshoots from the main mass of granite; they consist of granite-

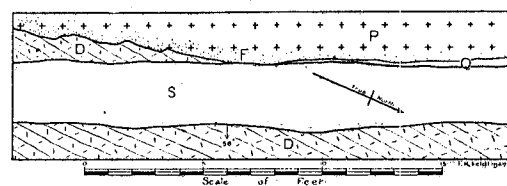
and secondary ore deposits. The primary ore deposits include quartz reefs and lode formations, whilst those of secondary origin consist of what may be called infra-lateritic material, in which gold, originally derived from gold-bearing quartz reefs, has been re-deposited, as has been the case at Kanowna (*vide p. 76*).

The quartz reefs, which constitute the chief source of the gold obtained from the belt, occur as irregular lenses of quartz arranged *en echelon*; these vary very much in width and seldom exceed four feet. The reefs occur in shear zones traversing the amphibolite, with at times considerable spaces between each lens of quartz, of which the Cooladdie at Mulline is a typical example (Fig. 69). The shear zones are usually three or four feet wide, though one instance of a zone 18 feet wide has been noticed.

The Cardinal Reef at Ularring is an example of a quartz porphyry assuming a flinty and felsitic character at its contact with the amphibolite, and with the development of auriferous quartz veins parallel to the shear zone (Fig. 70). A little quartz, with free gold, occurs as veinlets filling cracks in the altered amphibolite at right angles to and outside of the main shear zone.

The gold is practically confined to the quartz constituting the reefs in which pyrites is the most common accessory mineral. Galena and zinc blende also occur, but in small quantities, whilst

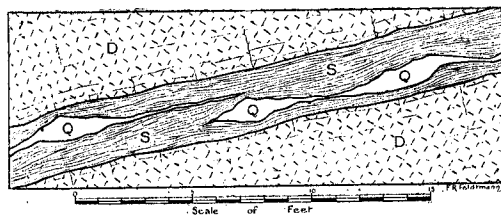
Fig. 70.



CARDINAL G.M.L. 954u. ULARRING — Sketch Plan showing shear zone S (stippled), with auriferous quartz vein Q, in altered amphibolite D and quartz porphyry P with felsitic margin F

malachite, azurite, and red oxide of copper are occasionally found filling cracks and joints in the quartz. Epidote is not an uncommon alteration product in the auriferous shear zones of Ularring, as well as those occurring at Mulline. The most important gold producer is the Lady Gladys Reef, which has produced, up to the close of 1918, 33,793.22 ozs. of fine gold; other consistent producers are the Young Australia, Belle Maie, Cooladdie, Victoria, Reprieve, Cardinal, Off Chance, and the Shamrock Reefs. From such geological evidence as is available it appears that there is a close connection between the introduction of the gold and the intrusion of the acid dykes into the amphibolites and the epidiorites. The "Lode Formation" type of deposit occurs at Riverina. The main lode of the Riverina group, which traverses the Riverina and Riverina South leases (Fig. 71), occupies a zone, traversing the amphibolite, which has been subject to intense shearing with subsequent and consequent mylonitisation, together with recrystallisation. The ore body trends generally north and south and is practically vertical; striae are to be seen in the walls, and the striae generally dip to the north. So far as observations on that portion of the lode formation traversing the Riverina South lease have gone it appears that the effects of the shearing are much more pronounced on the footwall than on the hanging wall, for that on the former shows more distinct foliation than that on the hanging wall rock. The central portion of the Riverina lode formation consists of white quartz varying in width from 1 to 3 feet enclosed in a zone which varies in width from 2 to 10 feet. Iron pyrites is disseminated in small quantities throughout the shear zones in addition to pyrrhotite. Small quantities of galena and zinc blende also occur and the gold values are said to follow and bear an intimate relationship to the pyrites itself. Flat dykes or veins of

Fig. 69.



COOLADDIE G.M., MULLINE. — Cross Section showing irregular quartz lenses Q, in shear zone S, in amphibolite D

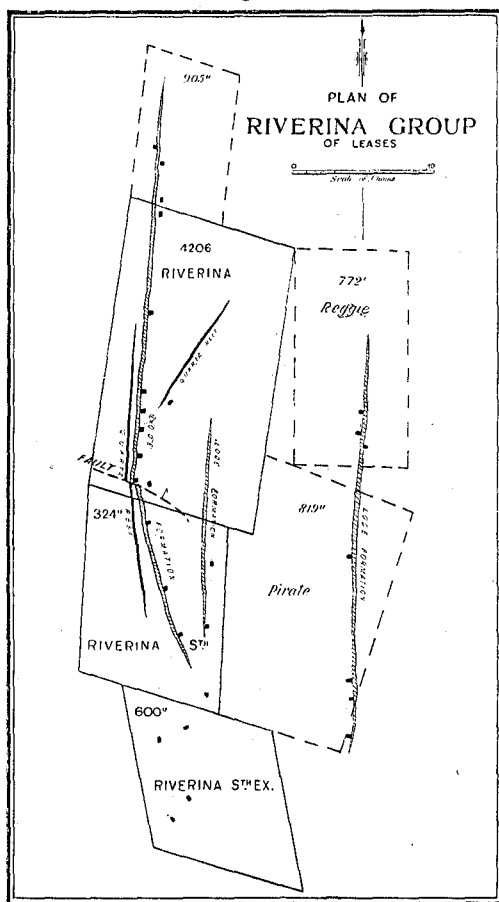
porphyry, quartz-porphyry and pegmatite. Some of the dykes are more recent than the quartz reefs of the district, for many are found cutting through the veins without exhibiting any appreciable effect on their strike, dip or gold contents. The quartz-and-gabbro-porphyrines, however, appear to be older than the auriferous quartz reefs.

The auriferous deposits of the Ularring Belt are, when viewed broadly, divisible into two categories, viz., primary ore deposits

pegmatite intersect the Riverina lode formation and have in places caught up and enclosed masses of the ore-body. The lode formation is also traversed by faults which at times have formed the channels along which the pegmatite reached their present positions.

The secondary gold deposits are well exemplified in the neighbourhood of the Belle Maie Lease, G.M.L. 955U, where a body of kaolinic material, lying beneath about 16 feet of laterite, has been

Fig. 71.



stoped for its gold contents to a depth of 40 feet (vertically) below the surface. The gold is of secondary origin and doubtless derived from pre-existing auriferous quartz reefs. The gold contents of the kaolinic material is said to vary from 5 to 35 dwts. per ton.

The Yerilla District covers an area of 3,160 square miles. It has produced 113,489.87 ounces of fine gold, of which a little over 44,000 ozs. have been raised from the mining centre of Edjudina, over 22,000 ozs. from Yarri, and 13,651 ozs. from Yerilla itself.

An important feature in the geology of the Yerilla district is the occurrence of a belt of almost vertical sedimentary rocks, trending generally northwest and southeast and about two or three miles wide. The beds consist of conglomerates, fine-grained grits, and phyllites, intersected by dykes of acid porphyry. The series is traversed by quartz reefs lying parallel to the bedding planes of the

sediments; they have only yielded 295.45 ozs. of fine gold, with an average of 1.35 ozs. per ton of ore milled. A belt of ferruginous jaspilites occurs in the eastern portion of the district and may be followed for a distance of about 50 miles in a north-westerly direction, from a point a little to the west of Pingin. The beds are arranged in a series of steeply inclined anticlinal folds, the average trend of which is parallel to the previously-mentioned belt of sediments.

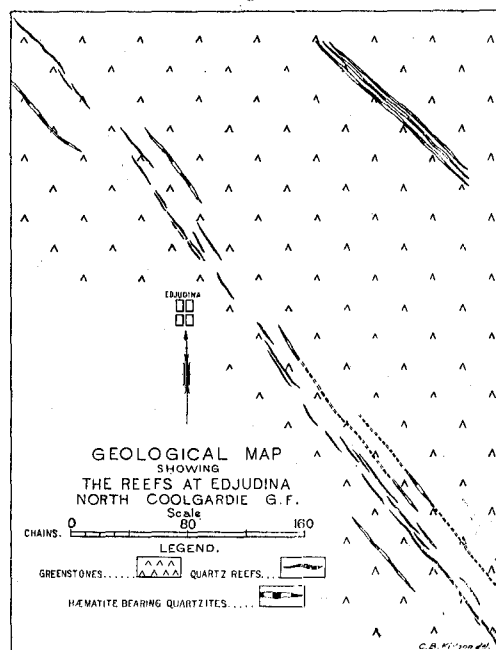
Some of the greenstones, with which the jaspilites are associated, are believed to be basic lava flows, exhibiting a marked bedded structure; it may, however, be that some are of sedimentary origin. Interbedded with them is a graphitic shale, resulting from the contact alteration of an aluminous carbonaceous shale.

Bands of serpentine and dolomite occur in parallel belts, which coincide in strike with the jaspilites and their associates; these serpentinous rocks may owe their origin to the alteration of dolomitic limestones associated with the other metamorphic rocks.

A very large area of the district, and more especially its western portion, is made up of granite and rocks genetically allied thereto; in several places the granitic rocks have undergone dynamic deformation, resulting in the production of granitic gneiss. There is a marked increase in basicity in the greenstones, producing rocks containing larger quantities of hornblende in many localities along the marginal contact of the granites and basic rocks.

There is in addition to the above a series of ancient amygdaloidal lavas, with tuffs and agglomerates, into which small dolerite dykes penetrate.

Fig. 72.



A noticeable economic feature in the Yerilla District is the grouping of the gold-bearing quartz reefs in the greenstones in the vicinity of the granite, but when in the latter, they are invariably in close proximity to the granite contact. The quartz reefs range from veinlets a fraction of an inch in width to solid veins, sometimes as much as 30 feet thick; they invariably have a high underlay, and,

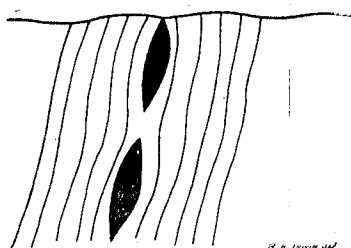
as a rule, conform closely both in dip and strike to the dominant structural planes of the enclosing rocks. The mineralogy of the gold ores is simple, quartz being the predominant gangue mineral, which is mostly uniform in character; sericite, galena and pyrites also occur as accessory constituents.

Some of the quartz reefs may be found to pass in depth out of the greenstone into the adjoining granite. Such evidence as is available seems to indicate that the gold occurring in the reefs owes its origin to magmatic waters, emanating from the granitic magma, in which it was probably originally contained.

The mining centres of the Yerilla district in nearly all cases occur in those areas which have undergone considerable dynamic disturbance, represented by shearing and faulting.

The mining centre of Edjudina lies on the eastern-most portion of the Yerilla district, and on the western side of Lake Raeside. The country rock of Edjudina is made up chiefly of greenstone schist, in which a more or less continuous line of reefs occurs in a belt, nowhere exceeding 20 chains in width, and which extends for a distance of about 8 to 10 miles in a general northwesterly direction. (Fig. 72.) There are several lines of reef, no single one of which is continuous over any considerable length, though they thin out and take up again on the same line of strike. The gold-bearing reefs of Edjudina consist of exceptionally lenticular veins of quartz occurring along the planes of foliation of the schist. Reefs of this type are locally known as "kidneys"; they are of various shapes and sizes, separated by patches of barren ground (Fig. 73). These kidney-shaped reefs are comparable to those occurring at Warra-

Fig. 73.



SECTION SHEWING THE MODE OF OCCURRENCE
OF THE EDJUDINA QUARTZ REEFS.

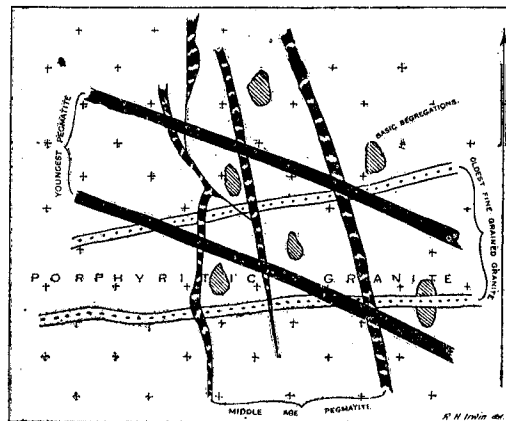
woona, on the Pilbara Goldfield, and which have been fully described on an earlier page. In many cases the payable kidney reefs of Edjudina are associated with what appears to be a sheared porphyry dyke, which is traceable by the fragments on nearly all the dumps along the belt, and at times traverse the whole length of some of the individual leases. The kidney-shaped ore lenses of Edjudina may contain several tons, or only a few pounds, of gold-bearing quartz, and their arrangement is comparable to that of a string of beads or a string of sausages. The quartz carries a fair quantity of iron pyrites in the lower levels. The quartz reefs are mostly rather small, which naturally renders it impossible to maintain a large tonnage output without having to take out a considerable amount of barren ground, whilst their mode of occurrence creates uncertainty regarding estimates of the ore available in any block of stoping ground.

An important feature in connection with the geology of the ore-bearing belt of Edjudina is the parallel belts of haematite-bearing quartzites (jaspilites) which lie on each side of the rim of the reefs. The jaspilite belts are made up of alternate over-lapping lenses, each of great horizontal extent; these are either vertical or are inclined at high angles to the northeast. The belts are often intersected by

irregular stringers of quartz, and, at times, associated with gold-bearing reefs. Many of these haematite jaspilites could readily be concentrated to high grade ores of iron.

The mineralised belt, of which Pingin is the mining centre, is the southeastern extension of the Edjudina line of country. The Pingin belt has been proved for about seven miles in length and two in width, and forms a low ridge of hills—the Jasper Range—which trends generally northnorthwest. Geologically the field is made up of greenstone schist, associated with jaspilites and intersected by intrusive quartz porphyry. At Pingin Rock Hole, about five miles distant from the township, is a porphyritic granite traversed by three pegmatite dykes of three distinct ages (Fig. 74). The quartz reefs,

Fig. 74.



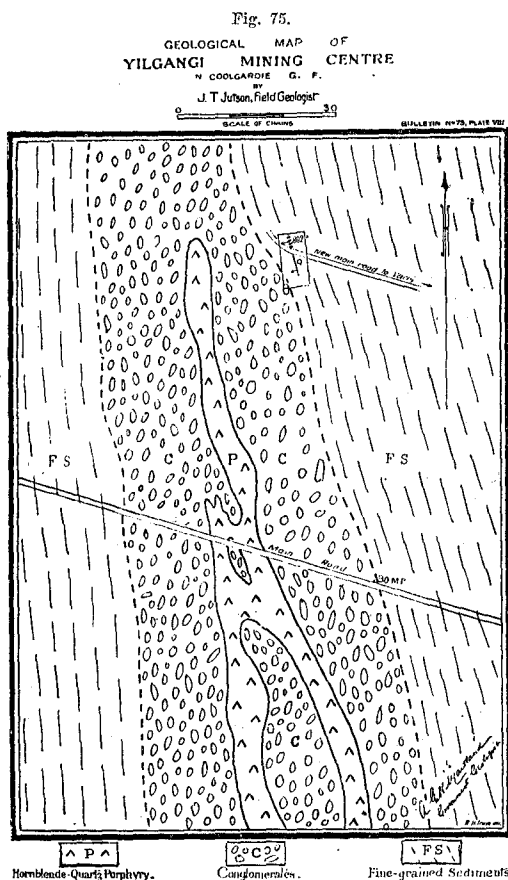
Showing dykes in Granite at Pingin Rock Hole.

which constitute the gold-bearing belt, lie to the east of the jaspilite horizon. There are several wide and extensive lodes carrying numbers of small kidney-shaped quartz reefs of the Edjudina type.

The mining centre of Yarri is situated about six miles west of Edjudina. The country rock consists of a massive diabase, penetrated by bosses of granite, from which several dykes of aplite emanate. The quartz reefs constituting the gold-bearing ore-bodies of Yarri invariably occur in close proximity to the contact between the granite and the diabase. The quartz reefs occurring in the granite all lie approximately parallel to one another, with a general northwesterly strike; those met in the granite, however, have individually a very variable strike, although when their position is laid down on a map a general east and west trend may be detected. Whatever may be the geological date of the intrusion of the granite, it is clear that the formation of the auriferous quartz reefs took place very much later. In the case of some of the ore-bodies, the adjacent country rock is a sericite schist or gneiss resulting from the alteration of the wall rock along a shear zone, whilst the quartz appears to owe its origin to a metasomatic replacement of the gneissic rocks, having a fibrous fissile structure conforming to that by which the foliated rock is characterised. In several cases large bodies of quartz merge into the schistose rocks within a few feet; but as the reefs owe their origin to relatively deep-seated causes, their persistence in depth is assured. The quartz of Yarri varies greatly in its character, some of it being amber-coloured and vitreous, some ice-like and semi-translucent, whilst others have a dull iron-stained appearance and carry a good deal of pyrites when followed below the surface.

A belt of highly inclined sedimentary rocks, conglomerates, and gritty rocks (the field relations of which indicate that they are metamorphosed sediments), with intrusive hornblende quartz porphyries occurs in the neighbourhood of Yilgani, which lies to the west of the

Edjudina ore channel (Fig. 75). The gold-bearing belt of Yilgangi is small and narrow; the lodes of which it is constituted are quartz reefs and somewhat irregular quartz veins. The lodes occur in the conglomerates and the finer-grained sediments as well as in the porphyry. The largest reef in the ancient sediments, the Yilgangi, is only a foot or two thick, with a strike which coincides with that



of the enclosing conglomerates. The Yilgangi ore body has been worked by an opencut and several underlay shafts, but only to a shallow depth. Only 109 tons of quartz have been crushed, with a return of 181.85 ozs. of fine gold. Some small irregular quartz veins occur in the porphyry and have had a moderate amount done on them. They, however, would be characterised rather as irregular leaders than well-defined quartz veins.

At Mount Catherine, which lies about 22 miles northeasterly from Yilgangi, is a range of massive diabase, intersected by granite dykes, upon which a massive quartz reef stands out boldly, in addition to having a considerable horizontal extent. The reef trends generally north and south, and has a slight underlay to the east. A good deal of work has been done on the reef in the early days; it was principally confined, however, to a large opencut on the surface. Several shafts were also sunk, one being a large main shaft which encountered hard massive diabase. The reef is of pure white quartz, which, as measured in the crosscut put in across the vein some distance below the surface, measured 12 feet from wall to wall. Several small crushings have been taken from different parts of the reef, viz.: (1)

19 tons returning 7 dwts. 16 grs. of gold per ton, (2) 27 tons, 8 dwts. per ton, whilst a third crushing of 12 tons returned 14 dwts. 15 grs. per ton.

Reviewing the Yerilla district as a whole, it is by no means improbable that there are ore deposits which yet await discovery along the extension of the known gold-bearing zones, though if the production is to be maintained, or in any way increased, it is rather to be looked for in the deposits already opened up than in the discovery of new ones.

BROAD ARROW GOLDFIELD.

The Broad Arrow Goldfield is the smallest of all the existing goldfields in the State; it embraces an area of 1,038 square miles. The goldfield, which was named after one of the chief centres, is stated to have been discovered by a prospector named Reison, and was so called because the discoverer on his initial journey marked at intervals on the ground a broad arrow, in order to indicate to his mates, who were following, the route along which he had travelled. Broad Arrow was first established as a goldfield by proclamation in 1896; its boundaries were, however, amended during 1906, so as to embrace its present area.

The goldfield has produced up to the end of 1918, 467,854.97 ozs. of fine gold obtained from the milling of 799,296.50 tons of ore, in addition to 30,809.60 ozs. of alluvial gold. This quantity of gold has been obtained from seven widely distributed mining centres and several other minor isolated localities of which details are given in the synoptical table.

Synoptical Table showing the Gold Yield of the Broad Arrow Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dolled and Specimens.	Ore treated.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	Tons. (2,240lbs.)	Fine ozs.	Fine ozs.
Bardoc ...	2,465.97	76,126.18	54,226.40	56,692.37
Black Flag ...	1,254.09	42,323.86	26,315.97	27,570.06
Broad Arrow ...	7,980.15	126,080.14	105,109.54	113,089.69
Carnage ...	...	138.00	251.97	251.97
Paddington ...	7,531.76	185,282.56	88,747.49	96,279.25
Siberia ...	1,558.82	350,265.15	125,936.73	127,495.25
Smithfield ...	23.79	1,076.50	350.37	374.16
District generally ...	9,995.02	18,004.11	36,106.90	46,101.92
Total ...	30,809.60*	799,296.50	437,045.37	467,854.67

*Includes 11,634.16 ozs. dolled and specimens.

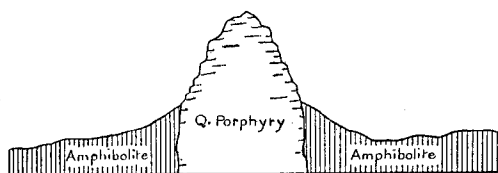
The Broad Arrow Goldfield is a tableland of an average altitude of about 1,400 feet above sea level, which is traversed by the Kalgoorlie-Menzies Railway Line. In its general geology the Broad Arrow Goldfield resembles, in many of its important aspects, that of the neighbouring fields; it is made up of massive and schistose basic rocks, invaded by granite and its allies; by far the larger portion of the goldfield is covered with a variable thickness of more or less loose incoherent superficial deposits and the ubiquitous laterite. The basic rocks consist for the most part of transmutated gabbros and dolerites, now represented by epidiorites and amphibolites, which have in places been altered to hornblende and chlorite schists. There are in addition hornblendites, serpentine, talc-chlorite and carbonate rocks. The basic rocks and their derivatives occur in two main and well-defined areas; the most westerly includes the mining centres of Waverley (Siberia), Ora Banda, Cashman's and Balgarri, Mount Pleasant and Black Flag; this area is made up geologically of amphibolites, serpentine, and porphyry, and their derivatives. What may be called the Bardoc Belt of basic rocks includes the mining centres of Paddington, Broad Arrow, Windanya and Vetersburg; it has a general north-north-west trend, with an average width of about seven miles. The area is

made up of serpentine and amphibolite together with tale schists and carbonate rocks.

A small patch of basic rocks, probably the extension of that from Mulgarrie, occurs on the eastern margin of the field and of these Mount Jewel forms the most prominent summit. The basic rocks constituting the auriferous series are separated by masses of, for the most part, biotite-microlite granites. These granite masses occur in three more or less parallel belts. The westernmost belt extends from Split Rocks to Water Reserve 3092, which is situated at the end of the northern arm from that chain of lakes which extends from the Gordon to Black Flag Lake; it does not, however, appear to have been traced much further south than this. The second or central belt extends from Cane Grass southwards to a point about three and a-half miles due west of Broad Arrow. The third and easternmost belt occurs in the extreme northwest corner of the field and extends from Wangine Soak to a point about a mile to the northwest of Siberia; from thence it continues southwards in the direction of Lake Carnage near the southwestern-most angle of the Goldfield.

The granitic rocks are intimately associated with acid dykes which in all probability form the apophyses therefrom. The greenstones are at times intersected by very large and well-defined dykes of quartz-porphry, many of which stand out in bold relief, their superior hardness enabling them to resist weathering much more readily than the basic rocks into which they intrude. An excellent example of one of these quartz-porphry dykes occurs near Christmas Gap in the neighbourhood of Ora Banda (Fig. 76).

Fig. 76.



Near Christmas Gap, Broad Arrow G.P.

Showing relative weathering of amphibolite and intrusive dyke of quartz porphyry.

The most northerly mining centre in the Broad Arrow field is Waverley (Siberia), which is made up chiefly of massive and schistose basic rocks, into which granite intrudes. The gold-bearing deposits are confined to a belt of basic schists, which trend generally north-northwest. Some bands of the schist exhibit strong evidences of squeezing and contortion; the schists contain numerous inter-laminated and cross veins of quartz, some of which have yielded rich bunches of ore. There are, in addition, several fairly distinct quartz reefs in the district, which, though poor in the aggregate, are notable for containing rich patches of specimen gold.

The Waverley district is noted as being one from which the dryblowers have obtained a fair quantity of gold, chiefly, however, from the country along the schist belt, in which most of the mines are situated. The shallow ground in the numerous flat gullies and depressions have been extensively worked, in addition to the fairly deep-buried watercourses, which fall both east and west from the central ridge at Siberia.

A good deal of boring has been carried out with the object of picking up other deep leads. In all, twenty-eight bore holes were sunk to depths varying from 26 to 117 feet, and bed-rock consisting of granite or greenstone met in nearly every case, without any defined gutter having been located.

A little gold was found in the detritus passed through in several of the bore holes, but in no case in such quantities as would warrant the sinking of shafts.

The mining centre of Ora Banda is situated near the western boundary of the goldfield, about 18 miles west-northwest of the Broad Arrow Railway Station, at an altitude of from 1,300 to 1,500 feet above sea-level. The history of Ora Banda (Gimlet) proper as a mining centre dates, so far as official records show, from the year 1907.

The geological structure of the field is built up on a comparatively simple plan, the whole area being made up of igneous rocks forming part of that group which is often designated the Auriferous Series, but which might be better styled the Auriferous Igneous Complex. The rocks, owing to the cover of laterite and other more or less unconsolidated superficial deposits, are visible at the surface only in a very few places, whilst the ore deposits are only to be seen in the underlying workings.

The rocks belonging to the igneous complex are represented by a series having a fairly wide range as regards acidity. They are divisible into basic, mainly gabbro, dolerite, porphyrite, epidiorite, and serpentine, and their transmuted varieties, and an acidic series mainly granite and quartz-porphry. It is possible that the various rock types are genetically related, and may all owe their origin to some process of segregation from one parent magma. In their general petrographical characters the basic rocks very closely resemble those of the adjacent mining centres.

The more acid members of the complex comprise granite and porphyry (intrusive into the basic rocks), which, however, are somewhat restricted in distribution to the northeastern portion of the Ora Banda neighbourhood.

The porphyrite appears to be economically the most important rock at Ora Banda, as it forms the matrix of those ore bodies, the oxidised zones of which have been responsible for the major portion of the gold output. The schists and allied rocks are economically second in importance to the porphyrite, as they include the main auriferous quartz reefs of Ora Banda. The mapping and the recognition of the rock series into which the plutonic igneous may be divided, coupled with the distribution of the ore deposits, indicates an intimate genetic connection between them and the intrusion of the acid and intermediate igneous rocks—an association of the utmost practical importance.

The gold-bearing deposits of Ora Banda consist of alluvial deposits, quartz reefs, and lode formations.

Alluvial deposits are very scarce in the auriferous belt in which Ora Banda is situated, and only 1,558.82 ozs. of fine gold have been recorded from them.

The quartz reefs and veins of Ora Banda are chiefly confined to the eastern portion of the field, and occur in the schists which result from the transmutation of basic rocks. The quartz reefs, which are very numerous and at times of considerable thickness, generally lie along the foliation planes of the schists, the average strike of which is northwest, with an underlay to the southwest at angles varying from 40 to 50 degrees. The gold-bearing quartz reefs and veins in the eastern schist belt are intimately associated with intrusive quartz-porphry dykes which nearly always occur in and conform to the planes of foliation. The dykes have not been proved to be auriferous, except in those cases in which they are associated with occasional thin quartz veins.

The quartz-porphry dykes appear to be offshoots from the mass of granite which occurs on the eastern portion of the field. There are several irregular non-auriferous quartz reefs in and around the margin of the granite; they probably represent the residuals from the granite magma.

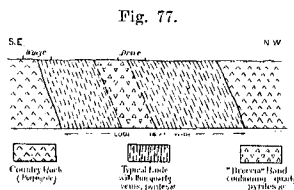
The lode formations of Ora Banda form the most important of the gold-bearing deposits occurring in the district, and have been responsible for a very large proportion of the gold which has been produced. This type of deposit, which is confined to the porphyrite, merely represents a highly altered and more or less mineralised form of that rock. The lode formations vary very much in thickness both in different lodes and in different portions of the same

lode. What is known as the Gimlet South lode is 50 feet thick where it is exposed in the Victorious Mine, and 70 feet from wall to wall in the Gimlet South Mine.

The lode formations are, within the zone of oxidation, made up of soft clayey material traversed by thin veins of quartz and ironstone, which on the whole have a general parallelism to that of the ore bodies themselves. The rock along the lode channels has been oxidised to great but varying depths; at the Gimlet Mine the level of the zone of oxidation is at 150 feet below the surface, whilst in the country, which contains the Victorious lode, oxidation has extended to a depth of 360 feet below the surface. The lode formations in the unoxidised or sulphide zone are metasomatically altered country rock with thin quartz veins carrying small calcite, pyrrhotite, tourmaline and a little arsenopyrite, together with veins of pyrites. Calaverite (telluride of gold) has been found in the Victorious lode.

The principal ore deposits of Ora Banda are the Slippery Gimlet, which has produced, up to the end of 1918, 9,992.31 ozs. of gold, the Gimlet South, 11,863 ozs., and the Victorious 72,785.74 ozs.

The Slippery Gimlet is practically vertical, varies from 2 to 18 feet in thickness, and is made up of metasomatically altered porphyrite, into which it at times passes by scarcely perceptible gradations, though there are several parallel smooth slickensided surfaces which have often been mistaken for the walls of the ore body. A section of the lode to be seen in the level at 150 feet shows it to be 16 feet wide (Fig. 77) and made up of altered porphyrite containing pyrites, pyrrhotite, and tourmaline, in addition to thin veins of



quartz, lying parallel to the general strike of the ore body. The central three feet of the lode is a breccia, made up of angular fragments of pyrites, pyrrhotite, grey quartz, calcite, and country rock, cemented and replaced by white quartz. From such evidence as is available it appears that the Slippery Gimlet lode is of deep-seated origin and resulted from the circulation of ore-bearing solutions (mineralisers) given off from a cooling plutonic rock, whilst the circulation ceased with the filling of the ore-bearing fissure with quartz and calcite.

The Victorious and the Gimlet South lodes, which are situated some little distance to the south of Ora Banda, adjoin one another and, between them, have produced 84,648.74 ozs. of fine gold. The Gimlet South lode (the main lode) has a general trend of westsouth-west, whilst that of the Victorious is westnorthwest. The two lodes have not been seen to intersect one another, though in the locality where they approach one another in levels Nos. 1 and 2 in the Victorious mine, the latter ore-body splits up into a number of small veins which peter out before reaching the Gimlet South lode.

The Victorious Lode is practically vertical, with some merely local minor deviations. It varies in width from a few inches up to about 12 feet, but it has no well defined walls. The ore-body carries thin veins of ironstone and quartz, the latter being sometimes four inches in thickness, and are occasionally highly auriferous. Mustard gold was found just above the No. 4 level in the eastern portion of the lode, and the telluride of gold, Calaverite, lower down. The lode had been opened out by a series of open-cuts at the surface and to a depth of about 470 feet below it, whilst a considerable amount of work had been done upon it.

The Gimlet South Lode has an outcrop of over a quarter of a mile; it has been more or less extensively worked in open-cuts at the eastern extremity in the adjoining Gimlet South Extended lease. The lode, which is practically vertical, often reaches a thickness of 70 feet. Like the Victorious lode, it has no defined walls, and contains numerous thin ironstone and quartz veins, both of which are, in addition to the ore-body itself, gold-bearing, though the distribution of the gold in them is very variable.

The mining centre of Bargarrie, which lies southeast of Ora Banda, is made up of massive and foliated greenstone, associated with which are two nearly parallel dykes of quartz-porphry trending northwesterly and traceable for about a mile. Porphyry dykes of this nature make a prominent feature in this portion of the State; in all probability they have some genetic connection with the main granite batholith lying to the west. The dykes are probably more or less continuous with those which occur to the west of Kalgoorlie.

A good deal of residual gold has been obtained from the alluvial workings along the outcrop of the dykes at Bargarrie. The porphyry carries a little gold itself. In the United Australia Mine the dyke, which is 100 feet in width, carries numerous quartz veins, and, in places, the quartz carries gold and pyrites. Mining experience has demonstrated that the value of the ore appears to largely depend upon the extent to which the dykes have been transmutated into quartz.

The mining centre of Bardoe is made up chiefly of greenstones, which form by far the largest area of any of the rocks exposed at the surface; there are also minor outcrops of coarse-grained micaceous granite. By far the larger portion of the Bardoe district is covered with a variable thickness of loose incoherent detritus and the ubiquitous laterite, which is found acting as a protecting cover to the rocks in the higher ground. A good deal of prospecting has been carried out in the search for deep leads in the vicinity of Bardoe, but despite the fact that some of the claims obtained good gold prospects, no defined lead was discovered. The field is traversed by narrow dykes of acid rocks which are traceable for considerable distances across country in a general northwesterly direction. In two instances these acid dykes have been worked for their gold contents; in these cases free quartz forms a stock-work in the rock, which, in addition, is impregnated with iron pyrites. The gold produced from Bardoe has been derived from three sources, viz., alluvial deposits, quartz reefs, and lode formations. The quartz reefs, which, so far as observations have at present been carried, almost invariably occur in the vicinity of the acid dykes, and have the same strike and underlay. There are two distinct varieties of quartz reefs: 1st, white opaque glassy quartz, usually occurring in lenticular patches, from which small but very rich quartz leaders emanate; and 2nd, crypto-crystalline quartz and haematite in alternating bands. Although some of these banded quartzes have proved to be auriferous, none of them have turned out to be payable. Experience on the field, however, shows, as on the Murchison, rich shoots of gold are often found where the first type of quartz reef intersects the banded quartz of the second. Few examples of the occurrence of lode formations are met with at Bardoe; they often contain numerous quartz leaders lying along the laminae of the ore body.

The mining centres of Broad Arrow and Paddington, which are situated about eight miles south of Bardoe, are in their geological features identical with those of Bardoe, with which the different rock series are coterminous. The gold-bearing belt is confined to a comparatively narrow strip of country a little over a mile in width, and is practically coincident with the area over which the rocks have undergone the greatest amount of movement. The gold produced from Broad Arrow and Paddington has been derived from three distinct sources, viz., superficial deposits, quartz reefs, and lode formations. The superficial deposits, which have been extensively dry-blown, cover a great extent of ground, and consist for the most part of rocks decomposed *in situ*, i.e., residual deposits. The reefs and

lode formations are all practically parallel and trend generally northwest and southeast. The drainage from the neighbourhood falls gradually into that chain of lakes to the south in which Black Flag Lake is situated, and has led to a certain amount of prospecting for buried watercourses, *i.e.*, deep leads, but so far no defined gold-bearing channels have been discovered.

THE EAST COOLGARDIE GOLDFIELD.

The East Coolgardie Goldfield, the most productive in Australia, which up to the end of 1918, has yielded over 17,000,000 ozs. of gold, or about 65.14 per cent. of the total yield of Western Australia, embraces an area of 1,800 square miles. It was originally proclaimed a goldfield in 1894, though its boundaries have been subject to amendment from time to time.

Kalgoorlie, the official centre of the East Coolgardie Goldfield, was in the first instance called Hannans, after Mr. Patrick Hannan, the original discoverer of the field. The principal mining centre on the goldfield is Boulder, the wealth of which, coupled with the skill which directs both the mining and the metallurgical operations, has raised Western Australia to the front rank of mining countries in the British Empire. The field has for purposes of administration been divided into the East Coolgardie and the Bulong Districts. The East Coolgardie Goldfield has produced, up to the end of 1918 17,100,149.39 ozs. of fine gold, derived from the milling of 26,616,776.78 tons of ore, in addition to 99,192.26 ozs of alluvial gold. The total quantity of gold from the field has been obtained from about 14 different mining centres, details of which are given in the subjoined table.

Synoptical Table showing the Gold Yield of the East Coolgardie Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dolled and Specimens.	Ore treated. Tons.	Gold therefrom.	Total Gold Yield.
EAST COOLGARDIE—	Fine ozs.	(2,240 lbs.)	Fine ozs.	Fine ozs.
Binduli ...	...	314.27	171.94	171.94
Boorara ...	435.51	302,534.15	169,346.00	169,781.51
Boulder ...	10,230.90	25,129,684.56	16,100,833.17	16,111,064.07
Peysville ...	4,781.17	28,293.80	7,404.51	12,185.68
Kalgoorlie ...	10,213.58	950,451.23	374,218.09	384,431.47
Wombola ...	613.86	6,162.30	6,794.22	7,408.08
District generally	31,386.59	45,337.40	222,572.35	253,958.94
	57,061.61*	26,462,777.71	16,881,340.28	16,939,001.89

* Includes 30,590.24 ozs. dolled and specimens.

BULONG—				
Belagundi ...	2,527.45	1,322.08	1,652.83	4,180.28
Bulong ...	11,177.77	106,441.97	96,915.74	108,093.51
Hogan's Find ...	908.82	309.50	276.51	1,185.33
Majestic ...	43.20	1,018.25	326.20	369.40
Mt. Monger ...	2,078.17	1,491.15	1,272.16	3,350.33
Randall's ...	80.49	33,713.59	11,132.02	11,212.51
Sudden Jerk ...	63.91	14.40	63.90	127.81
Taurus ...	118.45	1,954.15	1,171.84	1,200.29
Woodbine ...	...	832.08	672.14	672.14
District generally	24,532.39	6,892.90	6,133.51	30,665.90
	41,530.65*	153,990.07	119,616.85	161,147.50
Grand Total ...	99,192.26	26,616,767.78	17,000,957.13	17,100,149.39

* Includes 14,985.56 ozs. dolled and specimens.

One of the outstanding features in the constitution of the East Coolgardie Goldfield is the very large area occupied by a group of ancient metamorphic sedimentary rocks, which, when viewed as a whole, exhibit a marked parallelism. They have been found to extend to near Coolgardie, beyond the western boundary of the East Coolgardie Goldfield, Bulong and Kurnalpi on the west, near Black Flag on the north, whilst their southern extension has been noted at Norse-

man, on the Dundas Goldfield. The group of metamorphic rocks consists of shales, soft sandstones, mica and tale schists, grits, conglomerates, boulder beds and breccias. The sedimentary series, which is not the oldest group of rocks in the East Coolgardie Goldfield, has an average strike of north-north-west; the beds are, as a rule, highly inclined, and are disposed in a series of both anticlinal and synclinal folds, which have been modified by later crustal movements. The pebbles and boulders occurring in the conglomerates consist of jaspilite, hæmatite-bearing quartz, black chert, quartz, quartzite, granite, porphyry, gneiss, etc., embedded in a matrix, which is in some cases siliceous and contains much mica. Some of the conglomerates have undergone a certain amount of shearing, the effect of which has been to so arrange the pebbles that their longer axes lie parallel to that of the dominant structural features of the district. Other members of the series have been transmuted into mica and andalusite schists as the result of contact alteration induced by granitic and allied rocks.

Associated with these beds are amphibolites and derivatives therefrom, which in all probability represent igneous rocks; some are doubtless lava flows, whilst others are of an intrusive nature. There are, in addition, certain undoubtedly intrusive basic and acidic igneous rocks, as well as peridotite and serpentine.

The very coarse granite which occurs at the large rock hole on Water Reserve 3092, at the end of the arm running north from the chain of dry lakes stretching from Black Flag to Gordon, in all probability continues southward in the direction of Kalgoorlie, and may be represented by the dykes of quartz and felspar-porphyry, which make such a prominent feature in the latter portion of the East Coolgardie Goldfield. The large boss of granite-porphyry on the western bank of Hannan's Lake, just north of Peysville, the quartz porphyry of Boorara (Golden Ridge), as well as the granite dykes of Red Hill and elsewhere, also form the apophyses of the granite which doubtless lies at no very great depth beneath the surface in this portion of the East Coolgardie Goldfield.

The East Coolgardie District covers an area of 810 square miles and has produced 16,939,001.89 ozs. of fine gold, of which over 16 million ozs. have been obtained from the mining centre of Boulder.

The most important mining centre on the East Coolgardie Goldfield is that of Boulder, from which 16,111,064.07 ozs. of fine gold have been obtained up to the end of 1918. Boulder is situated about four miles south-east of Kalgoorlie and 379 miles from Perth, at an altitude of 1,280 feet above sea level. The first discovery of gold was made at Boulder shortly after the find made by Mr. P. Hannan and his associates at Kalgoorlie in 1893.

The productive area of Boulder comprises a relatively small block of ground, which by reason of the richness of the lodes by which it is riddled, has become known throughout the world as "The Golden Mile." This area includes the Great Boulder, Golden Horseshoe, Ivanhoe, Perseverance, Oroya Brown Hill, Kalgurli, Lake View Consols, and Associated Mines. The ore bodies in these mines have alone produced 13,370,732 ozs. of gold up to the end of 1918, details regarding which are set out in the following table.

Yields of the Principal Lodes of Boulder.

Lode.	Ore crushed.	Gold therefrom.
	Tons.	Ozs.
Great Boulder ...	3,063,790	2,770,216
Golden Horseshoe ...	4,023,062	2,550,770
Ivanhoe ...	3,558,123	2,234,000
Perseverance ...	3,090,437	1,908,544
Oroya Brown Hill ...	1,075,862	1,163,881
Kalgurli ...	1,597,702	1,027,134
Lake View Consols ...	1,179,303	1,016,875
Associated ...	1,780,602	993,252
Total ...	19,368,881	13,370,732

The deepest shaft in the Boulder is 3,470 feet vertically below the surface, and the country laid open for investigation by mining amounts to several miles, whilst the rocks have been riddled with bore holes in all directions, thus affording opportunities for the scientific study of many of the rocks in critical localities and in their relation to the ore deposits, such as are hardly to be found in any other single mining field on the globe. The recent discovery of fairly rich ore at a depth of about 3,000 feet in the Ivanhoe mine, shows that the lodes extend as far as the bottom levels in the chief mines and that the limits of ore deposition have not yet been reached.

The chief topographical feature of the district is the main central ridge of hills, trending generally northnorthwest, of which the highest summits are Mount Charlotte, 1,480, and Mount Gladden (better known as Maritima Hill), 1,450 feet above sea level. This central ridge of hills has a length of about four miles; it gradually dies out to the southeast in the direction of the flat ground which forms the northern end of Hannan's Lake (Gnamballa), just beyond the southern extremity of the Boulder group of mines. The chain of hills forms the main water-parting of the district. At the Golden Mile this prominent ridge, which forms the central feature, is made up of a broad mass of quartz-dolerite, more immediately flanked by amphibolites and other basic rocks, and it is along this ridge that the mines of the Golden Mile are situated.

A large portion of the lower ground in the Boulder and Kalgoorlie neighbourhood is covered with a mantle of reddish loamy soil and other superficial accumulations of variable thickness. These superficial deposits consist of ironstone gravels and cement, which in certain isolated localities pass into practically pure haematite; some of the deposits of this type have proved to be highly auriferous.

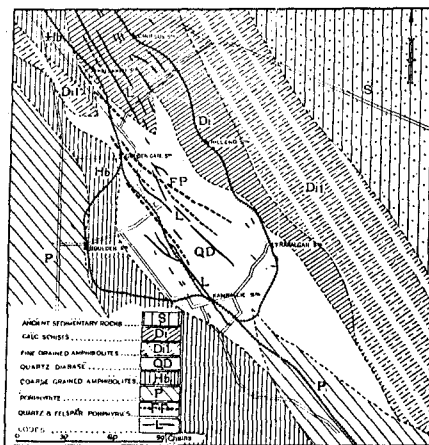
The rocks of Boulder and Kalgoorlie consist of: (a) ancient sedimentary rocks, (b) older greenstones (calc schists and fine-grained amphibolites), (c) newer greenstones (quartz-dolerites and coarse-grained amphibolites), (d) peridotites, (e) porphyrites, and (f) quartz and felspar porphyries. The ancient sedimentary rocks consist of shales, soft sandstones, conglomerates and boulder beds, associated with what appear to be inter-bedded lava flows. The beds have a general northnorthwest trend and an average dip of about 80 degrees to the west. The sedimentary series of Kalgoorlie is traversed by banded jaspilite and haematite-quartz of that type which forms such a conspicuous feature in the geology of the sedimentary area of Uaroo, in the Ashburton watershed. The sedimentary rocks are distinctly newer than the igneous complex which forms the axis of the Boulder auriferous belt, on both flanks of which the ancient sediments occur. Boulders and pebbles of the rocks forming the igneous complex are to be found in the conglomerates. The ancient sedimentary rocks are as a whole non-auriferous, and on this account are of no economic importance.

The older greenstones, the rocks of which have been designated fine-grained amphibolites, probably represent original lava flows; they have proved to be as a whole of little or no economic importance. The "calc schists," however, appear to be very closely allied to the fine-grained amphibolites, though they are more often massive than schistose. Their greatest development is on the eastern side of the igneous complex of Boulder and Kalgoorlie; many auriferous deposits of importance occur in them, *e.g.*, the lodes of the Oroya Brown Hill, Associated Northern, and the Associated Mines.

The gold deposits of Boulder are virtually confined to a group of plutonic rocks which all bear an intimate genetic relation, and are now represented by amphibolites and epidiorites; the original rock, however, appears to have been a quartz-dolerite (Fig. 78). Of all the rocks of the Boulder igneous complex the quartz-dolerite and its bleached varieties is the most important, as it is within this and its derivatives that the principal gold-bearing deposits at present known occur. The quartz-dolerite and its derivatives may be regarded as the central rock mass of the field, representing a denuded elevated ridge from which sedimentary formations dip away on both flanks. The quartz-dolerite assumes greater importance than is entirely warranted by the actual area it covers on account of the gold deposits

associated with it. The output of gold from the lodes in this matrix since the inception of mining operations up to the end of 1918 amounts to 16,111,064.07 fine ozs. The quartz-dolerite is, as a rule, massive, though owing to the dynamical and concomitant chemical alteration which it has undergone, the rock occasionally assumes a more or less schistose phase.

Fig. 78.



Geological Map of Boulder.

The porphyrites, which are never quite fresh, weather and disintegrate more rapidly than the greenstones and form the rock underlying the low ground constituting the wide valley to the west of the Kalgoorlie-Boulder ridge. The porphyrites, which are intrusive into the greenstones, are typically developed in the deep shaft on the Kalgoorlie Power Company's property, on Water Reserve 3398 on the west side of the Kalgoorlie Racecourse, and in the vicinity of the Boulder Abattoirs Reserve 7405. The porphyrites as a whole are of little economic importance, as they have not been found to contain payable ore deposits.

The peridotite and its derivatives occupies a fairly large area along the western shores of Hannan's Lake to the south of Boulder and appears to be one of the latest intrusive masses on the field; in places it is transmuted, as the result of shearing, into talc schists. The peridotite and its derivatives have not so far proved to be of any economic importance, and, with the exception of their relationship to certain gold-bearing lodes at the north end of Kalgoorlie, it may as a whole be regarded as non-auriferous.

Dykes or tongues of pierite, apparently one of the youngest rocks of the field, have been met with in a bore put down on the Black Flag G.M.L. 5310E at Boulder. The rock may possibly be an off-shoot of that large mass of black augite-peridotite occurring to the south on the western shores of Hannan's Lake. The pierite resembles in many of its respects that occurring in the neighbourhood of St. Ives, and possibly bears some magmatic relationship to the olivine-gabbros which have been recorded from the Warburton Range near the South Australian Border.

The quartz and felspar-porphyries are found occurring as dykes which traverse the other rocks of the district. They vary in width and are often traceable for considerable distances. Their possible occurrence as off-shoots from the main mass of granite, which does not reach the surface at Boulder or Kalgoorlie, seems to indicate that their after-effects bear an intimate relationship to the mineralisation of the lodes of the district.

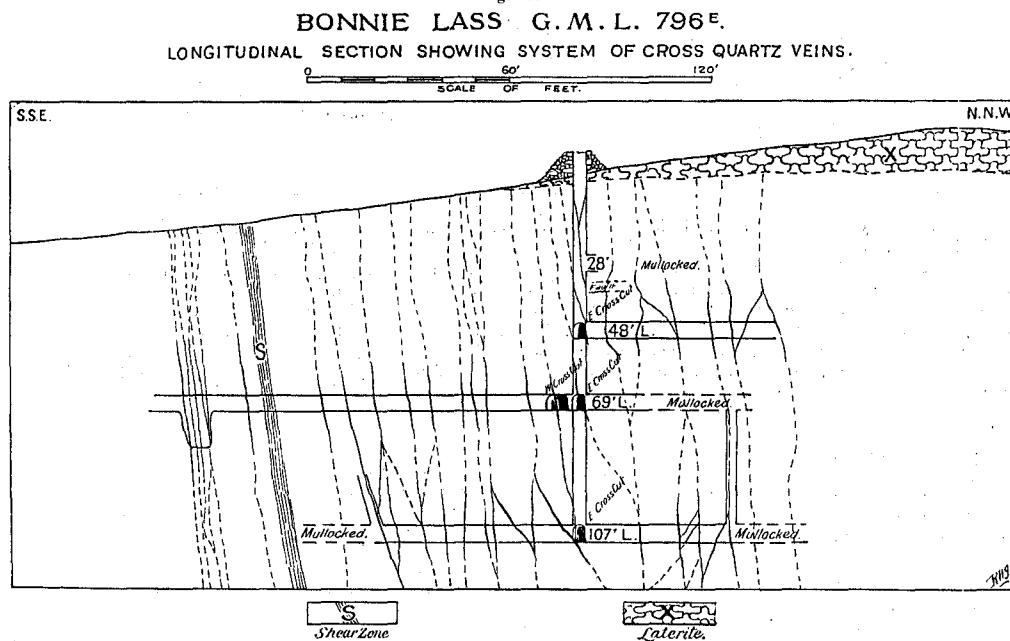
Many of the rocks of the goldfields appear to have been highly altered by dynamical causes together with a recrystallisation of their constituents. It is by no means

improbable that the mechanical movements to which the rocks have been subjected have been repeated more than once and that such structures as have been impressed upon them have been modified or even obliterated by those occurring at later periods. The dynamical action at times results in the production of a series of minor fractures which divide the rocks up into a system of approximately parallel plates or sheets. The normal form of zones of this class is approximately rectangular, one long attenuated lens succeeding another both on the surface and in depth. It is along zones of this type that the ore deposits occur. The principal effect of the concomitant chemical alteration has been the very extreme carbonating which has gone on over certain portions of the rocks, this being greatest where the shearing has been most pronounced. The quartz-dolerite, owing to the chemical alteration, has been converted into an indefinite mixture of carbonates of lime, iron and magnesia with some residual silicates and a good deal of secondary, and some original quartz. The carbonating is often of considerable extent and has proved to be fairly deep-seated, having been noticed at depths of over 2,000 feet below the surface.

The primary auriferous deposits of Boulder are divisible into two main groups, viz. (a) lode formations, *i.e.*, impregnations of zones of previously-existing rocks and confined largely to shear zones, characterised by much crushing and fracturing as well as the deposition of quartz along such fractures, and (b) quartz reefs, consisting of a granular matrix of quartz, accompanied by more or less pyrites or other sulphides, filling pre-existing fractures.

The lode formations of Boulder and Kalgoorlie consist of a series of almost vertical and relatively narrow schistose formations which have a general trend of from north 30 degrees west to north 50 degrees west. Many of these lenses are of great length and in some cases of considerable breadth; they consist of a series of overlapping lenticular masses or attenuated lenses arranged more or less *en echelon*. The longer axis of each lens generally makes a small angle with the average trend of the comb of the enclosing country. The shear-zones, constituting the lode formations, are merely bands of more or less completely metasomatised country rock, which are generally without any well-defined walls, some of which show much evidence of movement, such as polished and slickensided faces in addition to crushing and brecciation. The walls, however, do not limit the ore channels, for the latter at times pass almost insensibly into the surrounding country rock. As a rule the mineralisation is concentrated along certain zones which are in the main determined by the relative intensity of the shearing forces. In some cases there has been a marked silicification of the ore channel; but the sulphides, etc., occur in ore shoots which are limited to certain parts of the rock mass. The lodes are often traversed by a network of quartz veins which ramify in all directions (Fig. 79). Veins of this type rarely carry any appreciable gold values, though at times they contain considerable quantities of tourmaline. The gold-bearing mineralised shear zones are fairly numerous, and an extensive system of diamond drilling and cross-cutting in directions at right angles to their general strike is resorted

Fig. 79.



to in order to determine their position underground. The width of the ore bodies varies, but reaches a little over 100 feet in places, the whole carrying payable gold values. The lateral continuity of the ore lenses is at times interrupted by overthrust and normal faults of very variable downthrow.

Gold occurs in the Boulder lodes both in the native state and in combination with tellurium. The free gold is at times found as spongy or cellular masses of varying sizes and shapes; one piece alone, from the 200 feet level in the Great Boulder Mine, weighed

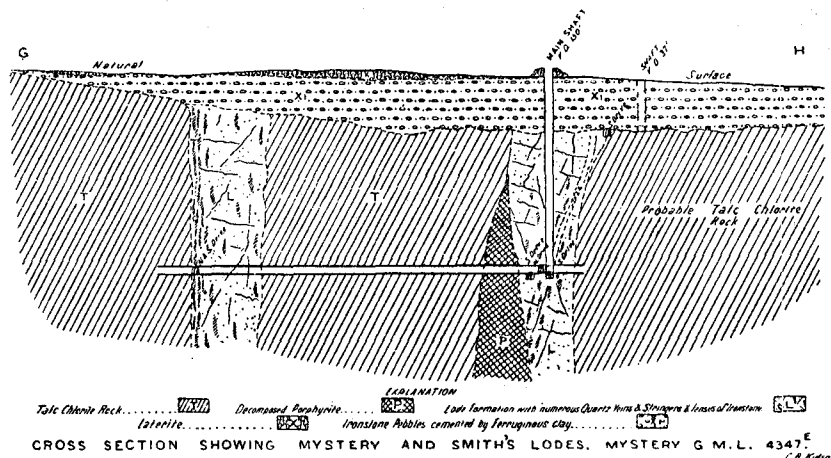
60 ozs. The free gold is occasionally coated with a dull clayey ferruginous material of such a yellow colour as to have resulted in its being named "mustard gold"; it is closely related in structure to sponge gold. The free gold presents many characters which point to its having been derived from the oxidation of the tellurium-bearing minerals. Tellurides constitute one of the most distinguishing characteristics of the ores of Boulder and consist of the following forms: calaverite, petzite, sylvanite, hessite, coloradoite and altaite. The tellurides occur in the ore channels as irregular masses

of variable size and often along the secondary joint planes which lie obliquely to the general trend of the foliation. The tellurides occur in somewhat irregular crystalline masses, and are not, as a rule, finely disseminated through the lodes as is the case with the iron-pyrites which is an important constituent in all the productive ore deposits, not only in the rich but also in the poor sections. Next to the gold and the tellurides, iron pyrites is the most important of the lode minerals; the proportion of pyrites seldom, however, exceeds 12 per cent. The principle accessory minerals in addition to the iron pyrites are marcasite, chalcopyrite, tennantite, asbolite, carbonates of iron, lime and magnesia, sulphates of lime and magnesia, iron ore (haematite, magnetite, ilmenite, etc.), tourmaline, chlorite, albite, rutile, etc.

The ultimate derivation of the gold in the Boulder group of lodes would appear to have resulted from the action of a later series of igneous intrusions than that in which the ore bodies are contained; and it may be that the introduction of the gold bears an intimate relationship to the action of the granite which makes such a prominent feature to the north of Kalgoorlie, but which has not reached the surface in the vicinity of Boulder; though it is probably represented by the acid dykes which traverse the field. The geology of the Western Australian Goldfields shows that the gold-bearing deposits are almost everywhere related to intrusive granitic and allied rocks which cover a wide expanse of territory.

The alluvial and residual gold-bearing deposits of Kalgoorlie cover a fairly extensive area. A very large proportion, however,

Fig 80



of the residual gold, mostly fine in grain and of high grade, obtained from the vicinity of Kalgoorlie and Boulder has been derived from the thin mantle of sand and clay occurring in close proximity to the outcrops of the known auriferous formations. The gold occurring in deposits of this character, owing to its angular and ragged nature, cannot have travelled very far from its parent source.

One of the most noteworthy patches of residual deposits, resulting from the decomposition of the country rock *in situ*, occurs at what is known as the Tea Gardens near the Little Wonder Lease 4346E. Over £8,000 worth of gold was obtained from a bed 3 or 4 feet thick of angular and subangular quartz and clay cemented by hydrated oxide of iron, lying beneath 35 feet of over-burden and resting upon talc-chlorite rock and decomposed porphyrite. The gold in all probability owed its origin to the decomposition of the upper portion of the Mystery and Smith's Lodes which lie on either side of the auriferous patch (Fig. 80.)

A certain amount of water action has taken place in the district, though owing to the arid nature of the climate there are few well-defined natural watercourses in which any considerable concentration of gold has taken place.

True alluvial deposits occur at the north end of Kalgoorlie; they, however, are confined to a few narrow watercourses the trend of which is defined by greenstone dykes.

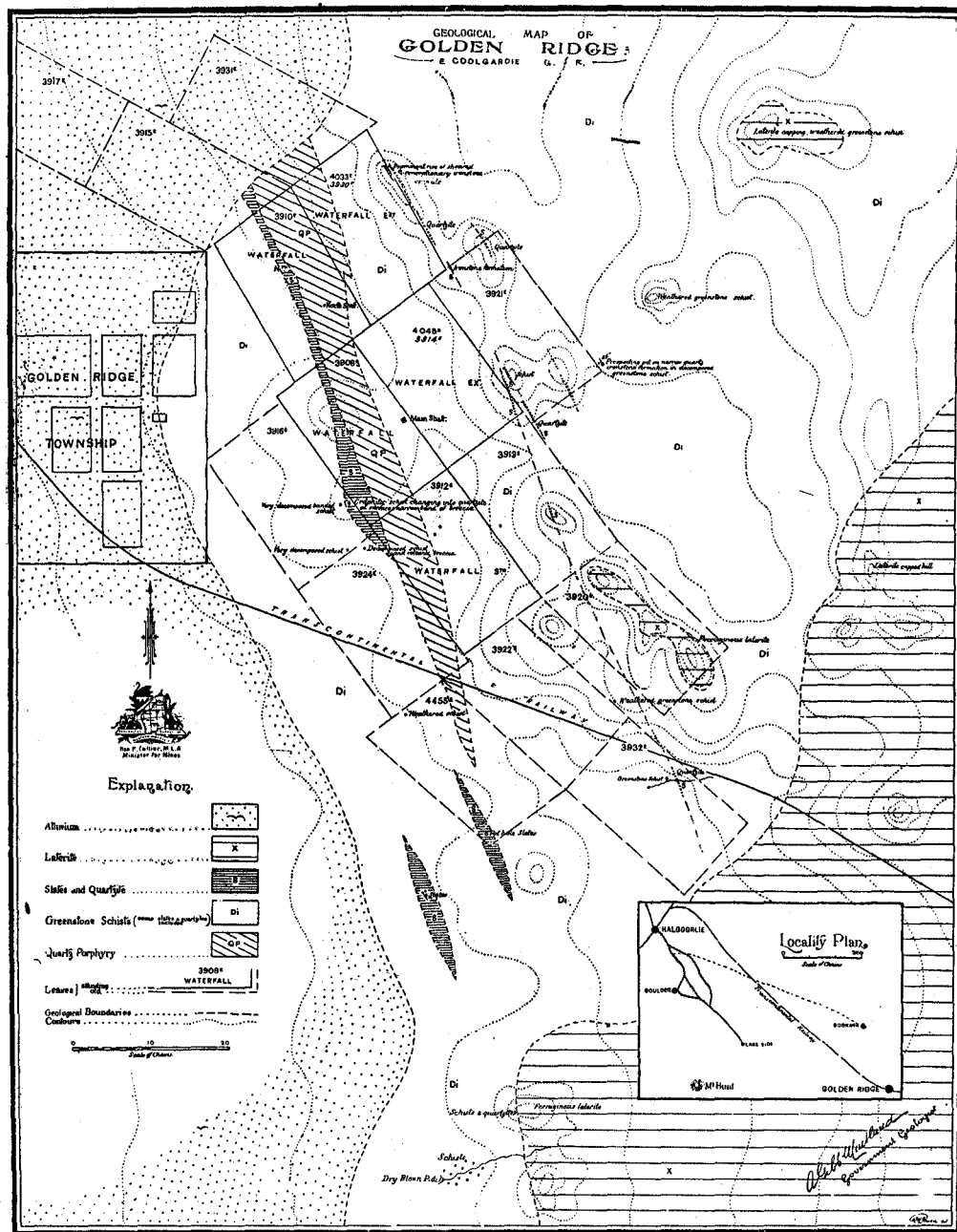
The south-western slope of the main central Kalgoorlie-Boulder Ridge is drained by one or two watercourses, of which the Adeline Lead and its tributary, the Town Lead, have proved to be the most important. The Adeline Lead takes its rise near the old Oratava Lease 1029E, from whence it trends generally southwestward to the Boulder North Extended No. 3 Lease 1285E, where it is joined by the Town Lead; from the junction the lead turns southeast and

loses itself in the flat country, upon which the townsite of Boulder is situated, and which gradually falls towards Hamman's Lake. The lead has been prospected for nearly the whole of its length; the wash consists of a layer of water-worn pebbles in a clayey matrix, which was met with at depths up to as much as 112 feet vertically below the present ground surface. The quantity of gold obtained from the Adeline Lead system cannot be ascertained.

Another type of ore deposit occurs in the Golden Ridge Auriferous Belt, which varies in width from two to three miles and which lies about six miles to the east of the Kalgoorlie-Boulder auriferous area. The belt is dominated by an irregular ridge of hills, which trends north-northwest, through Boorara and crosses the Bulong road about 7 miles from Kalgoorlie. The rocks of the belt consist of altered amphibolites, which have been highly carbonated and are comparable to and may be correlated with the calc-schists of Kalgoorlie. Some of the more dynamically altered rocks of the belt are represented by talc and chlorite schists. The basic rocks, some of which may be ancient lavas and ashes, are associated with a series of sedimentary beds represented by quartzites, quartz and ferruginous schists.

The Golden Ridge Belt has produced 169,781.51 ozs. of fine gold, of which 132,893.92 ozs. have been derived from the milling of 239,600.10 tons of ore obtained from the Golden Ridge Mine. There are in the Golden Ridge Mine two "lode formations" trending generally northwest with a cross lode running between them. The westerly lode as seen in the outcrop, is a banded iron-bearing jaspilite, whilst the eastern is represented by a soft whitish kaolin, traversed by several quartz veins and which is not characterised by any topographical feature. The rock series as developed at Golden Ridge consists in addition to the ubiquitous cover of comparatively recent superficial deposits, of slates, quartzites, greenstone schists and an

Fig. 81.



intrusive mass of quartz-porphyry. Economically, the quartz porphyry is the most important by reason of the fact that all the gold-bearing reefs in the Golden Ridge Mine are confined within its boundaries.

The quartz-porphyry is a fairly wide vertical dyke with an average strike of 340 degrees (Fig. 81), parallel to that of the dominant trend of the rocks of the Pre-Cambrian areas of the Interior Plateau, and has been traced across the surface for nearly a mile.

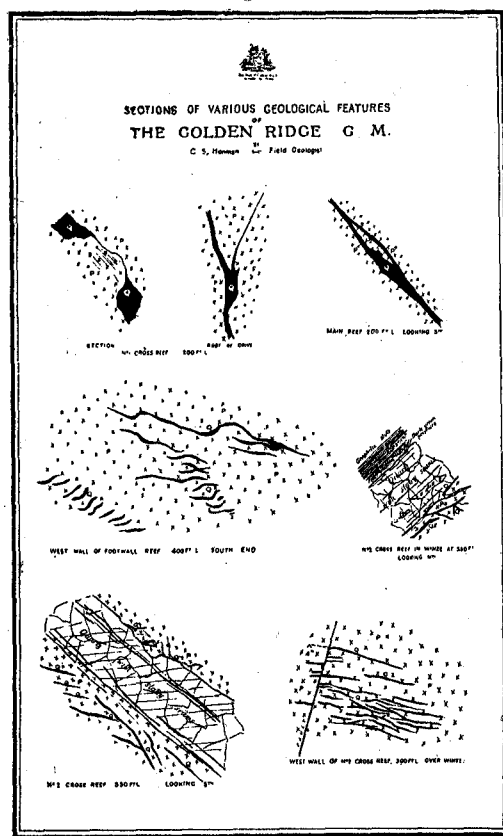
The porphyry is bounded on the east by talc-chlorite schist and on the west by quartzites and graphitic slates.

The porphyry has been oxidised to considerable depths, and there is a gradual change from oxidised to sulphide country, between 200 and 300 feet below the surface. The porphyry contains several brecciated zones. The rock has been considerably fractured and faulted, and the fissures resulting from this cause have formed the channels along which the mineral-bearing solutions circulated and deposited and its accessory constituents, which constitute the ore deposit. The quartz reefs in the porphyry trend in all directions and vary in thickness from mere threads up to as much as five feet; their boundaries are, as a rule, sharp and well defined. The mine has been worked down to the 500 feet level.

The different types of these quartz veins are shown in Fig. 82.

The reefs generally consist of milk-white drusy quartz, with crusts of calcite and somewhat irregular patches of gofena, as well as

Fig. 82.



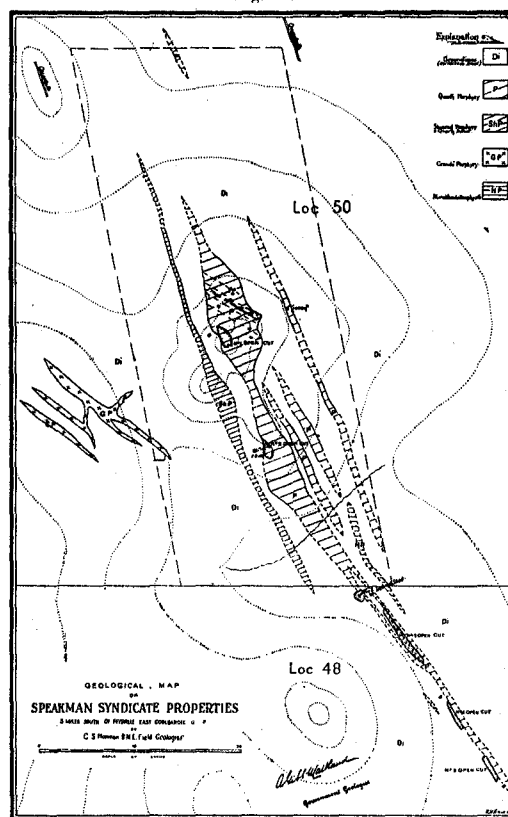
H. J. Pether, Government Lithographer, Perth, W. A.

zinc blende; iron pyrites generally occurs on the edges of the reef and also in marginal zones in the adjoining porphyry.

As a result of the circulation of meteoric waters within the belt of weathering, there has resulted a deposition of secondary minerals and a concentration of gold between 200 and 300 feet from the surface. The quartz-porphyry, which constitutes the ore-carrying matrix of the Golden Ridge, forms part of and in all probability an off-shoot from that mass of granite which underlies the surface of this portion of the district and which outcrops to the north of

Kalgoorlie and of which the acid dykes in that area form a part. The association of the gold deposits with the quartz-porphyry suggests that the mineralisation forms the end phase of the intrusion and differentiation of the granitic magma; the differentiation first giving rise to the porphyry, and later to its gold-bearing deposits.

Fig. 83.



H. J. Pether, Government Lithographer, Perth, W. A.

In the extreme southeastern portion of the district is a belt from 20 to 40 chains wide of serpentine and its derivatives, chlorite rock and talc-chlorite rock, which carries auriferous deposits. This belt of gold-bearing serpentine, which occurs at Mount Monger, about 40 miles from Kalgoorlie, is traceable more or less continuously northwest as far as Wombola. The gold occurs in the serpentine, scattered through the rock in directions which are not confined to any structural planes. One shoot of very rich ore, about 200 feet long, however, occurred in a shear-plane talc-chlorite-carbonate rock, which was also gold-bearing and had been followed to a depth of about 100 feet below the surface. Some of the serpentine ore-bodies contained large crystals of magnetite, and its pseudomorph, the faces of which at times were found to be covered with films of gold, which points to its introduction at a later period than that which gave rise to the metamorphism of original igneous rock. The serpentine is at times flanked by epidiorite and in certain parts is intersected by dykes and masses of intrusive granite and acid porphyry, which may bear some genetic relationship to the introduction of the gold.

The most westerly portion of the goldfield is made up of greenstones and their derivatives associated with a series of metamorphosed sedimentary rocks, intersected by dykes and masses of acidic

rocks—porphyries—some of which have been so crushed as to be virtually acidic schists; thence rocks are disposed in four more or less parallel belts, the general trend of which is northwest and southeast. These belts contain gold deposits of diverse types. Some of these porphyries, which contain seams of quartz and ironstone, have been worked for their gold contents and of which Speakman's Boulder (formerly Hampton Boulder Lease 15), Location 50, to the south of Peysville, may be regarded as a type (Fig. 83). The ore-body is a large lenticular mass of quartz-porphyry with some subordinate parallel bands trending generally 335 deg. occurring in greenstone schists. The gold-bearing quartz veins, which consist of iron-stained seams and quartz veinlets, are disposed in more or less parallel bands (Fig. 83). The country rock along the margin of the porphyry is often shattered and rubbly and contains veins of pyrites and of quartz distributed irregularly throughout the shattered rock, chiefly, however, on the western wall of the contact. The recoverable gold contents, however, from this deposit proved to be of a somewhat low grade.

Further to the south of Speakman's Boulder are some quartz veins occurring in granite which contain considerable quantities of gold, and which have been more or less perfunctorily worked. A fairly large quantity of residual gold has been obtained from the surface in the vicinity of these veins. Mining operations have been carried out on an acid dyke containing considerable quantities of coarse iron pyrites and intruding the greenstones. This acid dyke is situated at Red Hill on the western shores of Lake Lefroy; this occurrence is in all probability connected with that granite mass which intersects the basic rocks on Location 48. In another part of the area is a hard rockbound leader of quartz connected with an acid porphyry dyke in which considerable quantities of gold occurred. The occurrence is one of many in the area, and there seem reasons for believing these gold-bearing quartz veins to represent the ultra-acid portions of the porphyry.

The Bulong District forms the eastern portion of the East Coolgardie Goldfield; a large portion of the area, however, is occupied by a chain of dry lakes of which Lake Yindarlgooda, to the east of Bulong, is the largest.

The mining district of Bulong has produced, up to the end of 1918, 119,616.85 ozs. of fine gold, obtained from 153,990.07 tons of ore, in addition to 41,530.65 ozs. from alluvial and residual deposits, in which latter amount 14,985.65 ozs. of doliied and specimens are included. By far the largest quantity of gold has been obtained from the mining centre of Bulong itself, which alone has produced 108,093.51 ozs.; of this amount 61,895.42 ozs. are the product of the treatment of 62,707.05 tons of ore, raised from the Queen Margaret gold mine.

The Bulong district is geologically made up of a complex of basic and ultra-basic greenstones, many of which are talcose and highly carbonated, in addition to being highly foliated and in part graphitic. The basic rocks are associated with serpentines, the largest mass of which is 160 chains long and 18 chains wide. The serpentinised rock is traversed by a network of veins of dazzling white magnesite, which have been worked (*vide* Part II., Section II). There are in addition intrusive masses of porphyrite and porphyry. A very large area of country to the eastward of Bulong is occupied by an ancient series of highly inclined sedimentary rocks, quartzites, breccias, and conglomerates, some of which contain pebbles of porphyrite. The majority of these rocks, however, are in all probability conglomerates laid down under water, the component pebbles being derived from a land surface of porphyrite, though others may represent extensive masses of volcanic rocks.

The auriferous deposits of the Bulong neighbourhood are divisible geologically into three main groups: (a) veins, lodes, etc.; (b) residual; and (c) alluvial deposits.

There are several lines of reef of considerable importance at Bulong; these trend generally more or less north and south, but differ a good deal in both the direction and amount of underlay.

Some of the lodes, *e.g.*, The Great Eastern, consisted of white kaolinic matter, carrying very fine gold; others are made up of a series of iron-stained quartz veins, contained in a clayey formation, which often had smooth slickensided walls.

The residual deposits of Bulong, which result from the disintegration of rock *in situ*, often contain quantities of quartz fragments derived from gold-bearing veins of the type occurring in the district. A good deal of dry-blowing has been carried out on the superficial deposits occurring on the north side of the road between Bulong and Kalgoorlie, though none of the workings reached any considerable depth. Several slugs of gold up to 100 ozs. in weight have been obtained from a patch of residual deposits from 6 to 12 inches thick, covering an area of about 18 acres, and lying about six miles northeast of Bulong. The richest specimens were found lying round the roots of an old tree occurring on the edge of the flat covered by the deposits. Several prospecting shafts have been put down and a good deal of work done with the view to discovering the parent source of the gold with, however, but little success. The residual deposits were found resting upon ferruginous laterite, the under-surface of which passes gradually into the zone of decomposition of the country rock, which is a fine-grained greenstone, associated with a quartz-carbonate rock. The greenstone and its derivatives carry a series of more or less horizontal leaders of quartz, some of which contain tourmaline. These quartzose leaders are associated with vertical seams containing pseudomorphs of ironstone after pyrites, which are stated to carry gold in quantities varying from a trace up to 3 dwts. per ton. The vertical seams are associated with a secondary crystallisation of pyrites in the greenstone. It is possible that the residual gold may have owed its origin to the disintegration of deposits of the type of these vertical ferruginous seams.

The alluvial deposits of Bulong have been worked more or less vigorously, and up to the end of the year 1900 the official figures show that they have yielded 17,476 ozs. of gold; there are good grounds for believing that these returns are somewhat less than the actual output. The auriferous alluvial deposits have been met with at a depth of over 100 feet from the surface. There are three principal alluvial leads running in a general southerly direction and with a gradual dip of the bottom to the southward. The westernmost is known as the Margaret Lead, and runs to the west of the Queen Margaret Mine, then turning to the southeast, and unites with the Great Oversight lead to the west of the southern boundary of the Rifle Range Reserve. The Great Oversight Lead heads close to the town of Bulong and runs generally in a southsouth-westerly direction. The middle branch, known as the Slug Hill Lead, begins in G.M.L. 681Y and runs roughly parallel to the Margaret Lead, joining the Great Oversight about a quarter of a mile southwest from G.M.L. 643Y. The ground at the junction of the Slug Hill and Great Oversight Leads is from 90 to 100 feet deep, and at the junction of the Margaret with the Oversight it is about 140 feet deep. The leads have been worked out pretty completely, the gutters being somewhat narrow, up to 15 feet in width. In the Queen Margaret Consols No. 1 Lease, however, an auriferous drift 18 inches in thickness was met with at a depth of 110 feet in a gutter, which is stated to have attained a width of 300 feet. Forty tons of the wash dirt on being treated yielded gold at the rate of 7 dwts. per ton. A shaft on the Oversight Lead was put down to a vertical depth of 90 feet on G.M.L. 643Y, and showed a quartzose gravel resting directly upon a "bottom" of practically vertical decomposed silky schists. A good deal of the wash in the leads is fairly well water-worn, but has a good deal of clayey matter associated with it, whilst some of it contains very hard bands of dolomitic travertine. The alluvium lying more immediately on the wash filling the gutters is mostly sandy clay and ironstone not unlike that which covers the deep leads of Kanowna, to which reference is made on a later page (78).

The Mining centre of Karnilbinia or Randall's lies about 33 miles to the southeast of Bulong and not far from the western

boundary of the Mesozoic and more recent rocks which underlie the Nullabor Plains. This centre, which has produced 11,212.51 ozs. of gold, has not yet been geologically examined, but from such observations as have been made, the country rock of the field and the matrix of the known ore deposits is porphyrite which presents many points of resemblance to that which constitutes the western portion of Kalgoorlie and to which reference has already been made. The Karnilbinia porphyrite is intersected by many quartz veins and the more important lines of lode which present a distinct lamellar structure. The lodes contain a good deal of magnetite and chlorite. The ore bodies below the zone of oxidation contain a large quantity of arsenical pyrites, together with some iron pyrites and small amounts of chalcopyrite. The lodes occur in three groups: the most easterly is designated the Santa Claus group and is the one in which the most important of the mines in the district, the Santa Claus, is situated. The ore-body in the Santa Claus is a lode formation which varies in width from 40 to 60 feet, trends generally north 20 degrees west, and has an underlay to the east at an angle of 14 degrees. The formation is really more or less shattered porphyrite, which has been altered to lode matter by the circulation of mineral-bearing solutions through it; in one part of the lode there is a quartz vein of about six feet in thickness. There are, in addition, several other lines of lode running northnorthwest, whilst about two miles to the southwest there is another group, the Flagship, trending northnorthwest. The ore channels of the Flagship and the Santa Claus are about two miles in length. Another group of lodes, known as the Surprise, trends generally northnorthwest and occurs in a channel which is over two miles in length.

NORTH-EAST COOLGARDIE GOLDFIELD.

The North-East Coolgardie Goldfield was officially declared by proclamation in the *Government Gazette* in the early part of the year 1896; its boundaries, however, were amended in 1908 so as to embrace an area of 20,604 square miles.

The gold yield of the North-East Coolgardie Goldfield up to the end of the year 1918 has been 713,767.79 fine ozs., of which 581,969.20 ozs. have been obtained from the milling of 930,644.64 tons of ore, and 131,798.59 ozs. of alluvial, dollied and specimen gold. The yield of the field has been derived from ten gold-mining centres, details relating to the production of which are given in the table.

Synoptical Table showing the Gold Yield of the North-East Coolgardie Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dollied and Specimens.	Ore treated. Tons.	Gold therefrom.	Total Gold Yield.
KANOWNA—	Fine ozs.	(2,240 lbs.)	Fine ozs.	Fine ozs.
Black Swan	...	160.00	141.76	141.76
Gambier	309.37	13,587.75	7,408.72	7,718.09
Gindalbie	694.76	44,622.83	40,643.12	41,337.88
Gordon	342.90	42,407.80	12,083.74	12,426.64
Kanowna	5,830.98	658,639.45	356,278.99	362,109.97
Mulgarric	1,229.92	6,689.26	4,067.64	5,297.56
Six Mile	1,627.07	676.50	852.51	2,479.58
District generally...	25.01	1,663.88	37,952.41	37,977.42
Cement Deposits	105,103.52	157,104.16	110,164.61	215,268.13
	115,103.53*	925,551.63	569,593.50	684,737.03
KURNALPI—				
Jubilee	164.00	1,867.25	1,437.42	1,601.42
Kurnalpi	3,039.15	2,947.11	2,634.31	5,673.46
Mulgabbie	2,046.08	222.15	8,110.82	10,156.90
District generally...	11,385.83	56.50	193.15	11,578.98
	16,635.06†	5,093.01	12,375.70	29,010.76
Grand Total	131,798.59	930,644.64	581,969.20	713,767.79

*Includes 10,786.14 ozs. dollied and specimens.

†Includes 4,645.81 ozs. dollied and specimens.

The greater portion of the North-East Coolgardie Goldfield is made up of granite and allied rocks, which intersect the pre-existing sediments and associated basic rocks. The extreme eastern portion of the field is occupied by the Miocene, Tertiary and Upper Mesozoic beds of the Nullabor Plains (Premier Downs). Outliers of this formation occur along the valley of the Ponton River (Goddard's Creek), which forms the lower reaches of the ancient river channel constituted by the Lake Renside group of Salt Lakes. The Ponton River is, in part of its course, a deep channel with well-defined banks, which runs very strongly with salt water after heavy rains.

About nine miles to the north of the 95 miles post on the Trans-Australian Railway, and on the right bank of the river, the escarpment of a series of low hills exposes horizontal strata of sandstone and claystone with boulder beds made up of rounded and polished pebbles, which are in places cemented together with secondary silica. The Mesozoic and more recent rocks covered a very much wider area than they do at present, for a considerable amount of denudation has gone on along the margin of the ancient gulf in which these beds were deposited. The Ponton River empties itself into a large flat at a point about 40 miles from where it is crossed by the railway, which represents the uplifted estuary into which the river flowed; this ancient estuary is 120 miles due north of the coast line along the Great Australian Bight. The occurrence of these beds limits the area occupied by the gold and mineral-bearing formations to the western portion of the goldfield.

The North-East Coolgardie Goldfield has, for the purpose of facilitating administration, been divided into two districts: Kanowna (White Feather) and Kurnalpi.

Kanowna lies about 12 miles from Kalgoorlie and is the terminus of the railway line running eastward from the latter city. Kanowna has been a large producer of gold, there having been obtained from it, up to the close of the year 1918 no less than 577,378.10 ozs. of fine gold. The town of Kanowna is situated on some low hills which apparently form the northern end of the high country seen at Ballagundi further to the south. The main ridge trends in a general southeasterly direction from Red Hill to near the Lily Australis Mine, and ultimately unites with a mass of low hills situated to the south of the town. The fall in the surface of the country is very slight; from the main ridge of high country the ground slopes away gradually and spreads out into extensive flats several miles in length, some of which are occupied by chains of salt or dry lakes. The country in the more immediate vicinity of Kanowna is made up of rocks of at least three widely different geological ages, viz.:—

1. A thick series of sedimentary rocks in intimate association with which are some metamorphic conglomerates, kaolinised slates and mica phyllites. These sedimentary rocks, believed to be of Pre-Cambrian age, are exposed at the "break-away" to the north-east from the Moonlight lead, at the quarries for building-stone near the racecourse, in the country to the east of the Government dam, and at the Six Mile.

2. These sedimentary rocks have been invaded by epidiorites and amphibolites, and are associated with a rock the derivative of a serpentine rich in olivine as well as a series of quartz-porphry dykes which seem to have some genetic relationship to the gold-bearing quartz reefs of the district.

3. Tertiary (?) and Recent alluvial deposits of the various deep leads and superficial workings for alluvial gold.

One of the most important features in the geology of Kanowna is the boss of intrusive acid porphyry occurring at Red Hill; from this mass several dykes emanate, and are met with in certain portions of the field. The boss is made up of a rock composed essentially of quartz, sericitised, orthoclase felspar, and muscovite, which is allied to the aplites rather than the quartz-porphyrries. This acid rock has been noted for the very rich auriferous quartz veins found in it at Red Hill. The occurrence of this intrusive mass of acid rock may have an important bearing on, and is possibly genetically connected with the introduction of the gold in the reefs. The intrusive

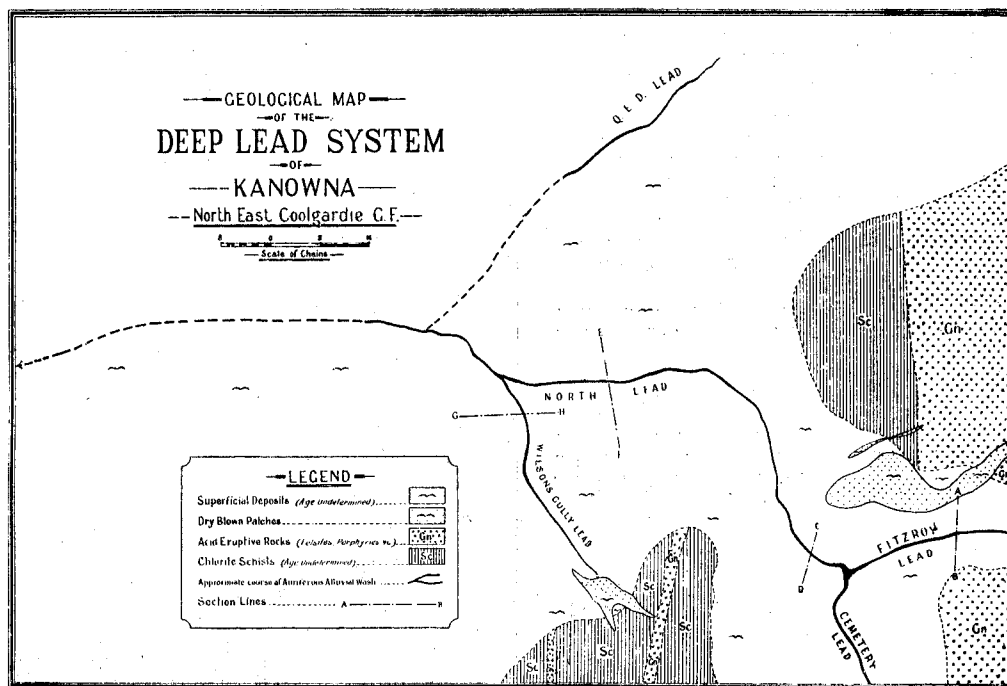
boss of Red Hill is associated with and almost entirely surrounded by a mass of breccia or coarse tuff, which may possibly represent the pyroclastic material filling the throat of an eruptive vent of which the acid rock and satellitic dykes form the denuded relics. A significant feature is the extensive alunition which has gone on in an area surrounding the Red Hill mass. The alunite is found occurring in horizontal or gently inclined veins, varying in thickness from mere threads up to two feet in a matrix of kaolinised slates or mica phyllites. The mineral, of which over 500 tons have been raised for the potash salts it contains, is a soft white material which according to the investigations of Dr. E. S. Simpson varies from true alunite with 9.32 per cent. of potash, and 2.14 of soda, to a natro-alunite containing 5.42 per cent. of potash and of soda 4.07 parts per hundred. Assays failed to detect gold in any of the

Kanowna alunites. The minerals associated with the alunite are finely divided quartz and kaolin, muscovite mica, and a little iron hydrate. The alunite veins may represent off-shoots from the Red Hill intrusive mass. It has been suggested that alunite owes its origin to the action of (a) sulphurous fumarolic vapours upon felspathic rocks, or (b) percolating surface waters charged with sulphuric acid by the oxidation of pyrites upon rocks containing a fairly large proportion of felspar.

Many of the gold-bearing quartz veins of Kanowna contain iron pyrites and galena, whilst some of the country rocks carry varying amounts of pyrites also.

The gold from the Kanowna district has been derived from three principal sources, viz: (a) quartz reefs, etc., (b) alluvial and detrital deposits, and (c) secondary depositions of gold in the deep

Fig. 84.



leads, etc., and in the underlying bed rock, as impregnated gold deposits.

The quartz reefs and veins of Kanowna constitute the most abundant of the primary ore deposits and form the main gold-bearing belts of the district. There are several long and strong lines of reef, the principal ones being those which pass through the Lily Australis, White Feather Main Reef and Reward Mines, the Golden Crown Reefs, the Ballarat and Sunbeam Reefs, and the Robinson Group. Most of the principal reefs of Kanowna have an underlay to the eastward at angles varying from 40 to 70 degrees. The veinstone is ordinarily white and sometimes glassy quartz with occasional fragments of shattered country rock derived from the walls; at times the quartz is found adhering tightly to the wall rock. The quartz as a rule exhibits few signs of mineralisation, though it does at times contain small quantities of iron pyrites and galena, the latter being held to be indicative of probable good gold values. The reefs have been worked to various depths, the greatest being

that in the Lily Australis Mine where the vein has been followed down to about 1,000 feet below the surface.

By far the most valuable deposit hitherto discovered in the district is that group of quartz veins collectively known as the Kanowna Main Reef, from which 200,700.39 ozs. of gold, the result of the milling of 390,681.08 tons of ore, were won up to the end of 1918. The two chief mines on this deposit are the North White Feather and the White Feather Main Reef. The Kanowna Main Reef has in places a fairly prominent outcrop, which in one locality near the White Feather Reward Shaft is about six feet in thickness; the length of the reef is over a mile and a half. The thickness of the reef, as disclosed in the mine workings, varies from a mere thread of quartz up to as much as 8 or 10 feet; it has a few subsidiary reefs branching off it and trending in different directions. The main reef is inclined at a high angle to the eastward. The ore-body occurs in the steeply inclined conglomerates to the east of the Red Hill porphyry and is everywhere closely associated with dykes

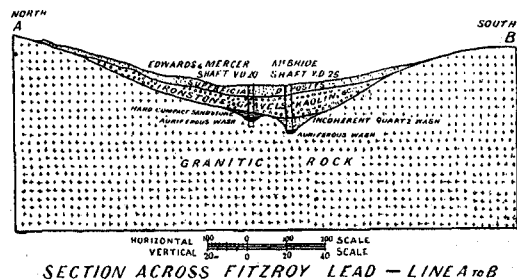
of porphyry; in no case was it seen to intersect the acid rocks, though in some places the walls of the reef are made up of porphyry. The reef has been proved by mining operations to extend to 1,000 feet below the surface.

Another important group of auriferous quartz deposits are the flat veins and leaders traversing the porphyry belts and dykes of which the principal occur in the Red Hill boss, where the veins have been proved to carry a high gold content. A remarkable group of very flat quartz leaders occurs in the Gentle Polly Mine at Red Hill; these have a regional though slight underlay to the northeast, and there is a succession of leaders, one below the other. The highest gold values are recorded to occur in those localities where the veins assume an arch or dome-like form, and are joined by smaller veins coming in from the roof. The quartz carries a little iron pyrites together with some galena.

There are, in addition to the quartz reefs and veins, a series of gold-bearing deposits which are merely highly mineralised and altered country rock; these constitute the lode formations of the district. These lode formations consist of amphibolites and their alteration products; they occur in a belt which is fractured in many directions, the two principal and most prominent, the Last Chance and the Golden Crown, having an average strike of east and west, with an underlay to the south at a high angle. The Last Chance deposit is a highly sheared and metasomatised amphibolite into which silica, iron pyrites and gold have been introduced. The ore-body averages about six feet in thickness and is traversed by small quartz veins, lying parallel to the trend and underlay of the lode. There are several flat quartz veins from one to four inches in thickness occurring in the lode on the hanging-wall side. The lode, which is strong and well-defined, has been followed to a depth of over 500 feet below the surface.

Considerable interest and importance attaches to the alluvial deposits, the most prominent of which is The North Lead with its branches, Wilson's Lead, Cemetery Lead, Fitzroy Lead, and the Moonlight Lead (Fig. 84). The North Lead lies in an old watercourse carved out of the older rocks, which are very much decomposed, and has been proved to be not merely a single isolated run of auriferous gravel, but part of a series of old stream deposits which took their rise in the comparatively elevated ground to the east, and which flowed in a general westerly direction. The North Lead trends generally in a northerly direction as far as old Gold

Fig. 85.



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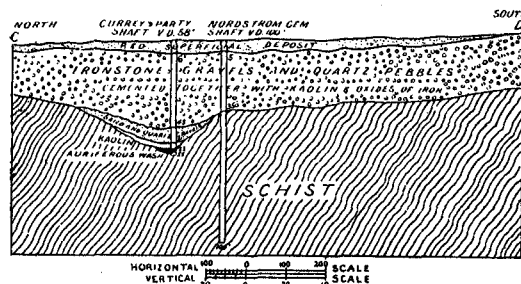
Mining Lease 923, Kanowna Lode Amalgamated, when its course is suddenly deflected to the east; it is joined near the "Birthday Gift" by the Wilson's Gully Lead, which enters it from the south. Some distance below the junction the North Lead loses itself in an extensive flat and efforts have been made by a series of bores put down across its course with the view to locating its extension at about ten chains below the junction: bottom was reached at 211 feet from the surface.

The connection with the Q.E.D. Lease on the north, although it trends in such a direction as to fall into the North Lead, has not yet been definitely proved; everything points to such a connection, though it may be that that lead has been lost by denudation.

The width of the old stream varies from 2 to 80 feet, having an average of about 15 feet. The thickness of the deposits in the old channel varies from a few inches up to 90 feet, and the fall of the lead is about at the rate of 40 feet to the mile.

The deposits filling the old watercourse naturally vary somewhat in different portions; they consist first of a variable thickness of surface loam, etc., succeeded by ironstone gravels, partially cemented in places by kaolin and oxide of iron into solid rock; beneath this lies a bed or beds of practically pure kaolin, "pug," and a varying thickness of pebbly quartz-wash (Figs. 85, 86, 87, and 88). The wash contains rounded or sub-angular pebbles of quartz,

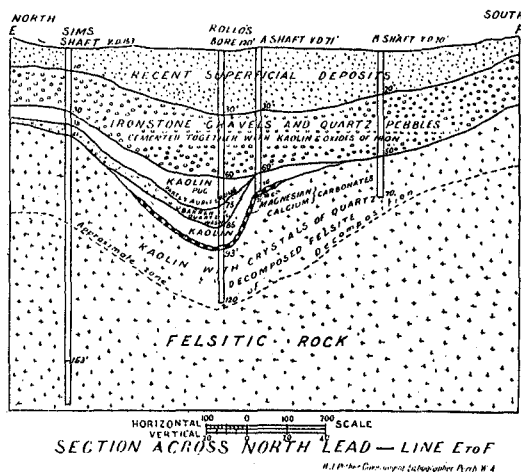
Fig. 86.



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which in the upper portion of the deposit is often associated with kaolin and sand. This wash is cemented by secondary silica into a hard compact rock which, in hand specimens, might easily be mistaken for quartzite. So far as mining operations have been carried, it appears that the whole of

Fig. 87.



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the detrital deposits are not gold-bearing. Most of the alluvial gold has been won from the pebbly quartz wash, although the overlying kaolin ("pug") and ironstone gravels have also yielded a certain quantity. The "pug" consists of a thick deposit of clay of a very

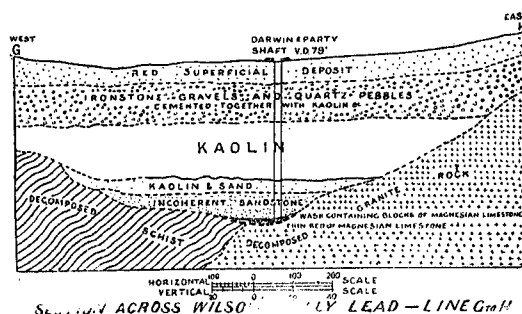
tenaceous nature, of which the main constituent is kaolin. An analysis of a typical sample of this material made in the Geological Survey Laboratory showed its composition to be:—

Silica, SiO_2	44.16
Titanium Dioxide, TiO_2	3.74
Combined Water, H_2O	11.80
Soda, Na_2O	1.05
Potash, K_2O} ... ..	.33
Magnesia, MgO} ... ..	.70
Lime, CaO} ... ..	.53
Manganese Protoxide, MnO	Nil
Iron Peroxide, Fe_2O_3	4.44
Alumina, Al_2O_3	30.38
Hygroscopic Water, H_2O	3.81
100.94	

Gold—1oz. 19dwts. per ton.

Difficulties have been met with in the treatment of the "pug" for the extraction of the gold contents owing to—(a) the extremely fine state of division of the gold which floats on water and cannot be caught in a battery, (b) the very fine-grained and sticky or puggy

Fig. 88.



nature of the material which prevents it crushing freely in a battery in the ordinary wet way, and (c) when attempts have been made at cyanidation it settles into a solid sticky mass through which the solutions cannot percolate.

The ultimate derivation of the gold in the North Lead is from the quartz veins and lodes by which the crystalline rocks are traversed (and upon which the wash directly reposes in places), for the gold is not exclusively in the form of grains, scales, etc., but is found occurring in the quartz pebbles themselves.

In addition to what may be called detrital gold there is another massive, arborescent, or coarsely crystalline form, which occurs filling certain irregular fissures and vugs and covering cleavage planes or shrinkage cracks, so as to present the appearance of painted surfaces. The mode of occurrence, associations, and character of this gold all point to a secondary origin. It is of importance to note that this, which may be called secondary gold, has been deposited from solution not only in the alluvium and other superficial deposits but also in the zone of decomposition of the bed rock. These secondary forms, which result in the secondary enrichment of many auriferous deposits, are a common feature in the mineral fields of the State.

Of the age of the Kanowna Deep Lead system there is no evidence available at the present time. Owing to the fact that, at a date subsequent to its formation, a sufficient length of time has elapsed to allow of the lead being sealed up by accumulations of superficial deposits (some of which have been consolidated into solid rock) may point to a considerable geological antiquity.

There are no data available by which the average fineness of the gold from the leads can be obtained.

That other leads probably exist is obvious from the geological structure of the district, but owing to the completeness with which the old land surface has been buried beneath more recent accumulations, any other channels can only be tapped by a judicious system of boring, though they are hardly likely even then to be discovered without many failures.

The type of what has been designated *Impregnated Gold Deposits* is very extensive at Kanowna. The deposits result from the secondary deposition of gold from solutions percolating downwards from the overlying alluvial and detrital ground, hence any gold values of this nature cannot be expected to continue much below the zone of oxidation, and will prove to be somewhat erratic in occurrence as well as of low grade when treated in bulk. Secondary gold of this nature is found not only in the alluvium and other residual deposits but also in the belt of weathering in the rocks beneath. Ores of cobalt (asbolite) occur abundantly in the bedded kaolin of the deep leads as well as in the underlying much-weathered schists, and is frequently studded with minute crystals of gold.

The district of which *Kurnalpi* forms the centre constitutes the easternmost division of the North-East Coolgardie Goldfield; it is made up geologically of a variety of greenstones allied to the amphibolites, extending over a wide belt of country, and a series of intrusive granitic rocks which cover by far the largest area of country in the division.

Kurnalpi occurs in a belt of country made up of steep-sided hills and ridges which are separated by gullies and alluvial flats. The drainage from the high country is carried south into the long narrow clay pan, Lake Lapage. The neighbourhood of Kurnalpi has long been noted for its extensive alluvial deposits as well as the size of the nuggets obtained from them. The following are the most important of the nuggets with their gross weights and the names of the finders:

Name of Discoverer.	Year of Discovery.	Weight of Nugget.
W. Eddy	1900	197 ozs.
J. Simmonds	1899	108 ozs.
Messrs. Hogan and O'Connor	1901	51 ozs.
Messrs. Simmonds and Hart	1898	109.5 ozs.
Messrs. Gessner and Huffa	1912	222.75 ozs.
		Weight of gold 215.20 ozs. Value £782 3s. 3d. This slug (Fig. 89) is believed to be contact gold, and not of detrital origin.

There are a large number of quartz reefs at Kurnalpi, upon which a considerable amount of mining has been done at different times.

The greenstones which form the bulk of the rocks of Kurnalpi are economically the most important of all the rocks; they have undergone a considerable amount of shearing, and have been converted into greenstone schists. Many of the quartz reefs occur along the planes of foliation (? shear zones), to the strike and underlay of which they generally conform. The greenstones have been invaded by quartz-porphry, of which that forming Billy Billy Hill may be regarded as the type; between the contact of the two is a thin quartz vein, known as the Maori Reef, upon which a little work has been done. All the reefs of Kurnalpi are, with this exception, in greenstone; they occur as fairly thick, though comparatively small lenses.

Points of considerable interest are the very rich patches of gold in association with thin veins of haematite pseudomorphs after iron pyrites. Veins of quartz, varying from half an inch up to three inches in thickness, are intersected by the haematite (the indicator), and at the junction rich patches of gold have been met with. One of the most important of these occurred in a claim on the south-eastern side of Cooke's Hill, about a mile east-southeast of Kurnalpi, and from the contact a patch of about 720 ounces of gold was met

with. The quartz vein abutted against the haematite indicator and ran parallel to it for about 15 to 20 inches; the rich patch was made up of thin flat pieces of gold, a little over two inches in length.

Another rich patch of gold somewhat similar in its mode of occurrence to that previously described, was met with in Messrs. Gessner and Huffa's lease 337K, about two miles north of the township.

A patch containing over 400 ozs. was met with at a depth of about three feet from the surface, associated with ironstone veins and quartz leaders. In the rich patch a large slug of gold, 15 inches long (Fig. 89), weighing 215 ozs., was found. The country rock consisted of somewhat altered greenstone. A slug of gold weighing 140 ozs. was obtained from the surface at a locality known as the

Fig. 89.

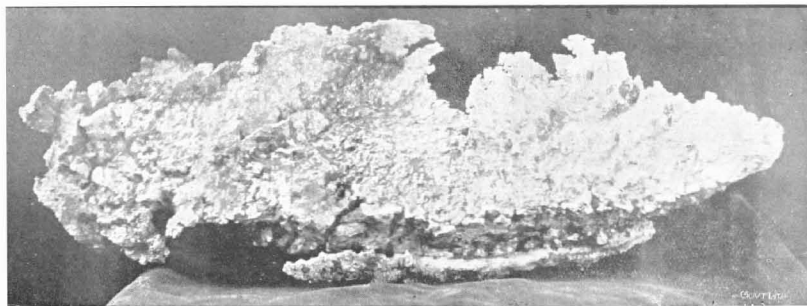


Photo.: R. H. Irwin.

Neg. 906.

Large Slug of Gold found on Gressner & Huffa's Lease, G.M.L. 337K, Kurnalpi.

Weight, 215ozs.; value, £782.

Six-Mile, situated about four and a half miles north-west of Kurnalpi. The underlying country rock consists of decomposed sheared greenstone, carrying quartz leaders and ironstone veins, from the contact of which the gold in all probability was derived, as from its character the slug referred to could not have travelled very far.

The extensive gold-bearing alluvial and residual deposits of Kurnalpi imply the existence of other auriferous deposits than those already opened up.

The alluvial deposits in the main consist, in places, in addition to the ubiquitous red soil, of beds of angular quartz, up to two feet in thickness, which could not have travelled very far from their parent source and were in all probability collected from some adjacent reef.

Two deep leads exist at Kurnalpi and have been worked. One of them has been traced by means of a series of shafts for over a quarter of a mile. The bottom of the lead at its deepest part was 40 feet from the surface, and it shallowed to about 20 feet towards its head. The full extent of the lead was not determined, but the gutter is said to have been of considerable width. Slugs of gold up to 30 ounces or more, associated with angular pieces of quartz and ironstone, are reported to have been obtained from the lead.

The Kurnalpi district, including Mulgabbie, Jubilee, and other smaller outlying centres, has produced 16,635 ounces of fine gold from alluvial deposits, but there are reasons for believing that a good deal of the gold from this source was never officially reported.

Some telluride minerals, chiefly petzite, have been discovered at Mulgabbie, an outlying mining centre about 35 miles to the north of Kurnalpi. According to the official returns it appears that up to the end of 1918 Mulgabbie has produced 10,156.90 ounces of fine gold. The output of gold from this centre has been derived from two distinct sources: (a) alluvial and residual deposits, and (b) small rich veins or leaders. The quantity of alluvial gold has been recorded as 2,046 ounces, whilst that obtained from the veins and leaders is 8,110.82 ounces. The discovery of payable gold at Mulgabbie was made in the year 1897 by Messrs. Reid, Mackay, and Johnson. The prominent feature in the neighbourhood is Mulgabbie Hill, which rises to a height of about 200 feet above the general level of the surrounding country, and from it there emanate several

prominent ridges with a dominant northwesterly strike, between which lie the alluvial flats. These flats carry the drainage more or less directly to the chain of salt or dry lakes lying to the south and east.

The formation of chief economic importance is that system of basic rocks which extend over a large area, and in addition are concealed in many places by a considerable development of lateritic deposits. These basic rocks have been rendered more or less schistose, the direction of the foliation planes varying from 20 to 40 degrees with a high westerly underlay. The greenstones are invaded by porphyry, of which the most important development occurs at Mulgabbie Hill, forming an elongated mass adjacent to the ore-bearing belt on its western flank; this in all probability forms an off-shoot from the main granite mass which covers such an extensive area in the district. The chief development of the rich and highly inclined quartz veins and leaders for which Mulgabbie has been noted lies on the western side of the alluvial flats, and to the denudation of the country rock which constitutes the matrix, the detrital gold obtained has been derived. Most of this gold has been found at a depth of from 10 to 14 feet on the surface of underlying decomposed basic rock. A considerable amount of gold has been obtained by dollying rich specimens from the outcrops of these veins.

A rich patch of telluride ore, from which about 60 ounces of gold was obtained, was made on Gold Mining Lease 200K in the year 1903. The ore was met with at a depth of 90 feet below the surface, along the contact between a narrow belt of hard compact pyritous chlorite schist ("the indicator") forming a persistent shear zone. In the acute angle formed by the contact (Fig. 90) a bunch of telluride ore of about one and a-half tons in weight was met with, and from it 60 ounces of gold was obtained. Free gold was visible in the vein in addition to the black metallic telluride, petzite, and the light-coloured mineral, calaverite, a telluride containing 40 per cent. of gold.

COOLGARDIE GOLDFIELD.

The Coolgardie Goldfield, which was officially created by proclamation in the *Government Gazette* during the year 1894, included within its limits the country forming the present Coolgardie, East Coolgardie, Broad Arrow, North-East Coolgardie, and North Cool-

gardie Goldfields, together with portions of the Mount Margaret field. The original boundaries of the Coolgardie Goldfield were amended in 1907 so as to embrace an area of 11,702 square miles. The goldfield is divided, for purposes of facilitating administration, into the districts of Coolgardie and Kunanalling, the former covering an area of 9,384 square miles as against 2,318 square miles possessed by Kunanalling.

The history of the Coolgardie Goldfield is for all practical purposes that of gold-mining in Western Australia. Its real history began in June, 1892, with the discovery by Messrs. Arthur Bayley and John Ford of a half-ounce gold nugget in the vicinity of what is now the town of Coolgardie. This was followed by the finding of about 200 ounces of detrital gold, and a little later by the discovery of a quartz reef, from the cap of which Messrs. Bayley and Ford obtained over £2,000 worth of gold in the evening. The deposit was the famous Bayley's reef, from which 100,407.43 ounces of fine gold has been produced. Within three weeks of the discovery of this reef, 3,000 ounces of gold were obtained from the alluvial workings adjoining. It was these gold discoveries that induced prospectors to go out, and ultimately led to the opening up of the other fields to the south of the Gascoyne.

The Coolgardie Goldfield has produced up to the end of the year 1918, 1,175,958.59 ounces of fine gold, which has been obtained from about 25 different mining centres, particulars of which are given in the subjoined table.

Synoptical Table showing the Gold Yield of the Coolgardie Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dolled and Specimens.	Ore treated. Tons.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	(2,240lbs.)	Fine ozs.	Fine ozs.
COOLGARDIE.				
Bonnievale ...	48.54	352,615.12	189,106.63	189,155.17
Bullabulling ...	12.82	926.98	528.32	541.14
Burbanks ...	516.32	410,048.36	302,241.43	302,757.75
Cave Rocks ...	...	63.00	10.82	10.82
Coolgardie ...	7,946.88	579,034.28	338,580.33	346,527.21
Eundynie ...	...	20,799.50	14,918.85	14,918.85
Gibraltar ...	41.49	1,519.50	1,047.54	1,089.03
Gnarlbine ...	12.25	2,084.50	1,147.26	1,159.51
Higginsville ...	303.78	32,836.90	15,334.25	15,638.03
Londonderry ...	52.25	28,068.76	19,263.69	19,315.94
Mungari ...	125.53	1,075.01	532.55	658.08
Red Hill ...	1,576.10	46,953.62	31,351.95	32,928.05
Ryan's Find ...	.44	86.88	254.95	255.39
Widgiemooltha ...	846.65	12,274.56	7,471.89	8,318.54
District generally	7,798.17	4,498.61	26,960.24	34,758.41
	19,281.22*	1,495,885.58	948,750.70	968,031.92
KUNANALLING.				
Balgarric ...	104.99	6,174.50	5,188.78	5,293.77
Carbine ...	687.98	40,093.36	26,884.23	27,572.21
Carnage ...	835.35	2,463.00	2,198.17	3,033.52
Cashman's (Siberia)	867.11	7,545.65	6,942.75	7,809.86
Chadwin ...	8.87	1,618.75	2,511.34	2,520.21
Dunnsville ...	270.81	17,700.19	8,247.34	8,518.15
Jourdie Hills ...	18.00	28,770.24	19,821.98	19,839.98
Kandana ...	...	465.00	68.12	68.12
Kintore ...	251.40	45,391.84	33,033.60	33,285.00
Siberia ...	1,588.79	8,439.85	10,880.00	12,468.79
25-Mile ...	808.18	106,175.49	82,578.27	83,386.45
District generally	255.69	1,751.26	3,874.92	4,130.61
	5,697.17†	267,489.13	202,229.50	207,926.67
Grand Total ...	24,978.39	1,763,374.71	1,150,980.20	1,175,958.59

*Includes 10,580.84ozs. dolled and specimens.

†Includes 5,036.50ozs. dolled and specimens.

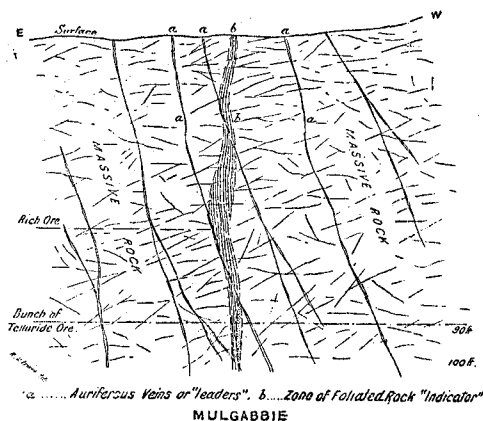
In this connection it may be noted that Table V. of the Mining Statistics contained in the Annual Report of the Department of Mines for the year 1918 gives—(a) the output of gold bullion from

the Coolgardie Goldfield entered for export, and (b) that received at the Perth Branch of the Royal Mint as being:—

	fine ozs.
Export (Customs House) ...	661,131.91
Royal Mint (Perth Branch) ...	829,821.10
Total ...	1,491,053.01

These figures are 316,094.72 ounces in excess of those furnished to the Mines Department. The discrepancy may be partly accounted for by the difficulty experienced in obtaining any record of the output of alluvial gold, and in part attributed to the fact that a good deal of the gold won in the early days of the Coolgardie Goldfield was never officially reported to the Department of Mines, and deemed worthy of no better record than the ephemeral currency of the newspaper.

Fig. 90.



The two principal mining centres on the field are Coolgardie and Burbanks, which have produced respectively 346,527.17 and 302,757.75 ounces of fine gold.

The official centre of the goldfield is Coolgardie, situated at an altitude of 1,400 feet above sea-level, on the main railway line from Perth to Port Augusta in South Australia.

The eastern portion of the Coolgardie Goldfield consists of a series of highly inclined and folded metamorphic sedimentary rocks, with beds which are regarded as being volcanic flows and tuffs. This sedimentary series and its associates appear to have been invaded by basic and acidic intrusives. The sedimentary rocks which form the western extension of the beds occurring at Kurrawang and Kuramia have a dominant northwest strike; they are disposed in a large syncline, the axis of which crosses the main line close to the Kurrawang Railway Station. The volcanic rocks are represented by fine-grained greenstones (dolerites and amphibolites) and their schistose varieties, together with brecciated bands which have certain resemblances to solidified volcanic ejectamenta.

A very large irregularly shaped mass of greenstone and its alteration products occurs in the neighbourhood of Jourdie Hills, where it forms a belt of about 55 miles in length and 13 miles in width in the country to the north of Jourdie Hills. The belt, which extends from about four miles south of that, including the mining centres of Mulline and Callian in South Latitude 30 degrees 30 minutes *circa* to the neighbourhood of Gnarlbine Soak, is everywhere surrounded by granite. The rocks at the northern end of the belt are massive fine-grained greenstone with subsidiary schistose zones, trending generally north-northwest. In the vicinity of many of the schists there are dykes of quartz-porphry, aplite and pegma-

tite. The basic rocks of the neighbourhood of Gibraltar, situated near the southern end of the Jaurdie Hills Belt, consist of slightly sheared hornblendite and its probable derivative hornblende schist, together with a granulitic hornblende gneiss; the precise relation of which to those previously mentioned is not quite clear. A considerable amount of gold has been obtained from the rocks of the Jaurdie Hills Belt. The deposits in the vicinity of the Jaurdie Hills have yielded about 20,000 ounces of gold, those of Dunsville over 8,500 ounces, whilst from the Gibraltar ore bodies 1,089 ounces have been recorded. There are good grounds for believing the actual gold yield of these localities has been very much greater than given in the figures.

The extreme northwesternmost portion of the Coolgardie Goldfield is made up of a belt (the Wallangie Belt) consisting principally of epidiorite and amphibolised dolerite, together with a development of highly inclined beds of ferruginous jaspilites, one of which forms a very conspicuous ridge, rising to a height of about 300 feet above the general level of the surrounding country, and is traceable for several miles. This belt of greenstone extends from the vicinity of Mount Walter on the south, in a general northwesterly direction, through Iron Knob for a distance of about 62 miles, and continues beyond the western boundary of the Coolgardie Goldfield. The belt, which has a maximum width of about five miles, is bounded on both sides by intrusive granitic rocks, from which numerous acid dykes emanate. The greenstones and their allies at both ends of the belt are traversed by dykes of pegmatite, which vary in thickness from a few inches up to as much as 50 feet. The basic rocks are traversed by highly inclined shear zones, which trend generally northnorthwest and dip to the west. A little gold has been met with in these shear zones in a series of more or less parallel deposits occurring along the planes of foliation. Some of the jaspilites occurring in the belt are highly ferruginous; some contain considerable quantities of magnetite and specular iron ore, whilst others pass gradually into ores carrying fairly high percentages of manganese, chiefly the mineral psilomelane.

The other important greenstone belt is that which includes the mining centres of Carbine, Kintore, Bonnievale, Coolgardie, Burbanks, and Londonderry, and that area to the eastward in which Mount Marion and Red Hill (Kambalda) near Lake Lefroy are situated.

The northern end of this belt, at Carbine, is made up of greenstone schist, the foliation planes of which trend northwest, and is associated with those irregular veins of quartz constituting the ore bodies of the district. A similar belt of schist occurs at Dunn's Eight Mile, about six miles south of Carbine, and also carries small auriferous quartz veins along the planes of foliation, which in this locality strike northwest also. The basic rocks are intersected with small granite dykes, which are off-shoots from the main mass to the south.

The Kintore area is made up of fine-grained foliated and massive greenstone penetrated by a mass of intrusive granite about four miles in length and with a maximum width of a mile and a-half, which in certain parts forms the matrix of the principal gold-bearing reefs.

The Kunanalling centre is about six miles southward from Kintore, and is geologically identical therewith, the greenstones being of the type usually found occurring on the Goldfields areas.

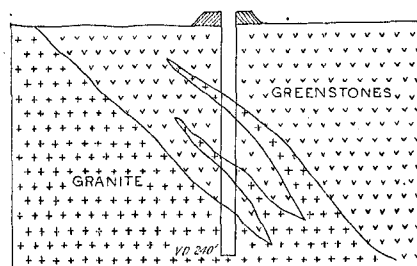
At Mount Burgess, the highest summit in the district, the basic rocks are intersected by serpentine somewhat similar in character to the ultra-basic rocks of the Mount Monger serpentine area.

The massive and foliated greenstones extend south through Bonnievale, where they are penetrated by intrusive granite, the precise geological relations of which are to be seen in the vertical shaft on the Bendigo G.M.L. 4006 (Fig. 91). The principal gold-bearing reefs at Bonnievale are almost entirely confined to the granite areas. There is in addition to the intrusive granite a series of acid dykes

which vary in thickness from a foot up to as much as two chains in width; nowhere, however, have they proved to be of any great length.

At Coolgardie the geological features are marked by a mass of intrusive granite on the west, which is succeeded by a belt of hornblende and talcose schists, with a strike which varies from north 20 degrees west to north 20 degrees east, and an easterly dip of from

Fig. 91.



30 to 60 degrees. The whole of the above is succeeded by dykes of both basic and acidic rocks, the latter occurring as narrow dykes which emanate from the main granite mass. Bosses and dykes of diorite and andesite occur, intersecting both the schists and the granites; so far as observations have been carried the diorites are of an earlier geological age than the andesites.

The country in the vicinity of Burbanks is made up of a succession of low greenstone hills constituting the continuation of the series of basic rocks of Coolgardie, and, like it, lies for the most part to the east of the main granite belt. The Burbanks belt continues about seven miles south of Londonderry. Along the western edge of the greenstones, and in close proximity to the main granite mass, is a series of alteration products of both granite and basic rocks, viz., mica, actinolite, chlorite, and talc schists. Numerous fissures, underlying to the east and trending generally parallel to the eastern boundary of the granite, extend more or less throughout the whole of the greenstone areas. These fissures when filled with quartz constitute the numerous quartz reefs, some of which have been mined for their gold contents; other fissures are filled with intrusions of acid rocks, which occur as narrow veins varying in composition from quartz to pegmatite, microgranite, and porphyry, some of which have been proved to have been gold-bearing. A well-defined dyke of porphyry several miles in length occurs in the greenstones at no great distance from their junction with the main western mass of granite to which it is parallel; it extends from the neighbourhood of the Old Faith Mine at Coolgardie southward past the Londonderry Mine. This porphyry, which is earlier in age than the acid dykes, does not appear to have any bearing upon the gold occurrences.

The rocks of the Coolgardie Goldfield have been intruded by granite, which appears to have exerted metamorphic effects along and adjacent to the contacts.

By far the largest area of the Coolgardie Goldfield is made up of granitic rocks, which extend over the greater portion of the field. The granite has been penetrated to a depth of about 3,000 feet by a diamond drill put down on the Gnarlbine Road, about two miles to the southwest of the township of Coolgardie.

In certain portions of the Coolgardie Goldfield both the granite, the ancient metamorphic rocks, and their associated intrusives are covered with a variable thickness of their own weathered *débris* and other superficial deposits. These superficial deposits extend over a very large portion of the field; they vary in thickness from a few

inches up to several hundred feet. In some portions of the Coolgardie Goldfield there occurs resting on the denuded granite surface a thin bed of cement of the type present at Kanowna and the Twenty-five Mile. What now remains of this cement occurs in every case at levels between 1,380 and 1,460 feet above sea-level, indicating that the deposit has a somewhat uniform altitude. The cement, the average thickness of which does not exceed three feet, is in places auriferous.

Ancient water channels exist in the vicinity of Coolgardie; one of these has been pierced by a bore to a depth of 162 feet, put down at a spot about eight miles from the township. The deposit has been utilised as a source of the water supplied to Coolgardie by the Hampton Plains Company. The water struck in the bore rose to some considerable height above the level at which it was first met with. The geological age of the alluvial deposit is somewhat conjectural, though there are reasonable grounds for believing it to be at any rate late tertiary.

There is no trace of any comparatively recent marine beds such as occur in the vicinity of Norseman, though in a bore put down at Coolgardie on Reserve No. 23 certain plant remains referable to the *Eucalypti* have been discovered. It may in this connection be noted that McCoy has described definite eucalyptus foliage from the older gold drifts in Victoria, whilst Ellinghausen has described several species from the upper tertiaries and the deep lead in the New England Tinfield in New South Wales.

The gold from the Coolgardie field occurs in the free state and also intimately associated with iron pyrites, galena, arsenical pyrites, pyrrhotite, zinc blende, ores of copper and native bismuth. The gangue mineral is quartz in most cases.

The gold deposits of the Coolgardie Goldfield cover a wide extent of country; the mineral itself has been obtained from four principal sources, viz.—(a) quartz reefs, (b) acid dykes which have some genetic connection with the quartz reefs, (c) lode formations, and (d) alluvial and residual deposits. The gold deposits of the above mentioned types have produced, up to the end of 1918, 1,175,958.59 ounces of fine gold.

The quartz reefs of the Coolgardie Goldfield are distributed marginally with reference to the mass of intrusive granite which covers such an extensive area; they occur both in the granite and the metamorphic and allied rocks into which it penetrates. Many of the reefs, more especially in the neighbourhood of Coolgardie itself, stand up from the surface like walls of masonry to heights of from 15 to 20 feet, having resisted the denuding action of the atmosphere better than the enclosing country rocks. The quartz veins in any particular portion of the field have a certain more or less definite bearing which varies slightly for each locality common to the whole. The average strike of the reefs in the mining centre of Coolgardie is generally north and south, whilst that in the neighbourhood of Burbanks is northeast and southwest.

All the main lines of reef at Jaurdie Hills exhibit a marked parallelism the trend of which is as a rule about five to ten degrees west of north. The quartz reefs of the neighbourhood of Bonnievale have no regular bearing, though the more continuous lines generally run approximately parallel to the junction of the granite with the greenstones and other metamorphic rocks. The principal quartz reefs underlay to the east, though in the case of those at Jaurdie Hills it is to the westward. The auriferous quartz veins, whether as single fissures or mineralised zones, are, when viewed broadly, trac-

Fig. 92.



Photo.: W. Nicholas.

Neg. 634.

Burbanks Main Lode, showing occurrence of Quartz Reef.

able for considerable distances across country. In many parts of the field, however, the reefs are very irregular and uncertain in their length, despite the fact that the channels in which they occur are in themselves of considerable length; one or two of those, however, in the vicinity of Jaurdie Hills have been proved for a distance of about half a mile, and it may be that their full length has not in all cases been determined underground, for owing to the low grade

of many of the reefs it is unlikely that they would be followed from end to end. The thickness of the quartz reefs varies within very wide limits—from less than an inch up to several feet.

Some of the quartz reefs have undergone a certain amount of folding, the trend of which is parallel to the major structural axes of the Coolgardie field. This folding in all probability results from lateral pressure exerted on the rocks subsequent to the formation

of the quartz veins, and tends to produce enlarged ore bodies which are usually of a somewhat higher grade than the average. A typical instance of folding occurs in the Burbanks Main Lode Mine at Coolgardie. (Fig. 92.)

Cases occur where in close proximity to minor cross fissures along lines of fault ("slides") the veins are represented by small lenses of quartz in a fine-grained matrix of fault rock.

A typical instance of this mode of occurrence is to be seen in the workings on the Burbanks Main Lode (Fig. 93) where the

quartz veins occur in a matrix of crushed hornblende rock. In such cases the value of the gold contents of the quartz is somewhat lower than the average of that in what may be called the continuous solid reef.

One of the most sensational of the finds on the Coolgardie Goldfield was that on the Londonderry G.M.L. 4204, where an exceptionally rich pocket of gold was met with in 1894 by a party of six prospectors. A rich quartz specimen was picked up by a member of the party from the vicinity of the outcrop of a massive quartz

Fig. 93.

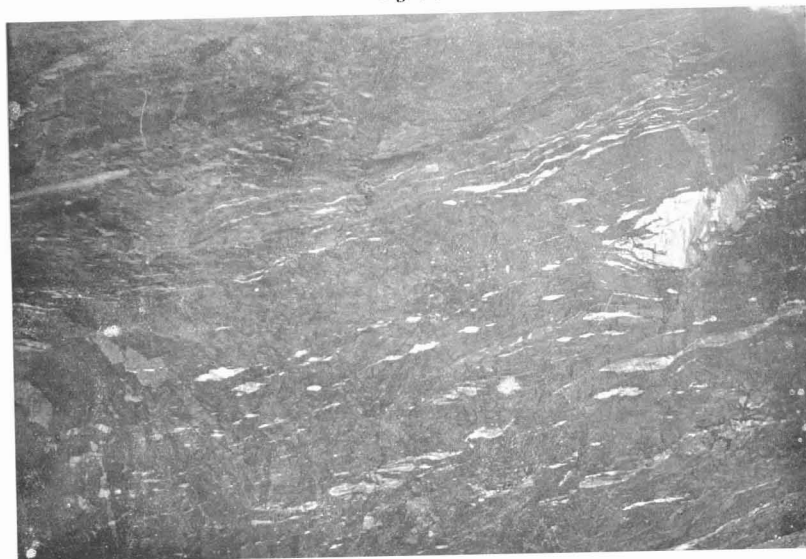


Photo.: T. Blatchford.

Burbanks Main Lode, showing occurrence of Quartz Reef.

Neg. 779.

reef, and between 4,000 and 5,000 ounces of gold were obtained from this reef; one notable specimen, "Big Ben," weighing 240 lbs. was estimated to contain gold to the value of over £3,500. The prospectors obtained at least 10,000 ounces of gold, valued at over £40,000 during the first few weeks of their work subsequent to the first discovery.

The gold continued as a very narrow shoot in a quartz reef of granitic affinities to 400 feet vertically below the surface, at which depth it proved too small for profitable mining. It appears from such geological observations as have been made in that portion of the Londonderry ore body from which such a large quantity of gold was obtained, that the gold occurred on the apex of a double fold in the vein, being in reality a modified saddle reef of which examples are met with in other parts of the field. The site of this historic find, "The Golden Hole," is shown on Fig. 94. The actual amount of gold from this deposit has not been recorded, and can probably never be ascertained; since the first discoveries, however, 11,915 tons of ore have been mined with a return of 11,951 ounces of fine gold.

The Wealth of Nations deposit at Dunnsville has the reputation of being one of the principal of what may be called the great specimen mines of Western Australia. The Wealth of Nations reef was discovered in 1894. The first pieces broken out from the cap of the reef contained fully 800 ounces of gold with which the quartz appeared to be glittering; subsequently about £20,000 worth of gold was obtained from a prospecting shaft about 10 feet deep. A good deal of residual and detrital gold was obtained from the flat just

below where the rich pocket was found in the reef; one slug secured weighed 197 and another 147 ounces. The Wealth of Nations reef, which occurs in a schistose greenstone, has an average trend of 5 degrees west of north, with an underlay to the westward of about 45 degrees in the upper workings and 35 degrees in the lower. The reef, which is quartz, varies in thickness from a mere thread up to 10 or 12 feet, and has been followed below the surface to a vertical depth of 300 feet. Its walls are not well defined, and consist of greenstone schist. There are no defined shoots of gold in the reef, and with the exception of the extremely rich patches the quartz is of very low grade. The recorded gold yield from the Wealth of Nations reef, other than the rich pockets, has only been 6,035.27 ounces derived from the milling of 15,976.50 tons of ore.

The *acid dykes* of the Coolgardie Goldfield form one of the important sources from which the gold has been derived. Considerable tonnages have been mined from deposits of this type, and payable gold has been found down to depths of about 400 feet from the surface.

A typical deposit of this class occurs in the Tindall's Mine (G.M.Ls. 33, 34, etc.), which has proved to be one of the largest gold producers in the Coolgardie auriferous belt. The Tindall's ore bodies consist of fine-grained granite dykes carrying a fairly large percentage of "white pyrites," and traversed by small veins and patches of quartz through which latter free gold is of frequent occurrence. The thickness of these gold bearing dykes varies within wide limits; an instance occurs in one of the deeper levels in which it reaches as much as 40 feet. The gold-bearing dyke trends gener-

ally north and south with an underlay to the west at an angle of about 35 degrees; it forms a small branch of the much larger dyke traversing the property in a north and south direction. A little scheelite occurs in association with the quartz. The ore bodies have been followed down to a vertical depth of 320 feet from the surface, and a considerable amount of driving has been done upon them. The country rock traversed by the gold-bearing acid dykes is massive amphibolite. These ore bodies have produced 31,612.89 ounces of fine gold from 125,645.25 tons of ore.

Fig. 94.



Photo.: T. Blatchford.

Neg. 781.

"The Golden Hole," Londonderry Gold Mines.

The Griffith Mine (G.M.L. 73, etc.), near Coolgardie, contains a gold-bearing granite dyke, parallel to those occurring at Tindall's, which has been more or less extensively worked, with a return of 162,283.84 ounces of gold from 36,606 tons of ore. The main workings of the Griffith Mine are on a granite dyke, reaching as much as 20 feet in width, encased in well-defined walls, and traversing massive amphibolites.

The *Lode Formations* of the Coolgardie Goldfield are well typified in the deposits of the Gibraltar area.

The mining centre of Gibraltar is situated about six miles east-southeast of Bullabulling Station on the Eastern Goldfields Railway. The district is made up by a belt of highly schistose rocks, which form the extension of the Dunnsville-Jaurdie Hills belt of greenstone to the north. The schistose rocks are made up of sheared hornblendite, hornblende-schist, and granulitic hornblende gneiss; these rocks are bounded on the south, west, and east by granite, and

are intersected by acid dykes, which vary lithologically from normal granite, through phases of pegmatite, to buck quartz reefs. The pegmatites have yielded mangano-columbite, one fragment of which weighed three pounds. The gold-bearing deposits of the Gibraltar district are made up of wide bands of impregnated schists, carrying short but rich shoots. The underlay and strike of the ore bodies conform to those of the enclosing schists, which in this neighbourhood are usually very flat.

The schists often contain quartz stringers, the gold contents of which are usually lower in grade than those present in the main body of the schist, the width and richness of which results from secondary impregnation and enrichment. A little iron pyrites occurs in the unoxidised ore.

The *Alluvial and Residual Deposits* of the Coolgardie Goldfield cover a very wide extent of country, though they have only returned 24,978.39 ounces of fine gold, which, however, is believed to be far below the actual quantity obtained, for much of it in the early days of the field was never officially recorded.

The principal interest, however, centres in the Cement Deposits of Kintore, about sixty miles from Kunanalling, which filled an old river channel carved out in a much eroded granite. What now remains of this cement, which appears to have been very extensively worked, occurs everywhere between 1,380 and 1,460 feet above sea level. The old river channel has been followed by mining operations for over a mile and a-half, though there are numerous breaks, which may be ascribed to erosion, the results of which are strongly marked by numerous pot holes and deep gutters. The deposits filling the old water course consisted of rounded and sub-angular fragments of quartz of all sizes cemented by a ferruginous silicate of alumina in varying proportions. The deposit has a maximum thickness of 15 and a width of from 90 to 100 feet.

So far as mining operations have been carried the payable gold was mainly found in the cementing medium, though before the gold could be obtained the ore had to be passed through a battery. The quartz pebbles in the cement were, as a general rule, barren, though in one or two very rare cases gold was found in some of the pebbles, and this affords evidence as to the ultimate source from which it was derived. The portion of the deposit which had the highest gold content was found to be that made up of the coarser material lying on the granite bottom. There are good scientific reasons for believing the gold to have been deposited mechanically, though a certain quantity may have been added from solution. The ultimate derivation of the gold is from the disintegration of the quartz veins, leaders, and formations occurring in the country drained by the adjacent watercourse. The geological age of the cement deposits is somewhat conjectural, but there appears to be some evidence for believing it to be either late tertiary or pleistocene.

According to the available official figures, which there are good grounds for believing to be an under-statement, there have been crushed from the cement deposits of Kintore 30,248.75 tons of consolidated alluvium yielding 20,217.46 ounces of fine gold, or at the rate of .63 ounces per ton.

DUNDAS GOLDFIELD.

The Dundas Goldfield owed its discovery to Mr. Wm. Moir of Fanny's Cove, who found alluvial gold in the detritus of one of the creeks on the western shores of Lake Dundas during a journey he made in search of pastoral land in the year 1892. It was not, however, until some years later that the rich quartz reef known as the "May Bell" was found and followed by the discovery of the "Scotia."

The Dundas Goldfield was legally established by proclamation in the year 1893; its boundaries were amended in 1897 so as to embrace an area of 11,430 square miles. The field has, up to the end of 1918, produced 594,823.10 ounces of fine gold, which has been

obtained from the mining centres of Buldania, Dundas, Killaloe, Norseman, and Peninsula, particulars regarding which are to be found in the subjoined table.

Synoptical Table showing the Gold Yield of the Dundas Goldfield up to the end of 1918.

District or Mining Centre.	Alluvial, Dolled and Specimens.	Ore treated. Tons.	Gold therefrom.	Total Gold Yield.
	Fine ozs.	(2,240lbs.)	Fine ozs.	Fine ozs.
Buldania	39.55	1,187.32	1,228.76	1,268.31
Dundas	385.37	4,725.73	2,352.36	2,737.73
Killaloe ... ..	...	20.65	6.88	6.88
Norseman	12,385.05	848,407.25	552,294.86	564,679.91
Peninsula	17.61	7,764.00	4,705.10	4,722.71
District generally...	1,080.81	828.75	20,326.75	21,407.56
Total	13,908.39*	862,933.70	580,914.71	594,823.10

*Includes 11,881.27ozs. dolled and specimens.

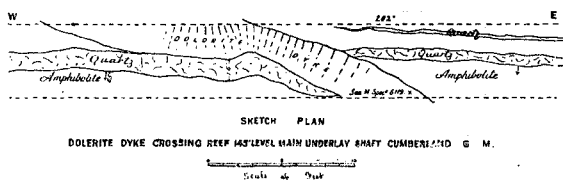
The principal goldmining centre on the field is Norseman, which has produced 564,697.91 ounces of gold, of which 552,294.86 ounces have been extracted from 848,407.25 tons of ore, the balance being the produce of the alluvial and residual deposits.

Norseman, the official centre of the field, is 927 feet above sea-level, and is connected with the main railway system of the State.

The centre of the Dundas Goldfield is occupied by a strip of low-lying country in which the system of lakes occurs and of which Lakes Cowan and Dundas are the most important. They are dry for the greater part of the year. The width of Lake Cowan varies from a few feet up to twenty miles, and it contains a number of islands of different sizes. The height of the floor of Lake Cowan above sea-level is 685 feet, whilst that of Lake Dundas is twenty feet lower. Lake Cowan, as is the case with most of these inland lakes, is shallow, though it is stated that at a point about 1,100 feet from its edge a thickness of 377 feet of silt was met with in a bore put down in the lake in connection with water supply. The water (brine) of Lake Cowan is highly charged with salt, and that obtained from a trench was found to contain about a quarter of its own weight of solid matter, over 18 per cent. of which was sodium chloride and three of chloride of magnesium. The western shores of this system of brine or salt lakes are mostly steep and rugged, whilst the eastern are mostly gently sloping ground upon which are ridges of blown sand and banks of seed gypsum. Several "deep leads" debouch into the lake, but nowhere have they proved to be very extensive.

The district of which Norseman forms the centre is made up, geologically, of a series of metamorphic sedimentary rocks, estimated to reach a thickness, making due allowance for repetition

Fig. 95.



by folding, of about 800 feet, which occupies a strip of country skirting the west side of Lake Dundas and near the west side of Lake Kirk. Some of these ancient sedimentary rocks have been permeated by secondary silica and oxide of iron and are in places represented by the bands of laminated quartzite and jaspilite, which make a very pronounced feature in the vicinity of Norseman. These rocks are often much fractured and traversed by numerous veins

of white quartz and brown oxide of iron; some of the larger veins coincide in dip and strike with that of the lamination of the enclosing sediments, whilst the smaller ones ramify in all directions.

Bedded amygdaloidal amphibolites, representing ancient lava flows, are associated with the sedimentary rocks. There is in addition a series of epidiorites and allied rocks, the mode of occurrence of which suggests the possibility of their being intrusive sills or dykes. More or less isolated veins and dykes of dolerite have also been met with; one of these is seen to cross the quartz reef at the 145 feet level in the main underlay shaft of the Cumberland Gold Mine. (Fig. 95.)

Small areas of mica and chlorite schist are met with; they appear to owe their origin to the transmutation of those igneous rocks which make up the larger portion of the surface of Norseman. These greenstone schists pass in depth into hard dark green rocks in which the fissile structure is not in all cases readily distinguishable.

Granite rocks of intrusive origin occupy both flanks of the Norseman gold-bearing belt. An important feature in the structure of the belt is the large number of quartz porphyry and felsite dykes, which trend generally north-east and south-west, roughly parallel to the line of contact between the granite and the adjacent rocks. These acid dykes vary much in colour; they are sometimes fissile, pyritous and occasionally slightly auriferous, and in this regard may stand in close relation to the gold-bearing reefs. The porphyries, which often run along the planes of foliation of the greenstones, traverse all the other rock series on the field other than the metamorphic sediments and the norite dyke.

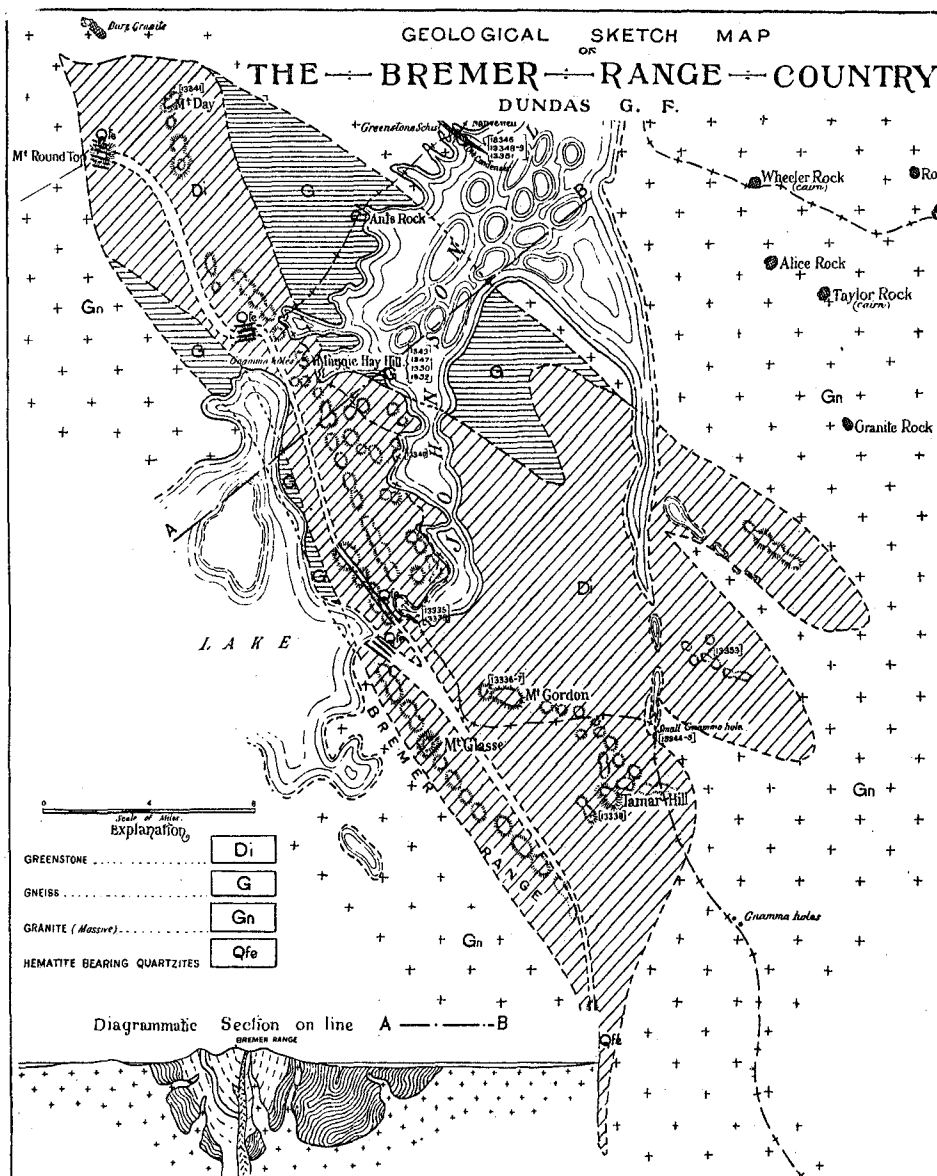
One of the youngest of the solid rocks of the district is the huge dyke of norite which runs generally east and west for miles across the district. Lithologically the dyke ranges from hypersthene through olivine to a quartz-norite. The dyke varies from 40 to 80 chains in width and is well seen in Trig. Hill B23, near Princess Royal township; it extends in an uninterrupted line to Mount Norcott, about 12 miles to the east, and for a considerable distance further. The norite dyke has no effect upon the gold contents of any of the quartz reefs it traverses and is not traversed by any quartz veins. The dyke crosses Lake Cowan and extends some considerable distance to the westward.

The western portion of the Dundas Goldfield contains a relatively small patch of potentially gold-bearing country, lying about 65 miles due west of the town of Norseman and which is occupied by Bremer Range, Mount Glass forming the highest point. The area is about 40 miles long; it is about five miles in width at the northern end and 15 at the southern, and has an average trend of northnorth-west. The belt (Fig. 96) is made up chiefly of fine-grained massive greenstone with bands of coarser grained varieties; at Mount Gordon there are fine-grained amygdaloidal amphibolites derived from the alteration of dolerites, and which point to their being volcanic flows. There is also a series of banded haematite quartzites (jaspilites) forming steep razor-backed ridges, with a high westerly dip, and which are traceable for over 40 miles in a general northnorthwest direction. These beds in all probability represent metamorphic sediments interbedded with the basic lavas. A fairly extensive belt of gneiss occupies the northeastern portion of the country, and is believed to represent highly transmuted sedimentary rocks. The whole of the Bremer Range country is surrounded by biotite-granite, intruding the greenstones, which are at times rendered highly schistose along and in the vicinity of the contact. Granite and pegmatite dykes are of frequent occurrence in the contact zone between the granite and greenstones, especially on the eastern margin. The pegmatites occasionally contain garnets, and at times pass into pure white quartz, one vein of which at Maggie May Hill has margins of solid epidote, with crystals of the mineral in the centre. Quartz reefs from 50 to 75 feet long and from 12 to 18 inches in thickness are met with to the south of Maggie May Hill. An iron-bearing formation over 40 chains long trending 120° occurs about a mile to the southsoutheast of Plover Rock; upon it some shallow shafts

have been put down. The formation, which at times is brecciated, contains masses of solid marcasite, which, however, proved to be destitute of gold. The thickness of the iron-bearing deposit averages

about two feet, and it contains a little pyrites. The Bremer Range greenstone belt is in all probability the southward extension of some of those belts on the Coolgardie Goldfield (*q.v.*).

Fig. 96.



Another outlying belt is that of the Frazer's Range, which is situated in the northeast angle of the Dundas Goldfield. The range trends generally northeast and southwest; the highest summit, known as The Peak, rises to an elevation of about 2,010 feet above sea-level or nearly 800 feet above that of the general level of the sur-

rounding country. The Frazer's Range, which is entirely surrounded by granite and garnetiferous gneiss, is made up mostly of indistinctly laminated basic rocks, together with felspathic and siliceous quartz schists, intersected by greenstone dykes, quartz reefs, and veins of magnetite and manganese. A somewhat similar norite dyke

to that occurring near Norseman has been recorded from the Frazer's Range, but its geological relationships are as yet unknown. A series of parallel dykes of granite, with perpendicular walls standing up like tiers of masonry, traverse the fundamental rocks of the district, and can be followed across country for considerable distances. Some of the pegmatite veins contain fair sized crystals of black tourmaline in addition to small quantities of the pink variety, and considerable quantities of mica, some of which may be of exploitable value. Allanite (the silicate of iron, aluminium, calcium, and cerium) has been detected in the pegmatites of the vicinity of Simon's Hill at the northern end of the Frazer's Range just outside the limits of the Dundas Goldfield. The geological constitution and structure of the Frazer's Range country seems to offer possibilities for the occurrence of mineral deposits, and is worthy of the attention of prospectors.

The gold deposits of Norseman, which are scattered over a fairly large extent of country, are situated on the western slopes of the range of low hills to the east of the township; most of the reefs have an underlay to the east, but those on the eastern slopes underlay to the west. The reefs trend generally north and south and underlay to the eastward at an angle of about 45°, whilst those which strike east and west underlay south at angles varying from 60 to 70 degrees. The reefs, with one or two notable exceptions, are mostly short and consist chiefly of white quartz with a relatively small proportion of pyrites and galena, with (in certain localities) scheelite and bismuth ore. The walls of the reefs are usually well-defined with smooth and striated surfaces. On the whole the reefs are of low grade, though many have carried rich shoots of gold.

The principal gold producers of Norseman have been the Mararoon, Princess Royal, and Viking Reefs. These have produced, up to the end of 1918, 333,574.38 ounces of fine gold, or more than one-half of the total yield of the Dundas field. The details regarding the gold yield of these deposits are set out in the following table:—

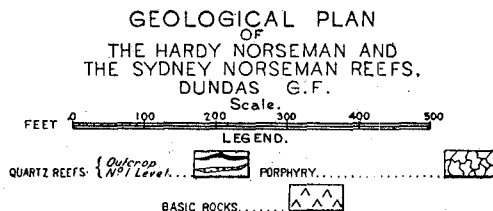
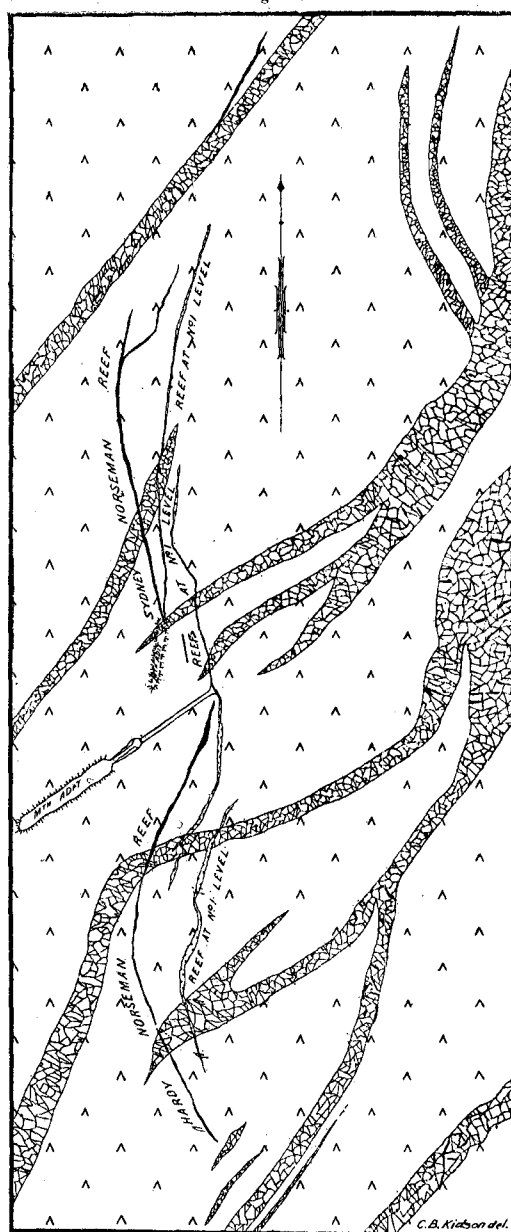
Yield of the Principal Ore Bodies of Norseman.

Lode.	Ore crushed.	Gold therefrom.
	Tons.	Fine ozs.
Mararoon	304,763.50	146,137.41
Princess Royal	169,584.59	144,170.48
Viking	45,142.75	43,266.49
Total	519,490.84	333,574.38

The Mararoon Reef is one of the westernmost of the ore-bodies on the field; its outcrop extends in a general north and south direction along the northern portion of the foot of the western front of the Norseman Hill for a distance of about three-quarters of a mile. The reef, which is of quartz, underlays to the eastward at an angle of about 45 degrees. The Mararoon Reef, which is a good strong fissure vein right along its known length, averages about four feet in width, though in certain portions it reaches as much as 25 to 30 feet. The reef is encased in schistose greenstone with laminations parallel to the vein, and it has smooth and striated walls.

There is a very long line of reef known as The Norseman Reef lying about a quarter of a mile to the east of the Mararoon. The Norseman Reef, which has an outcrop of about 7,000 feet, underlays to the east at an angle of about 45 degrees; it is made up of quartz ranging up to as much as eight feet in thickness. The country rock of the Norseman reef is amphibolite, which in close proximity to the vein is often very highly foliated; in the hard unoxidised country the reef has smooth walls and contains large lens-shaped masses of wall rock ("horses") as well as numerous small angular fragments of the same with bunches and strings of quartz. The quartz of which the reef is composed contains sulphides of iron,

Fig. 97.



The average gold yield of the quartz reefs occurring in the amphibolite rocks at Norseman has been at the rate of 1.003 ounces per ton, whilst that of those in the other metamorphic rocks has been 1.182 ounces per ton.

Deep Leads and Alluvial Deposits.—There is in addition to the ore deposits previously mentioned a considerable development of shallow and deep detrital deposits. A considerable amount of gold has been obtained from the "deep lead" passing through the township of Princess Royal, and which disappears beneath or merges into the wide flats skirting the margin of Lake Cowan. The wash in this buried river channel consists of clay, containing nodules of ironstone and water-worn pebbles of quartz, in which the detrital gold occurred often in pieces of considerable size. The gutter (?) which in places lay at a depth of from 80 to 90 feet below the surface, at times proved to be as much as 90 feet wide. The surface upon which the auriferous gravel rested consisted of decomposed amphibolite, traversed in places by quartz veins of from three to four inches in thickness.

Another "deep lead" has been worked at the Lady Mary Gully, near the Lady Mary Mine, towards Lake Dundas. Several shafts varying in depth from 70 to 90 feet have been sunk upon the lead, and well water-worn pebbles and boulders of quartz and clayey rocks met with. The best gold is stated to have been obtained where the large quartz boulders predominated; some of this wash yielded gold at the rate of about 12 dwts. per ton. Some fairly large gold nuggets were obtained from the wash, though much of the gold was finely crystalline and deposited on the faces of small crevices in the clayey material in addition to occurring along many of the tree rootlets which had penetrated down from the surface. A good deal of secondary silica was present in some parts of the wash, which, coupled with the nature of some of the gold, seems to indicate that much of it had been redistributed by solution and precipitation in the *débris* filling the old drainage channel.

Many of the shallow watercourses have been found to carry a fair quantity of gold in the basal gravels, ranging from a few inches to eight feet in depth. Most of this gold was of a shotty character, and ranged from very fine gold to small nuggets weighing from three to four pennyweights.

STATE GENERALLY.

There are in addition to those areas occurring within the limits of the goldfields of the State, some in which gold-bearing deposits have been mined, and others in which the occurrence of auriferous deposits of possible exploitable value may be looked for with reasonable degree of confidence. The total quantity of gold recorded from these extra-goldfields areas has been very small indeed, amounting only to 8,502.56 fine ozs., of which 8,354.33 ozs. have been obtained from the milling of 1,680.30 tons of ore and 148.13 from alluvial and detrital sources.

The most westerly of all the areas from which gold has been obtained is at *Donnybrook*, situated in the extreme south-west corner of the State between Geographe Bay and the Greenbushes Tinfeld on the Bumbury to Bridgetown Railway. Gold was first discovered in the district in 1897 by a party of prospectors searching for alluvial gold; further investigations carried on eventually led to the discovery of gold-bearing quartz veins from which most of the gold has originally been shed. A crushing of 173 tons of ore, giving a return of 501 ozs. of gold, or at the rate of 2 ozs. 8 dwts. per ton, led to the proclamation of an area of 1,020 square miles as a gold-field in 1899. The goldfield, however, was ultimately cancelled after 841.76 ozs. of gold had been obtained from the milling of 1,653.30 tons of ore. The gold deposits of Donnybrook do not lie on the strike of any of the great auriferous belts, of which the nearest is about 225 miles to the eastward. The country in the vicinity of Donnybrook, which is extremely hilly and thickly timbered, is for the most part covered with the ubiquitous laterite deposits, effectually concealing the underlying rocks, except in the gullies and sides of the

hills. Lying beneath the laterites is an extensive deposit of almost horizontal sedimentary rocks, consisting of light grey, fine grained and even textured sandstones alternating with bluish grey pyritous clay shales, coal seams and conglomerates. In one of the bands of shale there occurred a seam of iron pyrites six inches thick. The basal beds of the series are lithologically in reality arkoses. These sedimentary rocks form part of what has been designated The Donnybrook Series, which are believed to be of Permian-Carboniferous age and the equivalents of the Collier River Beds. The sedimentary rocks of Donnybrook cover a wide extent of country to the eastward, where they have been proved by boring at the Vasse to be about 600 feet thick. The Donnybrook sedimentaries rest upon or abut against the ancient crystalline rocks which make up the Darling Range as developed in the south-west corner of the State. The crystalline rocks of Donnybrook consist of massive hornblende and gneissic granite, intersected by an intrusive (?) mass of hornblende rock trending north and south and which is traceable for some considerable distance in a southerly direction. The width of this belt of basic rock varies from a quarter of a mile, though it has never been found to exceed a mile. The western edge of the mass has a schistose structure and is virtually a hornblende schist, which in isolated cases is very fine in grain and exceptionally hard. The granite varies both in composition and texture; as a whole it is a hornblende granite, though in several localities muscovite mica replaces the hornblende. The quartz reefs all occur in the granite to the west of the basic dyke, but always in close proximity to the junction of the two rocks. The dominant strike of the reefs is to the north-west, with a high underlay to the eastward. The thickness of the reefs varies from one to nine feet, and they have been followed down to depths of about 200 feet below the surface. The quartz contained cubical pyrites and a little chalcocite or secondary silicea. The quartz in some of the reefs is in the upper portions very friable and crumbles readily to powder, whilst the harder varieties, occurring at depths of from 70 to 90 feet contain varying proportions of felspar, which seems to point to a granitic origin of the ore bodies. Chemical analyses of some of the quartzes showed from 1.36 to 1.93 parts per hundred of silicate of alumina. Some of the gold in the reefs of Donnybrook occurs in the filmy arborescent form resembling the finest filigree work, which points to a secondary origin and enrichment. The following table of crushings from the Jackson Reef affords evidence of this secondary superficial enrichment above the level of ground water:—

Ore crushed.		Gold therefrom.		Rates per ton.	
tons.		ozs.	dwts.	ozs.	dwts.
6		27	0	4	10
16		48	17	3	5
80		230	15	2	17
11		20	5	2	17
60		175	0	2	18
173		501	17	2	18

The Darling Range in the vicinity of *Brunswick* is auriferous, as is shown by the discovery in 1898 of a sheared micaceous quartz rock containing a fair proportion of iron pyrites. One of these beds of pyritous quartz rock had a width of 18 feet. Official assays of the pyritic concentrates yielded 19 dwts. 14 grains of gold per ton, but as the pyrites represented only about four and a half per cent. of the picked ore the actual assay value proved to be only about 21 grains per ton.

A little gold was found near the headwaters of the *Ferguson River* in 1900, and some alluvial gold in the bed of one of the branches of the Preston River in 1901, none of which, however, proved to be payable.

Auriferous deposits have been found and worked on Location 1830 at *Cantineuti* (generally known at *Black Boy Hill*), situated

at the head of Toodyay Brook, about two to four miles north-west of the township of Bolgart on the Clackline and Piawaning railway line. The auriferous area lies to the east of Black Boy Hill, which latter consists of a mass of granitic gneiss succeeded to the eastward by a belt of flaggy beds of micaceous and quartz schist about a mile in width. These metamorphic rocks trend generally north and south and dip eastward at varying angles. The quartz schists are often iron bearing and in many respects resemble the haematite quartzites (jaspilites) of the goldfields areas. The rocks are associated with and intersected by greenstones, chiefly epidiorites characteristic of the goldfields areas, with local developments of amphibolites and allied rocks. The greenstones trend generally north-west and south-east. The rocks of the Black Boy Hill neighbourhood are often concealed in part by a covering of residual sand and ferruginous rubble, the latter containing in one or two localities free gold. There are a number of deposits of the "lode formation" type in addition to several quartz veins, though none have been followed down below 40 feet vertically from the surface. The ore bodies of the lode formation type consist of lenticular quartz veins arranged in more or less continuous lines along and parallel to the dominant structural planes of the enclosing rocks, to the dip of which they conform. These lenticular quartz veins are as a rule of small dimensions, though in one isolated case a well-defined mass of ferruginous quartz proved to be six feet in thickness. Some of the quartz veins have been found to carry fairly high gold values, though they only form a small proportion of the whole formation, and proved to be too small to be worked separately by hand picking. Assays made of a considerable number of these in the Geological Survey laboratory gave results varying from as much as 1 oz. 3 dwts. 23 grs. to 4 ozs. 6 dwts. 13 grs. per ton, in addition to others yielding up to 12 dwts. of gold per ton. The quartz contains in places finely disseminated iron pyrites and its oxidation products. There are in addition to the bedded veins several cross reefs trending generally east and west and varying in width from 12 to 15 inches, and which have proved to be gold-bearing. One very large quartz reef exposed in a trench was 15 feet wide, but it contained only traces of gold. The district outside the limits of Location 1830, which forms the extension of the Black Boy Hill belt, contains quartz reefs, acid dykes and bands of jaspilite, geological associations which render it worthy of judicious systematic prospecting.

The Black Boy Hill auriferous belt is continued some miles south-eastward towards Bolgart where a belt of sometimes highly sheared greenstones, intersected by acid dykes, and a newer series of dykes of epidiorite, occurs in association with granite. In the Bolgart neighbourhood there are several short lenticular quartz reefs of granitic habit, in addition to small glassy stringers of quartz, which in some respects resemble those occurring at Black Boy Hill.

A pyritous quartz reef has been worked at *Bindoon* about 20 miles south-west of Black Boy Hill. The rocks in the district are slates and schists, carrying quartz veins, and associated with basic dykes, both of which have proved to contain fairly large quantities of iron pyrites.

A well-defined quartz reef has been worked on the western slopes of the *Darling Range* on Locations 333 and 109, situated about two miles north-east from Gosnells Station on the South-Western Railway line. The quartz reef is very large and strong and makes a prominent outcrop traceable for a considerable distance from the flat almost to the top of the Darling Range along a bearing of north 74 degrees east. The thickness of the quartz reef at the spot where prospecting operations have principally centred, is 150 feet, though in other places it is very much narrower. The reef, which occurs in granite, is intersected by two basic dykes, one of which is 200 feet in width. The quartz reef has an underlay to the south-south-east. The quartz as seen in the outcrop is very dense and contains numerous vughs filled with the oxidation products of iron pyrites, with which is some copper pyrites. Some of the quartz is very much

banded and contains a considerable amount of felspar, pointing to either a granitic origin for the reef or a secondary silicification of the granite.

Another quartz reef about three feet in thickness has been opened up in the *Helena River Valley* about a mile and a half north-east from Gooseberry Hill Station on the Midland Junction to Karragullen Railway line. The reef, which is a strong body of glassy quartz much stained by iron oxide, occurs in granite and trends generally north 60 degrees west, proved to be gold-bearing though of low grade; it is associated with other quartz reefs in the lower parts of the Helena River Valley.

The occurrence of small quantities of gold in various parts of the Darling Range is of importance in the evidence it affords as to its geological constitution and structure being favourable to gold deposition.

Gold has been found and worked in the *Wongan Hills*, on the Northern Railway, about 30 miles to the north-north-east of Black Boy Hill. The year 1888 would appear to have seen the first recorded occurrence of gold in the Wongan Hills, the rocks in which contained small mineralised quartz veins. The country rock of the hills consists of hornblende and micaceous schists, which are either vertical or are inclined to the west, with a dominant northerly strike, and surrounded on all sides by granite. The crystalline rocks are intersected by practically vertical basic dykes, which, when viewed broadly, are arranged in two series approximately at right angles to each other. In addition to these there is a group of acid dykes with a strike which conforms to that of the enclosing schists; these dykes are of two types: a very coarse variety of pegmatite and a fine-grained micaceous felsite. The beds are covered by laterite, which does not constitute a horizontal tableland, but adapts itself to the original shape of the ground upon which it was formed. Outliers of the laterite occur at several localities showing that extensive denudation has taken place since the rock formed part of one continuous deposit. The gold-bearing deposits of the Wongan Hills consist of ordinary quartz reefs, through which various metalliferous ores are disseminated. The reefs have a strike which coincides with that of the enclosing rocks, viz., north-east and south-west, and a westerly underlay of about 65 degrees and over. Some of the reefs which have well-defined walls reach as much as 8 feet in thickness, though as a general rule they are very small. The slopes of the hills in several localities are strewn with fragments of quartz of such a character as to leave no doubt but that they had not travelled far from the position in which they originated. The quartz as a general rule is of sugary white appearance with the exception of some of the veins at Little Wongan, which are limpid and glassy. The white sugary varieties of quartz carries haematite, limonite, azurite, malachite, tile ore (red oxide of copper), together with actinolite, serpentine and garnets. The iron oxides are disseminated through the quartz in the form of irregular grains as well as rain-fying veins. A small trial crushing from Payne's Reef at Little Wongan about 35 years ago yielded gold at the rate of 19 dwts. per ton. This reef was of a limpid glassy quartz, trending north-east, and with a steep underlay to the westward. The workings are inaccessible, but an assay of the results of a sampling of the outcrop made in the Geological Survey laboratory yielded gold at the rate of 7 dwts. 7 grains per ton.

Some well-defined quartz reefs occur near *Wagin* on the Great Southern Railway line, and have been more or less perfunctorily worked in the year 1907. The district of which Wagin forms the centre lies in one of the main valleys draining the tableland of the interior, though the fall is so slight that its course is represented by a series of more or less fresh-water lakes, the flood waters of which eventually find their way into the Beaufort River. Gold had been known to occur in the hills on the northern side of the lake area, about 16 or 17 miles to the eastward of Wagin, in country traversed by several small veins of quartz and ironstone. The country rock in the more immediate vicinity of Wagin is granite of the

type prevailing in the Darling Range Plateau, and is penetrated by a few basic dykes. The surface of portions of the granite area is covered by a variable thickness of felspathic and micaceous grit, which owes its origin to the disintegration of the granite *in situ*. There are in addition some limestone deposits outcropping on the eastern side of the main valley. The limestones, which are of lacustrine origin, are made up of small shells, which have not yet been specifically determined, but are of comparatively recent origin. The reefs of Wagin are large bodies of quartz of, in places, great width, which are traceable along the surface for considerable distances; some of the quartz reefs are arranged *en echelon* rather than as one continuous ore body. Some of the quartz veins have associated with them ferruginous quartz veins which have yielded fair prospects of fine gold. A small trial crushing of ten tons of ore from one of the quartz reefs crushed at the Coolgardie State Battery returned 5 ozs. 14 dwts., or at the rate of 57 ozs. (11.5 dwts.) of gold per ton. All the quartz reefs from the Wagin district, while they have invariably proved to be of low grade, demonstrate that there is little gold in the district and that it is chiefly confined to small veins traversing the larger pegmatitic quartz reefs.

Gold-bearing quartz reefs containing much iron pyrites have been met with and worked in the neighbourhood of *Kendenup*, on the Great Southern Railway line. A small trial crushing of five tons of ore from one of the Kendenup reefs was sent to Victoria and is stated to have yielded a very good result, though the exact figures are not now available.

Gold finds have been reported from time to time from the neighbourhood of *York* and at different localities throughout the *Eastern Districts*, though none have so far proved to be of any

value, despite the fact that the geological constitution of the country is in many localities favourable to gold deposition.

The occurrence of the minerals sillimanite and andalusite in the garnetiferous mica schists containing much graphite at Kununoppin, between Wongan Hills and Westonia, is of importance from the fact that similar rocks and identical mineral associations are found associated with the gold-bearing lodes at Marvel Loch in the Yilgarn Goldfield about 80 miles to the eastsoutheast. This occurrence at Kununoppin points to the possibility of the presence of gold deposits much further to the westward than the present administrative limits of the Yilgarn Goldfield. It is quite possible that this forms part of a mineral-bearing zone, which includes the gold deposits of Ravensthorpe in the Phillips River Goldfield and the Warriedar and Mount Singleton belt on the Yilgarn Goldfield.

The banks of the more important watercourses in the Champion Bay district are skirted by recent superficial deposits of considerable extent, in which, during the year 1861, Mr. F. T. Gregory recorded the occurrence of alluvial gold from the detritus in the *Bowes River*.

A little gold was found in the year 1868 in the detrital deposits on the north side of *Peterwangey Hill* on the Irwin River to the south of Mullewa.

The geological occurrence and geographical distribution of the known gold deposits of Western Australia have been given in considerable detail. The data show that the deposits cover a very wide extent of country, and there are sound scientific reasons for the belief that there are other auriferous deposits like those already described yet to be discovered. Erosive action has been so extensive that only the lower portions of the original gold-bearing formations now remain.

Rare Metals

of

Western Australia

By
Edward S. Simpson, D.Sc., B.E., F.C.S.

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Conclusion.

Extract from
The Mining Handbook.
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Part III., Section XVIII.
1919.

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Rare Metals

By
E. S. Simpson.

PART III.—Section XVIII.—RARE METALS.

E. S. SIMPSON.

LITHIUM.—This is one of the least rare of the rare metals, and, being an essential constituent of several characteristic minerals, and yielding a simple flame test, is one whose presence is soon recognised. The existence of the element was first recognised by Arfvedson in 1817, but it was not till 1855 that it was obtained in metallic form by Bunsen and Matthieson.

Lithium minerals are almost invariably associated with granitic rocks and are concentrated in the pegmatite veins associated with them. They are frequently accompanied by tin ore. The commonest lithia mineral is Lepidolite (lithia mica). Zinnwaldite (lithia-iron mica), Spodumene (lithia jade), and Amblygonite (a fluorophosphate of lithium and aluminium) are less common minerals comparatively rich in lithium. Smaller quantities of lithium occur in other micas, and in some varieties of tourmaline, as well as in several rarer minerals. Lithium is detectable in traces in most granites, the average quantity present being about one part in ten thousand, or, in other words, about three ounces to the ton of rock. It is also present in minute quantities in almost all natural waters.

Of the above-mentioned minerals, the following are found in the State:—

Lepidolite.—Wodgina, Stannum, Poona, Ubini, Londonderry, Cocanarup, Ravensthorpe.

Spodumene.—Ravensthorpe.

Amblygonite.—Ubini, Ravensthorpe.

Lithia Tourmaline.—Ravensthorpe, Simon's Hill, Greenbushes.

Lithia Biotite.—Ubini.†

The proportions of the metal present in these minerals are naturally very variable, the few exact figures available being shown in Table II.

Lithium minerals in this State are found almost, if not quite entirely round the outskirts of intrusive granite masses, where they are concentrated in pegmatite veins usually in association with large quantities of soda felspar (albite) and at times with ores of tin and tantalum.

Metallic lithium has no practical application at present, but some of its compounds are commercial products, being used in medicine, in the aerated water trade, and in charging Edison's latest storage battery. So far as our information goes, Western Australia is well endowed with lithium minerals, and could supply the market with them in case of present sources of supply becoming depleted.

TABLE II.—Composition of Lithium Minerals occurring in Western Australia.

Mineral.	Amblygonite. Large crystalline mass.	Spodumene. Large crystal.	Lepidolite. Large shoot.	Lepidolite. Small radiating shoots.	Lepidolite. Small radiating shoots.	Lepidolite. Small shoots.	Biotite. Spheroidal concentric shoots.
Locality.	Amblygonite Mine, Ubini.	Hoads Smelter, Ravensthorpe.	Mica Mine, Londonderry.	Cocanarup.	Fraser's Tin Find, Londonderry.	Hoads Smelter, Ravensthorpe.	Amblygonite Mine, Ubini.
Colour.	White.	Apple green.	Amoethyst	Pearl grey.	Violet.	Rose pink.	Dark red-brown.
Lithia, Li ₂ O ...	9.31	7.02	5.83	2.60	2.05	3.07	1.13
Soda, Na ₂ O ...	.78	1.93	1.03	.64	.82	2.63	.08
Potash, K ₂ O ...	none	.47	11.18	10.94	10.66	10.57	10.42
Alumina, Al ₂ O ₃ ...	34.71	26.48	23.22	29.01	30.07	27.40	26.96
Silica, SiO ₂ ...	none	61.94	51.67	47.58	45.19	48.78	43.12
Phosphoric Oxide, P ₂ O ₅ ...	48.01	none	none	none	none	none	none
Analyst ...	E. S. Simpson	C. G. Gibson	H. Bowley	H. Bowley	E. S. Simpson	H. Bowley	E. S. Simpson

CAESIUM AND RUBIDIUM.—These two very rare metals are closely related to lithium, with which they are usually associated in nature. Rubidium is not known as an essential constituent of any mineral species, and caesium only of two, viz., Pollucite (silicate of caesium and aluminium) and Worobiewite (caesium-beryl). Traces of both metals are of frequent occurrence in lithia-micas and other lithia minerals. They are concentrated in granitic extrusions. According to Vernadsky* "Caesium and rubidium withdraw from the magnus into the pegmatite veins in the aluminous silicates."

Neither metal has as yet been detected in this State. They are, however, to be expected in the lithium minerals already described and in beryl, which has been recorded from several localities, *vide infra*.

* W. J. Vernadsky: On Worobiewite and the Chemical Composition of Beryl. Trans. Musé. Geol. Pierre le Grand, 1908, 11, 81.

BERYLLIUM.—This somewhat rare metal was first detected by Vauquelin in 1797, though it was not till a generation later that it was separated in the metallic state, similar in appearance, weight and many chemical and physical properties to aluminium.

It is an essential constituent of a number of minerals of which the best known is Beryl (silicate of beryllium and aluminium), a mineral recorded, up to the present, from six localities in this State, viz., Yinnietharra Station, Ravensthorpe, Poona, Londonderry, Balingup, and Greenbushes. At Ravensthorpe large pale yellow crystals are somewhat plentiful in an albite pegmatite vein. Green beryl, at times of gem quality, is somewhat abundant at Poona, where it occurs in detrital material, and *in situ* in a pegmatite vein, and in the adjacent biotite schist. At Greenbushes, a few small

† E. S. Simpson: "A Peculiar Biotite (Anomite) from Ubini." Geol. Surv., W.A., Bulletin 48, p. 56.

ZIRCONIUM.—This is one of the least rare of the rare metals and one of the first to be discovered (Klaproth, 1788). The oxide zirconia is considered by Clarke to form two parts in every ten thousand of the solid crust of the earth.* It is an important constituent of one very widely distributed mineral, zircon, and of many much rarer minerals. It is not known in nature in the metallic state. Baddeleyite, an impure oxide of zirconium found only in Brazil, is the chief source of commercial supplies. Zircon is present in all igneous rocks, particularly in granites and syenites. Being very resistant to atmospheric attack, it is detectable in most clays and sands and usually forms an appreciable percentage of titaniferous iron sands and other heavy sands.

Metallic zirconium has been prepared but not put to any practical use except as an alloy with tungsten. The oxide is used for a great variety of purposes; it is, for instance, the chief constituent of the glow of the Nernst lamp, enters into the composition of certain glasses and enamels, is used in Röntgen-therapy, and as refractory material in electric furnace linings, etc.

Zircon has been proved by both microscopic and chemical means to be present in many crystalline rocks in this State. It can be detected in small well-formed colorless or smoky crystals by panning off any of our clays (*e.g.*, Bellevue, Belmont, Mijar) or river or beach sands, especially those sands which show by the presence of black iron compounds that they have been naturally concentrated. Examples of the latter kind are:—

South Perth.—Black sand, estuary beach.
Cottesloe.—White and black sand, sea beach.
Koombana Bay.—Black sand, sea beach.
Nannup.—With cassiterite in river sand.
Greenbushes.—With cassiterite in alluvium of all kinds.
Gooseberry Hill.—Black and white sand, stream.
Donnelly River.—Forms large proportion, and at times the whole of the concentrates from river sand.
Cheyne's Bay.—Abundant in beach sand.

At Greenbushes zircon sand could be produced in commercial quantities as a by-product in tin sluicing. A bulk sample of about 30lbs. weight of such sand was found to have the following composition:—

<i>Zircon sand, Greenbushes.</i>			
ZrO ₂	...	47.63	(Zr, 35.2%)
ThO ₂	...	trace	
TiO ₂	...	17.12	
SnO ₂	...	2.83	
SiO ₂	...	23.84	
CaO	...	.84	
Fe ₂ O ₃	...	6.30	
P ₂ O ₅	...	.83	
Undetermined	...	.61	
			Analyst,
			E. S. Simpson.
			100.00

From this analysis, and from microscopical examination the following mineral composition has been calculated:—

	per cent.
Zircon	about 71
Rutile	11
Ilmenite	12
Cassiterite	3
Monazite	1
Cyanite	traces
Gahnite	"
Magnetite	"
Apatite	"

GERMANIUM.—This very rare metal was first recognised in 1886 by Winkler, and has since been prepared in metallic form in light grey lustrous crystals. It is an essential constituent of one mineral, Argyrodite, a sulphide of silver and germanium. Small proportions occur in Canfieldite, another silver ore, whilst traces have been detected in Euxenite and other tantalum minerals.

Germanium occurs in quite appreciable quantities in the Stibiotantalite from Greenbushes.

* F. W. Clarke: Data of Geochemistry.

VANADIUM.—Vanadium, first discovered in Mexican ores by del Rio in 1801, is one of the few rare metals the presence of which in rocks or minerals in as small proportion as one part in ten thousand can readily be detected with the help of the simplest apparatus. Largely because of this fact it is known to be widespread in small quantities. Clarke† estimates that it forms about one part in every five thousand of the whole earth's crust, but this figure is a rough approximation only. In addition to this wide distribution in small quantities in most rock masses, the metal is concentrated in larger proportion in certain characteristic minerals which form the source of the world's supply of the metal and its compounds. The most important of these minerals are Carnotite (vanadate and uranate of potash) and Vanadinite (chlorovanadate of lead). Other less common minerals are Roscoelite, a vanadium mica, and Pucherite, a vanadate of bismuth, both of which are recorded in Western Australia.

The chief commercial use for vanadium is an addition in small amounts to steel for certain purposes, particularly springs, saws, motor car parts, etc. Several compounds are used in small quantities.

In Western Australia, vanadium has already been proved to be widespread in small quantities, particularly in the ancient greenstones, in the laterites, in the clays, and in coal ashes. In the two first named the proportion present is often far above the average given by Clarke. In many of these the exact proportion has been determined by the usual analytical methods with the following results:—

Laterites—

Turgito laterite, Kalgoorlie (1)	...	V ₂ O ₅ per cent.	0.40
" " " (2)	...		0.45
" " " (3)	...		0.65
Limonite laterite, Kalgoorlie	...		0.15
" " Ora Banda	...		0.10
Turgito laterite, Coolgardie	...		0.55
Bauxite laterite, Gooseberry Hill	...		0.23

Greenstones and Allied Rocks—

Diabase, Mt. Holmes	...	V ₂ O ₅ per cent.	0.09
Gabbro, Boulder, Kalgoorlie	...		0.06
Amphibolite, Mt. Hunt	...		0.04
" Kalgoorlie	...		0.10
" Holl's Gatos	...		0.20
Quartz Epidiorite, Boulder	...		0.25
Epidiorite, Boulder	...		0.08
" Westonia	...		0.04
Propylite, Kalgoorlie	...		0.30
" Boulder	...		0.04
Carbonated Amphibolite, Boulder	...		0.33
Norite, Ora Banda	...		0.12
Porphyrite, Ora Banda	...		0.09

Gold Ores—

Greenstone schists, Boulder	...	V ₂ O ₅ per cent.	0.11, 0.06, 0.12, 0.32
" " Kalgoorlie	...		0.32, 1.21
Crushed Porphyrite, Ora Banda	...		0.41

Traces of vanadium in clays are disclosed by the yellow or green efflorescence of vanadium compounds of potash on the surface of a brick which has for the first time been vetted and then slowly dried. In the laboratory the presence of the same compounds is shown by the bright yellow colour of water which has been made to slowly percolate through a trial briquette burnt at a temperature not exceeding 1,050 deg. C., or thereabouts. In one or other of these ways vanadium has been detected in the following:—

Albany—Brickearth (an estuarine silt), four miles north of town.

Clackline—Fireclay, a granite decomposed *in situ*.

Bellevue—Red brick earths, talus and flood earths.

Belmont—Brown brick and tile clay, sedimentary.

Collie—Brown surface clay.

Jacob's Well—White clay, sedimentary (?).

† Data of Geochemistry.

The ashes from Collie coal contain appreciable amounts of vanadium, the following figures being available:—

Soam.	Proprietary.	Co-operative No. 2.	Cardiff No. 1.	Cardiff No. 2.	Collieburn No. 1.
V ₂ O ₅ per cent.	0.21	0.10	0.07 0.04	0.05	0.02 trace

Several minerals, of which vanadium is an essential constituent, are known in Western Australia, viz.:—

Rosecolite (vanadium mica) and an undescribed chrome-vanadium mica are moderately plentiful in the gold ores at Kalgoorlie and account for the relatively high proportions of vanadium shown in analyses of these ores. An incomplete analysis has been published of this mineral, *vide infra*.

Pucherite (vanadate of bismuth) in small crystals is found in the concentrates from a gold mine at Niagara* (North Coolgardie). Analysis below. This mineral also occurs in a pegmatite vein at Westonia.

Vanadinite (chlorovanadate of lead) has been detected in small yellow crystalline crusts in fractures and vugs in auriferous quartz from Burbanks, Coolgardie, Menzies, Pinyalling, and elsewhere; and in considerable masses associated with pyromorphite at Gregory Ranges.

Vanadium Minerals, W.A.

	Pucherite, Niagara.	Rosecolite, Kalgoorlie. †
SiO ₂ ...	81	43.65
V ₂ O ₅ ...	...	27.11
V ₂ O ₅ ...	25.31	...
P ₂ O ₅ ...	trace	...
Al ₂ O ₃ ...	...	9.95
Fe ₂ O ₃ ...	36	not det.
B ₂ O ₃ ...	73.77	...
CaO ...	...	1.43
MgO ...	...	1.51
Alkalis ...	...	not det.
Analyst ...	100.25 E. Griffiths.	83.65 Pearse.

TANTALUM AND NIOBIUM.—Owing to their wide and comparatively plentiful distribution in this State, these two closely-related metals are of special interest to us. Like many other rare metals they are invariably found in association in offshoots from masses of intrusive granite or syenite. Metallic tantalum has recently been recorded in traces from Siberia, but the only important sources of the metals are the compounds of tantalic and niobic acid with iron, manganese and lime.

Recently the practical utilisation of tantalum in metallic filaments for electric lights and its experimental application in other directions, either in the pure state or as an alloy of steel, have led to a careful search for this metal throughout the world. So far, no use has been found for niobium.

Many details of the occurrence of these metals in the State have already been published by the author,† so that only a brief recapitulation will be attempted here, together with a few notes on more recent discoveries. In brief, it may be said that tantalum minerals containing also niobium have been found over a large area extending

from the North-West to the South Coast, usually in association with tin ore; in fact, hardly a sample of alluvial tin concentrates produced in the State is free from them; some carry more tantalum than tin.

The following are brief particulars of known occurrences starting from the northern part of the State and working southwards:—

TABBA TABBA CREEK.—Tapiolite with more than 80 per cent. Ta₂O₅ is common in alluvial wash in this creek near the Marble Bar railway crossing. See analysis in Table IV.

MOOLYELLA TINFIELD (Moolyella, Tadgebanna and Mud Springs).—Manganocolumbite (niobate and tantalate of manganese) and at times a little manganotantalite (tantalate and niobate of manganese) present in all stream tin concentrates. Quantities actually recorded were 8.5, 13.5, 15.5, and 46.5 per cent.

COOGLEGONG AND ELEYS.—Fergusonite (tantalate and niobate of yttrium, erbium, etc.), appears to be somewhat plentiful in small detrital masses, and in a pegmatite vein. An analysis is given below of a typical fragment. Profs. Wedekind and Maas, of the Strasburg University, have recommended this material as a good basis for the preparation of tantalum and its compounds on a commercial scale.‡ Alluvial euxenite (tantalate, niobate and titanate of yttrium, etc.), columbite and tantalite have been also recorded in small quantities from this district.

LALLA ROOKIE (16 miles north of). Detrital columbite, mostly well crystallised, has been obtained here.

GREEN'S WHEEL.—Columbite and tantalite, much of it well crystallised, have been obtained from here in alluvium and in a pegmatite vein. A small parcel has been marketed. A little microlite (tantalate of lime) occurred in this parcel. See analyses below.

WODGINA.—Over 80 tons of high-grade tantalum ore (Manganotantalite) have been raised in this locality. It is found *in situ* in an albite pegmatite vein and as detrital masses on the slopes of the hills and in the stream beds, in the latter case with more or less tin ore. Manganocolumbite and ixiolite (tetragonal tantalate of manganese) are also recorded from this centre. Analyses are given below.

MOUNT FRANCISCO.—Manganocolumbite is moderately plentiful here in an albite pegmatite and in alluvium.

POONAH.—Several fragments of detrital manganocolumbite weighing up to 13 grammes have been picked out from stream tin ore. The specific gravity averaged 5.7 and the content in Ta₂O₅ varied from 17 to 25 per cent., in Nb₂O₅ from 65 to 57 per cent.

COODABY.—Detrital manganocolumbite is somewhat common close to the outcrop of a tin-bearing pegmatite vein.

YALGOO GOLDFIELD.—A few fragments (weighing from 12 to 43 grammes) of iron columbite have been received from here, exact locality not stated. Average assay Ta₂O₅, 20 per cent; Nb₂O₅, 62 per cent.

LONDONDERRY.—Two large fragments of supposed tin ore found by Fraser three miles west of the famous Londonderry gold mine in 1909 proved to be manganocolumbite carrying 49 per cent. Ta₂O₅ and 34 per cent. Nb₂O₅. Both of these fragments were well crystallised. Later many more small detrital fragments were obtained, ranging in weight from 0.5 to 50 grammes. They were mostly manganotantalite or manganocolumbite in about equal proportions. Several crystalline fragments contained much tin oxide as well as tantalite oxide. These are probably ixiolite.

VICTORIA ROCKS.—Mr. Fraser, the veteran prospector, reports that tantalite occurs at this locality and at intervals between here and his Londonderry find.

BELLINGER.—In a mica vein at this locality a little tantalum ore occurs, ranging from ferrotantalite to manganocolumbite in composition.

FRASER RANGE.—A single specimen of euxenite has been obtained in this Range.

GREENBUSHES.—High-grade tantalite is moderately abundant in a greisen vein and in alluvium at the south end of this tinfield.

‡ Zeitschrift für angew. Chemie, 1910, Heft. 49, S. 2314.

* E. Griffiths: "Notes on Pucherite from West Australia." Jour. Roy. Soc. N.S.W., Vol. XLII, 251.

† Pearse, Bull. Colorado Sci. Soc. No. 8, 1897.

‡ "Tantalum and Niobium in Australia," Rept. Aust. Assoc. Adv. Sci. 1907. "Further occurrences of Tantalum and Niobium in Western Australia," Rept. Aust. Assoc. Adv. Sci., 1909. "Tantalum (in W.A.)," Geol. Surv. W.A. Bull. 50. "Tantalite at Londonderry," An. Prog. Rept. of the G.S.W.A. for 1909, p. 27. "Tapiolite in the Pilbara Goldfield," Mineral Mag. XVIII, 107.

Several tons have been raised for the market. The mineral rarely shows any trace of crystallisation. On splitting some lumps of this ore one finds thin fracture fillings and surface replacements of the tantalite by a yellow resinous crystalline mineral. This is stibiotantalite (tantalate and niobate of antimony), an extremely rare mineral first discovered in Greenbushes by Mr. J. J. East, and only recently found at one other locality in the world (Mesa Grande, California). Stibiotantalite is also found in small quantities in the stream tin ore, as also is tantalite.

Tantalum also occurs at Greenbushes in small amounts in solid solution in the clean cassiterite. A crystal from the South Cornwall lode had the following composition:—

	Per cent.
SnO ₂	97.63
Ta ₂ O ₅	1.76
FeO, etc. ... ..	.61
	100.00

TABLE IV.—Analyses of Tantalum Minerals, Western Australia.

Mineral Locality	Fergusonite, Cooglogong.	Exxonite, Cooglogong.	Microlite, Groon's Woll.	Mn-tantalite, Wodgina.	Ixiolite, Wodgina.	Tantalite, Greenbushes.	Mn-columbite, Poona.
Ta ₂ O ₅	Alluvial. 55.51	Lode. 51.32	21.92	73.54	68.65	70.49	39.48
Nb ₂ O ₅	2.15	4.72	5.53	3.62	15.11	7.63	40.74
SnO ₂	none	.39	none	.90	.48	8.92	.36
TiO ₂	2.20	.31	29.95	...	.40	...	.48
ThO ₂	1.02	.53	1.76	...	...	...	...
SiO ₂ ... ..	...	...	...	...	...	...	...
WO ₃ ... ..	...	...	...	trace	...	...	...
H ₂ O	3.36	3.82	2.82	1.28	.07	.18	.20
FeO	trace	.81	trace	3.64	1.63	1.34	3.07
Fe ₂ O ₃ ... ..	...	...	...	...	...	...	...
MnO ... ..	.87	.74	.34	.60	14.15	10.87	16.00
NiO ... ..	...	...	...	...	trace	...	...
CuO ... ..	...	.18*	...	...	...	...	...
CaO	2.18	4.57	1.02	13.46	trace	.42	...
MgO ... ..	...	...	.35	.42	.15	.37	...
Sb ₂ O ₃ ... ..	...	...	...	...	...	...	...
Bi ₂ O ₃ ... ..	...	...	...	...	...	...	...
Y ₂ O ₃	23.00	18.37	15.76	...	none	...	...
Er ₂ O ₃	8.38	8.98	9.27	...	...	...	...
Co ₂ O ₃ ... ..	.94	3.12	1.82	...	none	...	...
La ₂ O ₃ , Di ₂ O ₃ ... ..	...	...	1.73	...	...	...	...
UO ₂	1.18	2.38	6.69	...	...	...	...
Al ₂ O ₃ ... ..	...	...	.76	...	...	...	...
K ₂ O ... ..	...	...	...	.20	...	...	...
Na ₂ O ... ..	...	...	...	1.66	...	...	...
	100.79	100.24	99.72	99.32	100.64	100.22	100.33

Analyses by E. S. Simpson. * PbO.

TABLE IV—continued.

Mineral Locality	Stibiotantalite, Greenbushes.	Tapiolite, Tabba-Tabba.	Exxonite, Cooglogong.	Mangano-columbite, Poona.	Mangano-tantalite, Ubini.	Ixiolite, Londonderry.	Mangano-tantalite, Wodgina.
Ta ₂ O ₅	51.95	82.55	47.31	39.48	68.24	74.39	69.63
Nb ₂ O ₅	4.49	1.37	3.83	40.74	14.38	3.18	12.38
SnO ₂ ... ..	...	.34	.14	.36	.26	10.04	.90
TiO ₂ ... ..	...	.18	14.17	.48	Nil	.12	.25
ThO ₂ ... ..	...	...	traces	...	...	...	...
SiO ₂	3.14	...	.90	...	...	...	.36
WO ₃ ... ..	...	...	...	...	...	...	...
H ₂ O ... ..	.61	.31	2.40	.20	.28	...	.31
FeO ... ..	...	10.69	1.06	3.07	2.02	.59	2.05
Fe ₂ O ₃ ... ..	.39	.83	...	...	...	...	.04
MnO	trace	1.49	.35	16.00	15.19	12.04	12.71
NiO	trace	...	...	...	...	...	...
CuO ... ..	.20	...	...	...	...	...	...
CaO ... ..	...	1.96	2.22	...	Nil	Nil	1.63
MgO ... ..	...	.10	...	...	Nil	Nil	.10
Sb ₂ O ₃	38.04	...	...	...	...	...	...
Bi ₂ O ₃ ... ..	.79	...	...	...	...	...	...
Y ₂ O ₃ ... ..	...	...	...	...	Nil	...	...
Er ₂ O ₃ ... ..	...	...	17.48	...	Nil	...	...
Co ₂ O ₃ ... ..	...	...	7.22	...	Nil	...	...
(La, Di) ₂ O ₃ ... ..	...	...	...	...	...	...	...
UO ₂ ... ..	...	...	3.35	...	...	...	...
Al ₂ O ₃ ... ..	...	...	...	...	...	...	.01
K ₂ O ... ..	...	...	...	...	...	...	...
Na ₂ O ... ..	...	...	...	...	...	...	trace
PbO ... ..	...	...	trace	...	...	...	...
	99.61	99.82	100.43	100.33	100.37	100.36	100.37

† 95lbs. sample. Stibiotantalite analysis by G. A. Goyders, other analyses by E. S. Simpson.

MOLYBDENUM.—This was one of the earliest of the rare metals to be discovered (Scheele, 1778), principally because the pure sulphide of the metal, molybdenite, is a very characteristic mineral, occurring somewhat widely distributed in small quantities, usually in close association with granitic rocks. A few other much rarer minerals are known containing this metal as an essential constituent, whilst scheelite, a tungsten ore of commercial importance, contains molybdenum in proportions ranging from traces up to six per cent.

For some years past molybdenum has been used as a constituent of steel for tools, big guns, propeller shafts, etc. Quite recently the very pure metal has been produced in the form of ductile wire, which is already being used for winding electric furnaces, as supports in metallic filament lamps, etc. Ammonium molybdate is a salt of considerable commercial importance. Present indications point to a rapid increase in the use of metallic molybdenum and its consequent translation from the ranks of the rare metals to those of the commercially common metals.

With the immense areas of granite exposed in this State, molybdenum would be expected to be widespread. Already it has been detected in many localities, the list of which is being yearly added to. Details of its occurrence follow:—

CALLE SPRING (Murchison G.F.).—Molybdenite in small and large masses in quartz stringers and adjacent granite, associated with wolfram and scheelite.

MELVILLE.—Numerous small flakes of molybdenite in quartz.

MULGINE.—The occurrence of molybdenite at Mulgine is of considerable interest in that up to the present the entire commercial supply of the mineral in Western Australia has been obtained from this locality.

The locality where operations have been carried out lies on the western slope of Mount Mulgine and about 180 feet below the Trig. Station, or about 100 feet above the level of the main creek which crosses the western boundary of mineral lease M.L. 39 "Westonia." The discovery of molybdenite at this locality first came under the notice of the Department in 1915, with the receipt of a sample of ore at the office, which assayed 6.2 per cent. of molybdenum sulphide; molybdenite, however, had previously been reported from Gullewa, some distance to the north, where quartz, containing from 1.04 to 2.60 per cent. of molybdenum sulphide, occurred, indicating clearly that this western portion of the Yalgoo Goldfield lies in what may be called a molybdenite belt or zone.

Mount Mulgine itself is made up of an acid greisenised microcline-muscovite granite of varying texture, intersected by a network of veins of quartz and pegmatite, which when viewed broadly have a general north-westerly trend, and where seen in section are practically vertical. The granite, in addition to invading the neighbouring basic rocks, is traversed by several narrow dolerite (?) dykes which have a general north-easterly trend, and intersect both the quartz and pegmatite veins. The granite is made up of large quantities of quartz, microcline, oligoclase with muscovite and some pyrites. The feldspars are occasionally almost entirely kaolinised. The accessory minerals in the granite are zircon, epidote, zoisite, apatite, tourmaline, ilmenite (or magnetite), and chrysocolla. The coarser pegmatites are made up mainly of microcline, quartz, and muscovite, and contain kaolin and pyrites in addition to small quantities of limonite and ferrimolybdate. The molybdenite occurs in the quartz and the pegmatite veins as well as in the granite itself; generally it is found in flakes which vary in size from minute specks to irregular masses, sometimes, though rarely, about half an inch in diameter. The molybdenite often appears as crusts in which the flakes lie in radiating groups, producing small rosette-like forms. In some cases the molybdenite is associated with, and occurs in, large masses and ill-defined crystals of iron pyrites. Occasionally, though not often, molybdic ochre having the characteristic yellow colour and a fibrous structure is to be noticed occurring in the glassy quartz associated with damourite (?), whilst in some of the pegmatites there occurs ferrimolybdate, the only common alteration product of molybdenite.

Seldom, however, has the mineral been found so coarsely divided that it may be hand-picked; one solid vein, however, upon which operations had principally been confined, was about half an inch in thickness and occurred in the granite, which latter also contained molybdenite disseminated through it, though in quantities which were governed by the distance from the vein itself.

The quantity of molybdenite to be found is at present difficult of determination owing to the very unequal distribution.

COOLGABIE.—Molybdenite, a few small specimens embedded in amphibolite.

BULLABULLING.—Molybdenite moderately plentiful in small quartz leaders in granite.

THE TERRACES (Mt. Margaret G.F.).—Small flakes of molybdenite plentiful in quartz leaders in granite.

SOUTHERN CROSS.—Molybdenite flakes and crystals in quartz veins.

SWAN VIEW.—Small masses of molybdenite plentiful in solid grey granite.

MAHOGANY CREEK.—Small masses of molybdenite in a pegmatite vein. The mineral altered near the surface to powellite (molybdate of calcium).

CLACKLINE.—Small flakes of molybdenite in quartz. At surface a little molybdic ochre.

BLACKBOY HILL.—Small flakes of molybdenite in quartz.

WAGIN.—Small flakes of molybdenite in quartz.

BULDANIA.—Single specimen showing a mass of molybdenite in greenstone.

RAVENSTHORPE (near).—Flakes of molybdenite in quartz.

Scheelite is moderately abundant in this State, but none of it has ever been examined with a view to determining the possible presence of molybdenum in it.

URANIUM AND RADIUM.—Uranium, one of the first of the rare metals to be discovered, and Radium, one of the latest, have no resemblance in chemical properties. They are, however, conveniently considered together as in Nature they are invariably associated, usually in the ratio of one part by weight of radium to each three million parts by weight of uranium. The reason for this constant association proves to be that radium is one of the products of disintegration of uranium.

Metallic uranium is so far only of scientific interest. Compounds of it are in use in photography, analytical chemistry, enamelling and glass making. The chief demand for uranium compounds at present, however, is for the sake of their contained radium.

Radium, the most interesting, most rare, and most precious of all metals, has only been prepared in minute quantities as a scientific curiosity. Its compounds, however, particularly the bromide, are in strong demand for therapeutic and experimental purposes.

Uranium, with its accompanying traces of radium, is present in minute traces in all rocks and mineral waters. The commercial supply of the metals comes from several minerals carrying several parts per cent. of uranium, whose habitat is the pegmatite veins associated with intrusive granite or syenite. One uranium mineral, Carnotite, is found in economically important quantities in sandstone in Colorado. The best known and richest ore of uranium is Pitchblende or Uraninite (oxide of uranium).

Neither pitchblende nor carnotite have been located as yet in W.A. The State, however, is not devoid of uranium ores, as the following notes show.

Known occurrences are:—

COOGLEGONG.—Detrital Fergusonite somewhat plentiful, carrying 1.18 per cent. UO_3 , equal to 0.98 per cent. uranium, and about three and a-half milligrams of radium per ton. Detrital euxenite rare, carrying 6.69 per cent. UO_3 , equal to 5.57 per cent. uranium and about two centigrams of radium per ton. See also page 8.

WODGINA.—An important and interesting deposit of uranium ores occurs here in an albite pegmatite vein. The minerals present are mackintoshite, thorogummite and pilbarite, all of them hydrous silicates of uranium, thorium and lead, of which analyses are appended. When pilbarite was first discovered it was recognised that it was a surface alteration product of some as then unknown deep-seated mineral or minerals. The parent mineral, mackintoshite, and an intermediate product, thorogummite, have since been encountered at Wodgina, and a full description of them has now been published.*

Briefly, the primary mineral, mackintoshite, is black, subvitreous and massive. It carries 35.60 per cent. UO_2 , partly oxidised to UO_3 by incipient development of the intermediate mineral, thorogummite. The latter is bright yellow, vitreous and massive. It carries 37.33 per cent of UO_2 . The final product of weathering, pilbarite, is granular massive, bright yellow in colour, but with dull lustre. It carries 27.09 per cent. UO_2 .

All three minerals contain radium in the following estimated proportions:—

Mackintoshite,	11	centigrams per ton.
Thorogummite, 11	"	"
Pilbarite, 7	"	"

Such quantities of radium might well be expected to more than pay for the cost of extraction, even though the process is complicated by the presence of so much thorium, which in its turn would form with uranium oxide a valuable by-product.

The composition of these minerals is as follow:—

Uranium Minerals, Wodgina, W.A.

—	Mackintoshite.	Thorogummite.	Pilbarite.
UO_2	present	37.33	27.09
UO_3	35.60	none	none
ThO_2	24.72	24.46	31.34
Ca_2O_3 ... ..	.10	.12	.19
Y_2O_3 ... ..	.25	.32	.49
Al_2O_3	trace	trace	.15
Fe_2O_3 ... ..	...	trace	.20
FeO ... ..	.20	...	...
PbO	7.90	7.78	17.26
CaO	1.28	1.62	.57
MgO ... ..	.15	.16	.21
MnO ... ..	.07	none	none
K_2O ... ..	...	...	.09
Na_2O ... ..	...	...	.04
SiO_2	16.19	15.30	12.72
P_2O_5 ... ..	...	...	1.08
Ta_2O_5 ... ..	.67	.40	.47
H_2O +	12.04	8.37	4.16
H_2O — ... ..	.88	4.19	3.50
Radium and Radium	present	present	present
	100.05	100.05	99.56
Sp. gr	4.45	4.13	4.68
Analyses by E. S. Simpson.			

* E. S. Simpson: "Radium-uranium Ores from Wodgina," Geol. Surv. W.A., Bull. 48.

PLATINUM AND THE PLATINOID METALS.—The noble metals of the platinum group form two sub-groups, viz.:—

(a) Platinum, iridium, and osmium;

(b) Ruthenium, rhodium, and palladium.

They are invariably found associated with one another near the outcrops of rocks of a basic or ultrabasic type. In this and in many other respects they differ from all other rare metals, particularly in that they occur almost invariably in the metallic state uncombined with non-metallic elements. The only natural compounds are Sperrylite (platinum arsenide) and Lanrite (ruthenium sulphide). All the metals of this group are "noble" metals, i.e., particularly resistant to the action of the air and most common chemical agents. Platinum was first described in 1755, the other metals in the group have been known since early in the 19th century.

Platinum is by far the most abundant of these metals and is indispensable to many industries and arts. Its demand for jewellery and for acid and for fire-resistant chemical ware, for the manufacture of sulphuric acid, and for electrical purposes, is very large, three-quarter million pounds' worth being used in the United States alone during 1910.

Iridium is the next most important of these metals, being largely alloyed with platinum to harden and strengthen it.

Osmium, palladium and rhodium are utilised to a small extent. Ruthenium, the least abundant of these metals, has no practical application. Alloys of palladium and rhodium with gold are used as substitutes for platinum in chemical operations.

None of these metals has yet been proved to occur in this State, though ultrabasic rocks, the *fons et origo* of such metals, are fairly common and widespread, as, for example, at Kalgoorlie, Northam and Soanessville. A good platinum deposit would be worth infinitely more at the present time than a correspondingly rich gold deposit.

The author has at times looked for platinum in various ores and black sands from localities in which highly basic rocks are known to exist, and from other likely localities such as Kalgoorlie, Cossack, Kundip, and Golden Valley. Although the method employed (Mingaye's) should serve to detect, on the charges of ores taken, amounts as small as four grains to the ton, none of this metal has yet been recognised in any of these ores.

CONCLUSION.

In this short sketch of the Rare Metals and their distribution in this State sufficient facts have been adduced to show that Western Australia is a province liberally endowed by Nature with those rare metals which are commonly associated with granitic rocks. In this respect it appears to differ entirely from Eastern Australia, being worthy of rank with such famous repositories of these metals as Norway, Madagascar and certain areas of the United States. Many of these metals are already not only of great scientific interest, but also of high economic importance, and doubtless others will become so in the near future as the results of the world-wide experimentation in this direction. With regard to the other rare metals, with few exceptions, practically nothing is known of their occurrence in this area, because diligent search for them has not been made. Doubtless, however, time will prove that we have been endowed with a goodly heritage of these also.

Relation of the Law to Prospecting

And

Mining in Western Australia.

By

J. T. Jutson.

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State Assistance to Mining.

Conclusion.

Extract from
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1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

Relation of the Law to Prospecting and Mining in Western Australia

By
J. T. Jutson.

CHAPTER VI.

RELATION OF THE LAW TO PROSPECTING AND MINING IN WESTERN AUSTRALIA.

By J. T. Jutson.

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I.—INTRODUCTION.

This article is written mainly as a guide to prospectors and working miners with regard to the general mining law of the State, and to the procedure necessary to obtain and maintain the various kinds of mining rights existing under such law. It makes no pretensions to being a legal treatise, nor to cover the whole of the law relating to mining in Western Australia. It is a summary rather than a commentary. The writer's aim has been to put in as plain language as possible what prospectors and working miners may desire to know, but in treating of such technical matters, this is extremely difficult to do consistently with accuracy and statements of detail.

It is believed that the work may be of some service to others than the class for whom it is specially written.

This article may be taken as summarising the law relating to the various matters dealt with up to the 30th June, 1917.

In the preparation of this work, the writer desires to acknowledge the assistance he has received from Mr. A. Gibb Maitland, the Government Geologist, and from the officers of the Mines Department at Perth.

II.—SOURCES OF THE LAW AND ABBREVIATIONS USED.

The following are the principal sources of Western Australian mining and related law with any abbreviations, subsequently used throughout this article:—

TITLE OF ACT OF PARLIAMENT, REGULATIONS, OR OTHER PUBLICATION.	Abbreviation.
<i>Western Australia Constitution Act, 1890</i> (an Act of the British Parliament).	W.A.C.
<i>Act 40 Victoria, No. IX., 12th September, 1876.</i>	
<i>Mining Act, 1904.</i>	M.
<i>Mining on Private Property Act, 1898</i> (the unrepealed portion, which relates to the Hampton Plains Estate alone).	M.P.P.
<i> sluicing and Dredging for Gold Act, 1899.</i>	S.D.G.
<i>Mining Development Act, 1902.</i>	M.D.

Where there is no marginal abbreviation, the Act has usually not been quoted.

R.M. 73 (as amended). The applicant also marks off and applies for the land as a claim (Registration fee 5s.). Presumably any kind of a claim can be applied for according to the nature of the ground or the mineral sought. The Warden obtains a report, and the applicant may be asked to lodge a sum of money to cover any damage either to the land applied for or adjoining land, or the adjoining owners' consent may be required. Further moneys to satisfy other possible damage to adjoining lands may have to be deposited. The penalty for breach of any special conditions is up to £50 in addition to liability to forfeiture of the holding. The claim is liable to cancellation if the holder ceases to hold a miner's right for 30 days, and also if it is considered that the occupation of the land for mining purposes cannot be further maintained without injury or obstruction to the enjoyment by the public of the same. (See also below "Leases of Reserves and Authorised Holdings," where, amongst other matters, section 277 of the Mining Act, 1904, which relates to reserves, is summarised.)

R.M. 19. (E) REWARD LEASES OF CROWN LANDS.

Instead of accepting a reward claim, a discoverer of payable gold or mineral can apply (fee, 10s.) for a reward lease, if the ground is not exempt from leasing.

If the application is granted, the area and term are not to exceed that of an ordinary mining lease for the same metal or mineral, and the lease must not be within a mile from any mine for the same metal or mineral, the mine to be working or to have worked within the six months preceding. A reward lease may be exempt from rent for a period not greater than five years, the length of time for such non-payment to be according to distance from the nearest mine. No survey fee is payable. There are certain restrictions while the rent is remitted as to transferring and mortgaging, etc. The labour conditions and rights of exemption are the same as in an ordinary mining lease for the same metal or mineral.

See under Coal-mining Leases for a lease with special privileges for the discovery of payable coal (this page).

S. 42, M. S. 47, M. (F) GOLD-MINING LEASES OF CROWN LANDS.

These leases are, as the name indicates, principally for gold. After the approval of the application for lease, the holder has the exclusive right of mining for gold and other minerals (both lode and alluvial).

S. 43 (1), M. Land likely to contain alluvial gold is exempted from lease, except land worked and abandoned, land that may be too deep or wet or too costly to work, and land that otherwise should not be exempt.

S. 43 (2), M. Land occupied under a miner's right is also exempt unless the holder consents, but any such land, except that held as a claim, may be leased either on payment of compensation for improvements to such holder, or for mining below the surface as provided by the Mining Acts and Regulations.

S. 44, M. R.M. 80. The area comprised in any one lease is not to exceed 24 acres, except in the case of alluvial gold land which has been already worked and abandoned, or which is very deep or wet or costly to work, in which cases the area allowed can be up to 48 acres. The length of a lease is not, where practicable, to exceed twice the width.

S. 45 and 46, M. The term is 21 years or less, but may be renewed. The rent after the first year is £1 per acre per annum, and 5s. per acre for the first year unless £1 per acre be fixed. In the case of worked and abandoned land, or deep, wet, or costly working land, as mentioned above, the rent runs from 5s. to £1 per acre per annum. Fee on issue of lease, £1.

S. 42, M. S. 114, M. No Asiatic or African alien can hold a lease.¹ A leaseholder or an applicant for a lease need not hold a miner's right.

(See also below "Mining Leases (of Crown lands) Generally" for further information, page 13.)

(G) MINERAL LEASES OF CROWN LANDS.

These comprise leases of any minerals except gold. They include coal, oil, and precious stones. It will be as well to divide them into mineral leases (other than coal and oil), and coal and oil leases. Fee on issue of all mineral leases, £1.

¹ See further above "Who may hold miners' rights, mining leases, etc.," (page 7).

(1) MINERAL LEASES, OTHER THAN COAL AND OIL.—S. 48, M. These leases are granted for mining for any mineral except gold (but see below as to gold being found on the lease). The mineral or combination of minerals to be worked is specified in the lease.

Land consisting of payable alluvial ground will not be leased unless similar conditions to those mentioned under gold mining leases apply. Land occupied under a miner's right is also exempt without the holder's consent, unless the conditions set out in the Act, which are similar to those already mentioned under gold-mining leases, are complied with.

Area.—The maximum allowed for one lease is: For S. 50, M. precious stones, 24 acres; for other minerals, 48 acres R.M. 80. (except as now mentioned); for minerals in abandoned, deep, wet, or costly to work ground, 96 acres. The length of the area as far as practicable is not to exceed twice the width.

Term.—21 years or less, but it may be renewed. S. 53, M.

Rent.—Five shillings per acre per annum, except for S. 54, M. abandoned, deep, wet, etc., ground already referred to, when it may be reduced, but it is not to be less than 2s. per acre.

If gold is found on the lease, royalties of 1s. or 10s. per ounce of gold, according to its payability, become payable, or the lease may have to be surrendered, and a gold-mining lease taken up (see Sections 57 and 58, Mining Act, 1904). The discovery of gold must be reported.

Permission to mine for any mineral other than that specified S. 59, M. in the lease is necessary. Fee on application, 10s.

Asiatic and African aliens are prohibited from holding S. 48, M. mineral leases. (See also above as to others.)

A leaseholder or an applicant for a lease need not hold a S. 114, M. miner's right. (See below "Mining Leases (of Crown lands) Generally" for further information, page 13.)

(2) COAL AND OIL LEASES.—Except as specially noted here, the statements under "Mineral Leases other than Coal and Oil" apply to this class of lease.

In ordinary cases, the area of one coal-mining lease is S. 52, M. not to exceed 320 acres, but any number of such leases can R.M. 80 (a).

be taken up. When, however, a miner, who holds a prospecting area, discovers payable coal at a distance of not less than 15 miles from any payable coal previously discovered, or discovers a payable seam of coal 600 feet or more deep from the surface, he is entitled to a reward lease of 640 acres, if available, free of royalty for 10 years.

S. 56, M. R.M. 80 (b). Thereafter the royalty as to all coal raised in the first-mentioned case, and in the second, as to all coal raised from below 600 feet, is at the rate of one penny per ton. "Payable" coal means coal of such thickness and quality that it can be worked under ordinary circumstances at a profit. Under a reward lease the rent may be also remitted for a certain period.

In ordinary cases the royalty under a coal-mining lease S. 55, M. is at the rate of threepence per ton during the first ten years of the lease, and sixpence per ton thereafter.

The rent of a coal-mining lease is sixpence per acre per annum. S. 55, M.

Coal-mining leases owned by the same lessee may be amalgamated up to 2,560 acres where the seam is not below 1,000 feet, and up to 5,120 acres where the seam is below that depth. S. 58, M.

As to certain conditions in regard to cutting timber on coal-mining leases, see Regulations 205a and 205b under the Mining Act, 1904. R.M. 205a, 205b.

The remarks as to gold and other minerals, made under "Mineral Leases other than Coal and Oil," and as to the term of the leases apply to coal-mining leases.² (See below "Mining Leases (of Crown Lands) Generally" for further information, page 13.)

¹ See above under "Lodes and Mineral Deposits" as to the definition of alluvial when applied to minerals other than gold, and as to "payable quantity" or "payable" when applied to gold or other minerals, see footnote under "Prospecting Areas on Crown lands" (page 9).

² For the legal definitions of "coal" and "oil," see above "Prospecting Areas on Crown lands." (Page 9.)

³ No oil leases have yet been issued by the State.

(II) GOLD MINING AND MINERAL LEASES OVER LAND IN MINERAL CLAIMS.

R.M. 40b.

The holder of a prospecting area of any land comprised in a mineral claim¹ can apply for a lease (or a claim) of any of the land for the working of gold or a mineral other than that for which the mineral claim has been granted. The mineral claim holder may then be required to surrender such portion of his claim as the Minister thinks necessary for the working of such gold or mineral deposit; but such surrender is not to be made (a) unless the Minister is satisfied by report from a professional officer that the gold or mineral deposit exists; or (b) until reasonable notice has been given to the mineral claim holder; or (c) without the latter's consent until three months' notice to him (or such longer time as the Minister thinks reasonable) has expired, unless the area shall have been previously worked out by the mineral claim holder.

In the event of surrender being required as above, only such parts of the mineral claim will be taken as the Minister thinks necessary for the proper working of the gold or mineral deposit, and not for machinery or other purposes. If the discovery of the mineral is the direct result of the work of the mineral claim holder, the latter has a preferential right for 14 days after the discovery to apply for a mining lease or leases.

The marking off and mode of application, etc., are the same as for an ordinary gold mining or mineral lease.

(I.) LEASES OF RESERVES AND AUTHORISED HOLDINGS.

S. 61, M.

Mining leases are issued (fee on issue, £1) of land comprised in a townsite, suburban area, or other reserve, or in an authorised holding. (The latter term means any mining tenement except a lease, an application for a lease, or a claim.) The holder, however, is not to disturb the surface of any street, road, or other reserve or to do anything that may affect their use, without authority under the lease or from the Minister. A lease as regards any land comprised in an authorised holding is to be considered to be of the mines under such land, and not of the surface. But the latter may on certain conditions, and on compensation being arranged, be resumed or used.

S. 62, M.

No mining is to be within less than 40 feet of the surface (except of course such surface as is granted for working), but a greater depth than this can be fixed in order to protect any buildings. The holder of the lease is bound to make good any subsidence caused by the mining, and to pay damages for injury thereby caused. The rent is the same as for a gold mining or mineral lease according to whether the lease is for gold or other minerals.²

S. 277, M.

The holder of a mining tenement lying under any railway reserve or under land resumed for railway or tramway purposes is not to mine under such reserve or resumed land without giving at least 14 days' written notice to the Minister, who fixes such terms as he thinks necessary for the public safety, and these terms must be observed. The Government on being asked by the holder, and at his expense, can deviate any railway or tramway to allow for the working of any lode or reef.

(J) TRAMWAY, MACHINERY, WATER, AND RESIDENCE LEASES OF CROWN LAND.

S. 42, 48, M.

In addition to the ordinary gold-mining and mineral leases, leases may be issued (fee, £1) for (1) tramways, etc., (2) machinery, (3) water, and (4) residence. They are not, strictly speaking, mining leases (although they may conveniently be included in that general term), but they are usually required, and generally will only be issued in connection with mining operations. These leases must be marked out and applied for similarly to an ordinary gold-mining or mineral lease.

¹ See above under "Prospecting Areas on Crown Lands" (3) and "Mineral Claims" (page 11).

² See also above "Claims on Reserved and Exempted Crown Lands" (page 11).

The conditions as to survey, objections to the application, transfer, mortgage, etc., forfeiture, and other matters relating to ordinary gold mining or mineral leases, except the special labour conditions of such ordinary leases, apply to these tramway, etc., leases. The lessee must use the land for the purpose for which it is granted, and carry out any conditions of the lease and the regulations under the Act. S. 79, M.

Exemption from the conditions of holding may be applied for in the usual way.

The rent is at the rate of £1 per acre, or fraction of an acre, per annum. The term is up to 21 years, and the area up to 24 acres.

The following describes the purposes for which leases of the kind referred to may be granted:—(1) Cutting and constructing on the land, water-races, drains, dams, reservoirs, roads or tramways to be used in connection with mining. (2) Erecting on the land any buildings or machinery to be used in connection with mining. (3) Boring or sinking for, pumping or raising water. (4) Residence in connection with mining.


Leases of the kind here referred to are akin to the Residence, Business, and Machinery Areas, and the Water Rights described below. Companies usually prefer leases on account of the larger areas that can be taken up.

(K) MINING LEASES (OF CROWN LANDS) GENERALLY.¹

The land must be marked out and applied for in accordance with the Regulations (Details are given below under "Procedure.")

If there is more than one application for a lease of the same land, the applicant who has first properly taken possession and marked out the land has priority. S. 66 (2), M.

Pending the application being dealt with, the applicant holds the land, but at any time before the approval of the lease, any miner can enter to search for alluvial gold or alluvial minerals, but only on an area not larger than an ordinary alluvial claim, which must be marked off in the usual way, and the ordinary labour conditions of such a claim then apply. S. 67, M.

Notice in the proper form must be given to the applicant for the lease, who then has the right to mark off up to one-eighth of the total area as a site for buildings, shafts, etc., the area to be marked off to be in the form of a rectangular parallelogram, which is as drawn,  and the length not to exceed twice the breadth. R.M. 101.

Except as just mentioned, and for the purposes of marking out and posting notices, any person entering upon land applied for as a lease is a trespasser. R.M. 100.

Applications for leases are heard by the Warden in open Court, and objections in the proper form can be lodged against the granting of a lease. The Warden hears the matter and then makes a recommendation to the Minister. S. 68, M.

A survey by a Mining Surveyor is required, usually before approval of the lease. S. 69-75, M. R.M. 82-89.

The Warden can postpone an application up to 12 months if he believes that the land contains or is likely to develop alluvial. S. 71, M. R.M. 85, 88.

It is purely within the discretion of the Crown to grant a lease. It cannot be forced to do so. S. 75, M.

An application for a lease may be postponed, but in the meantime the applicant can sometimes obtain permission to work the reef or lode, but during the same time the right of other miners to search for alluvial holds good. S. 77, M.

If the ground applied for as a lease is withheld as alluvial ground, the applicant can obtain an alluvial reward claim for any new discovery of alluvial that he makes within the boundaries. S. 78, M.

The holder of a lease is bound to carry out the conditions of the lease, including payment of rent, to use and work the land bona fide and in accordance with the regulations, not to transfer, sublet, mortgage, etc., or part with possession of the land without consent in writing, not to mine under any railway reserve or under land resumed for rail- S. 79, 81, M. S. 277, M.

¹ Most of what is said here applies to Tramway, Machinery, Water, and Residence Leases of Crown Land, except as regards the special labour conditions.

² The approval of a lease is published in the Government Gazette.

way or tramway purposes (except upon notice to and under conditions fixed by the Minister). *Forfeiture* is always possible for breach of conditions.

R.M. 190. A *tribute agreement* can be entered into without consent, but the agreement or a verified copy must be lodged with the Warden or Mining Registrar within 28 days from date of signing. Tribute agreements are dealt with separately below.

S. 81, 84, M. All *transfers, mortgages, etc.*, are required to be registered (fee £1 for each lease), and persons dealing with the registered holder are not affected by unregistered interests except in the case of fraud.

R.M. 208. The holder of two or more adjoining leases (except coal mining leases¹) with a total area of not more than 96 acres may *amalgamate* them, but amalgamation cannot take place if the length of the reef or lode exceeds 66 chains in the case of a gold mining lease, or 90 chains in a mineral lease; but without permitting any further length of reef or lode, the Minister has discretionary power to permit amalgamation beyond 96 acres, if it is necessary to have a larger area to follow, within the boundaries of the lessee, the reef or lode on its underly to a depth not greater than 3,000 feet measured on the underly. The Minister can impose conditions as to method of working etc. Any amalgamation of leases (including coal-mining leases) may be cancelled on the lessee's request, or on the transfer, surrender, or forfeiture of any lease in the amalgamation. Amalgamation only extends to the labour covenants, and the labour required for the aggregate area is the total of the separate leases. (Fee for amalgamation of leases, each £1.)

R.M. 90. *Labour Conditions*.—A lease must be efficiently worked (unless exemption or partial exemption has been granted) on every working day after 30 days from the date of posting at the Warden's office of the *Government Gazette* containing notice of the approval of the lease. (What "efficiently worked" means is set out in Regulation 166 of "The Mining Act, 1904.") *Coal and oil leases* require not less than one man for every 60 acres or fraction of same for the first 12 months, not less than two men for every 60 acres or fraction of same for the second 12 months, and not less than three men for every 60 acres or fraction of same for every succeeding year. *Gold and mineral leases* of abandoned, deep, wet, or costly to work ground (as before described) require at least one man for every 12 acres or fraction of same. *All other leases* require not less than two men for the first 12 months, and thereafter not less than one man for every six acres or fraction of same. No lease is to be worked by less than two men.

S. 91, M. *Exemption from labour covenants*.—Total or partial exemption from the labour covenants of any mining lease may be granted. There are two kinds of exemption. One is at the Minister's discretion, and the other is of right, that is, provided the conditions are observed, exemption cannot be refused.

R.M. 154-157. The first one may be granted on various grounds, including want of capital, time for erection of machinery, influx or scarcity of water, scarcity of labour, collapse of working shaft, temporarily unworkable character of the mine, death of owner, necessity of absence, sickness, dispute as to title, bankruptcy proceedings pending, desire to concentrate on a particular lease or leases where several held. The Warden can grant exemption up to one month, but beyond that—up to six months in all—the Minister decides. A special license may be issued by the Minister, dispensing with the continuous working of a coal-mining lease up to six months, with possible renewals if he is satisfied that reasonable efforts have been made to work the same, and that continued working would result in unnecessary loss. (Fee 2s. per month for each lease, with a minimum fee of £7.)

S. 93, M. The second kind of exemption (as of right) is granted for varying periods of three, four, six, and twelve months, according to the kinds of owners, the periods of previous consecutive work, and amounts expended on machinery. The Minister can also lay down the conditions as to tribute, except in the main workings² of the lease. The application for exemption

¹ As to the areas of amalgamated coal-mining leases, see above under "Coal and Oil Leases" (page 12).

² In the event of dispute, the Minister decides what are "main workings."

must furnish the information required by the Act and the Regulations. S. 94 M.

It is necessary in all cases to see that on the application for, and after the grant of exemption, the Regulations are complied with. They cannot be set out here. R.M. 155-159.

Fees for exemption: For each lease, not exceeding 14 days, 10s.; not exceeding one month, £1; for each additional month, £1.

Forfeiture of leases.—When the conditions of a lease are not carried out the latter is liable to forfeiture, but except for breaches relating to labour or to the inspection or working of the mine, notice is given to the lessee requiring the breach to be remedied. A fine may sometimes be imposed as an alternative to forfeiture. Forfeiture may at times be cancelled and re-instatement take place on terms that the Government fixes. S. 96-98, M. R.M. 91, 161-170, 214. S. 79 (c), M. R.M. 91.

A miner can *apply for forfeiture* of a lease on the ground that it is not being worked³ in accordance with the regulations. S. 99-106, M. R.M. 99, 104, 165.

He may be required to deposit £10 if the lessee lodges an answer. Notice must be given and other conditions observed. The Warden hears the matter in open Court, and he may dismiss the application or recommend to the Minister forfeiture or fine. The matter is finally dealt with by the Government, who, if it forfeits the lease, may give to the applicant the first option of a lease, or may otherwise deal with the same as set out in section 105 of the Mining Act, 1904. Pending the application for forfeiture, the conditions of the lease need not be complied with. Forfeiture for failure of the labour conditions is not to take place if such failure is caused by a general strike among the persons engaged in mining in the district. R.M. 165.

On forfeiture a lessee can remove the plant and machinery within the fixed time. Failure to do so may result in the Minister directing a sale of it. Timber used to support shafts, drives, etc., in the mine is not to be sold, removed, or destroyed. S. 107, M. R.M. 93.

Even without forfeiture a lessee must not remove any props or timber so as to endanger the workings of any other lease or to obstruct ventilation between two adjoining leases without the consent of the lessee affected. R.M. 205.

Tailings on land of void lease.—If a lease is surrendered (except a surrender to obtain a new lease), or runs out by length of time, or becomes forfeited, and the lessee does not within six months (or such further time as the Minister may allow), either remove or *bona fide* treat and continue to treat any tailings or other mining material upon the land, such tailings or material become the property of the Government, unless the lessee applies to occupy the land, and pays a fixed rent. If the tailings or other material do become Crown property, a *license* (for a period up to 12 months with a possibility of renewal) may be granted to another person to remove or treat the same. (Fee, 10s. per month during the term of the license.) S. 109, M. R.M. 94.

Subject to such license, gold mining or mineral leases may be granted over the land occupied by the tailings or other material. (For method of application for license, etc., see below and Regulation 94.) S. 110, M.

Resumption.—When the total area held under adjoining mining leases, owned by the same lessee and worked as one mine, or the area of a mineral lease (except coal mining leases) exceeds 48 acres, any portion of the excess can be resumed by the Government for residential or other purposes, except mining, without compensation. S. 111, M.

This power can, however, only be used if the nearest point of the resumed land is over 300 yards distant from the outcrop of any reef or lode, or ore reduction works, on the leases, and if the authorised officer of the Government reports that the land is not likely to be required for mining or by the lessee in connection with mining purposes. Any person occupying the resumed land has no redress against the lessee for any nuisance, damage, or inconvenience caused by noxious fumes derived from ore treatment, or from other work, or from flow of water from mining operations, if the water is discharged as far as possible into its natural channel.

Coal-mining leases are exempt from this power of resumption under section 111 of the Mining Act, 1904.

³ See *The Crown v. Forster* W.A.L.R. 11 (1912), 72.

⁴ This refers to the labour conditions.

S. 112, M. A lessee has the right, with the approval of the Minister, and subject to the regulations, to *discharge water* from his lease land over any adjacent land through any natural channel. No person is to obstruct any such flow.

S. 113, M. A lessee with the Government's consent can *surrender* his R.M. 98. lease at any time.

S. 278, 279, M. With the Minister's written consent, and on compliance with the conditions and regulations (see below) a person has the right to enter upon and break up the soil of any mining tenement in order (1) to erect, repair, or remove poles to carry *electric lines*, and (2) to construct, repair, and remove *tramways*.

The conditions imposed will be to secure the safety of the public, and to permit inspection and inquiry by the Minister. There are heavy penalties for breaches of the conditions.

S. 280, M. On due notice, the Warden may permit a person to construct a *road, race or drain*, or to *lay water pipes* in a mining tenement.

Compensation (if any) is fixed by the Warden. Permission may be withdrawn if the grantee is making no use of the privilege.

It will be noticed that the provisions as to electric lines, tramways, roads, drains, etc., just noted, apply not only to leases but to all mining tenements.

(I.) MINERS' HOMESTEAD LEASES.

S. 174, 203, M. A miner's homestead lease is a lease of Crown land within a goldfield or a mineral field for residential and other purposes except mining.

S. 202, M. The land taken up is not private land under Part VI. (the part treating of mining on private land) of the Mining Act, 1904.

S. 174, M. To acquire a lease a person must be the holder of a miner's right, must be a resident on a gold or mineral field, and must be at least 18 years of age.

S. 272, M. Any incorporated company may apply, but a lease is not divisible into shares or units, although more than one person may hold jointly. No Asiatic or African alien can hold a lease. (Fee on issue of lease, £1.)

S. 176, M. The *maximum areas* that may be held by a person either in one or several holdings within the limits of the same gold or mineral field are—20 acres within two miles of the nearest boundary of any townsite or suburban area; 500 acres beyond two miles from such boundary; and 500 acres are also the maximum to be held by any one person under both conditions.

But any areas distant more than 20 miles from each other are, with regard to these leases, considered as forming parts of different gold or mineral fields.

R.M. 117. The land must be in one block, and in the form of a rectangle, with due north and south and east and west boundaries. The proportion of depth to breadth must not exceed three to one, but where the area is bounded by a frontage line, the proportion shall be as two to one. The form and proportions may be varied with the Minister's consent.

R.M. 116. Marking out similarly to a mining lease must be done, and an *application* made. The holder of a miner's right, or of any pastoral or timber lease can object, and the Warden decides the matter in open Court.

S. 182, M. The Warden considers the rights of holders of claims and authorised holdings on the land (and they, as holders of miners' rights, have the right to object to the application), and the possibility of the lease interfering with mining or the public requirements.

R.M. 118. If *improvements* exist on the land, it may be a condition that the applicant pays for them. Compensation must also be paid for improvements on the portion taken of a pastoral lease.

S. 183, 189, M. *Term*.—So long as the rent is paid, and the conditions are observed, the lease runs on, but subject to resumption by the Crown as mentioned below. Ordinary *rent* is payable for 20 years only, and after that time it is nominal. The ordinary rent is, for 20 acres or under, 2s. per acre per annum; over 20 acres sixpence per acre per annum. There is, however, a minimum ordinary rent of 10s. per annum. The land must be surveyed.

Within six months from notice in the *Government Gazette* S. 185, 186, M. of approval of lease, the lessee must either reside on and substantially fence one-tenth part, or make substantial improvements, or carry on some manufacture. Within three years from date of survey the whole of the land must be fenced with a substantial (not a brush) fence; and within five years from the same date an amount must be spent on improvements equal to ten shillings per acre. The improvements must be of a S. 188, M. certain class, as defined by section 188 of the Mining Act, 1904.

Leases may be transferred, sublet, and mortgaged (fee, £1 S. 190-192, M. for transfer and 5s. for mortgage) with the approval of the Minister, generally similar to mining leases, and in accordance with the Acts and Regulations, but there is a partial restriction of transferring to a person who already holds the maximum area under the Act. Asiatic and African aliens are barred S. 192, M. from taking mortgages; similarly, unless with the Minister's written consent, any person of Asiatic or African race claiming to be a British subject. A person taking a transfer must be the holder of a miner's right.

Any part of the land in a lease may be marked off and S. 196-199, M. applied for as an ordinary mining tenement, as if the land were unoccupied Crown land, but if a mining lease is granted it will be only of the mines under the land, and not of the surface.

The person entitled to mine has, however, the right to erect machinery, sink shafts, and carry on mining operations generally on the land, and also of access to same, through the residue of the land in the homestead lease. Compensation must be paid by the mining person for any damage to the improvements, but not for the value of the land taken or the homestead lessee's interest in same. The mining person's buildings S. 200, M. and shafts are protected under penalty against the homestead lessee, even though the former has left the land.

The Crown on six months' notice may resume all or part S. 201, M. of a miner's homestead lease on paying compensation for improvements, subject to the powers of resumption contained in the lease.

A homestead lease provides for forfeiture for not carrying out the conditions.

(M) GOLD DREDGING LEASES.

Under the Sluicing and Dredging for Gold Act, 1899, gold mining leases may be granted of any Crown land for the purposes of sluicing and dredging for gold in any lakes, S. 3, S.D.G. swamps or marshes not suited to ordinary mining. What "ordinary mining" is, is not defined. The regulations under the Mining Act, 1904, provide for *dredging claims* for R.M. 40a. gold or minerals in lakes, swamps, marshes, rivers and other areas. A *dredging lease* cannot be over a river and can only be for gold. "Lake" presumably includes the "salt" or "dry" lakes.

Term.—21 years.

S. 4, S.D.G.

Rent.—Sixpence per acre per annum.

Royalty.—One shilling per ounce on all gold won.

Area.—Not to exceed 5,000 acres.

Amongst the *conditions* are that the lessee, after the first S. 5, S.D.G. twelve months, must keep working machinery not less than £3,000 in value for every 2,000 acres in the lease, and that persons not interfering with or impeding the lessee have the right to go upon the land for water-condensing purposes, and also to take water from same. The lease is liable to forfeiture for breach.

Land held under a gold sluicing or dredging lease is private S. 6, S.D.G. land under the Mining on Private Property Act, 1898 (now chiefly Part VI. of the Mining Act, 1904), for mining for gold in any lode, reef, or vein, and the procedure with regard to ordinary private land would therefore have to be followed out. If the land is enclosed, a person entitled to and desirous of taking up a claim, or a lease for mining in any lode, reef, or vein, is not to be debarred from entering merely on account of a spring, lake, or dam being on the land.

Under special circumstances the Minister can waive or sus- S. 8 S.D.G. pend any of the conditions of the lease.

The gold dredging leases have been almost generally superseded by the gold dredging claims, which have been already described. If a lease is taken up, the procedure on taking up a dredging claim is followed.

* Note the limitation. Other minerals can not apparently be mined for.

(N) PRIVATE LAND—PROSPECTING AREAS, RESERVED AREAS, CLAIMS AND LEASES OF.

(1) GENERAL REMARKS.

What is private land within the meaning of the Mining Act, 1904, what private land is exempt from mining, and also the rights of private owners with regard to gold and other precious metals on the one hand, and to the base metals and other minerals, including coal, on the other hand, have already been set out under the headings of "Mineral Rights of the Crown and of Owners of Private Land," and "What Lands may be mined upon." These matters must be remembered, especially when it is desired to seek on private land for the base metals and other minerals.

(2) PERMIT TO SEARCH PRIVATE LAND.

S. 124-128, M. A person who desires to search private land for minerals, or to mark out a prospecting and reserved area, or a mining lease or claim, must hold a miner's right, and must first apply for a permit to enter to the Warden, who may grant same for a period not exceeding 30 days, and at the same time may require a sum of money to be deposited with him to compensate the owner of the land if any damage be done. **R.M. 104-112.**

S. 129, M. The permit must be produced when asked to the owner or occupier or his agent.

S. 130, M. A permit holder can go on to the land, search for gold or any mineral (except coal where the land is leased for coal-mining), and detach and remove samples from any outcropping vein or lode, not exceeding a total weight of 28lbs., for assay or test. He may also mark out a prospecting and reserved area, a mining lease or a claim, but he is not to mine or otherwise disturb the surface until he obtains a holding. **R.M. 108.**

Some particulars are added in respect to the different kinds of holdings.

(3) PROSPECTING AND RESERVED AREAS ON PRIVATE LAND.*

After obtaining a permit a miner may desire to test the land for gold or minerals before taking up a mining lease or claim. He therefore applies to the Warden for a prospecting area over portion of the land, up to six acres in extent, with a reserved area of such further portion of the private land as he proposes to apply for as a mining lease or claim,† specifying in his application the minerals to be searched for. The owner or occupier of the land must receive notice of the application. When the compensation to be paid to the owner or occupier is arranged, the prospecting area may be registered (fee 10s.) for a period up to six months with possibility of renewal for a further three months, and the holder can then search the land for the period allowed, and before it expires, can apply for a mining lease or claim over the whole or a portion of the prospecting or reserved area. **R.M. 108.**

R.M. 110. In order to thoroughly test the land, a prospecting area can be surrendered, and a fresh one, up to six acres in extent, applied for out of the reserved area. This in turn may be surrendered and another one applied for, and so on, until the reserved area is exhausted or a mining lease or claim is granted or refused. But in every case before the granting of an application the compensation must be settled as provided by Regulations 106 and 107. The Minister can cancel a prospecting area if he thinks that the land has been sufficiently tested, and if a mining lease or claim is not applied for when required by the Warden so to do. **R.M. 109.**

(4) CLAIMS AND MINING LEASES ON PRIVATE LAND.†

S. 133, M. An application for a claim or mining lease (whether gold or mineral) of private land is made in the same manner as for a claim or mining lease of Crown land, including marking out, except when the application does not include any surface area, in which case marking out is unnecessary. The area and for what purpose it is required must be stated.

* See also General Remarks above.

† The quantity of land that can be taken up as a Prospecting and a Reserved Area is therefore governed by the areas that can be taken up under gold-mining and mineral leases, and according to whether gold or other minerals are sought for.

‡ See also General Remarks above.

The areas that can be taken up and the fees are the same as under claims and gold mining or mineral leases of Crown land.

Notice of the application must be given (in form No. 10) to the owner and occupier, who can be heard before the application is granted. If there is no occupier, the notice is to be affixed in a conspicuous place on the land. **S. 133, M.**

Where compensation is payable by the applicant, he has no right to mine or make preparations for mining until a certificate of registration (of a claim) or a lease is actually issued, and until, in the case of a lease, notice of approval has been published in the *Government Gazette*, and until the amount of compensation to the owner and occupier has been paid or arranged for. **S. 136, M.**

The amount and terms of compensation can be arranged between the parties, but to be valid, there must be a written agreement which requires filing in the Mines Department. **S. 146-151, M. R.M. 106, 107.**

In fixing the compensation, gold or minerals pertaining to the land are not allowed for except in the case of a coal mining lease, when compensation must be allowed for any payable coal that the owner is deprived of by the granting or registration of the lease or claim. Where the parties cannot agree as to compensation, the Warden fixes it. Neighbouring owners and occupiers are entitled to compensation (to be determined as mentioned above) for damage and loss through the mining operations. Further compensation may become payable to the various owners and occupiers if damage is subsequently done, which has not been provided for in the original compensation.

A lease or a claim may comprise (a) a surface area and (b) an area below the surface but outside the boundaries of the surface area. **S. 134, M.**

In (a) there is the right to mine on and under the surface, but in (b) mining can only take place at a depth of not less than 100 feet from the lowest part of the surface, or at a greater depth to be fixed by the Minister. When no surface land but mining at a greater depth than 100 feet is applied for, if the consent of the owner has not been obtained, the Warden must be satisfied that the land can be reached at the depth mentioned by reason of the applicant either owning or holding as a mining tenement adjoining land, or holding a mining tenement which does not join but from which he has the right to pass through the intermediate land. **S. 135, M.**

Under the law of mining on private land the local authorities are regarded as the owners of streets and roads, so as to prevent damage to same. **S. 145, M.**

The owner of private land can acquire a mining lease or claim over his own land, if not already held under another lease or claim. **S. 137, M.**

A lease or claim holder can go to and from his land over other land by a right of way which must be marked out by the lease or claim holder, but unless the owner of the other land consents there can be no right of way through any yard, garden, orchard, or cultivated field. Moreover such holder cannot, without the consent of the owner and occupier of the land held under lease or claim, use water artificially conserved by such owner or occupier, or fell trees, strip bark, cut timber, or, except in connection with mining operations, remove earth or rock from the land. Neither is he to impound or interfere with stock or other animals of adjoining owners or occupiers, nor to prevent them depasturing on the land (unless fenced) held under the lease or claim. **S. 140, M.**

Owners and occupiers of land held under lease or claim, as well as adjoining owners and occupiers, can, with the Warden's permission, inspect and survey the underground workings. **S. 138, M.**

Owners of divided mining tenements, whether on Crown or private land, may be granted a license by the Government to cut drives through the intervening land on such terms as may be thought equitable to enable the whole of the mining tenements to be effectually worked and mined. The license is not to exceed 21 years, with a possibility of renewal. Any person interested in the land is entitled to be heard before the license is granted. **S. 152, M. R.M. 193, 194.**

An owner of private land may apply to re-take possession of the land on the ground that mining operations have not been commenced within 12 months from the registration of a lease or claim or that such operations have wholly ceased. **S. 153, M.**

The Mining Acts and Regulations apply to private lands except where otherwise provided. Exemption and labour conditions are therefore the same as in claims and mining leases of Crown lands. **S. 144, M.**

(O) BRINGING CERTAIN PRIVATE LAND UNDER PART VI. OF THE MINING ACT, 1904.

(See above, under "Mineral Rights of the Crown and of Owners of Private Land," and "What Lands may be mined upon," page 6.)

S. 154, M.

Petition may be made that any "private land alienated before the first of January, 1899, or the subject of any conditional purchase agreement or lease or concession, with or without the right of acquiring the fee simple, granted before that date, may for the purpose of mining for minerals other than gold, silver, and precious metals be brought within the operation of this Part of this Act." The land here referred to does not include land held under certain leases (e.g., timber and pastoral leases). See definition of private land under "What Lands may be mined upon."

The gist of the section is that mining for gold, silver, and other precious metals may be done on any private land, no matter when acquired, on the conditions already explained, and similarly in respect to other minerals on private land alienated since the end of the year 1898; but that as regards these other minerals, mining cannot take place on land that comes within the meaning of the section until the conditions now to be stated are complied with.

S. 155, 156, 158, M.
R.M. 113-115.

On receipt of the petition a report is obtained from a professional officer, and if the Government approves of the petition the land is brought within the operation of this Part of the Act within a period of not less than six months from publication of a notice in the *Government Gazette*. Fee on petition, 5s.

S. 156, 157, 159, M.
R.M. 115.

The owner, however, of the land must receive a copy of the notice, and he may, within the time fixed, register (fee 10s.) a right to mine for specified minerals to the exclusion of other persons. For the purpose of all labour conditions, he will be considered to hold the land as under a mineral lease, and he must work it accordingly, but he pays no rent or royalty. If the owner does not exercise his right, the land becomes available for mining in the same way as private land which was disposed of by the Crown since the end of the year 1898.

S. 160-164, M.

If a miner thinks that the land is not being properly worked by the owner, he can apply for cancellation, but he may have to deposit £10 within seven days of applying.

After the responsible officer has heard the evidence, the Minister finally deals with the matter. If the owner's right is cancelled the land becomes available for a lease or claim as ordinary private land, but the miner who applied for cancellation may obtain the first right to take it up. On cancellation of the owner's right, he (the owner) receives all rent and royalties collected by the Crown for minerals won, less ten per cent.

S. 168, M.

(P) WATER RIGHTS ON CROWN LANDS.

The Water Supply Act, 1893, the Mining Act, 1904, and Regulations principally control the use of water (other than that provided by any regular scheme) for mining purposes.

Water Rights are divided into six classes, as follows:—

R.M. 41.

(1.) **STREAM WATER RIGHT**, entitling the holder to take from a river, whether the supply of water in the river is permanent or intermittent, a maximum quantity of water to be fixed by the Warden, with the right to an area on which to erect works and machinery at the point of intake, but no existing right must be affected nor any injury caused either of a public or private nature.

(2.) **LAGOON, LAKE, SPRING, OR SWAMP RIGHT**, giving the holder permission to take from any such place a maximum quantity of water to be fixed by the Warden; with the right to an area for erecting machinery, etc., at the point of intake, similar to the stream water right, and subject to the same provision as to existing rights and injury.

(3.) **WATERSHED OR STORM-WATER RIGHT**, under which the holder can collect the rain water falling on the area of the watershed granted, with a right to construct catch drains.

(4.) **DAM, TANK, OR RESERVOIR WATER RIGHT**, under which the holder can construct water storage dams, tanks, and reservoirs, and erect buildings, machinery, etc.

(5.) **SUBTERRANEAN WATER RIGHT**, under which the holder has the right to bore or sink for and collect underground water within the boundaries, taken vertically downward, of the area granted.

(6.) **A RACE OR PIPE TRACK WATER RIGHT**, under which the holder can cut or construct a race or lay a water pipe on or under the land comprised in the right. When a Race Water Right is granted for a tail-race, the latter can be used to carry off water, tailings, sludge, or refuse from mining or (over a part allowed by the Warden) for a ground sluice or race, for saving gold or other minerals.

GENERAL REMARKS.

Space does not permit the addition of more than a few general remarks as to water rights. The conditions are fully set out in Regulations 41 to 66a of the Mining Act, 1904, to which reference must be made for full information.

The areas must be marked off in accordance with the Regulations.

Rent.—(2) Lagoon, etc., (4) Dam, and (5) Subterranean Water Rights, all £1 per acre per annum; (1) Stream, and (3) Watershed Rights (both sixpence per acre per annum); (6) Race or Pipe Track Right, £1 per annum.

Registration fees for all rights 5s. each.

The holder of any water right can sell water obtained under such right, but the Minister has power to regulate the price at which the water is to be sold for mining, domestic, or other purposes. No business of any kind, except the sale of water, is to be carried on on any water right. Thus no mining can be undertaken. The holder must keep all works in repair and prevent water running to waste.

R.M. 63.

R.M. 66.

R.M. 64.

No water right in the Yilgarn, Coolgardie, East Coolgardie, or North-East Coolgardie Goldfields, or in any water area proclaimed under the Water Boards Act, 1904, is to be granted without the Minister's consent.

R.M. 66a.

With the written consent of the Minister, who may regulate the price to be charged, the holder of any mining tenement other than a water right may sell any water obtained in the course of mining operations.

R.M. 97, as amended.

Water rights can be transferred (5s. for each right) and mortgaged (10s. for each right) on compliance with the conditions.

R.M. 171, 172.

No water right is divisible into shares or units.

S. 272, M.

The holder of any water right must hold a miner's right.

S. 26, M.

A mining lease may apparently be granted over land held under a water right.

S. 61 (1), M.

(Q) OTHER AUTHORISED HOLDINGS ON CROWN LANDS.

(1) **GENERAL REMARKS.**—These are divided into seven classes, as follows:—(a) Residence or business area under Section 26, Subsection 10; (b) Residence or business area under Section 26, Subsection 11; (c) Machinery Area; (d) Tailings area; (e) Washing area; (f) Market garden area; (g) Quarrying Area.

The applicant for any of these holdings must be the holder of a miner's right. Such holdings can only be taken up in respect of Crown land within a proclaimed gold or mineral field or district. A miner cannot hold more than one residence area in any one goldfield, mineral field, or district without the Warden's consent. The holdings must be marked out in accordance with the Regulations. They, when registered, can be transferred (fee 5s. for each holding) or mortgaged (fee 10s. for each holding) on compliance with the conditions.

The holder of an authorised holding is not entitled to mine on same, but if gold or any other mineral is found there by the holder, or his servants or workmen, he can, within 10 days from his knowledge of the discovery, mark off and apply for a mining lease or claim. Prior to such discovery any person who considers that the area contains gold or other mineral may apply for a lease or claim. The holder of the authorised holding must receive notice, and he can object to the application. If the latter is granted, the area of the authorised holding may be reduced, and possibly the rent in proportion. The lease or claim applicant must pay compensation as fixed by the Warden; he is not entitled to any water raised on the lease or claim, except for mining or milling operations, and he must observe any other conditions imposed by the Minister or Warden.

R.M. 71.

S. 61, M.

R.M. 72.

L.	<i>Land Act, 1898.</i>
L. 99.	<i>Land Act Amendment Act, 1899.</i>
L. 02.	<i>Land Act Amendment Act, 1902.</i>
L. 06.	<i>Land Act Amendment Act, 1906.</i>
L. 09.	<i>Land Act Amendment Act, 1909.</i>
I.A.	<i>Industries Assistance Act, 1915.</i>
M.R.	<i>Mines Regulation Act, 1906.</i>
	<i>Mines Regulation Act Amendment Act, 1915.</i>
	<i>Coal Mines Regulation Act, 1902.</i>
	<i>Coal Mines Regulation Act, 1915.</i>
	<i>Inspection of Machinery Act, 1904.</i>
	<i>Mines and Machinery Inspection Act, 1911.</i>
W.S.	<i>Water Supply Act, 1893.</i>
	<i>Water Boards Act, 1904.</i>
	<i>Companies Act, 1893, and Amendments.</i>
	<i>Explosive Substances Act, 1894.</i>
	<i>Explosives Act, 1895.</i>
	<i>Explosives Act Amendment Act, 1902.</i>
C.W.P.	<i>The Commonwealth War Precautions Acts.</i>
R.M.	<i>Regulations under the Mining Act, 1904.</i>
R.G.L.	<i>Regulations relating to Guano Licenses, dated 16th January, 1907, under Act 40 Victoria, No. IX.</i>
R.H.P.	<i>Regulations relating to Gold Mining on the Hampton Plains Estate.</i>
R.M.D.	<i>Regulations under the Mining Development Act, 1902.</i>
R.T.	<i>Timber Regulations under the Land Acts.</i>
R.T.T.	<i>Timber Tramway Regulations under the Land Acts.</i>
S.	<i>Section or sections of the Act of Parliament referred to.</i>
Form No.	<i>Schedule of Forms to the Mining Act, 1904.¹</i>

The cases decided in the Western Australian law courts, and the appeal cases decided by the High Court of Australia and the Privy Council.

W.A.L.R. (with the number of the volume, year, and page added).

Unfortunately reports of the ordinary Supreme Court cases are not regularly published, and the regular reports of the Full Court judgments only date back to the year 1899. (Volumes 1 to 18 (1899 to 1916) have been published, and used for the purposes of this article.) The full interpretation of the mining statutes is not therefore available to most persons, although this is not such a loss as it might be, in consequence of many of the statutes governing mining being comparatively recent. It might also be mentioned here that the decisions of the Victorian law courts extending over a lengthy period have had a wide influence in the development of Australian mining law generally.

The following publications have also been consulted, and have been of considerable assistance.

Abbreviation.	TITLE.
A.C.V.	A. C. Veatch— <i>Mining Laws of Australia and New Zealand</i> . Bulletin 505 of the United States Geological Survey, 1911.
	<i>Instructions to Mining Registrars</i> in "Manual for Justices and Clerks of Court." Issued by the Crown Law Department of Western Australia, and edited by F. R. Barlee. Perth: By authority, 1911.
	C. H. Shamel— <i>Mining, Mineral and Geological Law</i> . New York, 1907.
	H. J. Armstrong— <i>A Treatise on the Law of Gold Mining in Australia and New Zealand</i> . Second edition, Melbourne, 1901.
R.C.M.	<i>Report of the Royal Commission on Mining, Western Australia</i> . Perth: By authority, 1898.

The Mining Act, 1904 is the principal statute dealing with mining in Western Australia.

Of the Acts of Parliament mentioned in the above list, the following, namely, the Coal Mines Regulation Act, 1902, and the 1915 amending Act; the Mines Regulation Act, 1906, and the 1915 amending Act; the Inspection of Machinery Act, 1904; the Mines and Machinery Inspection Act, 1911; the Explosive Substances Act, 1894; the Explosives Act, 1895, and the 1902 amending Act, are mainly concerned with the

¹ Unless otherwise specially noted.

internal management, working, inspection, and control of mines, and hardly come within the scope of this article. They are therefore practically not touched upon. Similarly the formation, management, and duties of mining companies under the various Companies Acts are not discussed. Also the jurisdiction and powers of the Wardens' Courts are only incidentally touched upon in the various other matters dealt with. There are also taxation statutes of both the Commonwealth and State Parliaments, which affect the assets and profits of mining concerns, but with which this article is not concerned.

III.—LODES AND ALLUVIAL DEPOSITS.

A few remarks on this matter may not be out of place, as in the past in Western Australia a good deal of confusion has arisen as to what are lodes and alluvial deposits respectively, and also as to what constitutes "alluvial gold." Some trouble arose owing to no satisfactory legal definitions being available, and the question was one considered by the Royal Commission on Mining in Western Australia in 1898. Legislation was later passed defining alluvial in regard to gold and other minerals, but "alluvial gold" has not been defined; neither has "lode." The definition, however, given to "alluvial" works out in practice satisfactorily on the whole.

It is well to give the legal definition of "alluvial." Under the Mining Act, 1904, section 3, it is as follows:—"Alluvial" s. 3, M.

"—(1) When applied to gold:—Any earth containing or "supposed to contain gold and not being a lode, dyke, reef, "or vein. (2) When applied to other minerals:—Any earth "from which any mineral is ordinarily obtained by washing."

"Alluvial Gold" is referred to in sections 67 and 204 of the same Act, and "alluvial minerals" in the same section 67.

A "deen lead" is not defined by the Mining Act, 1904, but by the Mining Development Act, 1902, section 3, it means "an ancient water course or gutter below the sur-

face of the earth containing alluvial deposits at a depth "of not less than fifty feet from such surface." Legally, therefore, a deep lead contains alluvial deposits, but these must be of the depth mentioned below the surface of the ground. Geologically speaking, the definition is unscientific, as part of a "lead" may be less, and part more than 50 feet from the surface, or it may be, so far as traceable, all above or below this depth. The depth however—amongst other factors—as is shown below, may determine whether a gold mining or a mineral lease shall or shall not be granted (sections 43 and 49 of the Mining Act, 1904), and also whether an ordinary alluvial or an extended alluvial claim (the latter comprising a greater area than the former) shall be granted. s. 43, 49, M. R.M. 29 (e).

Until the application for a lease is approved, a miner may prospect the ground for alluvial gold or alluvial minerals, but on the approval of the lease, the holder becomes entitled to the gold or other minerals as the case may be, according to the nature of his lease, whether found in alluvial deposits or in a lode. Formerly alluvial claims could be taken up on a lease to within a certain distance from the outcrop of the lode. This gave rise to much dispute, and in consequence the law was amended, and is now as above stated. s. 67, M. R.C.M., p. 2.

The distinctions between a lode and alluvial deposits may be shortly stated and illustrated. A lode may be a reef, vein (or a series of small veins), dyke, or a more or less defined portion of the country rock containing metals or minerals of economic value. It may lie at any angle from horizontal to vertical, but it is always in the country rock, and, in a sense, part and parcel of it, although formed later than such country rock. (The country rock is frequently the bedrock, that is the lowest known and below which no others are likely to occur within the outer crust of the earth.)

An *alluvial deposit*, from a mining standpoint, is one which has resulted from the accumulation, by running water, or by the wind, or by gradual surface drifting, of pebbles, sand, clay, or other rock debris, on the country rock. An alluvial deposit is therefore essentially a fragmentary one, sometimes hardened, but sometimes quite loose. Any valuable metal or mineral, in a more or less loose disconnected state,¹ in that deposit is treated as part of the alluvial. Illustrations of alluvial deposits are the sands, gravels and silts of sea beaches, river banks, river beds, flood plains, swamps and lakes, surface wash on a hill-side, soils, any rock or veinstone debris scattered about on the surface, as so commonly occurs on the Western Australian goldfields, "cements," and sand dunes.²

In some cases the bedrock has much decayed, and has cracks and crevices near its surface. These may receive minerals. An example is the bedrock of certain streams in Tasmania, in which the valuable mineral osmiridium has been found. Fragments of this mineral have been washed into the cracks and crevices of the bedrock, but these are regarded as alluvial. At Kanowna (Western Australia), the bedrock is similarly frequently decayed, and also has cracks. Gold has been precipitated from chemical solutions into these cracks, but it is also regarded as alluvial.

The term "*lode*" is sometimes used to cover all mineral deposits which are found as more or less continuous well-defined bodies in the country rock. It would therefore include the lodes proper (that is, those formed subsequently to the enclosing rock, comprising the metalliferous veins and ore-bodies), and those formed contemporaneously with the enclosing rock, which are known as seams or beds. These seams or beds comprise the coal seams, most of the iron ores, and the beds of salt and similar substances lying beneath the surface. The lodes proper are generally fairly close to the vertical, while the seams or beds, as a rule, approximate towards the horizontal. Substances that are now being formed at the surface and are not yet buried (such as bog iron ore³ and pyrites from chemical precipitation in lakes and swamps, salt as the result of evaporation of lake or lagoon waters, and guano, which represents the excreta of birds), would probably be regarded as alluvial, if the question were raised, but it is not likely to be, especially as the Government has provided for the issue of special leases for salt and guano. Some diagrams will illustrate the main features of common lodes and alluvial deposits (Figs. A, B, C, and D):—

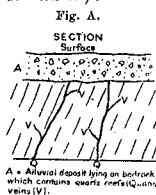


Fig. A. SECTION Surface.
A = Alluvial deposit lying on bedrock, which contains quartz reefs (Q) and veins (V).

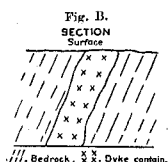


Fig. B. SECTION Surface.
B = Bedrock. X X. Dyke containing metals or minerals of economic value. This would be classed as a lode.

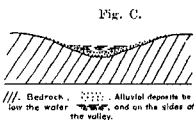


Fig. C. Bedrock. Alluvial deposits below the water level, and on the sides of the valley.

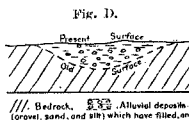


Fig. D. Bedrock. Alluvial deposits (gravel, sand, silt) which have never filled and buried an old river valley, now a deep reef.

¹ These words are used because it is possible that a distinct mineral-bearing vein may traverse an alluvial deposit.

² All these accumulations are not alluvial, scientifically speaking, the term in science being restricted to fragmentary material transported and deposited by the action of rain and rivers, but the illustrations given are correct as indicating a broad distinction from lodes, and they fit in with the legal definition.

³ So far as known, bog iron ore has not been found forming in Western Australia.

IV.—UNITED STATES AND WESTERN AUSTRALIAN MINING LAW.

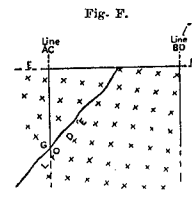
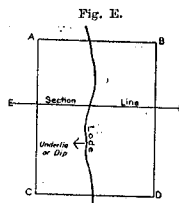
A brief statement as to some of the most important points of difference between the mining law of the United States of America and of Western Australia is instructive, showing as it does, on the one hand, the necessity for careful marking out in Western Australia, and, on the other hand, the advantages (in the opinion of most Australians) of our own law in comparison with that of the United States. The remarks apply equally to the other States of Australia as to Western Australia.

Three main features may be noticed:—

(a) *Discovery and Marking out.*—In the United States, discovery should precede marking out, and ground cannot be validly held on which a lode or alluvial containing some mineral has not been discovered.¹ In Western Australia this is unnecessary. Ground can be marked out and held without any lode or alluvial containing minerals being observable or discovered.

(b) *Nature of Holding.*—In the United States the freehold is acquired, subject to extra-lateral rights of adjoining owners, and to the employment of a small amount of labour. In Western Australia, the Crown does not part with the freehold. Leasehold is the rule coupled with the labour conditions.

(c) *Ownership of the Lode.*—A fundamental difference exists in this connection. In the United States the law of the "apex" and of extra-lateral rights holds good. That is to say, the person entitled to work the apex or outcrop of the lode at the surface can follow the lode wherever it goes on its dip or underlie, although it may pass beyond the lateral boundary of his land, and lie beneath the mining property of another holder. Generally speaking, however, it does not give the right to follow the lode along its strike, beyond the boundaries crossing such strike. These provisions have given rise to much litigation in America. In Western Australia (as in the rest of Australia) the owner of a mining tenement is only entitled to such portions of the lode or lodes as occur within the boundaries of his lease extended vertically downwards from the surface. Some diagrams (Figs. E and F) will make the position clearer.



Here the lode is running approximately north and south, and underlying to the west. The rectangular block ABCD represents the area held by the holder of the lode, who, however, does not hold any of the surrounding land. The section shows that the lode at a certain depth passes beyond the vertical extension of the boundary AC. In America the owner of the lode at the outcrop (that is in ABCD) can follow the lode down into the adjoining owner's land to any depth beyond G (section), but only between the lines AB and CD extended vertically downwards. In Western Australia, the holder of the lode could not pass down beyond the point G, and the lode below that point would belong to the holder of the land west of the line AC. It is

¹ Coal is treated differently, but need not be further discussed here.

thus seen how important it is in Western Australia to mark out plenty of ground in the direction of the underlie of the lode.

The statements as to the American law are believed to apply to most of the valuable mineral lands of the United States.

V.—GOLDFIELDS AND MINERAL FIELDS.

S. 10, 13, M.
S. 268, M.
S. 15, M.
S. 11, L. 02.

Goldfields and Mineral Fields may be proclaimed, and may be divided into districts. By such proclamation the provision becomes operative that no Crown land situated within a goldfield or a mineral field shall be leased or disposed of under the Land Acts without the approval of the Minister for Mines. When Crown land situate within the boundaries of any goldfield or mineral field is held under a pastoral or timber lease or license, such lease or license may be suspended or cancelled by the Crown, wholly or in part, in respect to such land, with, of course, a proportionate reduction in the rent. This provision is in the Mining Acts, but the Land Acts also provide that no timber lease or exclusive license over any timber land shall be granted within the boundaries of the declared goldfields. A *goldfield*, as the name implies, is primarily an area in which gold predominates, while a *mineral field* relates chiefly to minerals other than gold.

The term "Mineral Field" is little used outside Acts of Parliament. The areas which constitute the mineral fields sometimes officially receive a name according to the chief mineral, such as the Collie Coalfield and the Greenbushes Tinfield. In other cases "Mining District" is used, as in the "Northampton Mining District," where lead has hitherto been the chief mineral worked.

S. 132, 234, 271, M.
Land outside the boundaries of proclaimed goldfields and mineral fields can be mined upon subject to the provisions of the Act and of the Regulations.

VI.—MINERAL RIGHTS OF THE CROWN AND OF OWNERS OF PRIVATE LAND.

S. 3, W.A.C.
Under the (Imperial) Western Australia Constitution Act, 1890, Section 3, the entire management and control of the waste lands of the Crown in Western Australia, and of the proceeds of their sale, letting, and disposal, including all royalties, mines, and minerals, were vested in the legislature of the State.

S. 117, 267, M.
All gold, silver, and other precious metals on or below the surface of all land in Western Australia belong to the Crown, whether occurring on Crown or private land. *All other minerals* belong to the Crown in respect of land which was not disposed of by the Crown in fee simple (that is, for absolute ownership as generally understood) before the first of January, 1899. The owners in fee simple of all private land acquired before that date are the persons entitled to all minerals (including the base metals, coal, and mineral oil), except gold, silver, and other precious metals, found on or below such land, subject to the rights of other persons to mine for the minerals if the owner fails to do so after certain formalities have taken place, details of which are given under Part X (O).

S. 154-164, M.
S. 15 (as amended), L. S. 2, L. 09.
Crown Grants (of land) now issued reserve all gold and other minerals (including coal, mineral oil, and all phosphatic substances).

VII.—WHAT LANDS MAY BE MINED UPON.

Under certain restrictions and conditions, Crown, reserved, and private lands are available for mining, but as the conditions vary, they are separately treated.

(A) CROWN LANDS.

"Crown land," as defined by the Mining Acts, comprises **S. 3, M.** most lands of the Crown. It includes land held under pastoral and timber leases, commons, State forests, timber and mining reserves, and all land between high and low-water mark on the seashore, and on the margin of tidal rivers and below low-water mark. It excludes dedicated, other reserved, and sold lands, and also leased land, except that comprised in pastoral and timber leases.

Certain other Crown lands are excluded from occupation by the holder of a miner's right and from leasing. These further **S. 28-30, M. S. 34-37, M. S. 43, 49, M.** exceptions, and any special conditions that relate to mining on Crown lands generally, will be referred to under the section below treating of the various mining rights and holdings. (See especially miners' rights, claims and leases of Crown lands.)

(B) PUBLIC AND RESERVED LANDS.

Mining may be carried on, on certain conditions, on ex- **S. 30, M.** empted Crown lands, and upon or under a road, street, highway, navigable waters, or reserve; or a mining lease may be granted of any land comprised in a town-site, suburban area, or other reserve, or in any authorised holding. (An authorised holding is "any mining tenement other than a lease, an application for a lease, or a **S. 3, M.** claim.")

When a reserve becomes open for mining, it is treated **S. 275, M.** as Crown land within the meaning of the Mining Act.

Any Crown land may be temporarily reserved from **S. 276, M.** mining.

(C) PRIVATE LANDS.

Private land, no matter at what date acquired from the **S. 117, M.** Crown, may be mined for gold, silver, and other precious metals. Private land acquired from the Crown since the 1st of January, 1899,¹ may be mined as well for other minerals (including those containing the base metals and the rare metals, and also gems, precious stones, coal, and oil). Private land acquired before that date can only be mined by persons other than the owner, for any of the other minerals just referred to, after the land has been brought under the operation of the general law relating to mining on private land, and after the owner of the land has failed to do so. Particulars as to the conditions of mining on any private land are stated below, under "Mining Tenements or Holdings" and "Procedure." It is first, however, necessary in view of the various distinctions to know exactly what "private land" means under the part of the Mining Act, 1904, relating to mining on private land. It means any land that has been or will be acquired from the Crown as a freehold or under a conditional purchase agreement or under a lease or concession with or without the right of acquiring the fee simple. It does not include land held under a pastoral or timber lease or under a miner's homestead lease; neither does it include land held or occupied for mining purposes, except coal mining.²

The provisions of Part VI. (Mining on Private Land) of the Mining Act, 1904, do not apply to the lands held by the *Hampton Plains Estate, Limited* under special agreement with the Government of Western Australia, which lands are referred to in the Second Schedule to the Mining Act, 1904.

The Government has power to exempt private lands from **S. 118, M.** mining by notice in the *Government Gazette*.

No mining tenement is to be granted or occupied in respect **S. 119, M.** of private land which—

- (1.) Is used as, or at a less distance than 50 yards from, a yard, garden, orchard, or cultivated field, or

¹ Crown Grants now issued limit the rights of the owner to 40 feet below the surface on lands within goldfields and mining districts, and to 200 feet for all other lands, but the owner can sink wells and bores to any depth.

² "Private land" under the Act does not include (in relation to mining for minerals other than gold, silver, and precious metals) land alienated before the 1st of January, 1899, except such land is brought under the operation of the Part relating to mining on private land, as provided in sections 154 to 164 of the Act. The gist of the matter is stated above in the text. For gold mining purposes the land of a gold sluicing or dredging lease is "private land."

S. 15, L. Regulations at 7-3-99 and 1-3-04

S. 6, S.D.G.

- (2.) Is of less extent than half an acre within the limits of any municipality or township, or
- (3.) Is used as a cemetery, or
- (4.) Is at a less distance than 150 yards laterally from any cemetery, or reservoir, or substantial improvement, unless (a) the written consent of every owner of the land in question has been first obtained, or (b) such grant or occupation is limited to a greater depth than 100 feet from the lowest part of the surface of the land, or
- (5.) Is within 200 yards laterally of the workings, whether above or below ground, of any coal mine without the consent of the owner.

"Reservoir" in clause (4) means "any natural or artificial storage or accumulation of water, and includes a spring, dam, bore, and artesian well." In every case the Minister is the sole judge whether any improvement is substantial and of what constitutes a working within clause (5) above.

S. 121-123, M.

The Crown may resume private land¹ for mining purposes on payment of compensation, but no allowance is to be made for gold or minerals except coal when the land resumed is leased for coal mining. Mining leases, or claims granted on the resumed land become liable to the rent, royalty, or other payment to the Government that the Minister fixes.

S. 121, M.
R.M. 103.

Three months' notice to the owner of intention to resume in the Form No. 18 must be given, and a copy published in the *Government Gazette* at least three times between the date of the notice and one month prior to the resumption taking place.

VIII.—WHO MAY HOLD MINERS' RIGHTS, MINING LEASES, ETC., AND ENGAGE IN MINING.

Practically nothing can be done in the way of mining or prospecting by any person or company who does not hold either a miner's right or a lease.

C.W.P.

Under the regulations of the Commonwealth War Precautions Acts no application for a mining lease to or for the benefit of any person other than a natural-born British subject for a term of more than five years can be granted, nor any assignment or other means of acquisition of a mining lease for which a period of five years is unexpired be entered into, with any person other than a natural-born British subject, without the written consent of the Federal Attorney General. Where an option for renewal of a mining lease exists, the period of the option is regarded as part of the term of the mining lease.

A "natural-born British subject" means a person who was born in some part of the British Dominions, and who is still a British subject residing or carrying on business in some part of the British Dominions, and includes the wife or widow of any such person, but does not include a woman born in a part of the British Dominions who is the wife of a person other than a natural-born British subject.

The regulations may be made to apply to a person who is a natural-born British subject, but whose father was or is a subject of an enemy country, and if so, such person will be considered, for the purposes of the regulations, to be a person other than a natural-born British subject.

S. 23, 24, M.

Asiatic and African aliens are absolutely prohibited from holding a miner's right, and consequently from taking up any claim or prospecting area or other authorised holding, and persons of Asiatic or African race who, however, claim to be British subjects, are similarly prohibited without first obtaining the Minister's written authority.

S. 42, 48, M.

Gold-mining and mineral leases are not granted to Asiatic or African aliens. There is no provision for the Minister's authority with regard to a person of Asiatic or African race claiming to be a British subject, who therefore stands on a different footing with regard to these

leases than he does with regard to a miner's right; but s. 75, M. the Government can refuse to issue a lease to any one.

Asiatic and African aliens cannot hold a miner's homestead lease, neither can a mortgage of such a lease be given or transferred to such alien. Persons of Asiatic or African race claiming to be British subjects cannot hold or have transferred to them a mortgage of a homestead lease, nor such a lease without the Minister's written authority.

S. 290-291, M.

Asiatic and African aliens are prohibited from working in any capacity in or about a mine, claim, or authorised holding; and the labour of aboriginal natives of Australia is not accepted as fulfilment of mining labour conditions—unless with permission in writing of the Warden.

Only persons who are able to speak and read English are to be employed as managers, under-managers, platmen, shift-bosses, or engine-drivers; and only persons who can speak English are to be employed underground. Foreigners unable to comply with these requirements are therefore barred. Asiatic and African aliens are, as noticed above, absolutely barred. These conditions apply to all mines (including coal mines).

S. 42, M.R.

Boys under 16 years of age and females are prohibited from working below ground in any mine.

S. 53, M.R.

It may be noticed that any person working in or upon a mine for wages only need not hold a miner's right.

S. 289, M.

The restrictions as to *Sunday labour* in mines are contained in the Mines Regulation Act, 1906, Sections 43 to 47.

S. 43-47, M.R.

A miner applying for a miner's homestead lease must be at least 18 years of age.

S. 174, M.

Unless a person comes within the prohibited list noted above, miners' rights and leases of available land are usually issued as a matter of course. Women can hold leases and miners' rights.

Any person under 21 years of age can sue and be sued in the Warden's Court in the same manner as if he were of full age.

S. 237, M.

Incorporated companies and co-operative bodies of persons can obtain consolidated miners' rights, and can also hold claims and gold and mineral leases. More than one person jointly and also an incorporated company can obtain a miner's homestead lease.

S. 19, M.

S. 174, M.

IX.—MINERS' RIGHTS.

The remarks following must be read bearing in mind the preceding statements as to the disqualification of certain persons. Any person or company may obtain one or more miners' rights, but before issuing the Minister or Warden will require to be satisfied that such person is not amongst the prohibited groups. Fee 5s. for each right.

S. 17, M.
R.M. 3.

Incorporated companies and co-operative bodies or their representatives may obtain a consolidated miners' right.¹ Fee 5s. multiplied by the number of miners' rights the consolidated miners' right represents. The office of such incorporated company and the name of its representative must be registered in the Warden's office.

S. 19-21, M.

The miner's right is the foundation for taking up all mining holdings except mining leases, for which leases an applicant need not hold such a right. Under the Mining Acts very wide privileges are conferred upon the holder of a miner's right, and he has a good title to his holding against the world except the Crown.

S. 114, M.

S. 31, M.

A miner's right gives the holder full liberty in common with all other holders to prospect upon all lands of the Crown that come within the definition of Crown land (see before),² but when he desires to prospect, work, or occupy a particular area

¹ Consolidated miners' rights are, however, practically never issued. S. 3, M.
² Of course land held by other persons under mining leases or claims cannot be entered upon, except in some special cases.

¹ In this connection, the definition given by the Act as to the meaning of "private land," must be remembered.

S. 28, M. For his own benefit, he must mark out the ground and comply with the other conditions, which are referred to below. Amongst the many things that the holder of a miner's right can do, he may take possession, mine, and occupy Crown land for mining purposes and as authorised holdings, cut races, dams, etc., construct roads and tramways, take, divert, or sell surface water (for "mining purposes"), bore, sink for, store and sell underground water (also for mining purposes), erect and remove buildings, cut and remove live or dead timber, remove stone, and use land for residence or business. This brief statement gives some idea of the privileges of the holder of a miner's right, and acts as a guide, but to use these privileges he must take up land for the purpose for which he may require same or obtain the necessary authority, and conform to the conditions. The nature of the various holdings is set out below under "Mining Tenements or Holdings."

S. 31 (2), M. The holder of a miner's right who takes up Crown land for mining for gold under such right is entitled to all gold and minerals found upon the land. In this connection, with regard to mining leases, there are special conditions (see below).

S. 28, M. Certain Crown lands are exempt from occupation under a miner's right.

Those so exempted include land already occupied under a miner's right, or a mining lease, land lawfully occupied as a yard, garden, orchard, or cultivated field, or on which buildings have been erected or dams or reservoirs built, or wells or bores sunk, but if such land is not a claim, it may be occupied as a claim by another person either for mining from the surface on compensation for improvements being paid to the occupier, the compensation to be assessed by the warden, or for mining below the surface on certain conditions.

S. 29, M. The Crown may also exempt other Crown lands from occupation under a miner's right.

S. 30, M. The holder of a miner's right can in some cases obtain authority to take up for mining certain exempted Crown lands, or to mine upon or under roads, navigable waters, and reserves, or to construct drives under such land on complying with the necessary conditions, which include advertising, and the right of objection by others.

S. 34-36, M. When land occupied under a miner's right becomes exempted from further occupation or becomes included in a townsite and available for sale, the holder is entitled to compensation for substantial business or residential buildings if sold to other than the holder.

S. 37, M. When a substantial building for residence or business of the prescribed value has been erected upon land held under a miner's right for at least 12 months, the holder usually acquires the right of first purchase if the land becomes open for sale.

S. 40, M. To sue in a Warden's Court with respect to an interest in a claim, or an authorised holding, a person must be the holder of a miner's right, except a beneficiary under a trust.

S. 22 M.
S. 38, 39, M. Miners' rights are granted for twelve months from the date of issue, but application for renewal can be made before they run out. If they do run out without application for renewal having been made, the Minister or Warden may allow renewal on conditions set out in the Act. An additional fee of 2s. 6d. is payable if application is not made within seven days of the running out of the right. If not renewed, any land held under a miner's right shall be considered to be abandoned, and registration may be cancelled.

S. 32, M. Exemption from the conditions of labour, occupation, or use may be granted by the Warden up to six months. For a longer period than 14 days application must be made in open court.

S. 33, M. On the death or bankruptcy of the holder of a miner's right his interest goes to his representatives, or to the trustee in bankruptcy, as the case may be (fee for registration 5s.). A miner's right, however, is not transferable; but claims and other mining tenements held under a miner's right can be transferred on the conditions of transfer being complied with. (See below under claims, etc.)

S. 3, M.

¹ For definition of Crown land, see preceding pages.
² See below "Timber."
³ "Minerals" are defined by the Mining Act, 1904, to be "All minerals other than gold, and all precious stones."
⁴ It may for instance be held as an authorised holding, for which and for claims see below.
⁵ See below, particularly under "Claims."

Upon application for registration of a mining tenement, R.M. 4. except a mining lease, the miner's right must be produced. For the purposes of the Mining Act, 1904, a "miner" is defined as "any person being the holder of a miner's right." S. 3, M.

X.—MINING TENEMENTS OR HOLDINGS.

These are fairly numerous, comprising prospecting areas, reward areas, claims of various kinds, gold-mining leases, mineral leases, various other leases (machinery, etc.), gold-dredging leases, authorised holdings, and miners' home-
stead leases, to which for completeness may be added quarrying, guano or other manure, salt, and mineral spring leases, and guano licenses.

The nature and principal conditions of these will be shortly stated, after which the procedure necessary to obtain same will be set out. Before doing so, it may be mentioned that every mining tenement, and every share and interest in same, pass on the death or bankruptcy of the holder to (as the case may be) his personal representative or trustee in bankruptcy or liquidator, who must apply to the Warden or Mining Registrar to be registered as such. (Fees for registration: Claim or authorised holding, 5s.; Lease, £1.) They are also liable to be seized and sold under order of a Court. S. 274, M. R.M. 207.

Records must be kept of all bore-holes put down on a mining tenement and particulars supplied to the Government on demand. For the nature of the record, see Regulation 196a under the Mining Act, 1904. R.M. 196a.

(A) PROSPECTING AREAS ON CROWN LANDS.

A Prospecting Area is a certain area of ground which has been marked out by a miner in order to prospect for gold or other minerals. On registration (fee, 10s.) the holder acquires the sole right to prospect, subject to conditions, which are epitomised below, without having to pay any rent or survey fees. This enables him to thoroughly test the ground. Two points, amongst others that require attention, may be emphasised. The applicant must be the holder of a miner's right, and the ground must be marked out in accordance with the Regulations. These areas may be transferred and mortgaged in the same way as claims. (See "Claims on Crown Land—General," page 10.)

There are three descriptions of prospecting areas on Crown lands.

(1) FOR GOLD OR OTHER MINERALS, EXCEPT COAL AND OIL.

The maximum area of a prospecting area is (a) 48 acres, when the ground taken up is outside the limits of a gold-field or a mineral field, or more than 50 miles from the nearest mine upon which mining operations for the same metals or minerals that are to be prospected for are being carried on; or have been carried on within six months. R.M. 5 (a). R.M. 16.

(b) When within a gold or mineral field, 24 acres, except when more than 50 miles from the nearest mine for the same metal or mineral as just mentioned. R.M. 5 (b).

A miner can hold no prospecting area within a distance of one mile from any lease or claim in which he has an interest. R.M. 5.

A prospecting area for gold or other mineral, except coal or oil, may be applied for within a prospecting area for coal or oil already registered. R.M. 7.

The Mining Registrar has power to immediately grant an application, or he may require notices of the application to be posted. If objections are lodged, the Warden decides the question. R.M. 8.

After marking off and posting notice (where required) on the ground, the applicant has a right to the ground for the purpose for which it is marked off, pending registration. R.M. 134.

The term is 12 months, provided the holder during that time has a miner's right. Any renewal of the latter must R.M. 9.

be notified to the Registrar. A further six months may be granted on certain conditions, including payment of the prescribed fee.

R.M. 10. After 10 clear days from registration, *bona fide prospecting work* is required on every working day as follows:—Areas under (a) (see above). By one man if the area does not exceed 24 acres, and by two men if it exceeds this acreage; under (b) by one man if the area does not exceed twelve acres, and by two men if it exceeds twelve acres.

R.M. 10, 12. Failure to comply with these working conditions or doing work other than *bona fide* prospecting, or removal without authority of a larger tonnage of earth than ordinarily allowed (for which see below) renders the prospecting area liable to forfeiture unless a satisfactory reason can be given.

R.M. 11. Exemption from labour conditions cannot be granted for longer than one month without the Minister's consent, except where the Warden is satisfied that the labour conditions have been complied with for eight consecutive months, he (the Warden) may grant four months' exemption. With the consent of the Minister up to six months may be granted.

R.M. 12 (as amended). Not more than 50 tons in all of earth containing or supposed to contain gold or other mineral are to be removed without the written permission of the Warden or Mining Registrar. A breach renders the prospecting area liable to forfeiture, and the holder to a fine.

R.M. 13. Records and plans of shaft sinking and boring should be supplied to the Warden.

R.M. 14, 15. When any *gold or mineral*¹ in *payable quantity*² has been discovered in any prospecting area or locality (except a lease or claim) the Warden must be notified within 10 days or a further allowed period. For breach, penalty in money, and (if the holder is the discoverer) liability to forfeiture of the prospecting area. If the Warden is satisfied as to such discovery, he may grant to the discoverer a Reward Claim, or accept an application for a Reward Lease. (See below as to Reward Claims and Leases.)

The Warden can require the holder of a prospecting area to apply for a lease or claim.

(2) FOR COAL OR OIL.

S. 3, M. R.M. 1. "Coal," under "The Mining Act, 1904," includes "stratified ironstone, shale, and fireclay," and "oil," under the Regulations, means "mineral oil, shale, bitumen, or any carbonaceous mineral fuel except coal."

R.M. 6-7. The area to be marked off and applied for is not to exceed 3,000 acres. When the prospecting area is registered, the Warden may decline to register another similar area within 10 miles of the nearest point of the former, or he may register the new area after reduction in its extent. As already noted, a prospecting area for gold or any other mineral except coal or oil may be registered at the Warden's discretion in a coal or oil prospecting area.

R.M. 10. After 30 clear days from registration *bona fide prospecting work* must be done on every working day by not less than three men for every 1,000 acres or fraction of same, and a statement and declaration in the form No. 3 must be sent in within twenty-one days after the expiration of every alternate month after registration.

The provisions already noted under (1) apply to prospecting areas for coal or oil except where expressly noted under either (1) or (2).

S. 56, M. As to the area of leases to which a discoverer of coal is entitled, see below under coal mining leases (page 12).

No money reward has been offered for the discovery of oil in Western Australia.

¹ This includes coal and oil (see further reference to coal under the second part of this subject).

R.M. 1. ² "Payable quantity" or "payable" means "When a quantity of earth containing gold or mineral is disclosed which in the opinion of the Warden is sufficient to pay current wages to the men required to work the particular mining tenement referred to in addition to other working expenses."

(3) OVER LAND IN MINERAL CLAIMS.¹

After 12 months from the date of approval of a mineral R.M. 40b. claim, any miner can apply for a prospecting area over any land in a mineral claim. The Warden obtains a report from a professional officer, and if prospecting cannot be carried on without detriment to the working of the mineral specified in the mineral claim, the Warden refuses the application. Otherwise he refers the matter, with a recommendation, to the Minister, who decides. No prospecting area, however, is to be granted within 300 feet of the buildings, machinery or workings on the mineral claim unless the applicant deposits with the Warden the estimated amount of damage likely to be done.

The holder of a prospecting area may apply for a claim or lease for gold or mineral other than that specified in the mineral claim, and, if granted, the mineral claim holder must surrender portion of his claim. (For particulars see below under Gold Mining and Mineral Leases over Land in Mineral Claims.)

The area granted in a prospecting area will depend on the mineral sought. (See above under Gold or Other Minerals except coal and oil, and also Coal and Oil.)

Generally the conditions set out under these headings apply to prospecting areas over mineral claims. Similarly the mode of marking out and application are the same as set out below under Prospecting Areas on Crown Lands in the part treating of Procedure.

(B) REWARD CLAIMS.

(1) FOR DISCOVERY OF PAYABLE² GOLD OR MINERALS OTHER THAN COAL OR OIL.

When gold or mineral in payable quantity is discovered, as mentioned under prospecting areas, a Reward Claim, or possibly a Reward Lease, may be granted. There are alluvial reward claims and lode reward claims, according to whether the discovery be alluvial or a lode.

The area to be granted under a Reward Claim, whether for lode or alluvial mining, varies according to the distance from the nearest mine, which must be working or have been worked within six months preceding the discovery, for the same metal or mineral. The distance varies from that under a mile to that exceeding 10 miles, and the areas from one to 16 acres, both distance and area varying, according to whether the discovery is in respect to gold, metallic minerals, precious stones, or other minerals. Particulars are given in Regulation 16 under the Mining Act, 1904.

If a Reward Claim is held in addition to and adjoining any ordinary claim or lease, no *labour conditions* apply to the reward claim while they are observed in the ordinary claim or lease. But a reward claim held alone must be worked by at least one man.

If a new discovery of alluvial is made within the boundaries of land applied for (by the discoverer) as a lease, and if the latter be refused because the land is alluvial ground, the applicant may obtain an alluvial reward claim.

No rent is, of course, payable on a reward claim, nor are there any registration or survey fees. A reward claim can be transferred. A reward lease is usually taken in preference to a reward claim. No rent is usually payable for some time, nor any survey fee, under the lease. More ground can be obtained, and the title is looked upon with more favour.

(2) FOR DISCOVERY OF PAYABLE COAL OR OIL.

Similar provisions apply to these materials, except as to the areas and distances, which are not specified. Under Section 56 of the Mining Act, 1904, a miner who is the holder of a prospecting area is entitled to a lease on the terms stated in the section, on the discovery of payable coal. This is dealt with under Coal-mining Leases. "Pay-

¹ See below as to Mineral Claims (page 11).

² For definition of "payable," see an earlier footnote under Prospecting Areas (this page).

able coal" means coal of such quality and thickness that it can under ordinary circumstances be worked at a profit. Prospecting areas for coal and oil are referred to above.

(C) MINING CLAIMS ON CROWN LANDS.

(1) **GENERAL.**—A claim is a definitely marked out area of ground taken possession of by any person who is the holder of a miner's right for the purpose of mining of some description. No rent is usually payable, except for dredging claims and mineral claims, and survey fees have seldom to be paid except also as regards dredging and mineral claims. Apart from alluvial claims, few other claims are applied for, the preference being for a lease despite the payment of rent and survey fees under the latter. The larger area available, the more marketable title, and the slower application of the labour conditions of a lease no doubt account for this preference, although custom has possibly something to do with it.

The foundation of the claim is the miner's right.

An application must be made for every kind of claim (except an ordinary alluvial one, which is not necessary to be formally applied for, although it may be done), and must state (1) the metal or mineral to be mined for; (2) the number of shares to be held in the claim, and how divided; (3) the name.

Any number of miners up to 10 may take up a *joint claim* or claims, and an individual miner can take up any number of claims or shares in claims under one miner's right provided the labour conditions are carried out with respect to each claim taken up.

The following are the *different kinds of claims*:—(1) Ordinary alluvial; (2) extended alluvial; (3) lode; (4) river and lake; (5) dredging; (6) mineral claims; and (7) claims of any of the preceding kinds on reserved and exempted lands.

Registration of claims (fee 5s.).—An ordinary alluvial claim can be registered, but it is not compulsory. All other claims are required by the regulations to be registered, and certificates of registration are issued. All dealings (transfers, mortgages, etc.) with registered claims must also be registered at the Warden's office.

The *areas of claims* are set out under the different kinds of claims treated below; but it may here be noted that the length of every claim shall be along the line of the "alluvial lead, reef, or lode," as the case may be, and the *width* shall be at right angles to the length, the latter not to exceed twice the width, and the shape to be, so far as possible, that of a rectangular parallelogram.

Application can be made for the *union of two or more adjoining claims* on the conditions set out in Regulations 34 and 40b under the Mining Act, 1904. If the application is granted, the united claims become a new claim and certificates of registration are issued which show the different shares held.

The *labour conditions* of claims are set out under the different claims below; but every claim must be worked on every working day, except during exemption granted by the Warden, or during any general exemption, or on a public holiday, or through flood, rain, or drought, or through sickness or sudden emergency. Breach of conditions involves liability to forfeiture.

Exemption may be granted for a period up to six months, and in the case of a mineral claim, for further periods up to six months.

Where a claim or other mining tenement (not including here a lease) has been forfeited or surrendered, and a *stack of earth* containing gold or other mineral, that has been raised before forfeiture or surrender, is on the ground, the old holder

can within 10 days of forfeiture or surrender apply to the Warden to register the stack, provided it does not interfere with the working or use of the tenement. On registration the right to the stack, without interference by others, remains in the old holder for a period up to 12 months fixed by the Warden (Forms 32 and 41). If an application is not made within the time mentioned, then the stack is to be regarded as abandoned by the old holder.

Tribute Agreements can be made by claim holders on complying with the necessary conditions. For tribute agreements generally, see separate section below.

It is within the discretion of the Warden to require a *survey* of a claim which is to be registered. He may therefore require the survey fee to be deposited with the application. In many cases, however, survey is dispensed with.

The holder of any interest in a claim can *transfer* same (registration fee 5s.) except a fraction of any share, and such interest may also be *mortgaged* with the approval of the Warden or Mining Registrar (fee 10s.). The regulations must be complied with.

(2) **ORDINARY ALLUVIAL CLAIMS.**—These claims may be taken up for gold, silver, and platinum, all other metallic minerals, non-metallic minerals, and precious stones, that is, practically everything of a mineral character that can occur as an alluvial deposit.

An ordinary alluvial claim need not, but can, be registered. It must, however, be taken possession of and marked off and notices posted in accordance with the regulations. In all registered claims the *application* must state the metal or mineral to be mined for, and where no application is made for an ordinary alluvial claim, presumably such metal or mineral should be stated in the notice. A re-adjustment of the claim as to area in accordance with the amount of ground allotted to the different minerals may sometimes be required.

Area.—For gold, silver, and platinum, 25 yards both in length and width; all other metallic minerals, 100 yards both in length and width; non-metallic minerals, 125 yards in length, 100 yards in width; precious stones, 50 yards both in length and width. This represents one miner's ground. There is no limitation as to depth, but when the alluvial is below 50 feet, an extended alluvial claim can, perhaps, be obtained. This gives more ground (see below).

After three clear days from marking off in unregistered claims, and from date of registration in registered claims, *claims must be efficiently worked* by one man for every one man's ground in the claim, otherwise the latter is liable to forfeiture. One man, therefore, holding a claim equal to ten men's ground must provide ten men's labour. What "efficiently worked" means is stated in Regulation 166 of the Mining Act, 1904.

(3) **EXTENDED ALLUVIAL CLAIMS.**—These claims may be granted by the Warden (a) in old or abandoned ground, not being in a river, creek, or lake; (b) in tested ground too poor to pay by the ordinary method of working, but which can be worked by puddling or sluicing; (c) in wet ground where other than surface water exists and timbering throughout is necessary; (d) in rocky ground where blasting within 50 feet of the surface is necessary in shaft sinking; and (e) when the alluvial is at a greater depth than 50 feet. Under this (e) a deep lead as defined by s. 3, M.D. Section 3 of the Mining Development Act, 1902, would come.

Areas.—For gold, silver, and platinum, 50 yards in length by 25 yards in width; all other metallic minerals, 200 yards in length by 100 yards in width; non-metallic minerals, 300 yards in length by 100 yards in width; and precious stones, 100 yards in length by 50 yards in width. These areas respectively represent one miner's ground.

* See also above as to claims generally.
* See also above under claims generally.

* In connection with this matter, see the case of *Murphy v. McNair* (W.A.L.J. 3, 1905-6, 140), where it was held that the holder of an unregistered alluvial claim had a good right to a lode subsequently found on the claim without marking out the ground as a lode claim.
* For the shape of this figure see below under "K" Mining Leases (of Crown Lands) generally (page 13).

R.M. 35, 37. The *labour conditions* are the same as those in ordinary alluvial claims (see above, under latter heading).

R.M. 27. Extended alluvial claims are required by the regulations to be registered.

(4) **LODE CLAIMS**.—These claims,² as the name implies, are in respect of lodes, which, in Western Australia, include quartz reefs, and what are known as "lode-formations," and also mineral-bearing dykes and mineral veins generally.

R.M. 28. *Areas*.—For gold, silver, and platinum, 25 yards in length by 130 yards in width; all other metallic minerals, 50 yards in length by 130 yards in width; for non-metallic minerals, 75 yards in length by 130 yards in width; and for precious stones, 50 yards in length by 130 yards in width. This represents one miner's ground.

R.M. 32. Regulation 32 states "lode claims may be marked off on either side of the supposed line of reef at the option of the miner."

R.M. 27. Lode claims are required by the regulations to be registered.

R.M. 30. The *labour conditions* are that every claim must, after three clear days from date of registration, when not payable, be efficiently worked by one man for every two men's ground, or fraction of same, comprised in the claim; and, when payable, by one man for each man's ground or fraction of same.

(5) **RIVER AND LAKE CLAIMS**.—These claims are really varieties of alluvial claims, or dredging claims, or both, but the question need not be discussed, as river or lake mineral-bearing ground is generally taken up as a dredging claim.

R.M. 31. The claim holder has to provide and keep a flood race through or past the claim. Mining within 10 feet on either side of the race is prohibited, unless an additional race satisfactory to the Warden is provided.

R.M. 40 (a), 8. The *labour conditions* of a dredging claim apply, if taken up as such (see below).

R.M. 40b. (6) **MINERAL CLAIMS**.—These are claims for mining *gypsum, graphite, limestone, magnesite, carbonaceous shale, oil shale, ochre, clay, felspar, mica, asbestos, barytes, diatomaceous earth, glass sand, minerals to be worked for potash contents, and materials for cement making*. A claim must be registered, and the application must specify the mineral to be mined. The method of marking off and application are described below under "Procedure."

Area.—Maximum, not to exceed 300 acres, and the length of the claim is not to be more than twice the breadth, except with the approval of the Minister. Two or more mineral claims held by the same person with a total area of not more than 600 acres may be amalgamated.

Rent.—2s. 6d. per acre per annum.

Labour Conditions and Exemption.—For three months from date of registration the holder need not employ any men or machinery, and this time may be extended by the Minister for a further period up to three months. After the first three months or the extended time, the holder must employ continuously upon the claim not less than three men for every 100 acres or fraction of same. The Minister can, however, modify these conditions if he is satisfied that expensive machinery has been installed for the proper working of the claim. He may also grant on conditions that he thinks fit a license dispensing with the working conditions up to six months (with a possibility of further renewals for periods not exceeding six months) if satisfied that the claim holder has reasonably endeavoured to work the claim and that continued working would result in unnecessary loss.

The Minister may at any time require the holder of a mineral claim for mining graphite, mica, asbestos, barytes, or minerals to be worked for potash contents to apply for a lease or leases of the ground held as a claim or any portion of it.

Breach of the general conditions makes the claim liable to forfeiture.

¹ See also above as to claims generally (page 10).

² They have taken the place of the old quartz claims.

Miners have the right to apply for and obtain prospecting areas, claims and leases for gold or minerals other than that being sought under the mineral claim on certain conditions. (See above under "Prospecting Areas on Crown Lands" (3), and below under "Gold Mining and Mineral Leases over Land in Mineral Claims.")

It may be noted that the Government has offered a bonus for the production in Western Australia of marketable graphite, mined and prepared for the market within the State.

The graphite must be "flake" graphite, and of good marketable quality; and the bonus is at the rate of five per cent. of the net proceeds at the mine or sale of each parcel as paid to the producer directly or indirectly by the manufacturer or consumer within the State, or the purchaser outside the State. Further particulars of the conditions can be obtained from the Mines Department, Perth.

(7) **DREDGING CLAIMS**.—These are claims for dredging for gold or other minerals in lakes, swamps, marshes or rivers and the adjacent land, or on the foreshore of the ocean, and the land beneath the latter, under the following circumstances: (a) when the ground has previously been worked for alluvial gold or minerals and abandoned, or (b) when the known poverty of the ground warrants such claims, or (c) when the ground is only suitable for dredging on account of its excessive wetness, or on account of the costliness of the appliances required to work it.

Any number of claims may be taken up by one miner.

Area.—The maximum of a claim is not to exceed 300 acres, and in all claims, except river dredging claims, the minimum width, taken at right angles to the shore-edge or bank, is not to be less than 15 chains. In river claims there is no restriction as to width, but a claim is not to be more than six miles in length. Two or more claims can be united, but the total length of the new claim must not be more than six miles.

Claims must be marked off, and application made, etc., as required by the regulations. A survey may be asked for.

Rent is at the rate of 2s. 6d. per acre per annum.

The *labour and machinery conditions* are that after six months from registration, and a further period up to six months, if the latter be allowed by the Warden, the claimholder must continuously employ upon the claim not less than three men for every 100 acres or fraction of same; or, alternatively, keep thereon fully-manned machinery of not less than £1,000 in value for every 100 acres or fraction, unless exempted. But in no case must the machinery be less than £3,000 in value, nor £5,000 in the case of a united claim.

A mining tenement holder on the banks of a river or in the vicinity can discharge tailings, waste water, or debris from his holding into the river although a dredging claim may exist over the bed of the latter.

A claim holder, if necessary to work his claim, can enter upon an adjoining mining tenement to do so, provided he gives due notice, and arranges to make compensation as set out in the Regulations.

(D) CLAIMS ON RESERVED AND EXEMPTED CROWN LANDS.

The holder of a miner's right is sometimes allowed to take up for mining any Crown land exempted from occupation under Section 29 of the Mining Act, 1904, or to mine upon or under any road, navigable waters, or reserve, or to construct drives under such land.

Application for authority must be made. Notice is published, and where the land is situated within a municipality a copy of the application is sent to the mayor. Objections may be lodged against the application.

¹ See also above as to claims generally (page 10).

R.M. 154. Exemption under authorised holdings may be granted for any period up to six months, but in the case of a residence or business area it is not granted unless improvements to the value of £10 have been made in the case of a residence area and £50 in that of a business area.

S. 26 (Subsec. 10), M. R.M. 67 (a). (2) RESIDENCE OR BUSINESS AREA UNDER SECTION 26, SUBSECTION 10.—Any Crown land can, with the approval of the Warden, be taken possession of and occupied for the purpose of residence or business. It is not to be more than one acre in area, and if for business only, it is not to exceed a quarter of an acre. It cannot, however, be within three miles from the nearest municipality or townsite without the Minister's written consent. Rent of business area £4 per acre per annum. Residence area, no rent.

S. 26 (Subsec. 11), M. R.M. 67 (b). (3) RESIDENCE OR BUSINESS AREA UNDER SECTION 26, SUBSECTION 11.—Any Crown land that is reserved for residence or business and open to selection can be taken possession of and occupied for this purpose. The area is not limited by the Act or regulations. Rent of business area, £4 per acre per annum. Residence area, no rent.

R.M. 69. Occupation of either kind of the above-mentioned areas cannot take place until the application is registered by the Warden.

R.M. 70 (1). Certain conditions must be observed (unless exemption has been obtained from the Warden and registered), including occupation within 30 days after registration of application. Liquor must not be sold contrary to the provisions of any Act.

R.M. 70a. R.M. 67 (c). (4) MACHINERY AREA.—This is for erecting machinery for the extraction of gold or minerals. Area not more than five acres. Within three months from date of registration, or any further time that the Warden allows, machinery must be erected and continued in use in a *bona fide* manner to the Warden's satisfaction. Rent £1 per acre per annum.

R.M. 70 (2). (5) A TAILINGS AREA is for stacking tailings or any earth containing gold or minerals, and for treating the same thereon. Area not more than five acres. Within three months from registration, or further time allowed, the land must be used for the purpose only for which it was granted. Rent £1 per acre per annum.

R.M. 67 (d). R.M. 70 (3). (6) WASHING AREA.—This is for washing any earth containing gold or minerals. Use must be made of it within the time mentioned under machinery areas. Area, not more than five acres. Rent £1 per acre per annum.

R.M. 67 (e). R.M. 70 (4). (7) MARKET GARDEN AREA.—This is for poultry farming or growing fruit, vegetables, fodder, or garden produce of any kind. Area not more than five acres. Within 30 days from registration the land must be used for the purpose mentioned, and within twelve months from registration it requires also to be securely fenced on all sides. The holder may sublet to a qualified person provided a copy of the tenancy agreement is filed at the Mining Registrar's office. Rent 5s. per acre per annum.

R.M. 67 (f). R.M. 70 (5). (8) QUARRYING AREA.—This is for the purpose of obtaining stone or gravel for building or other purposes. Area not more than 24 acres. Within 30 days from registration the land must be used, and continue to be used *bona fide* for the purpose mentioned. Rent £1 per acre or fraction of same per annum.

R.M. (67g) 70 (6). (R) SPECIAL LEASES UNDER THE LAND ACTS. Under Section 152 of the Land Act, 1893, as amended by later Acts, the Crown may grant leases of Crown land for any area not exceeding (except in the case of leases for guano or other manure or for the collection and manufacture of salt) 25 acres for a term up to 21 years at a yearly rental of not less than £2, and on payment of the cost of survey, for any (amongst others) of the following purposes:—

S. 152 L (as amended). For obtaining and removing guano or other manure. (See also below as to guano licenses for masters of vessels.)

For obtaining and removing stone or earth.

For the working of mineral springs.

For the collection and manufacture of salt.

For taking, diverting, conserving, and using water for mining, agricultural, industrial, and other purposes.

For works for supplying water, gas, or electricity.

For market gardens.

Where the lease is to be for a longer period than 10 years, notice must be advertised in the Government Gazette as provided.

These leases are issued by the Lands Department, to whom application in the proper form must be made accompanied by half the first year's rent.

In addition to other reservations, all minerals are reserved to the Crown.

There is also power to the Lands Department to issue s. 154, L. licenses for quarrying on Crown land not in a goldfield or a mining district; but such licenses are seldom issued, as a lease is generally obtained under the provisions mentioned above. (See also above under "Other Authorised Holdings on Crown Lands" as to Quarrying Areas, on this and preceding page.)

(S) GUANO LICENSES.

Special regulations have been made respecting the removal of guano existing upon islands or coasts within the territorial limits of Western Australia, and although such regulations only apply to licenses to be issued to the masters of vessels, yet inasmuch as guano is classified as a mineral deposit, brief reference to same may here be made. These licenses do not do away with the issue of special leases to remove guano or other manure, which may be granted to any ordinary qualified person or company, whether or not connected with any vessel, but of course it would have to be watched that the rights of lessees and licensees do not clash.

The Minister for Lands can license the master of any vessel to collect and remove guano. The license is issued under the Act 40 Victoria, No. IX., and it might here be noted that under this Act guano includes "all phosphorated substances, gypsum, dung, compost, and manure of any kind." There are three kinds of licenses—General, Special, and Exclusive.

(1) A General License applies to all coasts and islands within the territorial limits of the State except localities comprised in any Exclusive License (whether the latter be issued before or after the General License) and localities otherwise reserved by the Minister. But the localities comprised in an Exclusive License issued after the General License are not excluded from the latter until the holder of the Exclusive License or his agent produces same to the master of the vessel acting under the General License. General Licenses are only issued in exceptional cases to encourage the discovery and utilisation of new deposits of guano.

(2) A Special License applies to the localities specified therein, but is not to exclude the holder of a General License or the holder of any other Special License applicable to the same locality.

(3) An Exclusive License will only be issued to the master of a vessel the owners or charterers of which are under special agreement with the Government to remove the whole of the guano in a particular locality. Such a license confers the sole right to guano in the locality specified therein.

All kinds of licenses apply only to the vessel and the voyage named therein, and are not transferable.

The guano removed by virtue of a license is for use in the State and not for export. Bonds and sureties may be required for the observance of this Regulation.

- R.G.L. 8. A royalty of one shilling per ton calculated on the registered tonnage of the vessel must be paid before the issue of any license. In the case of an Exclusive License this charge may be increased.
- R.G.L. 9, 10, 11. The term is not to exceed 12 months. Any special conditions may be imposed by the Minister, and the latter or his agent will supervise the removal of the guano. He may also mark off spaces from which only the guano is to be taken, and shall prevent waste and unprofitable working of the deposits.
- R.G.L. 12. Licensees and their agents are liable to penalties, and the licenses to cancellation for breach of conditions.
- R.G.L. 13. The Government is not responsible for the quantity or quality of any guano licensed to be removed. Any dispute between the Government and a licensee must be referred for decision to the Governor in Executive Council, and such decision is final and binding upon both parties.
- R.G.L. 14.

XL—PROCEDURE, OR HOW TO ACQUIRE MINING RIGHTS AND TENEMENTS.

The following statements are mainly intended to indicate as clearly and yet as concisely as possible what must be done to acquire any of the various mining or other tenements or privileges, which have been briefly described above, to which reference may be made for further information. It may be pointed out here that there are many Mining Registrars in the country, and they will always supply any information that can be supplied. The necessary forms may also be obtained from them.

- S. 270, M. Applications for all mining tenements must be made at the office of the Warden of the goldfield or mineral field or district in which the land applied for is situated.

(A) MINERS' RIGHTS.

- S. 16-21, M. An ordinary right can be obtained from the Mines Department or through any Mining Registrar. No written application is necessary. Fee 5s.

A company must register its office, and the name of its legal manager, representative, or attorney in the office of the Warden of every goldfield or mineral field or district in which it has any mining tenement. But only one miner's right is necessary. Written application is not required.

A consolidated miner's right. A fee of 5s. must be paid for every miner's right represented by the consolidated right. These rights are, however, obsolete.

- S. 38, 39, M. A new miner's right should be applied for within 30 days before the expiration of the existing right, which must be produced. A new right may be granted within 30 days after the expiration of the old one, but if the application is made after seven days from such expiration a fee of 2s. 6d. in addition to the ordinary fee is chargeable for each right. The reason for keeping the right continuous is to maintain any interest held in a mining tenement under such right.

(B) PROSPECTING AREAS ON CROWN LANDS.

The following remarks apply to gold and other minerals,¹ including coal:—

- R.M. 131. The applicant takes possession of and marks off the land (unless previously surveyed) by fixing firmly in the ground at each corner or angle thereof (or as near as practicable thereto) a substantial post or cairn of stones projecting not less than three feet above the surface, and set in the angle of two trenches not less than four feet in length and six inches deep and cut in the general direction of the boundary lines. When the nature of the ground will not permit trenches being cut, rows of stones of similar length must be substituted. The boundary lines must also be cleared from post to post.

- R.M. 132. One of the corner posts or cairns shall be the datum post and thereon, or in proximity thereto, shall be firmly fixed, at the time of marking off, a notice in the prescribed form (see Form No. 31). The notice must show the dimensions of the ground and a description of its boundaries.

¹ See above under Mining Tenements or Holdings as to prospecting areas over land in mineral claims (page 9).

² Care must of course be taken that other persons' mining land is not being marked off.

Within ten days after marking off (or such further time as the Warden may allow) an application in duplicate in the form No. 32 must be lodged at the office of the Mining Registrar with the fee for registration, 10s.³ (With the application must be a sketch showing the boundaries of the land, which should be fixed, where possible, by reference to some existing survey mark, or to some feature on the land or adjacent thereto). The Mining Registrar hands to the applicant a certificate⁴ in duplicate in the form No. 33, which shows that application has been made, and fixes the time within which objections must be lodged at the Warden's office. The applicant must post forthwith one of the certificates on the notice board at the Warden's office, and the other, as soon as conveniently may be, must be affixed to the datum post⁵ on the ground. The certificates (*notices of application*) must be kept legible and intact until registration is completed.

It is not necessary to mark off ground which is identical with any forfeited, abandoned, or surrendered mining tenement which has been already surveyed, but the notices required to be affixed must be affixed to one of the existing survey posts.

Objections in the form No. 34 may be lodged with the Mining Registrar within seven clear days of the application, or such further time as the Warden may allow, on payment of the fee of 2s. 6d. A copy of such objection must be served on the applicant.

If no objections are lodged the Mining Registrar may deal with the application or refer it to the Warden. If objections are lodged the Warden determines the matter on a day of which notice is to be given to the applicant and the objector.

To withdraw an application notice in the form No. 35 must be lodged at the Warden's office. Fees are refunded if the application is withdrawn before the expiration of the time for lodging objections, or if refused, less a recording fee of 2s. 6d.

Surrenders of prospecting areas are in the form No. 15. They must be lodged (in duplicate if required) at the Warden's office.

No survey is necessary for a prospecting area.

To renew the prospecting area for another six months or less, beyond the 12 months for which it is granted, the holder must apply within the twelve months for renewal and pay the fee.

The boundary marks of all mining tenements must be maintained.

(C) REWARD CLAIMS.

A person entitled to a reward claim makes application to the Warden, and the latter registers same without charge.

The application is made in the form No. 32, and the ordinary marking out must be done, but no notices are necessary to be affixed. For method of marking out, see above under Prospecting Areas on Crown Lands.

(D) CLAIMS ON CROWN LAND.

(1) ALLUVIAL AND LOSE CLAIMS.

The following remarks apply to ordinary alluvial, extended alluvial, and lode claims. River and lake claims are taken up, as a rule, as dredging claims.

A claim must be marked off in the same way as set out above under Prospecting Areas on Crown lands. It should be in the form of a rectangular block except where existing boundaries interfere. The length shall be along the line of the alluvial lead, the reef, or lode, as the case may be, and the width at right angles thereto. The areas have been indicated under the various claims already referred to.

One of the corner posts or cairns must be the datum post, on which, or in proximity to it, must be firmly fixed at the time of marking off, a notice (the notice of marking off) in the form No. 31, containing the particulars required.

All claims, except ordinary alluvial claims (and these may be) must be registered. Formal application is therefore required.

¹ No survey fee is payable.

² This certificate is always later referred to as the notice of application in contrast to the notice of marking out.

³ See the preceding paragraph as to what is the "datum post."

s. 5, M.D. An application may be made to the Minister by any person or company for an advance by way of loan for (a) carrying on pioneering mining; (b) procuring, erecting, and connecting machinery, plant, or appliances for such purpose; (c) providing other works and things which, in the opinion of the Minister, may be necessary for such purpose.

s. 6, M.D. The application must be in the prescribed form and be accompanied by the particulars required to be supplied by section 6, all of which must be verified by declaration. Such particulars must include a description of the mine and workings, with an accurate plan and sections, a description and valuation of all machinery, plant, and effects on the land, a statement of the encumbrances (if any) affecting the mine or machinery, a description of the pioneering mining proposed, its object, probable cost, and of any machinery, plant, and effects proposed to be purchased in connection therewith, a statement as to how and on what work it is proposed to expend such advance, the time over which the expenditure will last, the time when and amounts in which the advance will be required, and such other information as the Minister may require; in addition, if the applicant is a company, evidence of incorporation and registration, a copy of its memorandum and articles of association, and particulars as to the amount of uncalled capital of the company, and of its assets and liabilities.

s. 7 and 8, M.D. The Minister refers the application to a professional officer who, after examining the mine, reports to the Minister. Such report must contain the information required by section 7. After consideration the Minister, with the approval of the Governor, may grant the application with or without modification on an agreement being entered into. The advance is payable by instalments, but no instalment will be paid unless pound for pound of the amount to be paid has been expended by the applicant (the "borrower") out of his own capital, since the date of the agreement, and all previous instalments have been properly expended, and all interest due paid. Interest is payable at a rate to be fixed from time to time by the Treasury, but not less than 5 per cent. per annum.

s. 9 and 10, M.D. The advance is secured by a first mortgage of the mine, and in the case of a company, its other property and assets (except uncalled capital); and no dividends or other moneys are payable to the members of a company until all the terms of the agreement are carried out.

s. 11, M.D. Moneys so advanced are Crown debts.

s. 12 and 13, M.D. Until all moneys advanced have been repaid and agreement complied with, the provisions of Section 12 apply.

These provide for inspection of the works, and of books, documents, and records, supply of further information by the borrower, right of the Crown to take possession on default, and to carry on operations and sell the property.

(2) ADVANCES FOR PROSPECTING.

s. 14, M.D. These are governed by Part III. of the Act.

An advance by way of loan may be made up to £300 to assist prospecting for gold or minerals.

A miner may apply to the Minister for an advance in the prescribed form. (It should be noted that a "miner" under the Act means the holder of a miner's right or a mining license.¹ As a company may hold a miner's right under the Mining Act, 1904, it could apparently apply under the Mining Development Act for an advance of the class now being dealt with.)

s. 15 and 16, M.D. The applicant must furnish the Minister with the information required under section 15, which includes a description of the mine in which it is proposed to prospect, the means by which prospecting is to be carried on, a statement of the period over which the advances are to extend, and the instalments required, what security is offered, and how and when the advance is to be repaid, and any further information required. The statements must be verified by declaration.

s. 14 (2), M.D. On receipt of the application the Minister obtains a report from a professional officer, and thereupon may grant an advance to prospect for gold or minerals on an agreement being entered into and the applicant giving the required security.

¹ Mining licenses are not now issued. A miner's right confers all necessary authority.

Before an instalment is paid, pound for pound must be expended by the applicant on the mine in work, labour, or material since making the application, and all previous instalments must have been properly expended on the mine.

(3) ESTABLISHMENT AND SUBSIDISING OF PLANTS FOR CRUSHING, ORE-DRESSING, CYANIDING, OR SMELTING.

Part IV. of the Act deals with this.

The Minister may purchase and erect or hire plant for s. 19, M.D. testing the value of or treating metalliferous material, or subsidise companies or persons who are willing to erect and work such testing plant for testing the value of, or treating metalliferous material for the public, at such rates as may be agreed upon or fixed.

Such plant is to be erected or subsidised only in districts s. 20, M.D. in which, from the report of a professional officer, the Minister is satisfied that large deposits of metalliferous ores exist, that the plant and appliances for testing or treating such deposits in bulk at reasonable rates are not available, and that the establishment of such plant is necessary for the development of mining.

The rates charged for testing or treating ores are as prescribed. s. 21, M.D.

Numerous State batteries for gold extraction have been erected, various private batteries have been subsidised, and the Government is the lessee of the State Smelting Works at Phillips River, where auriferous copper ores are treated.

(4) ASSISTANCE FOR BORING.

This comes under Part V. of the Act.

When the Minister is satisfied, after receiving a report s. 23, M.D. from a professional officer, that boring either for gold, minerals, or water is desirable in any mining centre or other locality, and that such boring has a reasonable prospect of success, he may agree with any miners' association or other body of persons, or with any person, to pay a proportion of the cost of such boring, not exceeding one half the total cost.

Application is made and granted in accordance with the s. 23, M.D. regulations, and, if granted, the association, other body, or person must pay the wages and expenses incidental to the boring, but will be entitled to a refund of the proportion payable by the Minister, on the latter being satisfied that the boring is being carefully and with dispatch carried out, and on production of receipted pay sheets or vouchers.

If after a report from a professional officer and the Minister is satisfied that boring in any locality is in the general interest of the State, the Government may pay the whole cost of such boring. s. 24, M.D.

When boring has been undertaken, the Minister can reserve Crown land adjacent to the bore site as will be tested by such boring, and the Government may grant a claim, gold mining or mineral lease, or other holding to any association, body, or person by whom the boring was undertaken in priority to any other person; but for this the Minister's written consent is required, and the applicants may have to pay by way of premium a proportion of the cost of boring. The Minister may also call for tenders for such lease, without being obliged to accept any tender, and he may at his discretion apply any premium or part of it to reimburse the moneys expended by such association, other body, or person in boring. s. 25, M.D.

(5) PURCHASE OR HIRE OF BORING PLANTS BY THE STATE.

Under Part VI., Section 26, the Minister can purchase s. 26, M.D. boring plants and accessories that he thinks necessary, and may hire such plant, in accordance with the regulations.

(6) ADVANCES AND EXPENDITURE FOR SINKING, ETC.—s. 27, M.D. The Minister may advance, or himself expend, moneys—

- (a) To drain any mining area.
- (b) To assist mining by sinking or cross-cutting for further make of stone; or
- (c) To sink shafts for prospecting at great depths below the surface at places in respect of which the expenditure of large sums of money, extending over a considerable period, will be necessary.

- (d) To provide means of transport for miners to prospect unproved country, and the Minister may call for tenders and enter into contracts for any such works.

S. 29, M.D. Regulations may be made under this Act either for the whole State or for any particular part of it.

(B) THE INDUSTRIES ASSISTANCE ACT, 1915.

S. 24, I.A. Part 3, Section 24, provides that the Colonial Treasurer may render financial assistance by making advances, or guaranteeing the repayment of advances, to be made to persons engaged in mining or any other industry, provided he is satisfied that in the interests of the State such assistance should be given, and that it is not practicable for the applicant to obtain assistance through the ordinary financial channels.

The advances are to be repayable as the Colonial Treasurer determines, and will bear interest at a rate not less than 6 per cent. per annum, calculated on the daily balance. The advance is to be secured by a mortgage or other security as seems fit to the Colonial Treasurer, who also has discretion to exempt any securities from stamp duty or registration fees.

(C) STATE TREATMENT AND PURCHASE OF, AND SUBSIDIES AND ADVANCES ON, ORE.

This subject comes conveniently under five heads, namely, (a) State batteries; (b) subsidies for certain ore crushed at State batteries; (c) subsidised private batteries; (d) purchase of auriferous copper ores at the State smelting works, Phillips River; (e) advances on ores generally.

Particulars can be obtained from the Mines Department, Perth, or from the various batteries and works.

(D) GOVERNMENT ASSAYS, ETC.

The Government undertakes assays, analyses, and determinations of any Western Australian ore, mineral, or rock. Some assays are free.

The conditions for all classes of work, including the charges for work that must be paid for, can be ascertained from the office of the Government Geologist, Perth.²

XXIII.—CONCLUSION.

In bringing this article to a close it is not out of place to quote the opinion, on the Western Australian mining law, of Mr. Arthur C. Veatch, a member of the United States Geological Survey, who, in 1907, was constituted by the President of the United States a special commissioner to visit Australia and New Zealand to make a study of the coal land laws of those countries, but who, nevertheless, paid much attention to the mining laws as a whole. Mr. Veatch's conclusion is thus expressed:—

"The Western Australian mining law is, in short, a wonderfully symmetrical and carefully balanced enactment; and while one may not regard it as applicable in all its features to American conditions, it contains many suggestive provisions, all of which merit careful consideration. They can not in any way be considered the idle visions of the theorist, but are the mature enactments of a Legislature whose members are entirely chosen by the voters of a great democratic mining State—a State which ranks among the great mining states of the world, and which has as recently as 1904 recognised and revised its mining laws to meet the practical workaday conditions of that region."

A.C.V., p. 39.

² In addition to the methods just enumerated, the State assists mining in other ways, such as money rewards for certain gold discoveries, bonuses, reward claims and leases, some particulars of which are given in the earlier portions of the text.

- R.M. 20.** The form, the time for lodging, and the posting of the notice of application, are the same (allowing for the necessary modifications) as for prospecting areas on Crown land, except that with the registration fee, 5s., the rent, and survey fee¹ (if any) must also be lodged. Similarly with regard to a sketch showing the boundaries of the land, etc. Where, however, the application has reference to an underground tenement, it must show the portion of the surface, if any, required. If no surface area is applied for or available, the applicant must satisfy the Warden that he can reach the land applied for to enable him to work the same.
- R.M. 138.** The application must state the number of shares or units into which the claim is to be divided, and where an application is by two or more persons, the number of shares or units to be held by each person; also the name by which the claim is to be known; and also the metal or mineral to be mined.
- S. 272, M. R.M. 133.** The regulations as to objections, withdrawal or refusal of application, and surrender of holdings, apply to claims as to prospecting areas on Crown land. See, therefore, details under the latter heading.
- R.M. 34.** For the union of claims, application must be made to the Warden in form No. 5, signed by partners together holding at least two-thirds of each claim. The registration certificates require to be produced, and the fees (2s. 6d. for each claim) paid with the application.

(2) MINERAL CLAIMS.

- R.M. 40b, 181.** These claims are taken possession of and marked off in the same way as set out above under Prospecting Areas on Crown Lands. The notice of marking off (form No. 31) should be affixed to the datum post at the time of marking off.
- R.M. 40b, 187.** Application for a mineral claim is made similarly to applications for prospecting areas on Crown Land, but it must be also advertised once in a local newspaper within 14 days of the application being lodged; and within 30 days of the lodging of the application an objection may be lodged in duplicate in the form No. 34. Before the hearing the Warden obtains a report from a professional officer, and after the hearing makes a recommendation to the Minister who decides the matter. On the lodging of the application, the registration fee 5s., the rent and survey fee (if any) must be paid.
- Generally the regulations stated above as to alluvial and lode claims apply.

(3) DREDGING CLAIMS.

- R.M. 131. R.M. 40a (3).** These claims are taken possession of and marked off as stated under Prospecting Areas on Crown lands, except that it is only necessary to erect posts or cairns at each end of the claim, and at each angle of same on the shoreward edge or bank; the opposite boundaries will be considered to be parallel to the marked boundaries. At each end of the claim, a tree (if available) is also to be marked with a distinguishing mark. If in any case one of the angle posts or cairns is not visible from the next succeeding angle, post, or cairn, there shall be erected so many intermediate posts or cairns as may be necessary to render each visible from the next in succession throughout the length of the claim.
- R.M. 40a (5) 137.** The application for registration is made similarly to a prospecting area on Crown lands, except that on lodging same the rent and survey fee (if any) must be paid as well as the ordinary fee, 5s. The notices of marking off and of the application are posted as in ordinary claims. In addition, the application has to be advertised once in a local newspaper within 14 days of the application being lodged; and within 30 days of the lodging of such application any person can lodge an objection in duplicate in the form No. 34. If no objection, instructions may issue to a mining surveyor to make a survey and report; but if an objection is lodged the survey may be postponed. The Warden hears the application and transmits his recommendation to the Minister, who finally decides the matter.
- R.M. 40a (6).**

¹ No rent is chargeable, nor is any survey required as a rule.

- (4) CLAIMS ON RESERVED AND EXEMPTED CROWN LANDS. **S. 30, M. R.M. 73 (as amended) and 74.** Application for authority is required to be in the form No. 7, and to be lodged with the Warden or Mining Registrar, and where the land is situated within a municipality, a copy of the application must be sent to the Mayor. Before lodging the application, or at the same time, the applicant (having, where possible, previously marked off the ground) makes application for same as a claim. (For method see above "Alluvial and Lode Claims on Crown Land" and "Prospecting Areas on Crown Land.") On receipt of the applications, the Warden causes a notice of the application for authority to be posted at the Mining Registrar's office, and the applicant must insert a copy of such notice in one issue of a local newspaper. The notice contains the date within which objections may be lodged, and the date of hearing the application. Previous to the hearing the Warden obtains a report as mentioned when treating of these claims under "Mining Tenements or Holdings," and according to that may require a deposit of money to cover damage.

The notices of marking off and of the claim application (forms Nos. 31 and 33) must also be posted as required for an ordinary claim, including the affixing to the datum post, where marking off is possible.

The application for authority and the application for a claim are dealt with by the Warden together.

(E) REWARD LEASES.

The application for a reward lease must be lodged at the time of lodging the report of the discovery with the Warden.

Such application should be in triplicate, in the form No. 9, and a fee of 10s. must be paid in lieu of the rent and survey fees payable in ordinary mining lease applications. In all other respects (including marking off) the regulations relating to the granting of ordinary mining leases apply to reward lease applications (See below as to mining lease applications.) **R.M. 20.**

(F) MINING LEASES GENERALLY OF CROWN LANDS.

Before making application for a lease, the applicant or a person authorised by him, takes possession of and marks off the ground by erecting a substantial post or cairn of stones projecting not less than three feet above the surface at or as near as possible to each corner of the land applied for. Such post or cairn has to be set in the angle of two trenches, each of which is not to be less than four feet in length and six inches in depth, and extending in the direction of the boundary lines. Where the nature of the ground will not permit of trenches being dug, rows of stones of similar length must be substituted. The boundary lines are also to be cleared from post to post. One of the posts or cairns has to be termed the "datum post," from which the survey of the land shall be commenced. The intended applicants must cause to be affixed to such post or cairn a notice of marking off in the form No. 8, which shall be kept legible until the notice of application later referred to is posted. (When the application is for a lease of a reserve or authorised holding under Division 3 (Sections 61-64) of Part V. of "The Mining Act, 1904," marking off may be dispensed with by the Warden or Mining Registrar.) **R.M. 81.**

Within 10 clear days after marking off the land, the application in the form No. 9 must be lodged with the Warden or Mining Registrar, accompanied by a deposit of the rent for the unexpired portion of the year, calculated from the beginning of the quarter in which the application is made, and the amount of the prescribed survey fee. **R.M. 82.**

If the application is not lodged within the time mentioned, no fresh marking off or posting of notice is allowed within 21 days from the first marking off or posting. **R.M. 83.**

If the application is made by an association or company, Footnote to except a company registered under the Companies Act, 1893, Form No. 8. the constitution of the association or company, the number of shares, and the names of the shareholders must be given.

¹ If an agent makes the application, the Warden may require confirmation of his authority prior to transmitting his recommendation to the Minister. **R.M. 82.**

R.M. 138. Every application is to be accompanied with or contain a sketch showing the boundaries of the land, which must be fixed, where possible, by reference to some existing survey mark, or to some feature on the land or adjacent to same, and where it has reference to an underground tenement, the sketch must show the portion of the surface, if any, required by the applicant. If no surface area is applied for or available, the applicant must satisfy the Warden that he can gain access to the land applied for to enable him to work the same.

R.M. 82. On receipt of the application, the Warden or Mining Registrar hands to the applicant a notice in triplicate in the form No. 10. One copy must be at once posted up by the applicant at the Warden's office, and another, as soon as possible, on the datum post of the land applied for. The third copy is to be inserted at least once in a local newspaper within 14 days after the date of lodging the application.

S. 70-72, M.
R.M. 84. An objection in duplicate in form No. 34 may be lodged within 30 days from the time of lodging the application for lease.

R.M. 85. If no objection, instructions may be given to survey the land, and if objection is lodged the survey may be postponed, but must be made if the application is granted.

R.M. 86. If no objection, the applicant need not appear before the Court unless ordered by the Warden to do so. If the application is refused or withdrawn the rent, less 10s., and also the survey fee (if the survey or inspection has not been made) will be refunded. The notice of withdrawal must be lodged in duplicate in form No. 11.

R.M. 87.
R.M. 89. Should the boundaries of the land applied for be identical with a forfeited, abandoned, or surrendered tenement previously surveyed, a fee of £2 only to cover the cost of inspection shall be paid, unless, where any re-marking or re-survey is necessary, the full prescribed survey fee shall be paid.

R.M. 140. Boundary marks must be maintained while the lease is in force.

R.M. 147, et seq. Fee on issue of lease, £1.

S. 86-90, M.
R.M. 95, 96. *Amalgamation of Leases.*—The application in the form No. 13 signed by the lessee or by some one who has written authority from him to do so, must be lodged with the Warden or Mining Registrar with the registration fee (£1 for each lease). The application must be accompanied by a sketch showing the position of the leases to be amalgamated. If the Minister grants the application, a certificate in form No. 14 is issued.

(G) TRAMWAY, MACHINERY, WATER, AND RESIDENCE LEASES OF CROWN LAND.

The ground must be marked off, notices posted, and application made in the same way as in ordinary gold-mining or mineral leases. Fee on issue of lease, £1.

R.M. 116. (H) MINERS' HOMESTEAD LEASES.

The ground (for areas and shape of which, see under the leases in the section on Mining Tenements and Holdings) must be taken possession of and marked off in the same way as an ordinary mining lease.

Similar notice of marking off has to be affixed, and the application to be in the same form (with merely the necessary changing of the wording) and lodged in the same way as the ordinary lease application, with the rent and survey fee (if any) and a sketch of the land.

S. 180, M.
R.M. 84. The notice of application must also be affixed to the Warden's office, to the datum post, and advertised as required for a mining lease. Similarly an objection may be lodged in the same way, and generally the methods are the same unless otherwise noted. An objection must be lodged within 21 days from the time of the lodging of the application, instead of 30 days as is the case with applications for mining leases.

R.M. 116. Where the land applied for comprises a portion of any land held under a pastoral or timber lease, a copy of the notice of application must be served on the lessee of such pastoral or timber lease.

Footnote to Application Form No. 8. The number, date, and place of issue of the applicant's miner's right should be furnished with the application. £1 fee is charged on the issue of the lease.

(I) GOLD DREDGING LEASES.

To obtain one of these leases, the same method of marking out, etc., is followed as in applying for a dredging claim, which is the holding usually applied for.

(J) PRIVATE LAND—PROSPECTING AND RESERVED AREAS, CLAIMS, AND MINING LEASES OF¹

The application for a permit to enter upon or mark off private land must be in form No. 19, and lodged with the Warden. No fee is payable for the permit. R.M. 104.

If after having obtained a permit a prospecting and reserved area is desired before making application for a lease or claim, application in form No. 20 is lodged with the Warden or Mining Registrar with the fee 10s., and a copy of the application is served on the owner or occupier of the land. R.M. 108.

When a mining lease or claim is desired, the holder of a permit can enter upon the land, mark off and apply for a mining lease or claim in the same way as if the application were one for a mining lease or claim of Crown lands; that is, he must mark off by posts, trenches, and clearing of boundaries, must affix the notice of marking off (in the case of a lease, form No. 8, and in the case of a claim, form No. 31) to the datum post, lodge his application (in the case of a lease, form No. 9, and in the case of a claim, form No. 32), with the necessary fees, and post the notice of the application (in the case of a claim, form No. 33, and in the case of a lease, form No. 10, with, in the latter case, the necessary advertising of such notice). Details of these matters have been already stated in connection with applications for leases and claims on Crown land. In addition, notice of the application for either a claim or a lease (form No. 33 for a claim, and No. 10 for a lease), must also be given to the owner and occupier, or, if there is no occupier, it must be affixed in some conspicuous place on the land. The application must state and describe the area of surface, if any, applied for, and the purpose for which same is required. If no surface area is applied for, it is not necessary to mark out the tenement applied for on the surface. S. 133, M.
R.M. 105.

All agreements as to compensation must be in writing S. 146, M., and be filed with the Warden or Mining Registrar (fee 5s.) R.M. 106, 107; within 30 clear days from the date of application for any mining lease or claim.

Fee on issue of a lease £1, and for registration of a claim 5s.

(K) PETITION TO BRING CERTAIN PRIVATE LAND UNDER PART VI. OF THE MINING ACT, 1904.

The petition, with the fee (5s.), is lodged with the Department of Mines giving full particulars of the position and area of the land, and of the reasons for believing that the same contains minerals other than gold, silver, or precious metals, in payable quantities.² S. 154, M.
R.M. 113.

Before a professional officer inspects the land, the Minister must give not less than 30 days' notice to the owner of his intention to do so. R.M. 114.

Application by the owner for the exclusive right to mine on the land for specified minerals is in form No. 21. Registration fee 10s. R.M. 115.

(L) WATER RIGHTS ON CROWN LANDS.

For all water rights, the applicant must be the holder of a miner's right. The registration fee for each right is 5s.

(1) STREAM WATER RIGHTS, AND LAGOON, LAKE, SPRING AND SWAMP WATER RIGHTS.

The method of taking possession of and marking off is the same with regard to these two rights, so they may be treated together. R.M. 49.

¹ See also under Mining Tenements or Holdings for general information. M. 1; page 10.

² For what "payable" and "payable quantity" mean, see foot note in the section above dealing with Prospecting Areas on Crown lands under "Mining Tenements or Holdings." (page 9).

R.M. 45. Before making application for either right, the applicant or some person authorised on his behalf, erects a substantial post or cairn of stones projecting not less than three feet above the surface at or as near as possible to the point of intake of either right. On the post or cairn a *notice of marking off* (form No. 31), signed by the applicant or his agent, is posted, setting forth the date and hour at which the water right was taken possession of. Should the applicant desire to obtain a site for the purpose of erecting works or machinery, such site is to be marked as nearly as possible in the form of a square, and at each corner thereof similar posts or cairns of stones are to be erected, set in the angle of two trenches, not less than four feet long and six inches deep, cut in the general direction of the boundary lines, and on one of such posts a similar notice of marking off, specifying the area of such site, is to be posted. The boundary lines of such site must be cleared from post to post.

R.M. 131.

R.M. 137, 138.

The application (with a sketch of the machinery site if taken up) must be in the form, and lodged within the time, and in the way set out under Prospecting Areas of Crown land (which see), together with the fee for registration, rent and survey fee (if any). The *notice of application* under Regulation 137 (form No. 33) must also be posted at the office of the Warden, and on the datum posts of the water right, and of the machinery site (if taken up) in the same way as for a prospecting area.

R.M. 45, 137-146a.

The regulations as to objections, withdrawal, or refusal of application, and surrender, as to prospecting areas on Crown land, apply to these two water rights. See details under such areas.

(2) WATERSHED OR STORMWATER RIGHTS.

R.M. 52.

Before making application, the applicant, or someone on his behalf, marks out the boundaries of the watershed he proposes to apply for by means of substantial posts projecting not less than three feet above the surface, firmly sunk in the ground, and not being a greater distance apart than forty chains, and if the contour of the country is of such a character as may require posts at a closer distance, then the posts must be placed sufficiently close to enable the surveyor to easily locate the boundaries. Trenches must be cut at each post. *Notice of marking off* in form No. 31 requires to be affixed to the datum post at time of marking off.

R.M. 132.

R.M. 137, 138.

The application, as to form and time, the posting of the *notice of application*, and the regulations as to objections, withdrawal, or refusal of application, and surrender, are as set out under Prospecting Areas on Crown land, but the boundaries have not to be cut. The registration fee, rent, and survey fee (if any) must be lodged with the application.

(3) DAM, TANK, OR RESERVOIR RIGHTS, AND SUBTERRANEAN WATER RIGHTS.

R.M. 56, 61.

The regulations as set out under Prospecting Areas on Crown land, including marking off, application, posting of notices (those of marking off and of application), objections, withdrawal, or refusal of application, and surrender, apply to these rights, except that rent and survey fee (if any) must be paid with the registration fee, and except that as regards the Dam, Tank, or Reservoir Rights, the notices to be posted must state the dimensions of the proposed dam, tank, or reservoir, and its capacity in gallons.

R.M. 62a.

(4) RACE OR PIPE TRACK WATER RIGHTS.

Before making application for a Race or Pipe Track Water Right, the applicant, or someone on his behalf, erects a substantial post or cairn of stones projecting not less than three feet above the surface at each end of the proposed race or pipe track, and on each of such posts or cairns there must be affixed a notice in the form No. 31, signed by the applicant or his agent, stating the date and hour at which the land was taken possession of, the approximate length of the proposed race or water pipe and its course.

The regulations set out under Prospecting Areas of Crown land, as to the application, posting of notices of application, objections, withdrawal or refusal of application, and surrender, apply to these rights. The registration fee, rent, and survey fee (if any) must be lodged with the application.

(M) ALL OTHER AUTHORISED HOLDINGS OF CROWN LAND.

These comprise, as already indicated, Residence or Business Areas, and Machinery, Tailings, Washing, Market Garden, and Quarrying Areas.

In the case of land previously surveyed, and specially set apart as a Residence or Business Area, an applicant, who must be the holder of a miner's right, need not erect posts or cairns to mark the boundaries. Except for this, all holdings must be taken possession of, marked off, and applied for in the same way as set out under Prospecting Areas of Crown land. R.M. 68, 129.

Similarly the regulations as to objections, withdrawal or refusal of application, and surrender are applicable to these areas as to prospecting areas.

An applicant is not entitled to occupy the Residence or Business Area applied for until the application is registered by the Warden. R.M. 69.

Registration fee for each holding, 5s.

(N) SPECIAL LEASES UNDER THE LAND ACTS.

Application must be made to the Lands Department in the form or to the effect of the 28th Schedule of the Act, in which the purpose for which the lease is required should be stated. The application must be accompanied by a deposit of half the first year's rent. When it is proposed to grant a lease for a longer term than 10 years, notice of the application must be published in four consecutive ordinary numbers of the *Government Gazette*, the first publication being at least one month before the grant of such lease. S. 152, L. (as amended).

(O) GUANO LICENSES.

These are controlled by the Department of Lands, but no regulations have been made as to formal application for same. The regulations respecting their nature and conditions have been summarised above under the Part dealing with Mining Tenements or Holdings. R.G.L. Note.—Licenses are issued under Act 40, Victoria No. IX.

(P) LICENSES FOR DRIVES.¹

The application for a license to construct a drive or drives under the provisions of Section 152 of the Mining Act, 1904, is required to be in form No. 53, and to be lodged at the Mines Department with a plan showing the position of the proposed drive or drives. R.M. 193, 194.

The applicant must serve a copy of the application on the owner of the land, or the holder of the mining tenement, through which any drive is to be constructed, or in the case of same being constructed under a road or street, on the Municipality or Road Board to whom such street or road belongs. Before the license is granted, the Minister will require the Warden to take the evidence of all parties interested and report to him thereon.

Fee £1 per annum during the term granted.

(Q) TAILINGS LICENSE.²

Application for a license to remove or treat tailings or other mining material is made to the Warden or Mining Registrar.

Notice of the application must be posted at the Warden's office at the time of lodging the application, and on the heap of tailings to be removed or treated, and advertised in a local newspaper. An objection can be made within 30 days from the posting of the notice in the form No. 34. The Warden hears the matter and reports to the Minister, who finally decides. S. 110, M. R.M. 94.

Fee on license, 10s. per month during the term.

¹ See also under "Claims and Mining Leases on Private Land" under "Mining Tenements or Holdings" above (page 16).

² See also above "Mining Tenements or Holdings" under "Mining Leases (of Crown lands) generally." (page 14).

(R) APPLICATION FOR FORFEITURE OF A MINING LEASE.¹

S. 99, M. R.M. 99. The notice to be given to the Warden that land held under a mining lease is not being worked in accordance with the regulations is in form No. 60, and it must be lodged in duplicate with the Mining Registrar with the prescribed fees.

S. 99 (2), M. The Registrar then issues a notice to the lessee in form No. 62. If the lessee files an answer, the Warden may require the applicant to deposit £10 within seven days, to be dealt with as provided, and if such deposit is not made he may dismiss the application; but if satisfied that the application is bona fide or that the rent is more than 30 days in arrear, the Warden (or, in his absence, the Registrar) may allow the applicant to proceed without such deposit being made.

S. 100-104, M. The application is to be heard in open Court, but the final decision, unless the application is dismissed by the Warden, rests with the Government.

(S) APPLICATIONS FOR EXEMPTION.²

S. 92 M. R.M. 155. Every application for exemption from the labour covenants, or from the conditions of use or occupation, for longer than 14 days³ on a mining tenement, including a lease, is to be in form No. 37, and to be lodged with the Warden or Mining Registrar, with the fee, and a copy of the application must be posted up on the notice board at the Warden's office by the applicant, and another on a conspicuous part of the mining tenement, and kept legible and intact for seven clear days before the hearing if the term applied for exceeds one month, and for three clear days if it is not more than one month. Anyone may lodge an objection to the application within the time fixed by the Warden.

R.M. 11, 156. The Warden hears the application in open Court and grants or refuses the same, except in most cases where it is for longer than one month, when the Minister decides on receiving the Warden's report.

R.M. 157. If exemption is granted the Warden issues a certificate in the form No. 38, which must be kept posted for the full period of the exemption in a conspicuous place at or near the shaft or other workings of the mining tenement.

S. 93, M. R.M. 159. In applications for exemption as of right under Section 93 of the Mining Act, 1904, a lessee must file with his application a statutory declaration in the form No. 39, setting out all the particulars required. In the event of any question arising as to what are "main workings," referred to in the declaration, the matter is referred to the Minister, whose decision is final.

S. 95, M. R.M. 159. An application under Section 95 of the Mining Act, 1904, by the holder of a coal-mining lease to dispense with the performance of his covenant to work the mine continuously is made in writing to the Minister, who, if he grants the application, issues a license in form No. 40, for not longer than six months, subject to such conditions as he thinks fit. There is power under the section to renew the license for further periods.

Exemption Fees.

Form 59.	Claim or Authorised Holding:	£	s.	d.
	Not exceeding 14 days	0	2	6
	Not exceeding one month	0	5	0
	Not exceeding six months (per month)	0	5	0
	Leases, for each lease:			
	Not exceeding 14 days	0	10	0
	Not exceeding one month	1	0	0
	For each additional month	1	0	0
	License to dispense with working coal-mining lease under Section 95:			
	For each lease per month during term	0	2	0
	Minimum fee for same	3	0	0

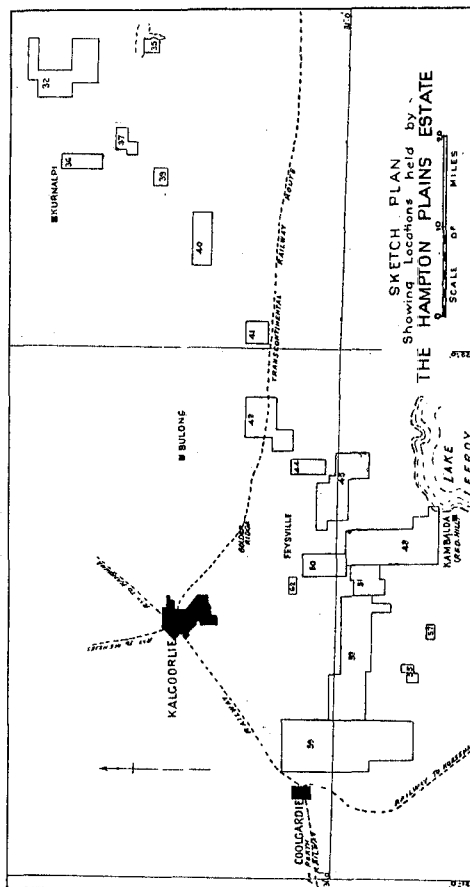
¹ See also above under "Mining Leases (of Crown lands) Generally." (page 14).

² As to exemption generally, see under leases, claims, etc., under the heading of Mining Tenements or Holdings.

³ For less than 14 days, the application is quite informal, either verbally or by letter.

XII.—THE HAMPTON PLAINS ESTATE.
REGULATIONS FOR GOLD MINING.

(1) INTRODUCTORY.—This estate comprises 216,000 acres of land situate to the south and east of Kalgoorlie, and shown on the plan attached. Many years ago this was



sold by the Government to the Hampton Lands and Railway Syndicate, Limited (now the Hampton Plains Estate, Limited, Western Australia). One of the conditions of the sale was that the company should have the right to work the metals reserved by the Crown Grants, on the company paying a royalty of two shillings per ounce on all gold won from the land. The royalty, however, was subsequently released by the Mining on Private Property Act, 1898, conditional on the company making regulations, approved by the Government, for the management of gold mining on the land. Such regulations have been made, and the existing ones govern the rights of persons to prospect and mine upon the land for gold. A short statement of such regulations, which are dated the 1st of January, 1900, is therefore necessary.

(2) MINING LICENSES.—The company issues two kinds of licenses, a mining license and a business license.

A mining license takes the place to some extent of a miner's right under the Mining Acts generally. The company will issue (but is not bound to do so) a license to any person who is not an Asiatic or African alien. Fee 10s. per annum, but

S. 56-62.
M.P.P.

R.H.P. 1 and 2.
R.H.P. 3 and 6.

- a half year only is charged when application is made after 30th of June. The license must be produced when asked for by the company's officer.
- R.H.P. 8 and 2. A license expires on the 31st of December of the year of issue, but may be renewed on payment of the fee. It is not transferable.
- R.H.P. 9. The holder of a mining license can prospect for and obtain gold upon any unoccupied portion of the estate not already reserved, or let on lease or otherwise held under the company's regulations.
- R.H.P. 7. As regards timber, the holder of a mining or business license may fell and make use of live timber within the pegs of his claim or business area. He is not restricted to this area as regards dead timber. No timber is to be removed from the estate without the consent of the attorney of the company, who may also permit the holder of a mining or business license to sink wells and conserve water for mining and domestic purposes upon any unoccupied portion of the estate not already reserved. All sandalwood on the estate is reserved to the company.
- R.H.P. 8. (3.) ALLUVIAL CLAIMS.—There is no provision for extended alluvial claims, river and lake claims, dredging claims, or lode claims, nor for prospecting areas. Ordinary alluvial claims are alone dealt with. When a lode is desired to be worked, a lease must be taken out.
- R.H.P. 9. A person desiring to take up an ordinary alluvial claim must be the holder of a mining license. He is then entitled to mark off and occupy an area of the size mentioned below for alluvial mining, provided such area is not already reserved or occupied, or disposed of by the company. The marking off must be done in the same way as a claim under the ordinary Government regulations, and the claim must be rectangular when possible. The maximum area of an ordinary alluvial claim is:—
- | | |
|---------------------|-----------------------|
| For one man | 70 feet by 70 feet. |
| For two men | 100 feet by 100 feet. |
| For three men | 125 feet by 125 feet. |
| For four men | 150 feet by 150 feet. |
| For five men | 170 feet by 170 feet. |
| For six men | 200 feet by 200 feet. |
- No alluvial claim is to be greater than 200 feet by 200 feet.
- Twenty-four hours after marking out, the claim must be efficiently and continuously worked by the number of miners taking up the claim for six clear days per week (public holidays excepted).
- On payment of a fee of 10s., and also survey and mileage fees, the claim may be registered for 12 months in the name of the holder and may be renewed. Registration is evidently compulsory (see regulation 55).
- R.H.P. 10, 11. Discovery of alluvial gold must be reported so as to obtain an alluvial reward claim as provided by regulations 10 and 11. Failure to report within six days of the discovery forfeits the right to the alluvial reward claim.
- R.H.P. 12. Regulation 12 states that the holder of a mining license upon his marking out and occupying an alluvial claim in accordance with the regulations is to be deemed to be possessed of all alluvial gold therein, subject to the company's right of resumption of the claim for the purpose of issuing leases. This is different from the rights of the holder of a miner's right, who takes up an alluvial claim for gold on Crown land, as such holder is entitled to all gold (found both in alluvial deposits and lodes) and all other minerals there discovered.
- R.H.P. 14. No miner (that is, any person possessed of a current mining license issued by the company) is entitled to hold more than one alluvial area at one and the same time.
- R.H.P. 14, 15. (4.) GOLD MINING LEASES.—A lessee has the sole right to all gold on the land. He must be the holder of a mining license when he marks off the land and applies for the lease. The marking off must be done similarly to the marking off of an ordinary gold mining lease from the Government, and the area must be rectangular when possible.
- R.H.P. 15-17. Application is in the form No. 6¹ for land not reserved or disposed of by the company, and must be accompanied with the first year's rent, together with the survey and mileage fees. The application must state the number of shares into which the lease is to be divided.
- R.H.P. 16. A notice of the application in form No. 7 must be posted by the applicant outside the company's mining office, and on the datum peg on the land, stating that objections may be lodged up to a day named in the notice, being not more than 30 days from the date of such application.
- R.H.P. 18. Term 21 years. Rent 20s. per acre per annum.
- R.H.P. 19. The company has reserved the right "to retain every alternate block not exceeding 24 acres along the line of reef on which leases may be applied for," and in the case of a deep lead the right "to retain alternate blocks on any two sides of such lease." The company has notified that it will not grant leases over any land occupied by licensees under Regulation 9 (that dealing with alluvial claims) until satisfied that such land is no longer being worked for alluvial gold.
- A lease must be efficiently worked for six clear days per week (public holidays excepted) by one man for every 12 acres or part thereof.
- R.H.P. 21.
- R.H.P. 23. Area of lease.—For a gold-bearing reef, not more than 24 acres or less than 12 acres; for a deep lead lease, not more than two acres. The length of the area along the line of reef or deep lead is not to exceed double the width.
- R.H.P. 22. A protection period for one month may be obtained in respect of a newly discovered gold-bearing reef or deep lead. The ground must be marked off in the usual way and application made in form No. 8. Application for a lease must be made within the month.
- R.H.P. 24-28. Other regulations provide for issue and conditions of lease, transfer of lease, conditions of forfeiture and exemption. Particulars cannot be set out here.
- R.H.P. 29. No lessee is to cut or cause to be cut any timber outside the boundary of his lease except by permission of the company's attorney.
- R.H.P. 31-39. (5.) BUSINESS LICENSES AND AREAS are provided for by Regulations 31 to 36, and MACHINERY AREAS by Regulations 37 to 39.
- R.H.P. 39. It may be noted here that the holder of a business, residence, or machinery area is not by reason of holding such area to be entitled to mine for gold thereon or thereunder. Any holder of a mining license may enter upon such land to mine on payment to the lawful occupants of compensation, which, if disputed, is fixed by the company's attorney.
- R.H.P. 45. (6.) GENERAL.—The company reserves a right of way to itself and agents, etc., over any holding, and also to construct any roads, water races, or drains, reservoirs or dams, and any railways, tramways, or other means of communication, and to lay gas, water or other pipes upon, under, and across any holding, subject, however, to compensation for actual surface damage only (if any).
- R.H.P. 49. A return of all gold won on the estate by miners or holders must be made to the company and to the Government, when and as required by the Government regulations.
- R.H.P. 9, 25, 31 (e), 38, 55. To give title, registration of leases, business and machinery areas, and apparently alluvial claims, as well as approved transfers of any of these, is necessary. Fee on transfer of lease, business license, and machinery area, £1 each.
- R.H.P. 56. A holder of land for mining purposes must not allow any portion of the surface to be occupied for business purposes at all, or for residence, except by the holder himself and his employees.
- R.H.P. 57. Nothing but mining and the necessary work connected with mining are to be done upon land taken up for that purpose, and no mining is to be carried on upon land granted for any other purpose.
- R.H.P. 58. All registrations are to be made in the company's mining office.

XIII.—TIMBER.

As timber is of great importance in mining operations, both as firewood and for the actual purposes of mining, the following remarks will not be out of place.

(A) TIMBER LICENSES.

Various timber licenses are issued by the Forests Department, from which all information can be obtained. From a mining point of view, the Woodcutter's or Charcoal-burner's License and the Mining Timber License are important.

A Woodcutter's or Charcoal-burner's License is for cutting or splitting and removing firewood from any live or R.T. dead wood growing or lying on Crown lands in the locality named in the license, but no license is required for cutting, obtaining, and removing dead wood lying on Crown land for domestic purposes but not for sale. Fee 1s. per month per man.

Mining Timber Licenses are issued for cutting or splitting and removing timber from the locality named in the license for mining props, slabs, poles, posts and logs. Fee 2s. 6d. per month per man. The cutting of firewood and mining timber upon State forests is only allowed under a special permit.

A "deep lead" is defined in the regulations to mean "any soil, earth, or other substance containing gold not being a seam, lode, or quartz vein, and being 20 feet or more in depth from the surface of the ground." Compare with the definition in Section 3 of "The Mining Development Act, 1902" (page 4).

¹ The reference to the various forms in this part dealing with the Hampden Plains Estate is to those with similar numbers in the Schedule to the Regulations governing mining on the Estate.

R.T. The cutting or removal of Kurrajong, Quandong, Red-flowering gum, and Christmas trees of every kind or size is absolutely prohibited throughout the State.

(B) TIMBER TRAMWAYS.

S. 8, 10, L. 02. S. 68, L. 06. A timber lessee or licensee may obtain permission to construct and use tramways upon Crown lands or reserves, for the haulage of timber, piles, poles, barks, sandalwood or firewood, and to connect the tramway with any Government railway; but as regards a tramway constructed over a timber reserve, the owner of the tramway is not to cut any timber or firewood outside a limit of one chain on each side of the line without the Minister's written permission.

R.T.T.

The application must be made in accordance with the regulations, and rent is payable. The regulations in force are those of the 19th of January, 1905, as amended, and particulars of same may be obtained from the Forests Department.

(C) GENERAL PRACTICE.

With regard to mining and firewood timber for use on the goldfields, the practice is for wood-cutters to obtain a wood-cutter's (firewood) license, or a mining timber license, or both when necessary, and for them to supply the mines with the required firewood or mining timber. The mining companies may, however, obtain licenses for certain of their employees, and under these, they obtain their supplies. In the case of timber tramways, the holder of the permission to construct must be a timber licensee or lessee, so that he (or the company, if the latter is the holder) may cut timber in accordance with the license or lease; but the ordinary licensed woodcutters usually largely supply the tramways with wood, the owner of the tramway often acting merely as a purchaser and a carrier.

XIV.—MONEY REWARD FOR GOLD DISCOVERY.

S. 12, M. Up to £1,000 may be paid for the discovery of payable¹ gold at a place distant more than 10 miles from the nearest place where payable gold has, up to then, been discovered.

R.M. 14, 25.

Some conditions, before payment will be made, must be observed, such as marking out and applying for the ground, and reporting discovery at the nearest Warden's office, with particulars of same, as provided in the Regulations.

XV.—PURCHASE AND SALE OF GOLD.

(A) GENERAL CONDITIONS.

Part IX. of the Mining Act, 1904, is the principal law regulating traffic in gold.

S. 204, M.

"Gold," for the purposes of this Part of the Act, includes gold, gold bullion, retorted gold, gold ores, gold amalgam, gold alloys, precipitates containing gold, slag, concentrates, tailings, and residues; but does not include alluvial gold or coin or things manufactured of gold.

"Buyer" includes dealer and the agent of any buyer or dealer.

S. 205, M.

The important point for the prospector and miner to bear in mind with regard to this Part of the Act is that except as to be immediately mentioned, no person is to buy or sell gold unless either the buyer or the seller is the holder of a gold dealer's license, and the sale is effected at the registered place of business of the gold dealer, and under his personal supervision. This, however, does not apply to the purchase of gold-bearing earth or tailings from any registered leaseholder or claim-holder, if it is proved by the buyer that the sale was effected by a written agreement signed by or on behalf of the seller and the buyer, setting out that the earth or tailings were produced from and taken out of the ground comprised in the lease or claim of which the seller is the registered holder, and which lease or claim is sufficiently described in the agreement.

¹ For definition of "payable" see "Prospecting Areas on Crown Lands" under "Mining Tenements or Holdings" (page 9).

The effect of this legislation is that alluvial gold, or coin, or things manufactured of gold may be bought or sold, or otherwise dealt with without regard to the conditions mentioned, and that goldbearing earth or tailings may be purchased under the special conditions just stated without either party holding a gold dealer's license. The incorporated banks act generally as gold buyers.

(B) GOLD DEALERS' LICENSES.

How to obtain a license.—Application in duplicate in form No. 22 by any person¹ must be lodged with the Warden of the goldfield or mineral field, or the Resident Magistrate of the magisterial district for which the license is required, at least 30 days before the hearing, with the fee £2. The duplicate on the day of its receipt by the Mining Registrar or Clerk of Court is posted in a conspicuous place either within or without the court, and shall be kept so posted (legible and intact) till the day of hearing. A copy of the application must also be published in three consecutive issues of a local newspaper, and a copy must also be kept posted until the hearing in a conspicuous place on the building in which the applicant intends to carry on his business as a licensed gold dealer. Any person may object to the application by ordinary letter through the post to the Court or to the Minister.

S. 206, M.
R.M. 120.

The license is in form No. 23, and it has effect only within the goldfield, mineral field, or magisterial district therein specified. The granting or refusal of a license is in the absolute discretion of the Minister, after report by the Warden or Magistrate.

R.M. 121.

R.M. 122.

S. 209, M.

S. 207, 210, M.

An incorporated bank can, by application to the Secretary for Mines and on payment of a fee of £5, obtain a license in form No. 24 to cover such of its branches as it specifies. The officer in charge of the head office and of each branch specified becomes then a licensee under the Act.

S. 211, M.

R.M. 123 (as amended).

Term of license.—The license remains in force until the 31st of December next following the granting of same, unless it be cancelled by the Minister on the licensee being convicted of any offence against this Part of the Act, or of any other offence which the Minister thinks makes the licensee unfit to hold a license. Application for renewal must be made before the expiration of the license.

S. 212, M.

S. 213, M.

A *Register of licenses* is kept at the Mines Department in Perth, and an official copy at the office of every Warden and Resident Magistrate so far as it relates to his gold or mineral field or district. It is open for inspection without fee, so that anyone can ascertain who are licensed to buy gold.

Registered address of gold dealer.—If change of the registered address is desired, application must be made to the Warden or Resident Magistrate, and a fee of 5s. paid. The change is endorsed on the license.

S. 214, M.

A *Gold Dealers' Book and Returns* must be kept and made in forms Nos. 25 and 26 respectively in accordance with the Act and Regulations. Every entry in the book must be signed by the person with whom the dealing is made. Penalty for false statement by this person or by licensee, imprisonment or fine. The proper officials have the right to inspect the book.

S. 215, 216, M.

R.M. 124, 125.

S. 218-220, M.

Temporary Licenses (form No. 28) may be issued by a Warden or Resident Magistrate for the goldfield or district where required for a period up to three months to a fit person to deal in gold in a remote locality. Applications are in form No. 27. Fee 10s. No copy of the application need be posted at the court house or be advertised, but apparently a copy must be kept posted at the applicant's place of business where he intends to act as a gold dealer.

S. 221, M.

R.M. 126.

(C) FORWARDING GOLD BY POST OR POLICE ESCORT.

When a person sends gold in this way to an incorporated bank holding a license under this Act, he must make a statutory declaration in Form No. 29 with the required particulars, and the same is to be sent with the parcel containing the gold to the bank. The latter must file the declaration in the gold dealer's book.

S. 217, M.

R.M. 127.

(D) RECEIPT OF GOLD AS A BAILEE.

When gold exceeding £20 in value is received for safe keeping, forwarding, or otherwise as a bailee, a record in writing must be kept which must be available for inspection by the proper officer.

S. 224, M.

¹ See below as to an incorporated bank.

(E) EXCHANGE OR PLEDGE OF GOLD.

S. 225, M.

Every exchange or pledge of gold is deemed a sale within the meaning of this Part of the Act, and therefore the conditions regarding a real sale must be observed.

(F) EXPORT OF GOLD.

S. 288, M.
R.M. 128.

A banker, gold dealer, or any other person exporting any gold, gold ore, gold dust or gold bullion, if the same shall have been found in or procured from the soil of the State must (under liability to a heavy penalty and to forfeiture of the gold) declare the weight and value of same at the time of export at the Customs or before the Secretary for Mines in Perth, or the Resident Magistrate at the port of export.

This does not apply to any coin of the realm or article manufactured of gold or in respect of any alluvial or specimen gold of a less value than £10. A return in form No. 30 showing date of shipment, port of export, name of vessel, amount exported (weight and value), whence derived, destination, and other remarks, must also be furnished to the Secretary for Mines at the expiration of the month in which the gold, etc., was exported.

XVI.—MINING PARTNERSHIPS.

S. 281, M.

A mining partnership¹ exists when two or more persons buy, hold or work any mining tenement, or jointly employ others to work it for them,² the partnership, however, only being in respect of such mining tenement. (This, however, does not apply to any incorporated company or association registered under any statute.)

S. 281 (Subsection 7), M.

R.M. 187.

R.M. 188.

S. 286, M.

S. 272, M.

A number of rights and liabilities exist with regard to each partner, particulars of which are set out in section 281 of the Mining Act, 1904, but which cannot be fully set out here. They relate to the position of a mortgagee in possession, what is partnership property, proportionate shares of profits and losses, liens³ of a member for partnership debts paid by him, sale, etc., of a partner's interest without dissolving the partnership, purchase of retiring partner's share, decision of majority of members, grounds for dissolution, possession of unrepresented share, putting on of wages man for unrepresented share, partnership suits (including either sale of the partnership property or purchase by one partner of another's interest). It may be noted here that the decision of the members owning a majority of two-thirds at least of the shares or interest in a mining partnership binds all the members of the partnership in the conduct of their business; and also that all lawful rules and agreements entered into by partners, holding a like majority of the shares or interests in a mining tenement, as to the management and working thereof, are binding on all existing and future partners, subject to cancellation and amendment by a like majority. All such rules and agreements are to be registered by filing the original, or a copy verified by declaration, at the Warden's office and by paying the fee.

A holder of a share in a claim may abandon his share on complying with the conditions of regulation 188, in which are set out the rights of the other holders, and a mortgagee (if any) consequent on such abandonment.

It may here be pointed out that Section 286 of the Mining Act, 1904, provides that no contract relating to any mining lease or application for the same, or any share or interest in the same, respectively, will be enforceable unless in writing and duly signed.

It would appear, therefore, that in a partnership connected with a mining lease, it is advisable to have the understanding in writing if all interests are not disclosed by the lease. Section 272 of the same Act provides, however, that in applications for mining leases and for registration of claims, the number of shares or units into which the lease or claim is to be divided, and the number of shares or units to be held by each person, where two or more persons, are to be stated. (See also Regulation 187 noted above.)

¹ See *Curator of Intestate Estates v. Graham*, W.A.L.R. 15 (1913), 93; also *West Australian Bank v. Hocking*, W.A.L.R. 11 (1908-9), 144. (The decision in this latter case was reversed by the High Court.)

² See *Cur Boyd v. Doyle*, W.A.L.R. 12 (1910), 178.

R.M. 173.

³ As to liens, see also Regulation 173.

XVII.—LIENS FOR WAGES.

The wages or other earnings of persons employed about a mining tenement by the owner, are, to an amount up to four weeks' pay, a first charge upon the mining tenement, and take priority over mortgages and other securities. In the case of a company being wound up, such wages or other earnings for the period mentioned are paid in priority to all other debts, secured or unsecured, of the company.

S. 282, M.

The persons entitled, however, to this right rank equally amongst themselves, and, if necessary, the amounts must be reduced in equal proportions.

Regulation 174 provides that a wages lien must be registered by the person entitled lodging with the Warden within 30 days from his ceasing work on the mining tenement a declaration in form No. 46, otherwise the lien will lapse. Fee 5s. Notice must be given to the Warden when the lien is satisfied or discharged. This regulation, however, both as regards requiring registration and the time limit, has been held by the Full Court of Western Australia to be invalid. Under this judgment the lien or charge does not require registration. Nevertheless, where possible and convenient, it is well to register, as it gives notice to persons who may consult the register.

R.M. 174.

Wells v. Finnanery
—W.A.L.R. 12
(1910), 41.

XVIII.—TRIBUTE AGREEMENTS.

A tribute is defined as a contract made between the holder of a mining lease or claim and any other person, whereby the latter, in lieu of receiving wages, agrees to work in, upon, or in connection therewith, upon the terms of his being paid a portion of the product won from the mining lease or claim, or a portion of the proceeds from the sale of such product.

R.M. 189.

A mining lease or claim holder can, without the written consent of the Minister, enter into a tribute, provided that the tribute, or a copy of it duly verified, is lodged at the office of the Warden or Mining Registrar, with the fee, within 28 days after its signing by the holder of the lease or claim, and provided the conditions of Regulation 192 (set out below) are observed. A lessee who does not lodge a tribute agreement is considered to be guilty of breaking the condition not to assign or underlet, and the holder of a claim who fails to lodge such agreement makes his holding liable to forfeiture, and in either case the lessee or holder is considered to be guilty of a breach of the regulations. Every tribute, if relating to a lease, must be lodged in duplicate (fee 5s.), and is to be recorded in the lease registers, both at the office of the Minister and of the Warden.

R.M. 190.

At the time of lodging the tribute the holder of the lease or claim states in writing:—

(1.) Whether he proposes, during the currency of the agreement, to employ sufficient men in addition to those working on tribute to fulfil the labour conditions of his lease or claim; or

(2.) Whether he intends that the tributers are to be looked upon as fulfilling such conditions.

The Warden can refuse to register any tribute where he considers any of its terms are inequitable, and in every case where the tributers are to be looked upon as fulfilling the labour conditions, before registering the tribute the Warden satisfies himself that it contains provisions to the following effect:—

R.M. 192.

(1.) That it is for not less than three months, and for a specified and definite block of ground.

(2.) That no tribute is payable unless the tributers have earned £2 per man per week after paying the costs and expenses of mining and treatment exclusive of their own wages.

(3.) That the terms on which any mining plant, machinery, etc., of the holder may be used by the tributers, and all other agreed terms, are fully set out.

(4.) That the agreement is liable to be cancelled if the tributers break any of the terms.

But if the Warden refuses registration he must, if requested, send a report to the Minister with a copy of the agreement, and the Minister, if he thinks fit, can order registration.

S. 93, M.

Section 93 of the Mining Act, 1904, states that in applications for exemption as of right, exemption may be granted on such conditions as to tribute, except in the main workings of the lease, as the Minister may fix. In the event of any question arising as to what are "main workings," the Minister decides.

R.M. 158

XIX.—DRAINAGE OF MINES.

S. 165-173

Part VII., Sections 165 to 173, of the Mining Act, 1904, relates to the drainage of mines, the substance of which is that mine-owners whose mines are drained by the machinery belonging to some other person are liable to contribute towards the expense of working such machinery. For details as to enforcement of payment, mode of calculation, etc., see the sections mentioned.

XX.—SURVEYS.

S. 236 (9) M.

The Warden's Court can, at any stage, order a survey plan or measurement of any land or mining tenement, or any part of same, to be made by an authorised mining surveyor.

R.M. 220-225.

All surveys required by the Act or the Regulations must be made by a Mining Surveyor.

Holders of mining tenements required to be surveyed have to point out to the surveyors the pegs or other boundary marks of the land to be surveyed. The surveyor can adjust the boundaries, having regard to adjoining interests. Excess areas can only be surveyed with the consent of the Warden, and no area in excess of the area pegged shall be surveyed if any adjoining interests are thereby affected. Disputes as to pegs or otherwise are to be referred to the Warden, who also deals with objections to the survey.

R.M. 226-227.

All roads, railway reserves, telegraph lines, and mining tenements on the land surveyed must be marked by the surveyor on the ground, and shown on his plan—the latter in duplicate—and a report must be sent by the surveyor to the Mines Department.

R.M. 228.

Residence or Business Areas are not to be held by a Mining Surveyor or Mining Registrar without the written consent of the Minister.

XXI.—MISCELLANEOUS.

R.M. 195.

S. 301, 302, M.

(A) RETURNS.—Owners, holders, or managers of land taken up for mining purposes must, within the first 10 days of every month, furnish the Warden or Mining Registrar with a statement in duplicate, in one of the forms No. 54 (applicable to the particular holding (that is, gold, tin, coal, etc.), showing plant, yield, and other particulars set out in the return.

R.M. 196.

S. 301, 302, M.

If any product of the holding is treated at any works outside the goldfield, mineral field, or district in which the holding is situated, the statement must be furnished within a reasonable time after the result of such treatment is known.

Penalty for breach of regulation up to £50.

The owner or person in charge of machinery for extracting gold or minerals must, within the first 10 days of every month, furnish the Warden or Mining Registrar with a statement in duplicate, in one of the forms No. 55 applicable to the particular class of machinery (gold, tin, or other minerals), showing the plant, quantity of mineral treated, yield, and other particulars. Like penalty up to £50 for breach.

S. 297-299, M.

(B) ROYALTIES.—Where royalties are payable, returns (presumably in one of the forms No. 54) must be sent during the first week of every month to the Secretary for Mines, showing amount of gold or minerals obtained during the preceding month, value of same, and amount due as royalty.

The books may be examined under the authority of the Minister. If the royalty is not paid within 30 days after the amount is ascertained, the gold or minerals obtained from the mine may be seized, and the lease or registration of the mine cancelled.

(C) STAMP DUTIES.—Various documents are liable to stamp duty. As to what are dutiable, and the amount of such duty, can be ascertained from the Mining Registrars or the Mines Department, Perth.

(D) FEES.—The scale of fees is set out in form No. 59. R.M. 213. They must be paid before any matter, in which fees are payable, can pass.

(E) FORMS.—The forms in the Schedule to the Regulations under the Mining Act, 1904, or forms to the like effect, may be used with the variations or additions that the particular circumstances may require. R.M. 216.

(F) BORE RECORDS.—Records of all bore holes put down on a mining tenement must be kept by the holder, and particulars supplied to the Government on demand. The nature of the records is set out in Regulation 196a under the Mining Act, 1904. R.M. 196a.

(G) GENERAL.

Shafts are not to be sunk, surface disturbed, works erected, earth, stone, or other material deposited, so as to interfere with public water supply or to obstruct a public thoroughfare. Roads, railways, dams, and buildings are not to be undermined in such a way as to endanger the public safety. As to mining on or under roads, reserves, etc., see sections 50 and 61 to 64 of the Mining Act, 1904, details of which have been given S. 30, 61-64, M. under the various mining tenements. R.M. 197.

Persons travelling with animals are not to remain more than 24 hours at any conserved or natural water, and use the latter to the detriment of public or private rights. R.M. 199.

Nuisances in connection with, or injury or obstruction of any road caused by detritus, dirt, sludge, refuse, garbage, or mine water are not permitted. R.M. 200.

Sanitary conditions must be observed on mining tenements. R.M. 201.

Shafts within 20 feet of a public road must be protected by fencing, logging, or filling the same, and no person must interfere with such protection, or with any shaft, drive, or other working. This regulation has, however, been held to be invalid by the Full Court of Western Australia. R.M. 202.

Unsafe shafts may have to be made safe, and, until this is done, further work may be prohibited. Walker v. White Feather Reef, W.A.L.R. 12 (1910), 25. R.M. 203.

Accidents must be reported to an Inspector of Mines, and if he is not available, then at the Warden's office. R.M. 204.

Props or timber in a lease or claim are not to be removed if, by removal, the workings of any other lease or claim are endangered, and ventilation between adjoining leases or claims is not to be obstructed without the consent of the owner of any lease or claim affected thereby. R.M. 205.

Intoxicated persons in or on any mine are guilty of an offence and liable to a penalty. No intoxicating liquor is to be taken on to or into any mine except by permission of the manager. Regulation 4(42) under M.R.

XXII.—STATE ASSISTANCE TO MINING.

(A) THE MINING DEVELOPMENT ACT, 1902.

The assistance provided by this Act takes the form of (1) advances for the purpose of "pioneer mining"; (2) advances for prospecting; (3) the establishment and subsidising of plants for crushing, ore-dressing, cyaniding, or smelting; (4) assistance for boring; (5) the purchase or hire of boring plants; and (6) the advance or expenditure of moneys for drainage, sinking or cross-cutting, shaft-sinking, and for providing means of transport in relation to mining or prospecting.

Each of these methods may be briefly stated.

(1) ADVANCES FOR "PIONEER MINING."

"Pioneer mining" is defined by the Act to mean carrying on mining operations at places where the expenditure of large sums of money extending over a considerable period of time will be necessary to test or develop the mine. Part II. of the Act governs the advances for pioneer mining.

"Company" means any incorporated company registered S. 3, M.D. under the Companies Act, 1893, or any amendment, and includes a foreign company registered under Part VIII. of such Act.

An advance by way of loan may be made of any sum or S. 3 (2), M.D. sums not exceeding in the whole £1,000.

Minerals of Economic Value

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With an Appendix

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CHAPTER IV.

MINERALS OF ECONOMIC VALUE.

By
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I.—INTRODUCTION.

In this chapter a brief account is given of all the more important minerals which have an economic value. Whilst no attempt has been made to reproduce a systematic text-book of Mineralogy, it has been found necessary, in order to facilitate the recognition of the various minerals, to give a short description of the appearance and character of each. In the case of precious stones this description has necessarily been in somewhat more detail than in the case of other minerals. In these descriptions the symbol "G" has been used instead of the words "Specific Gravity," and the symbol "H" for "Hardness" according to Mohr's scale. The following approximate terms have been used in connection with the hardness:—

Hardness	1. Talc	Very soft
"	2. Gypsum	" "
"	3. Calcite	Soft
"	4. Fluorite	" "
"	5. Apatite	Hard
"	6. Felspar	" "
"	7. Quartz	" "
"	8. Topaz	Very Hard
"	9. Sapphire	" "
"	10. Diamond	" "

The commercial value of most minerals depends upon their freedom from mechanically admixed impurities and upon their chemical composition, which even in absolutely clean, pure specimens is liable to some slight variation due to isomorphous replacement. Even traces of certain substances present from either of these causes have a marked effect upon the value of the bulk sample in certain instances. For this reason, as far as possible, these objectionable constituents have been pointed out in the following pages. The percentages of the various constituents given are those found in the clean mineral freed from all mechanical impurity.

II.—MINERALS OF ECONOMIC VALUE.

ALUMINIUM.

Aluminium compounds are amongst the commonest constituents of the earth's crust, but it was not till 1827 that the pure metal was first prepared, whilst it is only within the last twenty years that the cost of its production has been so cheapened as to bring it into rivalry with other more familiar metals.

The chief properties of aluminium which give it its present high importance in the arts are its lightness (its specific gravity is only 2.7 or about one-third that of iron), strength, high electric conductivity, non-poisonous character of its compounds, pleasing silver-white colour not readily tarnished or corroded, great affinity for oxygen, and finally the great modifications it produces in the properties of other metals when alloyed with them. It is also very malleable and ductile and a good conductor of heat.

Though compounds of aluminium are very abundant in nature, but few of them can be utilised as a source of the metal or its compounds. The most important of these are the hydrates, bauxite, gibbsite, and diaspore; and the double fluoride of sodium and aluminium known as cryolite. Clay, felspar, and other silicates of aluminium with other metals, are seldom if ever used as a source of the metal or its definite compounds, and will therefore be dealt with under a different heading.

The best commercial aluminium contains 99 to 99½ per cent. of the pure metal, the balance being mainly silicon and iron. Inferior grades of metal contain 92 to 99 per cent. of pure metal. Alumi-

nium is largely used for cooking and other domestic utensils, for army equipments, field glasses, and other uses where lightness and durability are essentials. It has largely replaced silver for toilet, ornamental, and surgical articles. Powdered aluminium has a strong affinity for oxygen, and is therefore used for the reduction of many metals from their ores, the prevention of flaws in steel and iron castings, and in the Thermite process of welding.

The most important alloys of aluminium are those with zinc and copper. These alloys are light and very strong and those with copper resist corrosion, with the result that they have been largely used for motors, yachts, flying machines, propellers, etc.

Many artificial compounds of aluminium are used in the arts, chief among them being alum, (sulphate of aluminium and potassium). This is largely used in sizing paper, dyeing, manufacture of the pigments known as "lakes," hardening plaster of Paris, tanning and curing, clarifying water and other liquids, purifying sewage, etc. Aluminium sulphate is used for the same purposes as alum. Sodium aluminate and aluminium acetate are used in dyeing. Ultramarine, a brilliant blue compound of aluminium, sodium, sulphur, and silica, is extensively used as a pigment and dye, and for blueing linen, paper, sugar, candles, etc.

Aluminium oxide (alumina), hydrate, chloride, and fluoride are manufactured on a large scale as intermediate products in the conversion of ores into metallic aluminium.

Corundum.—Oxide of aluminium, Al_2O_3 . Aluminium, 53 per cent. The impure variety known as emery contains iron oxide, and is therefore poorer in aluminium. Crystallised, massive, or granular. Grey or tinted, translucent. (The rare transparent highly-coloured varieties are valuable gems, see Ruby and Sapphire.) Very hard, brittle. G., 4.0. Found in veins or pockets in crystalline rocks, or in river gravels.

Uses.—Chiefly used as an abrasive, though to a slight extent it has been smelted into metal. For either purpose the purer the mineral the more valuable it is. Mechanically admixed impurities can be removed by mechanical concentration, but not so the iron oxide in the darker varieties known as emery. Exceptionally pure hard crystals fetch a high price for cutting and polishing diamonds and other gems.

Bauxite.—Hydrate of aluminium, with various proportions of hydrate of iron. Aluminium, 18 to 39 per cent.; alumina, 35 to 74 per cent. Massive, earthy, or concretionary. Grey, yellow, brown; opaque. Soft or hard. G., 2.5. Occurs very rarely in veins; commonly in superficial deposits produced by the weathering of crystalline rocks *in situ*, or the collection in hollows of the products of denudation.

Uses.—This is the most important source of the metal and its compounds. Its value depends directly upon the percentage of alumina present, and upon the smallness of the iron content. Bauxite with more than 3 per cent. of iron oxide is of little value for the production of alum, etc. Bauxite is also used in the manufacture of very high grade and refractory crucibles and firebricks.

Gibbsite.—Hydrate of aluminium, with more or less oxide of iron. Aluminium, 32 to 34 per cent.; alumina, 60 to 65 per cent. Much so called bauxite is in reality gibbsite, or a mixture of the two. Crystallised, massive, concretionary, or stalactitic. White, grey, yellow, red; translucent or opaque. Soft, tough. G., 2.4.

Uses, etc.—Same as bauxite.

Cryolite.—Fluoride of aluminium and sodium, Na_3AlF_6 . Aluminium, 13 per cent. Crystallised or massive, cleavable. Colourless, white or tinted, transparent or translucent, glassy lustre. Soft, brittle. G., 3.0. Occurs chiefly in Greenland in a vein in granite.

Uses.—A valuable ore of aluminium owing to its easy fusibility, and capacity for dissolving alumina. It is also used as a constituent of a variety of glass.

Alunite.—Hydrous sulphate of aluminium and potassium. Alumina, 37 per cent.; potash, 11 per cent. Massive or crystallised. Soft, brittle. White, grey, or pink. Transparent to opaque. G., 2.6.

Occurs as irregular nodules, pipes or veins in slates, trachytes or granites, and in irregular masses at the outcrops of pyrites deposits.

Uses.—A common source of alum and aluminium sulphate, and used also as a source of potassium compounds, particularly for fertilising purposes.

ANTIMONY.

Antimony has been known from time immemorial, an ancient Chaldean vase having been discovered made of this metal. It is a brilliant silver-white metal, coarsely crystalline in structure when melted and cooled slowly, but granular when quickly cooled. It is hard and very brittle, not affected by the air at ordinary temperatures, but, on heating, burns with the production of the oxide. It is attacked by most mineral acids.

The metal occurs native in several parts of the world, usually in veins in crystalline rocks. It is not, however, an important ore. The most common ore is the sulphide, stibnite, which, at the surface, is found altered to one or other of the oxides, cervantite, etc. An oxysulphide, kermesite, has been mined in Italy. Antimony ores occur in veins of quartz or calcite in slates, granites and other crystalline rocks.

Though known for so long, the use of pure antimony in the arts has never been very extended; even now, practically its only use is in the form of alloys with other metals, which are thereby rendered harder and more lustrous. The most important of all antimony alloys are those with lead. Type metal is an alloy of lead, tin, and antimony. The hard lead used for bullets, acid chamber linings in chemical factories, etc., contains several per cent. of antimony. Britannia metal, pewter, and many anti-friction metals contain a considerable percentage of this metal. Much of the antimony used for the preparation of these alloys comes into the market in the form of antimonial or hard lead, a by-product of lead smelters. It contains about 18 per cent. of antimony.

Of artificial compounds, the most important is the tri-sulphide, which is one of the chief constituents of the heads of safety matches, and is also used in pyrotechny and medicine. The penta-sulphide is used to vulcanise caoutchouc. Potassium antimonate, or tartar emetic, is used in medicine and as a constituent of certain varieties of glass. Neapolitan yellow, lead antimonate, is used as a pigment, and as a constituent of stained glass. Antimony-cinnabar (an oxysulphide) is used as a pigment.

Stibnite.—Trisulphide of antimony, Sb_2S_3 . Antimony, 71 per cent. Coarsely or finely crystallised, massive or granular. Lead coloured and brilliant or iridescent; opaque. Very soft and easily fusible. G., 4.6.

Uses.—This is the chief ore of antimony and most important source of the metal and its compounds. For export, it should be dressed by hand or otherwise up to at least 50 per cent. of the metal. By heating it may be melted and run off from the gangue and cast into ingots for export. The value of the concentrates will depend not only on their contents in the metal but also on their freedom from compounds of arsenic and lead, and in many cases upon the proportion of gold and silver present.

Valentinite.—Trioxide of antimony, Sb_2O_3 . Antimony, 83 per cent. Crystallised or massive, granular. Brilliant lustre; white, pink, or grey; translucent. Soft. G., 5.6.

Uses.—Used as a source of the metal and its compounds.

Cervantite.—Tetroxide of antimony, Sb_2O_4 . Antimony, 79 per cent. Crystallised or massive. Yellow, opaque. Soft, brittle. G., 4.0.

Uses.—Used as a source of the metal and its compounds.

Stibiconite.—Hydrated tetroxide of antimony, $Sb_2O_4 \cdot H_2O$. Antimony, 74 per cent. Massive. White or yellow, opaque. Hard, brittle. G., 5.2.

Uses.—A common oxidised ore, used as a source of the metal. This and other oxidised ores are paid for by smelters at slightly lower rates than the sulphide.

ARSENIC.

Arsenic in its properties lies on the borderland between the metals and the non-metals. It was known to the ancient Greeks. It is a steel-grey crystalline solid of metallic appearance, brittle, and a good conductor of electricity. It tarnishes rapidly in moist air, and when heated volatilises without melting. It is somewhat lighter than antimony.

Arsenic occurs occasionally uncombined in nature, but its commonest ore is arsenopyrite or mispickel, a sulpharsenide of iron. Sulphides of arsenic occur native, as also arsenides of iron, nickel, and cobalt. Arsenic and its compounds usually occur in veins in crystalline rocks.

The element has no use in the arts except to add to lead for making shot and to harden bronze.

Of its artificial compounds the most important is the trioxide, known as white arsenic. Owing to its extremely poisonous character large quantities of white arsenic are used, as such or in combination with soda, to destroy vermin and insect pests, and also as a preservative of timber, skins, leather, etc. It is also used to prevent and cure foot-rot in sheep. Large quantities are used to produce several green pigments (notably Paris green), which are compounds of this oxide with oxide of copper, etc. It also enters into the composition of some varieties of glass. Lead arsenate also is used to destroy insect pests. Several compounds of arsenic are used in medicine, and large quantities of several volatile arsenic compounds have been employed in gas warfare. Arsenious chloride is used for the destruction of prickly pear.

Mispickel (Arsenical Pyrites, Arsenopyrite).—Sulpharsenide of iron, FeAsS . Arsenic, 46 per cent. Crystallised or massive. Light grey, metallic, brilliant, opaque. Brittle, hard. G., 6.0

Uses.—Used as a source of white arsenic, etc. Some samples contain a notable proportion of gold, which will pay for extraction, when white arsenic may be collected as a by-product during the necessary roasting.

BARIUM.

This metal, which resembles calcium but is much more uncommon, was first separated early in the 19th century, though some of its compounds were known as far back as the 17th century. It is silver white, soft, and readily oxidises in the air. At ordinary temperatures it decomposes water with the evolution of hydrogen. At a dull red heat it melts.

Barium does not occur native. Its most important ore is the sulphate, barytes, which occurs either in veins in crystalline or other rocks or as boulders in residual clays resulting from the weathering of limestone. A less common though valuable ore is the carbonate, witherite, workable deposits of which occur as veins in limestone, etc.

Neither metallic barium nor alloys of it with other metals have any application in the arts. Pure artificial barium sulphate, or blanc fixe is used for the same purposes as the mineral sulphate, *q.v.* It forms the chief constituent of "lithophone," a white paint which has largely replaced white lead for many purposes. The hydrate is used to extract sugar from molasses, as well as to make white paints and to soften boiler waters. Barium peroxide is used to prepare hydrogen peroxide and oxygenated water for bleaching, etc. The chloride is used in making paint as also the sulphide. This latter compound is also used to remove hair from hides, etc. The carbonate is used in manufacturing cyanides and fire bricks.

Barytes (Barite).—Sulphate of barium, BaSO_4 . Baryta (barium oxide), 65 per cent. Crystallised, laminated, or granular massive. White or tinted, transparent to opaque. Brittle, soft. G., 4.5.

Uses.—After cleaning with acid and grinding is added to white lead and zinc white. It is used in weighting and filling paper, making enamels and porcelain, in pyrotechny, and as a source of various barium compounds. The value of barytes depends upon its freedom from mechanically and chemically contained impurities, especially from iron compounds and other colouring materials.

Witherite.—Carbonate of barium, BaCO_3 . Baryta, 77 per cent. Crystallised, massive, or globular. White, grey, or yellow, translucent. Soft, brittle. G., 4.3.

Uses.—An important source of all barium compounds, especially the peroxide.

BISMUTH.

This metal has been known to chemists for some centuries, though it is comparatively rare. It is a hard brittle metal of a dark reddish-grey colour, and coarsely crystalline in structure when slowly cooled after fusion. It oxidises slowly in air at ordinary temperatures, more rapidly on heating. It dissolves readily in most mineral acids. Its specific gravity is between those of copper and silver.

Bismuth occurs in nature as the almost pure metal as well as the sulphide, bismuthinite, and the carbonates, bismutite, and bismutosphaerite. These are the only important ores, though bismuth also occurs as the oxide and telluride, and in several complex sulphides of lead and copper. Bismuth ores are found in veins of pegmatite, quartz, or calcite in slates or crystalline rocks.

The metal bismuth is only employed in the form of alloys, many of which are of considerable value. The chief of them is fusible metal, which melts at a very low temperature.

Bismuth oxide is used as a constituent of optical glass and of various glazes for porcelain and stained glass. Basic bismuth nitrate is largely used in medicine and also as a cosmetic. Several other bismuth compounds are used in medicine.

Bismuth (Native).—Pure bismuth, 94 to 99 per cent. Opaque, metallic, reddish-white to reddish-grey. Foliated, massive or granular. Brittle, sectile. Very soft. G., 9.8.

Uses.—This is the chief source of bismuth and its compounds. Ore as low in grade as 5 per cent. is saleable, but it is more economical to hand-pick or otherwise dress the ore up to at least 25 per cent. before exporting. Gold and sometimes silver are constituents of native bismuth, and contribute largely to the value of the ore. The presence of tellurium in bismuth ore is a decided drawback, as it injures the qualities of the smelted metal.

Bismuthinite.—Sulphide of bismuth, Bi_2S_3 . Bismuth, 81 per cent. Sometimes crystallised, usually foliated or fibrous massive. Metallic, opaque, lead-grey. Very soft. G., 6.4.

Uses.—A less common ore of bismuth. (See remarks under Native Bismuth.)

Bismutite.—Hydrated carbonate of bismuth. Bismuth, 80 per cent. Opaque, earthy, or in crusts. White, yellow, or greenish. Soft. G., 7.0.

Uses.—See remarks under Bismuthinite.

Bismutosphaerite.—Carbonate of bismuth. Bismuth, 82 per cent. Opaque, earthy. Yellow or grey. Soft. G., 7.4.

Uses.—See remarks under Bismuthinite.

BORON.

This non-metallic element was first separated in the elemental state in 1808, but its most important compound, borax, has been known for several centuries. Boron is a light brown powder, very infusible, and a strong reducing agent.

Boron does not occur native. Its most widely-distributed compound is tourmaline, a complex silicate of boron, aluminium, etc., frequently occurring as a constituent of granite. This mineral is, however, not a source of the commercial compounds of boron. These are derived from deposits of sassolite (boracic acid), borax (sodium borate), colemanite (calcium borate), and boracite (magnesium chloro-borate). Sassolite is obtained from hot springs; the other boron minerals are found in recent beds, usually in marshes

or dry lakes in desert regions and in the neighbourhood of tourmaline granites or recent eruptive rocks.

By far the most important compound of boron is borax, the uses of which are described under the native mineral. Boracic acid is also of considerable use as described under sassolite. The uncombined element has no application in the arts.

Sassolite.—Boracic acid, H_2BO_3 . Boron trioxide, 56 per cent. Scaly or stalactitic. White, transparent, or translucent. Very soft. G., 1.5. Occurs solid in volcanic regions, or dissolved in the waters of hot springs.

Uses.—The crude mineral is purified by crystallisation, and is then used as an antiseptic and food preservative as well as for sundry medicinal purposes.

Borax (Native).—Hydrous borate of sodium; boron trioxide, 37 per cent. Crystalline, white, brittle. Translucent to opaque. Soft. G., 1.7. Occurs as a crystalline efflorescence on the surface of dry lakes and in crystals embedded in the mud beneath them. Also in solution in waters of arid regions.

Uses.—The crude mineral is purified by recrystallisation and is then used as a food preservative and antiseptic, as a flux in many metallurgical operations, as a constituent of glass, artificial gems, enamels, and pottery-glazes, as a flux in welding and soldering, for softening water, and for various medicinal purposes.

Colemanite.—Hydrous borate of calcium. Boron trioxide, 51 per cent. Crystallised or massive. White, brilliant lustre, transparent to translucent. Hard. G., 2.4. Occurs in recent or ancient lake beds similarly to borax.

Uses.—An important source of boracic acid and borax. Value depends upon percentage of boron trioxide.

CADMIUM.

This rare metal, discovered early in the 19th century, closely resembles zinc in appearance and properties, and is usually associated in nature with that metal. It is bluish-white in colour, malleable and ductile. It tarnishes readily in the air, and at a high temperature burns. Its weight is the same as that of copper.

Cadmium does not occur native, but is known as a sulphide, greenockite. The chief sources of the metal are, however, cadniferous varieties of the zinc ores blende and smithsonite (which see), cadmium being obtained as a by-product in the smelting of such ores for zinc.

Metallic cadmium is used to a slight extent in analytical chemistry and as a constituent of certain fusible metals.

Cadmium sulphide is used as a pigment and in pyrotechny, and the iodide in photography.

CALCIUM.

Though compounds of calcium are amongst the commonest minerals on the earth's surface, and their properties have in many cases been known for centuries, the metal itself was only obtained in a state which permitted of handling and examination in 1856. It is a soft yellowish metal, somewhat stable in perfectly dry air, but readily converted into the oxide (lime) in moist air, and acted on by water with violence. It is one of the lightest metals known, being much lighter than aluminium.

Calcium does not occur in nature in the metallic state. Its commonest compound is the carbonate, calcite, which forms the chief constituent of all limestones, as well as of the shells of molluscs. In combination with silica, calcium forms a large proportion of many igneous rocks; the hydrated sulphate, gypsum, is of common occurrence. Phosphate of calcium forms the chief constituent of the bones of men and animals, as well as occurring as rock phosphate and in guano.

The metal itself has not as yet been put to any useful purposes. Its most useful artificial compound is the oxide, known as lime, formed by burning calcite in the form of limestone. Portland cement is a mixed silicate and aluminate of calcium formed by burning a natural or artificial mixture of calcite and clay. A very

pure limestone on burning yields a fat or pure lime, one with a little clay yields a hydraulic lime, capable of setting under water, one with still more clay yields a hydraulic (or Portland) cement. Though the chief use of lime is for building, large quantities of it are also employed for other purposes, such as the preparation of bleaching powder (chloride of lime), ammonia, caustic soda, and caustic potash, for purifying water, in cyanide works for neutralising acid, and for various other metallurgical purposes, as well as a fertiliser.

Sulphate of lime, produced by burning gypsum, is known as Plaster of Paris, and is employed either solely or with various added chemicals for finishing off the interior walls of buildings, as well as for making various mouldings and castings. "Superphosphate," a material largely used as a fertiliser, is a mixture of calcium sulphate and acid calcium phosphate, formed by acting on natural lime phosphates with sulphuric acid.

Chloride of lime or bleaching powder, used extensively for disinfecting and for bleaching, is a compound formed by allowing fat lime to absorb chlorine gas. Calcium carbide, now used to generate acetylene gas for lighting purposes, is a compound obtained by smelting together charcoal, or coke, and lime in an electric furnace. Calcium cyanamide is of growing importance as a fertiliser.

Calcite.—Carbonate of calcium, CaCO_3 . Lime, 56 per cent.; carbon dioxide, 44 per cent. Crystallised or massive, white, or tinted various colours, transparent or opaque. G., 2.7. Calcite forms rock masses under the names of *limestone* and *marble*.

Uses.—Chiefly used for burning into lime. To make the best lime for agricultural purposes or for use in preparing other calcium compounds or for other chemical purposes, the limestone should be practically free from silica, alumina, iron, and magnesia. For making building lime a less pure limestone is better. For making Portland cement, limestone should be low in iron, magnesia, and sulphur, but may with advantage contain silica and alumina equivalent to anything up to 20 per cent. of clay. A limestone containing in itself sufficient clay to form, when burnt to a clinker, a Portland cement, is known as a "*natural cement-rock*."

Large quantities of limestone are used as a flux in smelting ores of iron, lead, copper, etc. For this purpose it is necessary that the stone should be rich in lime and low in silica (not more than 7 per cent.) and sulphur. Small proportions of iron and magnesia do not affect its value for this purpose.

The second constituent of calcite, viz., carbon dioxide or carbonic acid gas, is obtained from it by the action of sulphuric acid, and is largely used in aerated water factories, etc. Any pure limestone is suitable for this purpose.

Perfectly transparent flawless crystals of calcite (Iceland Spar) are of considerable value for optical purposes.

Dolomite.—Carbonate of calcium and magnesium, $\text{CaMg}(\text{CO}_3)_2$. Lime, 30 per cent.; carbon dioxide, 47 per cent. Similar to calcite, but slightly heavier. Forms rock-masses under the name of *magnesian limestone* or *dolomite*.

Uses.—With a natural or artificial admixture of clay, is burnt to form Rosendale hydraulic cement, for which purpose it should be low in iron and sulphur. Used in place of ordinary limestone as a flux, when the silica present should not exceed 7 per cent. Also used as a source of carbonic acid, for which purpose it is, if anything, more valuable than ordinary limestone. Large quantities are used as building stone. Sometimes used as a source of magnesia.

Gypsum.—Hydrated sulphate of calcium, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Lime, 32 per cent. Colourless, white or tinted; transparent to opaque, very soft. In large crystals, or crystalline masses, or as a fine crystalline powder. G., 2.3. Workable deposits occur in or near the beds of dry lakes or in sedimentary beds.

Uses.—Chiefly used in the manufacture of Plaster of Paris and various patent plasters. For this purpose it must be very pure and especially free from iron oxide and coloured organic compounds, which would give the plaster an objectionable tint. It is used occasionally as a fertiliser.

Apatite.—Phosphate and chloride or fluoride of calcium, $3\text{Ca}_3(\text{P}_2\text{O}_7)_2\text{Ca}(\text{F},\text{Cl})_2$. Lime, 54 per cent.; phosphorus pentoxide, 41 per cent. Massive or crystallised; white or tinted; transparent to opaque; brittle, hard. G., 3.2. Payable deposits occur in veins and bunches in pyroxenite and other crystalline rocks.

Phosphorite or Rock-phosphate is an impure apatite occurring in irregular beds or nodules in limestone and greensand.

Guano, the earthy or hardened excreta of sea-birds, consists largely of mineralised bones of fish, and therefore of impure calcium phosphate.

Uses.—The main use of apatite and similar compounds is as a fertiliser, either in the crude state or after conversion into "super-phosphate." They are also used as a source of phosphorus, and in the manufacture of white opaque glass. For these purposes the value of the ore depends upon the percentage of phosphorus pentoxide present. In addition to calcium phosphate, guano also contains ammonia and other nitrogen compounds, which add to its value as a fertiliser. Its value, therefore, depends primarily on the percentage of phosphorus pentoxide, next upon the percentage of nitrogen present. For use in the manufacture of superphosphate over 3 per cent. of oxides of iron and alumina is looked upon as a serious drawback in any sample of rock phosphate or apatite; while the presence of a few per cent. of carbonate of lime is an advantage.

Fluorite (Fluorspar).—Fluoride of calcium, CaF_2 . Calcium 51 per cent.; fluorine, 49 per cent. Crystallised, massive or granular. Transparent to translucent. Colourless or tinted various colours. Soft, brittle. G., 3.2. Occurs usually in veins in limestones and various crystalline rocks.

Uses.—Fluorspar is mainly used as a flux, in the open-hearth method of producing steel, in remelting pig iron in foundries, and in smelting aluminium. Smaller quantities are used in the production of opalescent glass and enamelled ware and of hydrofluoric acid. For use in steel production it should be free from sulphur and phosphorus, whilst for all purposes more than 1 per cent. of silica is a decided disadvantage.

CARBON.

Carbon is one of the commonest of the non-metallic elements, and numbers amongst its natural and artificial compounds many of the most useful substances known to civilisation.

The element is known in three different modifications, diamond, graphite, and charcoal. Diamond is crystalline, colourless, transparent, and of high refractive index. It is harder than any other known substance, but somewhat brittle. Its specific gravity is 3.5. Graphite is crystalline, grey-black, opaque, with metallic lustre. It is very soft and smooth to the touch. Its specific gravity is 2.3. Charcoal in its purest form is a black amorphous powder, dull and opaque. It is variable in hardness and specific gravity, according to the method by which it has been formed.

Both of the crystalline forms of carbon, diamond, and graphite, occur as minerals, but not so the amorphous form, unless possibly as a constituent of coals. The most important mineral compounds containing carbon are coals, petroleum, natural gas, and diamond, the first three of which owe their chief value to the ease with which they burn with the evolution of light, or heat, or both.

Diamond.—The purest forms of this mineral are dealt with under the heading "Gems," p. 67.

Bort and Carbonado.—Almost pure carbon of the diamond type. Grey or black, translucent to opaque. No distinct crystalline outline, usually in irregular water-worn grains. Extremely hard. G., 3.3. Occur in river gravels.

Uses.—The chief use of these minerals is for setting in the crowns of rock-drills and the edges of lapidaries cutting wheels, and for polishing diamonds or other gems.

Graphite.—Almost pure carbon of the graphitic type. Sometimes in tabular crystals, more often in scales, or in scaly, columnar, or earthy masses. Black or dark grey, lustre usually metallic, sometimes dull; opaque. Very soft. G., 2.2. Occurs in veins or bands in metamorphic rocks.

Uses.—The greater part of the world's production of graphite is used for mixing with fireclay to make crucibles for melting metals and alloys in. Smaller quantities are used for stove polish, foundry facings, paint, lubricating, lead pencils, and various electrical purposes. The purest forms of graphite are used for crucibles and lubricating. For these purposes the graphite should be in scales sufficiently large to be held on an 80-mesh sieve, and should contain 95 per cent. of pure carbon, whilst for crucibles the ash should be infusible, and for lubricating, the mineral very finely flaky and greasy. Less pure varieties of the mineral are at times used for crucibles, but more largely for the other purposes named, and command a much smaller price. Crude graphite is valued on the basis of the proportion of clean scale which can be extracted from it and on the size and carbon content of the scale so obtained.

Coal.—This is a mixture of various compounds of carbon, hydrogen, oxygen, nitrogen, and sulphur, derived from the gradual alteration of buried vegetable matter. Five main types exist, viz., brown coal, non-caking bituminous, caking bituminous, anthracite, and algal coal.

Brown Coal.—Contains moisture 15 to 50 per cent.; ash, 1 to 35 per cent. Balance of coal contains carbon 55 to 71, hydrogen, 4 to 6, oxygen and nitrogen, 21 to 37. Ratio of fixed carbon to volatile hydrocarbons, 1 : 2 to 2 : 1. Brown and dull to black and bright. Sometimes with woody structure and then known as *Lignite*; when very bright and black, known as *Jet*.

Uses.—This is the poorest class of coal, and owing to the high percentage of moisture in it, it has to be sun-dried or artificially dried before use. This coal is mainly used for household purposes, though it can also be used for steam-raising and the production of producer gas. The less ash and moisture in it the higher its calorific value, and therefore the more valuable it is.

Non-caking Bituminous Coal.—Contains moisture, 5 to 20 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 70 to 85; hydrogen, 4 to 6; oxygen and nitrogen, 12 to 20. Ratio of fixed carbon to volatile hydrocarbons, 1 : 1 to 2 : 1. Bright or dull, black.

Uses.—A more useful type of coal than lignite, and can be used for all ordinary purposes such as steam-raising, producer-gas making, household use, etc. It cannot be used for making coke and is less economical for marine and locomotive fuel than coal of either of the next two classes.

Caking Bituminous Coal.—Contains moisture, 1 to 5 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 75 to 90 per cent.; hydrogen, 4 to 6; oxygen and nitrogen, 5 to 11. Ratio of fixed carbon to volatile hydrocarbons, 2 : 1 to 6 : 1. Bright or dull, black.

Uses.—The most useful of all kinds of coal. Suitable for household use, steam-raising under all conditions, coke-making, and gas, with accompanying production of ammonia, tar, cyanides, and numberless organic compounds, including aniline dyes, explosives and poison gases. For steam raising its value depends upon the amount of heat generated in burning, freedom from ash, and infusibility of ash. For coking, its value depends upon quantity and hardness of coke and freedom from ash. For gas making, upon quantity and quality of gas given off on coking.

Anthracite.—Contains moisture 0.5 to 2 per cent.; ash, 1 to 30 per cent. Balance of coal contains carbon, 90 to 96 per cent.; hydrogen, 2.5 to 5 per cent.; oxygen and nitrogen, 2 to 6 per cent. Ratio of fixed carbon to volatile hydrocarbons 6 : 1 to 10 : 1. Black, bright, hard. Not easily combustible, and does not form coke.

Uses.—This is the best coal for marine and locomotive purposes. Navies use it very largely owing to its smokeless character and its high calorific value. It is also largely used for smelting and other purposes, but is useless for gas making. Its value depends upon the amount of heat generated in burning, freedom from ash, and infusibility of ash.

Algal Coal.—This includes *Kerosene Shale*, *Boghead Coal*, and *Torbanite*, all of which are largely composed of the *débris* of water plants. They contain moisture, 0.1 to 2 per cent.; ash, 1 to 40 per cent., graduating into an oil-shale as the ash increases. Balance of coal contains carbon, 78 to 80 per cent.; hydrogen, 12 to 14 per cent.; oxygen and nitrogen, 6 to 8 per cent. Ratio of fixed carbon to volatile hydrocarbons, 1 to 2 to 1 to 15. Dark brown; dull; tough; elastic. Catches fire readily and burns without melting.

Uses.—This coal is chiefly used to mix with bituminous coals for the production of illuminating gas. It is also distilled to yield oils (both illuminating and lubricating), paraffin wax, and ammonia. Its value depends upon the quantity and quality of its volatile products.

Petroleum.—A natural liquid oil varying considerably in composition, but consisting mainly of a mixture of hydrocarbons of the paraffin and naphthene series, the carbon varying from 79 to 87 per cent. Transparent to translucent; colourless, yellow, brown, or black. G., 0.7 to 1.0. Occurs in sedimentary deposits, in porous beds or cavities sealed by impervious beds of clay, etc., especially beneath anticlinal folds.

Uses.—Used extensively for steamers, locomotives, etc., in the crude state as fuel. Also distilled in large amounts, producing illuminating gas, light oils (petrol, etc., used for motors, etc.), illuminating oils (kerosene, etc.), heavy lubricating oils; vaseline or petroleum jelly, used as fuel, lubricant, etc.; paraffin wax, and sometimes asphalt or pitch.

Natural Gas.—This contains from 93 to 97 per cent. of marsh gas or methane, the balance being nitrogen. It is the most perfect and convenient fuel known, 11 cubic feet giving approximately the same amount of heat on burning as a pound of good steam coal. It occurs in pores and cavities in sedimentary rocks of all ages, usually in association with petroleum.

Uses.—Largely used as a fuel for domestic and manufacturing purposes, its freedom from soot and ashes being a great advantage. It is used for melting steel, reheating iron, burning brick, steam-raising, etc.

Asphaltum.—A mixture of various hydrocarbons partly oxygenated and invariably carrying sulphur. Analyses usually show the presence of ash, non-bituminous organic matter, petroleum, and asphaltene, all in varying quantities. Amorphous, solid, or semi fluid. Black or dark brown, opaque. Melts and burns readily. G., 1 to 1.8. Occurs in surface beds or disseminated through sandstones or limestones. Usually closely associated with petroleum.

Uses.—The chief use of asphaltum is as a binding material for crushed rock, etc., for roadways, footpaths, and foundations, damp courses in houses; as a protective covering for wood or iron; as an ingredient of roofing felt; as an ingredient of various varnishes and japans.

CERIUM, THORIUM, YTTRIUM.

These three rare metals are usually found in association in nature, and have many properties in common. Their ores (chiefly phosphates, silicates, and tantalates) are found either as constituents of granite-pegmatite veins or in the heavy sands resulting from the denudation of granite masses.

Cerium, discovered in 1803, is a soft grey ductile metal, which burns readily in air. Thorium, discovered in 1828, is similar in appearance to cerium, but less susceptible to the action of the atmosphere. Yttrium, discovered in 1794, is a dark grey metal, somewhat similar to thorium. None of these metals are of practical use as such, though several pyrophoric alloys of cerium have been prepared which are used for automatic igniters of gas lights, etc.

The most important compounds of the metals are the nitrates and oxides, which are all used in the preparation of incandescent gas mantles, etc. Cerium salts are also of medicinal value.

Monazite.—Phosphate of cerium, lanthanum, and didymium ($\text{Ce, La, Di} \text{PO}_4$), with variable amounts of thorium oxide from a trace up to 18 per cent., the average in the Brazilian ore being 6 per cent., in that from Travancore, 9 per cent.; very little yttrium present. Crystalline or in water-worn grains or pebbles, yellow or brown, semi-transparent to opaque, brittle, hard. G., 5.1.

Uses.—This mineral is the chief source of thorium and cerium salts, and its value is entirely dependent upon the percentage of thorium present. The sands containing the mineral are concentrated by hand or in hydraulic sluices, and if the resulting material does not contain 60 or 70 per cent. of monazite it is still further concentrated by drying and removing all magnetite and titaniferous iron by an electro-magnet. For the market the dressed ore should contain 70 to 95 per cent. of the pure mineral, and not less than $3\frac{1}{2}$ per cent. thorium oxide.

Thorite.—Silicate of thorium, $\text{ThO}_2 \cdot \text{SiO}_2$. Thorium oxide, 50 to 81 per cent. Crystallised or massive; yellow, brown, or black; semi-transparent, brittle, hard. G., 5.

Uses.—a source of thorium compounds, the value of the mineral depending on its thorium contents.

Allanite (Orthite).—Complex silicate of cerium, lanthanum, didymium, aluminium, iron, and calcium. Cerium oxide 2 to 18 per cent. In tabular or acicular crystals or massive. Black, brown green, grey, or yellow opaque; hard, brittle. G., 4.0.

Uses.—Used as a source of salts of cerium.

Gadolinite.—Silicate of yttrium, iron, and beryllium. Yttrium oxide, 35 to 45 per cent.; cerium oxide, trace to 5 per cent.; thorium oxide, trace to 1 per cent.; beryllium oxide, 8 to 10 per cent. Black, opaque, hard, brittle, vitreous lustre. G., 4.0-4.5.

Uses.—One of the main sources of yttrium and beryllium oxides, its value depending on the proportions present.

Other less important ores of these metals occurring in the State are:—

Pilbarite, hydrous silicate of thorium, uranium, and lead.

Mackintoshite, silicate of uranium and thorium.

Fergusonite, tantalate of yttrium, etc.

CHROMIUM.

This metal was discovered at the end of the 18th century, but is still, in its pure form, only of scientific interest. It is a very hard and infusible metal, of a white colour, and of the same weight as cast iron. It is not easily affected by the atmosphere.

Chromium does not occur in nature in the metallic state, but, in combination with silica, occurs in small quantities in all igneous rocks. The only workable ore of chromium is chromite, which is invariably found as scattered grains, pockets, or veins in the basic igneous rocks known as peridotite and serpentinite.

Pure metallic chromium is not produced commercially, but impure chromium and an alloy of chromium and iron, ferro-chromium, obtained by smelting chromite, are largely used as constituents of hard steel for rails, machine tools, safes, projectiles, and the wearing parts of crushing machinery.

The most important manufactured compounds of chromium are the chromates and bichromates of potash and soda, which are extensively used for tanning and dyeing, and to a minor extent in the manufacture of matches, in generating electricity, and in purifying oils and spirits. Chrome alum, sulphate of chromium and potash is used in dyeing, calico printing, and tanning.

Chromite or Chrome Iron Ore.—Chromite of iron, $\text{FeO} \cdot \text{Cr}_2\text{O}_3$. Chromium, 47 per cent.; chromium sesquioxide, 68 per cent. Sometimes crystallised; usually massive, granular, or compact. Black, opaque, massive. Lustre, metallic to glassy; hard, brittle. G., 4.4.

Uses.—Extensively used for the manufacture of chromates and other salts, and alloys, particularly ferrochromium. In its raw state the mineral is used as a lining for reverberatory copper and steel smelting furnaces. A recent adaptation is in the production of "Silichromite," a material used as a substitute for emery. The commercial value of chrome ore depends almost entirely upon

the percentage of chromium sesquioxide present in it, ore under 50 per cent. being marketed with difficulty. The usual market grade is from 50 to 55 per cent., up to which standard the ore is concentrated by hand picking or jigging.

COBALT.

Cobalt is a somewhat rare metal which has been known for about a century and a half, but for which very few uses have been found. It is a bluish-white hard metal, which takes a good polish, unaffected by the air. It is magnetic, malleable, and, when hot, very ductile. Its weight is about that of copper.

Cobalt does not occur in nature in the metallic state. Its chief ores are asbolite, an oxide of manganese and cobalt; the arsenide, smaltite; and sulpharsenide, cobaltite. More or less cobalt occurs in most nickel ores, and in most cases is recovered as a by-product.

Metallic cobalt has been used for electroplating, and as a constituent of "Stellite" a valuable alloy of this metal with chromium and tungsten or molybdenum. Black oxide of cobalt is largely used in the preparation of sundry pigments, principally smalt, which is a silicate of this metal and potassium, having a very fine and permanent blue colour. It is used for bleaching paper, linen, and starch, and for colouring and painting on glass and porcelain, and for enamels. Cobalt nitrate is used as a chemical re-agent and for making invisible inks, whilst various cobalt compounds are used as paint-driers.

Asbolite.—Hydrous oxide of manganese and cobalt. Cobalt oxide, 1 to 32 per cent.; nickel, trace to 10 per cent.; manganese dioxide, 50 to 70 per cent. Black or dark grey, opaque, massive, or stalactitic. Very soft to hard. G., 4.0. Usually occurs in irregular masses amongst the decomposition products of basic igneous rocks.

Uses.—A source of cobalt and its compounds. Its value is enhanced by the presence of a high percentage of manganese dioxide, since the ore can then be used for the production of chlorine and the cobalt and nickel subsequently recovered from the liquors. For export, ore should be dressed to at least 4 per cent. by washing, which removes some of the associated clay. Nickel in small proportions depreciates the value of the ore, in larger proportions enhances it.

Smaltite.—Arsenide of cobalt, CoAs_2 . Cobalt, 8 to 24 per cent.; nickel, trace to 8 per cent. Crystallised or massive. Metallic, white to grey, often tarnished. Hard; brittle. G., 6.5. Occurs in veins of quartz, etc.

Uses.—A source of cobalt (and nickel).

Cobaltite.—Sulpharsenide of cobalt, CoAsS . Cobalt, 9 to 34 per cent.; nickel, trace to 3 per cent. Crystallised or massive. Metallic, white, reddish, grey. Hard, brittle. G., 6.1. Occurs in quartz veins and lodes.

Uses.—A source of cobalt and its compounds.

COPPER.

Copper is one of the few metals that has been known to man and utilised by him since prehistoric times. This is partly because it is somewhat frequently found native, and partly because its surface ores are readily reduced to the metal by smelting.

Copper is a very tough red metal, highly ductile and malleable. It is, after silver, the best known conductor of electricity and heat. It is not readily attacked by air or water. Its specific gravity is 8.9.

As already stated, metallic copper occurs native in many parts of the world, especially on the shores of Lake Superior. It also occurs as an important constituent of a vast number of mineral compounds, only a few, however, of which occur in large deposits. These are the two oxides, cuprite and tenorite; the two hydrated carbonates, malachite and azurite; the simple sulphides, chalcocite and covellite; the sulphides of copper and iron, chalcopyrite and bornite; and, finally, fald-ore, a sulphide of copper, antimony, and arsenic.

Ores of copper are chiefly found in veins or lodes in crystalline rocks, slates, and sandstones; but also as impregnations in sedimentary beds, volcanic ash, etc.

Electrolytic refining is now carried out with such success that commercial copper contains less than one-tenth of one per cent. of impurities. Its chief uses are in making wire for electric conductors, and in making alloys. Smaller quantities of the metal are used for a multitude of purposes, including the manufacture of various utensils and apparatus, boiler tubes, nails, sheet-copper for roofing, battery plates, pile-sheathing, and ship-sheathing, etc.

The most important alloy of copper is brass, a variable mixture of copper and zinc, one variety of which, known as muntz-metal, is extensively used for sheathing ships and piles. Copper is also the main constituent of bronze, gun-metal, aluminium bronze, and German silver. Copper is invariably added to gold and silver in coinage, jewellery, and plate to harden them.

Of artificial compounds of copper the most important is blue-stone (copper sulphate), used in extracting silver from its ores, in generating electricity, in dyeing and printing, as an insecticide, etc. Several compounds of copper are used as pigments, yielding various shades of green, blue, and purple.

Copper (Native).—Practically pure copper with traces only of silver, bismuth, etc. In crystalline or irregular masses often coated with cuprite or malachite. Red, opaque, metallic. Soft, tough, malleable. G., 8.9.

Uses.—An important source of commercial copper.

Cuprite.—Red oxide of copper, Cu_2O . Copper, 88 per cent. Crystalline, massive or granular. Bright or dark red, translucent or opaque. Soft, brittle. G., 6.0.

Tile Ore.—A massive red variety of cuprite, containing oxide of iron intimately mixed with it. Copper, 50 to 80 per cent.

Uses.—An important ore of copper. The value of this ore, as of all others, depends primarily upon the percentage of copper present; secondly, upon the quantity of associated silver and gold; thirdly, upon the nature of the accompanying impurities and gangue. Of impurities bismuth is the most objectionable, and arsenic and antimony next. Other things being equal, that ore is the most valuable the gangue of which contains such a proportion of silica, lime, and iron oxide as to be self-fluxing, or nearly so.

Tenorite.—Black oxide of copper, CuO , frequently mixed intimately with more or less chalcocite (Cu_2S). Copper, 80 per cent. Sealy, massive, or earthy. Black, metallic or dull. Soft. G. 6.0.

Uses.—See Cuprite.

Malachite.—Hydrated carbonate of copper. Copper, 57 per cent. Crystallised or, more commonly, massive, stalactitic, radially fibrous, or earthy. Bright green, opaque. Soft, brittle. G., 4.0.

Uses.—See Cuprite. Some varieties are sufficiently beautiful when cut and polished to be used for inlaying and other ornamental work.

Azurite.—Hydrated carbonate of copper. Copper, 55 per cent. Crystalline, massive, compact, or earthy. Azure-blue, transparent to opaque. Soft, brittle. G., 3.8.

Uses.—See Cuprite.

Chalcocite.—Black sulphide of copper, Cu_2S . Copper, 80 per cent. Crystallised, massive, compact, or granular. Black, metallic, opaque. Soft, brittle. G., 5.7.

Uses.—See Cuprite.

Chalcopyrite (Copper pyrites).—Sulphide of copper and iron, CuFeS_2 . Copper, 34 per cent. Crystallised or massive. Brass-yellow, metallic, opaque. Sometimes tarnished or iridescent. Soft, brittle. G., 4.2.

Uses.—See Cuprite.

Bornite.—Sulphide of copper and iron, Cu_5FeS_4 . Copper, 55 per cent. Often intimately mixed with chalcopyrite or chalcocite, the copper contents then varying from 50 to 70 per cent. Crystallised, or massive, granular or compact. Usually iridescent. On fresh fracture copper-red to brown, but rapidly tarnishing. Metallic, opaque. Soft, brittle. G., 5.1.

Uses.—See Cuprite.

Tetrahedrite and Tennantite (Fahl-ore).—Sulphide of copper and antimony or arsenic, with variable amounts of bismuth, etc. Copper, 15 to 44 per cent.; silver, trace to 31 per cent. Crystallised or massive, compact or granular. Grey to black, metallic, brilliant, opaque. Soft, brittle. G., 4.7.

Uses.—See Cuprite. A very valuable ore owing to the almost constant presence of a notable amount of silver, which usually more than compensates for the presence of such objectionable constituents as bismuth, arsenic, and antimony.

GOLD.

From the earliest times gold has been known and valued for its great beauty. When pure it is a soft yellow metal susceptible of a brilliant polish and untarnished by exposure to air, water, or most chemicals. It is the most malleable and ductile of all metals, as well as one of the heaviest, its specific gravity being 19.3.

Gold is but rarely found in nature in a state of great purity, native gold being an alloy of this metal with more or less silver, seldom containing more than 95 per cent. of pure gold. This alloy is by far the most common source of the metal. Gold also occurs in nature alloyed with mercury as native amalgam, and in combination with tellurium and silver in various telluride ores, chiefly calaverite, sylvanite, and petzite. Gold also occurs in minute invisible specks scattered through many samples of pyrites, copper ores, etc., and can frequently be extracted from these ores at a profit.

Native gold occurs in veins or in disseminations in crystalline and other rocks, as well as in alluvial deposits, river gravels, etc. The telluride ores occur only below the zone of complete oxidation.

Pure gold is chiefly used as a surface covering or plating to ornaments and utensils of other metals. It is also used extensively for stopping teeth. When beaten out into leaf it is used for ornamental painting and lettering. For other purposes gold is hardened by being alloyed with copper or silver, or both, such alloys being used for coinage, jewellery, plate, etc. The most useful artificial compound of gold is the chloride, which is used in photography and in the manufacture of ruby glass.

Gold (Native).—Gold alloyed with more or less silver. Gold, 50 per cent. to 99 per cent.; silver, trace to 50 per cent. Varieties containing over 30 per cent. of silver are known as *Electrum*. Crystallised, dendritic, massive, granular, spongy, in flakes, and in rolled grains and nuggets. Opaque, metallic, yellow of various shades. Soft, malleable. G., 14 to 19.

Uses.—The chief source of gold and its compounds.

Calaverite.—Telluride of gold Au_2Te_2 . Gold, 34 to 42 per cent.; silver, 0.5 to 5 per cent. Massive, metallic, brilliant. White to yellow, opaque. Soft, brittle. G., 9.2.

Uses.—A source of gold and its compounds.

Krennerite.—Telluride of gold and silver $(\text{Au}, \text{Ag})_2\text{Te}_2$. Gold, 34 to 37 per cent.; silver, 3 to 6 per cent. Crystallised, with perfect cleavage. White to yellow, metallic, brilliant, opaque. Soft, brittle. G., 8.2.

Uses.—A source of gold and silver and their compounds.

Sylvanite.—Telluride of gold and silver $(\text{Au}, \text{Ag})_2\text{Te}_2$. Gold, 26 to 30 per cent.; silver, 8 to 13 per cent. Crystallised, arborescent, or massive, with a perfect cleavage. White, metallic, brilliant, opaque. Very soft, brittle. G., 8.1.

Uses.—A source of gold and silver and their compounds.

Petzite.—Telluride of gold and silver $(\text{Ag}, \text{Au})_2\text{Te}_2$. Gold, 23 to 26 per cent.; silver, 40 to 47 per cent. Massive, granular, or compact. Black, metallic, brilliant, opaque. Soft. G., 8.9.

Uses.—A source of gold and silver and their compounds.

IRON.

Of all the metals that have been pressed into the service of man, iron is by far the most common and most useful, and was first utilised in prehistoric times. The chemically pure metal is not an article of commerce. It is a white metal capable of taking a high polish. It is somewhat harder than copper, and considerably

stronger; it is malleable, and at a red heat can be welded. Iron can only be melted at a dazzling white heat. When heated somewhat and cooled suddenly it does not harden. Iron does not tarnish in perfectly dry air, but in moist air or water rapidly rusts. Salt water and weak acids attack it rapidly.

Iron appears in commerce in three states of varying purity, known respectively as wrought iron, steel, and cast iron. All these forms of iron contain as impurities carbon, silicon, phosphorus, sulphur, and manganese, and it is upon the relative proportions present of these elements, especially carbon, that the quality of the metal depends. Wrought iron is the purest form of commercial iron, and contains essentially from .03 to .30 per cent. of carbon. It closely resembles pure iron in its properties, but is slightly more fusible and less malleable than the latter. Steel contains, in addition to the usual impurities of all forms of iron, an amount of carbon varying from .3 per cent. to 1.5 per cent. It differs from wrought iron in being less malleable and less easily welded, more fusible, and stronger. Its most striking feature is its capacity for becoming extremely hard when heated and suddenly chilled. Cast iron contains from 1.5 to 5 per cent. of carbon and comparatively large quantities of sulphur, phosphorus, and silicon. It melts more easily than steel, is brittle when cold, and does not harden on heating and quenching.

Iron occurs in abundance in nature in many forms (very rarely as the metal), being an important constituent of almost all rocks. The only native compounds, however, that can be profitably employed as a source of the metal are the oxides, magnetite, etc., and the carbonate, siderite.

Pure iron, as already stated, is not used in the arts; the purest wire used for piano strings, etc., still containing 0.3 per cent. of impurities. Wrought iron is used for a multitude of purposes, chiefly for forged parts of machinery, boiler plates, pipes for water, gas, etc., girders and other structural members, roofs, etc. Steel has largely replaced wrought iron for many purposes. Its chief uses are for rails, ships, bridges, tools and parts of machinery, and structures of various kinds, etc. Cast iron is made mainly as an intermediate product in the manufacture of steel and wrought iron. It is also largely used for casting various machine details and industrial and domestic utensils.

The chief alloys of iron are those varieties of steel containing various proportions of manganese, nickel, and rarer metals. These are for the most part harder and stronger than ordinary steel. Various cast alloys of iron with manganese and other metals are produced solely for the production of the special steels above mentioned. Chief of these are spiegel and ferro-manganese, alloys of manganese and iron with considerable carbon, used in the manufacture of Bessemer steel, Hadfield's manganese steel, etc.

Compared with the metal itself, the artificial compounds of iron are of minor importance. Artificial ferric oxide is employed as a pigment and polishing powder (rouge). The hydrate, carbonate, and other salts are used in medicine. An artificial mixture of the oxides (iron-scale) is used in the conversion of cast iron into wrought iron and steel. Ferrous sulphate (copperas) is used to precipitate gold, and in the manufacture of Nordhausen sulphuric acid, iron mordants, inks, etc. Prussian blue, a cyanide, is a valuable pigment. Potassium ferrocyanide is used as a source of potassium cyanide and as a chemical reagent.

Magnetite.—Magnetic oxide of iron, Fe_3O_4 . Iron, 65 to 72 per cent. Crystallised or massive, granular or compact. Black, metallic, opaque. Magnetic, hard, brittle. G., 5.1. Occurs as irregular masses in volcanic rocks, and as lodes in schists.

Uses.—The richest and purest ore of iron; used largely for the production of the commercial metal, and to a slight extent as a flux in lead and copper smelting. Bulk samples of ore contain various impurities, which mostly exert a marked effect upon the final smelted metal, and hence influence to a very large extent the value of a deposit. The chief of these are phosphorus, sulphur, silica, and titanite oxide.

Phosphorus.—This element, in more than traces, is the most objectionable constituent of an iron ore. Ores containing more than .045 per cent. of phosphorus are practically useless for the production of Bessemer steel. Basic steel (Thomas steel) can be made most profitably from ores containing from 0.4 to 2.0 per cent. phosphorus. Intermediate ores are best suited for the production of wrought iron, and grey and white iron for castings. With ores rich in iron a slightly higher percentage of phosphorus is permissible than with poor ores.

Sulphur.—This element is not so objectionable as phosphorus. The best ores contain less than 0.05 per cent. of this element. Inferior ores contain up to 2.0 per cent., and are frequently roasted to remove this sulphur before smelting.

Silica.—Small amounts of this under 5 per cent. are no drawback to the ore; beyond that amount, the less the better, since the more silica contained in the ore the more lime is needed to flux it. If the ore contains lime or alumina this will serve to neutralise the bad effect of an increased content of silica. For iron smelting the best ores contain not more than 10 per cent., poorer ores 10 to 30 per cent. For fluxing lead or copper ores the silica must not exceed 7 per cent.

Titanic Oxide.—This constituent is usually stated to cause considerable difficulty in the smelting of pig-iron, and most iron smelters look askance at ores containing more than 0.5 per cent. In fluxing lead and copper ores titanite oxide acts like silica, and the total of these two constituents should not therefore exceed 7 per cent., whilst the titanite oxide alone should be under 5 per cent.

Other constituents.—Manganese oxide in small quantities increases the value of an iron ore for all purposes. Lime and alumina to the extent required for fluxing the silica of the ore are also an advantage.

Hæmatite.—Oxide of iron, Fe_2O_3 . Iron, 67 to 70 per cent. Crystallised, massive granular, earthy, micaceous. Earthy variety red, soft to hard, dull, opaque. Other varieties black, metallic, hard, opaque, brittle. G., 5.1.

Uses.—An important source of iron. (See remarks under Magnetite.)

Limonite.—Hydrated oxide of iron, $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$. Iron, 57 to 60 per cent. Stalactitic, fibrous, concretionary, massive or earthy. Brown or yellow, sometimes iridescent, opaque. Soft or hard. Brittle.

Other very similar hydrated oxides are : **Turgite**, $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$, and **Goethite**, $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$.

The *Laterite Ore* (surface clay ironstone) of Australia and India is a mixture of limonite or turgite with more or less bauxite (aluminium ore) and sometimes some hæmatite, goethite, or other hydrated oxides of iron. It is concretionary or cellular, massive, and contains up to 62 per cent. of iron.

Uses.—An important source of iron. (See remarks under Magnetite.)

The soft earthy yellow varieties known as *Ochre* contain more or less clay, and are used largely for the production of pigments and giving a body to linoleum. For this purpose the value of the ore depends upon the fineness of its grain, its freedom from grit, and its colour (both fresh and when calcined).

Concretionary limonites and laterites are largely used for ballasting roads and railways.

Siderite (Spathic iron ore).—Carbonate of iron, FeCO_3 . Iron, 40 to 48 per cent. Crystallised, massive granular, fibrous, compact, earthy. Grey, yellow, or brown, translucent to opaque. Soft, brittle. G., 3.8.

The *Clay-band Ironstone* of England is an impure siderite containing much clay. The *Black-band Ironstone* of Great Britain and America is a siderite mixed with much coaly matter.

Uses.—An important ore of iron. (See remarks under Magnetite.)

Chromite (see page 8) is used as a source of ferro-chromium, hæmatite as a source of ferro-titanium, and Wolfram (see page 17) as a source of ferro-tungsten.

LEAD.

This was one of the few metals known to man in very ancient times. It is a very soft bluish white metal, which can be readily rolled or pressed into sheet or wire. It rapidly tarnishes on exposure to the air and is then but little affected by air or many acids. It melts below a red heat and has a specific gravity of 11.3.

Occasional grains of metallic lead have been found in nature, but the metal chiefly occurs as a sulphide, galena. A second common ore is the carbonate, cerussite, whilst much less common are the sulphate, anglesite, and the chlorophosphate, pyromorphite. Ores of lead usually occur in veins and lodes in crystalline rocks, slates and limestones.

Commercial lead is largely used in sheets for roofing and making pipes. It is also used for bullets and for making white lead, red lead, litharge, etc. Lead hardened with a few per cent. of antimony is used for lining acid chambers, etc. Of lead alloys the most important is that with tin, known as solder, and that with tin and antimony, known as type metal.

Of the artificial compounds of lead, by far the most important is white lead, a basic carbonate, which is the most useful pigment known. Red lead, an oxide, is also a valuable pigment, and is used in the manufacture of flint glass. Litharge, another oxide, is used as pigment, as a constituent of many varieties of glass and of glazes for clay-ware, and in manufacturing white lead. Lead chromate is used as a pigment, also lead sulphate.

Lead ores are used almost solely as a source of the metal from which, after refining, the various artificial compounds are prepared. Two other minor, though still important, uses they are put to. One is in the metallurgy of the precious metals, the ores of these being smelted with ores of lead, to form the so-called base bullion, or pig lead containing all the gold and silver in solution in a convenient concentrated form for final recovery. The second use is in the production of lead fume, a fine mixture of lead sulphate and oxide used as a pigment.

Galena.—Sulphide of lead, PbS . Lead, 83 to 86 per cent.; silver, trace to 3 per cent. Crystallised with cubic cleavage, or granular massive. Lead grey, metallic, opaque. Soft, brittle. G., 7.5.

Uses.—The main source of metallic lead. Also used as a source of lead fume and in recovering gold and silver from their ores. The value of the ore depends upon the amount of lead and silver present. For the production of lead fume the galena should be practically free from silver.

Cerussite.—Carbonate of lead, PbCO_3 . Lead, 77 per cent.; silver, traces. Crystallised or granular or compact massive. White or grey, transparent to opaque. Soft, very brittle. G., 6.5.

Uses.—An important ore of lead.

Anglesite.—Sulphate of lead, PbSO_4 . Lead, 66 to 68 per cent.; silver, traces. Crystallised or massive, granular compact or stalactitic. White or tinted, transparent to opaque. Soft, very brittle. G., 6.2.

Uses.—A common ore of lead.

Pyromorphite.—Chlorophosphate of lead. Lead, 62 to 75 per cent.; silver, traces. Crystallised or massive, resinous. Green, yellow or brown, translucent to opaque. Soft, brittle. G., 6 to 7.

Uses.—A minor ore of lead.

LITHIUM.

Lithium is one of the alkali metals closely resembling sodium, but of much greater rarity, and was discovered in 1817. It is silver white, softer than lead and extremely light, being only a little over half as heavy as water. It melts at a low temperature and rapidly tarnishes when exposed to the air.

Lithium does not occur in nature in the metallic state but usually in combination with other metals and silica in pegmatite veins or dykes.

Lepidolite (*Lithia mica*).—Fluosilicate of lithium, aluminium, and potassium. Lithia (lithium oxide), 3 to 6 per cent. In sealy granular masses or in large cleavable plates. Pink, amethystine, white, or grey. Transparent or translucent. Soft, tough. G., 2.8
Uses.—This is the chief source from which lithium salts are prepared, and its value will depend upon the proportion of lithia present in it.

Other less important sources of lithium compounds are:

Spodumene.—Silicate of lithium and aluminium; and

Amblygonite.—Fluophosphate of lithium and aluminium.

The metal is not put to any use in the arts. Its most important artificial compounds are the chloride, carbonate, and citrate, all of which are used for medicinal purposes and also as constituents of aerated waters (lithia water, etc.).

MAGNESIUM.

This metal was first separated and described at the beginning of the 19th century, though its compounds had been in use for some time previously to this. It is a soft white metal, which does not tarnish in dry air but is coated with a film of oxide on exposure to moist air. It is easily dissolved by dilute acids. It melts at a red heat and burns readily in the air with a brilliant flame.

Magnesium does not occur native in the earth, but is a universal constituent of all rocks, forming a considerable proportion of serpentine and other basic igneous rocks. Comparatively few minerals are, however, capable of successful treatment for the production of the metal and its artificial compounds. Of these the most important is the carbonate, magnesite; the sulphates, epsomite and kieserite, and the chloride of potassium and magnesium, carnallite, are also valuable minerals. Asbestos, talc and other magnesium silicates are dealt with under the title "Silica and silicates." Magnesium chloride and sulphate are constituents of almost all well and bore waters.

Metallic magnesium in the form of ribbon or powder is burnt to produce a brilliant illumination of interiors, underground hollows, etc., for photographic or show purposes; it is also used for signalling purposes and in pyrotechny. Small quantities are used for various analytical purposes. Magnalium and duralum are commercial alloys of magnesium and aluminium.

Of artificial compounds the most important is the oxide, magnesia, large quantities of which are made into fire brick or pressed direct into the linings of furnaces for the production of "basic" steel, and of kilns for burning hydraulic cement. It is also used in the manufacture of sord cement, as a non-conducting covering for boilers, etc., and as a starting point for the manufacture of various other magnesium compounds. The hydrous sulphate, known as Epsom salts, is largely used in the manufacture of dyes, soaps, and paints, in tanning leather, and in medicine. The chloride is used in the textile industry, and as a source of metallic magnesium; the sulphide, in cleaning wood-pulp for paper manufacture.

Magnesite.—Carbonate of magnesium, $MgCO_3$. Magnesium, 25 to 28 per cent.; magnesia, 42 to 47 per cent.; carbon dioxide, 47 to 52 per cent. Occasionally crystallised, usually massive, compact, granular, or earthy. White, yellowish, brownish; translucent to opaque. Soft or hard, brittle. G., 3.1. Occurs in veins in serpentine and other rocks, and in boulders in the weathered rocks.

Uses.—Chiefly burnt to convert it into magnesia, for the manufacture of refractory bricks and furnace linings, and oxychloride cement. For this purpose it should contain a small proportion only of silica. Also used in the manufacture of magnesium chloride, sulphate, and sulphate (Epsom salts). Large quantities used for production of carbon dioxide for aerating waters, etc., magnesia or magnesium sulphate being obtained as by-products. Magnesite used as a source of magnesium salts should be as free as possible from iron and lime.

Other minerals employed in Europe as a source of magnesium or its compounds are:—

Epsomite (Native Epsom salts).—Hydrous sulphate of magnesium, $MgSO_4 \cdot 7H_2O$. Magnesia, 16 per cent.

Kieserite.—Hydrous sulphate of magnesium, $MgSO_4 \cdot H_2O$. Magnesia, 29 per cent.

Carnallite.—Hydrous chloride of magnesium and potassium. Magnesium, 8 per cent.; potassium, 14 per cent.

MANGANESE.

The metal manganese was discovered at the latter end of the 18th century. In its pure form it only appears in commerce as a chemical curiosity. It is a very hard, brittle metal, resembling cast iron in appearance and weight, but is so susceptible to the action of the air that it can only be preserved in sealed bottles or under mineral oil.

Manganese does not occur in nature in the metallic state, but is usually found combined with oxygen as one of the several oxides, which constitutes the chief source of the metal. It is also a constituent, in small proportion, of all rocks, especially limestones and the more basic igneous rocks. Workable deposits of the ores are largely found in close association with such rocks or the debris resulting from their decomposition.

In its pure state manganese has no application in the arts. Of its alloys, those with iron are the most important, viz., ferro-manganese and spiegel-eisen; both largely used in the manufacture of steel.

Compounds of manganese are used in large quantities for various technical purposes. This is especially true of the dioxide (MnO_2), which occurs in nature as Pyrolusite (*q.v.*). Potassium and sodium permanganates ($KMnO_4$ and $NaMnO_4$) are extensively used as disinfectants and deodorants, owing to the ease with which they give up part of the oxygen contained in them.

The natural oxides of manganese are all used for both coloring and decolorising glass; for coloring pottery and brick; for calico-printing and dyeing; and in manufacturing certain paints. A considerable quantity of manganese is also used as a flux in lead smelting, oxide of manganese in conjunction with oxides of iron and lime forming a readily fusible slag with the siliceous gangue of the lead ore. For fluxing purposes the value of the ore depends upon its richness in manganese and its freedom from silica; iron oxide is not looked upon as an objectionable constituent. The oxides and carbonate are the only ores used as a source of the metal in the form of spiegel or ferro-manganese. For this purpose the ore should be rich in manganese, poor in silica and iron, and contain only very minute amounts of sulphur or phosphorus. In England ores are divided into three grades: 1st, over 50 per cent. manganese; 2nd, 47 to 50 per cent.; 3rd, 40 to 47 per cent. A third main use of the natural oxides of manganese is in the production of chlorine, which is employed in extracting gold from its ores and refining it, and in the production of bleaching powder or chloride of lime for bleaching and disinfecting. For this purpose the value of the ore depends entirely upon the proportion of dioxide present, and is bought at so much "per unit," that is so much for every one per cent. of dioxide (MnO_2) in the ore.

The following are the chief compounds of manganese occurring in nature:—

Pyrolusite.—Dioxide of manganese, MnO_2 . Manganese, 60 to 63 per cent.; manganese dioxide, 95 to 100 per cent. Soft, black, crystalline or massive, opaque. G., 4.8.

Uses.—This mineral is the most useful ore for the production of chlorine and the manufacture of permanganates, owing to the fact that it is richer in the dioxide than any other manganese ore. It should be noted in this connection that the "pyrolusite" of the Australian miner and ore-dealer includes practically all native manganese oxides such as Psilomelane, etc. Pyrolusite is also used as a flux, as a source of manganese alloys, and for all other purposes mentioned above.

Manganite.—Hydrated oxide of manganese, $MnO \cdot MnO_2 \cdot H_2O$. Manganese, 63 per cent.; manganese dioxide, 50 per cent. Crystallised or massive. Soft, brittle, black, opaque, sub-metallic. G., 4.3.

Uses.—Of little use for the production of chlorine owing to the low percentage of the dioxide present. It can be used for all other purposes.

Psilomelane.—Hydrated oxide of manganese with potassium. Variable in composition, but averages: manganese 55 per cent.; manganese dioxide, 70 per cent.

A common variety of this mineral, known as *Asbolite*, sometimes contains sufficient cobalt and nickel to constitute an ore of those metals (*q.v.*). Massive or concretionary. Variable hardness, black, opaque. G., 3.7-4.7. A commonly occurring ore.

Uses.—This ore is used for all the purposes to which Pyrolusite is put, and, after that mineral, is the most valuable of the manganese ores.

Rhodocrosite.—Carbonate of manganese, $MnO.CO_2$. Manganese, 48 per cent. Crystalline or massive. Somewhat hard; pink, grey, or brown; semi-opaque. An uncommon ore. G., 4.4.

Uses.—Can be used as a flux or as a source of the metal.

MERCURY.

Mercury is the only metal which at ordinary temperatures is liquid. It was known some centuries before the Christian era. It is a bright, metallic, white, mobile liquid, which does not tarnish in the air, and readily dissolves gold, silver, and many other metals. Its specific gravity is 13.5.

Mercury is found native in small globules, but its commonest native compound and chief ore is the sulphide, cinnabar. It also occurs as the telluride, coloradoite, and in some varieties of fahl-ore, but neither of these minerals are sufficiently plentiful to constitute sources of the metal. Mercury ores usually occur in veins or stockworks in slate, limestone, or igneous rocks.

By far the greater part of the world's production of mercury is employed in extracting gold and silver from their ores. Smaller quantities are used in the electrolytic production of caustic soda, for thermometers, barometers, battery zines, etc., and the production of amalgams, or alloys of mercury with other metals. Sodium amalgam is added to ordinary mercury to make it dissolve gold more actively, and is also used as a reducing agent in preparing various organic products. Tin amalgam is used as a backing for glass to produce an ordinary mirror. Various amalgams are used in dentistry as stopping for teeth. Mercurous chloride, or calomel, is used in medicine; mercuric chloride, or corrosive sublimate, as an antiseptic and vermicide, especially for preserving timber, also in making aniline-red, in dyeing and calico printing, and in etching steel plates. Mercuric sulphide or vermilion is an important pigment. Mercury fulminate is an extremely explosive salt used for detonators and percussion caps.

Mercury (Native).—Practically pure mercury. In small liquid globules; white, metallic, brilliant. G., 13.6.

Uses.—A minor source of the metal and its compounds.

Cinnabar.—Sulphide of mercury, HgS . Mercury, 86 per cent. Crystalline, granular, massive, or earthy. Red, sometimes brownish or leaden; transparent to opaque. Lustre, brilliant to dull. Soft, slightly sectile. G., 8.1.

Uses.—The main source of the metal and its compounds. Ores as low as 0.3 per cent. have been worked at a profit, though 1 to 3 per cent. is the usual smelting grade.

MOLYBDENUM.

This rare metal, first discovered in 1780, is very similar to silver in appearance, but is somewhat harder, lighter, and more infusible. It is not affected by the air at ordinary temperatures, and resists the action of many acids. In spite of its many useful properties, it has not yet found any application in the arts except in combination with other metals, etc.

The commonest ore of molybdenum is the sulphide, molybdenite, the metal itself not occurring uncombined in nature. The usual matrices of this mineral are fracture zones and veins of quartz traversing igneous rocks, particularly granite.

Crude molybdenum, containing carbon and iron, is obtained by the electric smelting of the roasted ores, and ferro-molybdenum, an alloy of iron and molybdenum, by adding iron ores to the smelting mixture. A considerable demand for these products has arisen since the discovery that the addition of a little of either of them to chrome steel renders it self-hardening, such steel being used for machine tools and projectiles.

Ammonium molybdate is used largely in analytical work for the estimation of phosphorus. Molybdenum tannate is a useful dye for leather, producing, in conjunction with logwood, various shades of yellow and brown. In pottery molybdenum blue or blue carmine is used to impart a blue colour of great brilliancy and durability.

Molybdenite.—Sulphide of molybdenum, MoS_2 . Molybdenum, 60 per cent. Foliated, scaly, or sometimes granular. Metallic, opaque, lead-coloured, closely resembling graphite. Very soft. G., 4.7.

Uses.—This is the chief source of the crude metal and its alloys and salts. The ore to be saleable must be concentrated by hand or machinery up to at least 85 per cent. of MoS_2 , and must be entirely freed from copper compounds. The Elmore process of oil concentration has been found successful in many cases. In other cases concentration is effected by simple water flotation or by hand picking.

NICKEL.

This useful metal has been known for about a century and a half, but has only within recent years been extensively used in the arts. It is a bright, greyish-white metal; hard, ductile, and malleable. It is capable of taking a very high polish, which is not easily dulled by air or water. It is magnetic.

Nickel does not occur native, though an alloy with iron forms the chief constituent of many meteorites. Its chief ores are garnierite, a silicate of nickel and magnesium found chiefly in New Caledonia, and nickeliferous pyrrhotite, a sulphide of iron and nickel. Of minor importance are the sulphide and arsenide. Nickel occurs to a slight extent in all cobalt ores, and cobalt in all nickel ores. The ores occur usually in association with basic igneous rocks.

The chief use of nickel is in making various alloys, but the pure metal is largely used for various metal instruments, ornaments, and other articles, as well as for plating such articles when made of cheaper metals. By far the most important alloys of nickel are those with steel, which is thereby rendered much stronger, harder, more elastic, and less liable to corrosion. Such steels are extensively used for armour plate, projectiles, heavy guns, propeller-shafts, railway axles, etc. The nickel is added to the steel either in the form of the pure metal, or one of the alloys ferro-nickel, chrome-nickel, tungsten-nickel, or molybdenum-nickel, whose names indicate their composition. Alloys of nickel and copper in various proportions are used in many countries for coinage. An alloy of nickel, copper, and zinc, known as "German Silver" is extensively used for various implements and ornaments.

Nickel oxide is used to add to steel for making nickel-steel; nickel ammonium sulphate in solution for nickel-plating.

Garnierite.—Hydrous silicate of nickel and magnesium. Nickel, 43 to 48 per cent.; cobalt, trace to 0.5 per cent. Massive, clay-like. Dark or pale green, or chocolate; opaque, dull. Very soft. G., 2.5. Occurs in veins and stockworks in serpentine and peridotite.

Uses.—One of the chief sources of the metal and its compounds. Ores practically free from cobalt are the most valuable. For market the ore should be hand picked up to a minimum of 7 per cent.

Nickeliferous Pyrrhotite.—Sulphide of iron and nickel (Fe, Ni), S_2 . Nickel, 0.5 to 10 per cent.; cobalt, trace to 0.5 per cent. Metallic, massive, or crystallised. Bronze-brown, opaque, magnetic. Soft, brittle. G., 4.6. Occurs in veins with quartz, etc., in basic igneous rocks.

Uses.—An important source of nickel and its compounds. The freer the ore from cobalt the more valuable it is. For smelting, the ore should be dressed to a minimum of 2 per cent. nickel.

Other minor sources of nickel are:—

Millerite.—Sulphide of Nickel, NiS. Nickel, 64 per cent.

Nickelinite (Kupfernickel).—Arsenide of nickel, NiAs. Nickel, 33 to 44 per cent.

PLATINUM, IRIIDIUM, AND OSMIUM.

These are all rare metals resembling one another closely and found closely associated in nature, they will therefore be dealt with together.

Platinum is a bright, greyish-white, malleable, and ductile metal. It is very infusible and not readily acted on by the strongest acids. At a red heat platinum can be welded with ease. Its specific gravity is 21.5. Its chief use is in the manufacture of jewellery and chemical ware such as vessels for the concentration of acids, weights, etc. Other important uses are in the manufacture of platinotype photographic paper, and in various electrical appliances, particularly sparking plugs for motors. Besides this it is used in surgical instruments and in dentistry, and in the "Contact Process" of manufacturing sulphuric acid. Alloyed with iridium it is not only used for chemical ware, but also for standard weights and measures, etc. It varies somewhat largely in price; in 1919 it was about £20 per oz. Platinum tetrachloride is used as a chemical re-agent.

Iridium is a hard, white, brittle metal, extremely heavy, its specific gravity being 22.4. It is not used uncombined in the arts, but from 5 to 10 per cent. is frequently alloyed with platinum, which is rendered much harder and more durable thereby. Iridium oxide is used in porcelain painting. An alloy with osmium is used for compass bearings and for tipping pens.

Osmium is an extremely hard, bluish metal, insoluble in all acids, even aqua regia. It is one of the heaviest substances known, having a specific gravity of 22.5. Its chief use is in incandescent electric lights, and in alloys with iridium, as described above.

These three metals are almost always found in nature together, rarely in lodes, more frequently in river or beach sands in the form of native platinum, native iridium, and osmiridium. The only native compound of these metals of any importance is the arsenide of platinum, sperrylite.

Platinum (Native).—Platinum alloyed with iron, iridium, etc. Platinum, 50 to 86 per cent.; iridium, trace to 20 per cent.; osmium, trace to 10 per cent. In small grains or scales, occasionally in large nuggets. Greyish white, bright, metallic, malleable, soft, sometimes magnetic. G., 14 to 19.

Uses.—The chief source of platinum and its compounds, and to a minor degree, of iridium and osmium.

Iridium (Native).—Iridium alloyed with platinum, etc. Iridium, 30 to 76 per cent.; platinum, 20 to 55 per cent.; osmium, trace. In angular white metallic grains. Slightly malleable, hard. G., 22.7.

Uses.—A rare mineral, used as a source of iridium and platinum and their compounds.

Osmiridium (Iridosmine).—Native alloy of iridium and osmium. Iridium, 43 to 77 per cent.; osmium, 17 to 49 per cent.; platinum, trace to 3 per cent. In small flattened grains, sometimes hexagonal in outline, with basal cleavage. White or grey, metallic. Barely malleable, hard. G., 20. Found in sands associated with platinum, gold, etc.

Uses.—The chief source of iridium and osmium and their compounds.

POTASSIUM.

This metal was first separated early in the 19th century, though some of its compounds, notably nitre, had been in use by man from time immemorial. It is a very soft, white, plastic, and sectile metal, which is rapidly oxidised by air or water, so that it has to be preserved under mineral oils. It is one of the lightest metals known, its specific gravity being less than one.

Potassium occurs as a constituent of very many rocks, especially granites, but cannot be profitably extracted from them or from any of the natural silicates, such as potash mica or felspar. The commercially most important minerals containing potassium are the nitrate, nitre or saltpetre; the chloride, sylvite; the double chloride with magnesium, carnallite; the double sulphate and chloride kainite; and the sulphate of potassium and aluminium, alunite.

Metallic potassium is not of commercial importance. Of the highest importance, however, are the nitrate and chloride, used as constituents of various explosives, and the various soluble potash salts used as fertilisers. Potassium cyanide is largely used as a solvent for gold. Potassium chromate and bichromate are put to many uses (see p. 18). Potash alum is a most useful salt, and is described under aluminium, page 14. Potassium hydrate, carbonate, permanganate, ferrocyanide, iodide, bromide, etc., are put to various medicinal and other uses, *e.g.*, in photography, glass making, and soap making.

Nitre.—Nitrate of potassium, KNO₃. Potash, 46 per cent.; nitrogen pentoxide, 53 per cent. Crystallised, in thin crusts or powder. White, translucent. Very soft, brittle. G., 2.1. Occurs in the soil in dry countries.

Uses.—After refining, is largely used in manufacturing gunpowder and other explosives. Also used as a fertiliser and in curing meat, etc.

Sylvite.—Chloride of potassium, KCl. Potassium, 52 per cent. (equal to potash 62 per cent.), but frequently intimately mixed with common salt. Crystallised, massive, granular, or compact. Colourless, white, or tinted. Transparent to translucent. Very soft, brittle. G., 2.0. Occurs in beds in sedimentary deposits.

Uses.—Used as a fertiliser and as a source of various salts of potassium its value depending upon its purity and richness in potassium.

The other important potassium salts occurring in beds in Germany are:

Carnallite.—Hydrated chloride of potassium and magnesium; and

Kainite.—Hydrated chloride and sulphate of potassium and magnesium.

Alunite.—Hydrated sulphate of potassium and aluminium. Potash, 6 to 11 per cent. See page 4.

Uses.—In default of the richer German minerals has been used as a source of potash compounds, particularly as a fertiliser, either in its raw state or after roasting. For this purpose its value is determined solely by its content in "available potash," *i.e.*, potash soluble in water after roasting.

Jarosite.—Hydrated sulphate of potassium and iron. Potash, 4.8 to 9.4 per cent.

Uses.—Used as a source of potash compounds and of a pigment.

SILVER.

Silver has been known to man for many centuries, being one of the few metals known to the ancients. It is white, and capable of a most brilliant polish, which undergoes no change in air or water unless sulphur be present, when it is blackened. In malleability and ductility it is second only to gold. It is the best known conductor of heat and electricity. Its specific gravity is 10.5, or between that of copper and lead.

Silver occurs native in a state of considerable purity and also alloyed with gold. It also occurs in a vast number of compounds, comparatively few of which, however, described below, constitute important ores of the metal. Most lead ores, especially galena, contain more or less silver, also most copper ores, especially tetrahedrite (fahlore) and chalcocite. Blende, pyrites, and mispickel, also, at times, carry notable quantities of silver.

Metallic silver is largely used in the arts for preparing alloys and silver salts, and for plating various articles of utility and ornament. The chief alloy is that with copper, which possesses all

the beauty of the original silver, but is much harder. It is extensively used for coinage, tableware, jewellery, and innumerable articles of ornament, etc. The chief use for silver salts is in photography; the nitrate, bromide, chloride, and other compounds being used for this purpose. The nitrate is also used in analytical work, in medicine, and in the manufacture of marking inks.

Native ores of silver are used solely for the production of the metal, from which alloys or salts are subsequently obtained as desired. Their value depends upon the amount of the metal present and the ease with which it can be extracted. They occur in lodes and veins in crystalline and other rocks.

Silver (Native).—Silver, 70 to 99 per cent.; gold, trace to 30 per cent. Crystallised, dendritic, massive, or in scales. White, or tarnished grey or black, metallic, opaque. Malleable, soft. G., 10.5.

Uses.—*See* above. The gold present is occasionally of considerable value.

Argentite.—Sulphide of silver, Ag_2S . Silver, 87 per cent. Crystallised or massive. Black, metallic, opaque. Very soft, sectile. G., 7.3.

Uses.—*See* above.

Stephanite.—Sulphide of silver and antimony. Silver, 68 per cent. Crystallised or massive. Black, metallic, opaque. Very soft, brittle. G., 6.2.

Uses.—*See* above.

Pyrargyrite (Dark Ruby Silver Ore).—Sulphide of silver and antimony. Silver, 58 to 61 per cent. Crystallised or compact, massive. Black or deep red, metallic, opaque except in thin splinters. Soft, brittle. G., 5.8.

Uses.—*See* above.

Proustite (Light Ruby Silver Ore).—Sulphide of silver and arsenic. Silver, 63 to 65 per cent. Crystallised or compact, massive. Red, brilliant, transparent to translucent. Very soft, brittle. G., 5.6.

Uses.—*See* above.

Ocerargyrite (Horn Silver).—Chloride of silver, AgCl . Silver, 75 per cent. Sometimes crystallised, usually massive, waxlike. White, greyish, or greenish, turns brown on exposure to the light. Transparent or translucent. Very soft and sectile. G., 5.5.

Uses.—*See* above. Often associated with oxidised ores of lead and copper.

Embolite.—Chloro-bromide of silver, $\text{Ag}(\text{Cl}, \text{Br})$. Silver, 61 to 72 per cent. Crystallised or massive. Green or yellow, darkening on exposure to light. Transparent to translucent. Very soft, sectile. G., 5.4.

Uses.—*See* above.

Argentiferous Galena, Tetrahedrite, and Blende, are important ores of silver, but when argentiferous have their usual appearance and characteristics. They are described elsewhere. (Galena, page 11; tetrahedrite, page 10; blende, page 18.

SODIUM.

Sodium, the metallic constituent of common salt, was first isolated and examined early in the 19th century. It is a soft, white, plastic metal, which is slightly lighter than water. It melts at a temperature below that of boiling water, and is one of the best known conductors of heat and electricity. It oxidises rapidly in moist air or in contact with water.

Sodium does not occur native, but is widely distributed in the form of various rock-forming silicates and as the chloride, common salt. This latter is the chief source of the metal and its salts. The nitrate, chili-nitre; sulphate, thenardite; and sesquicarbonate, trona, also occur native.

Metallic sodium is a most useful reducing agent, and is therefore used in the reduction of aluminium and other metals from their ores, as well as in the preparation of many organic compounds. Sodium amalgam, formed by dissolving sodium in mercury, is a good solvent for gold, and is largely used in gold amalgamation.

The artificial compounds of sodium are manufactured on an enormous scale for many purposes. The peroxide is a most useful bleaching and general oxidising agent. Sodium chloride, both crude and refined, is perhaps the most useful of all sodium compounds (*see* under Salt, *infra*). The carbonate, "soda," is mainly used in the manufacture of soap and glass, besides being put to a great number of other industrial and domestic purposes. The bicarbonate is used as a source of carbonic acid for aerated waters, in cooking, in metallurgical processes, in scouring wool, etc. The hydrate, caustic soda, is used for the same purposes as the carbonate, as well as for the production of soluble glass, etc. The sulphate is used in the manufacture of many forms of glass; the thiosulphate in extracting silver from its ores, and in photography. Many other sodium salts are used for various industrial, medicinal, and other purposes.

Salt.—Chloride of sodium, NaCl . Sodium, 61 per cent.; chlorine, 39 per cent. Usually crystallised, also massive, compact, or granular. Colourless or tinted; transparent to translucent. Soft, brittle. G., 2.2. Occurs in stratified deposits or in beds of salt lakes. Also in solution, in large quantity, in sea water and the water of many lakes and springs.

Uses.—Chiefly used, both crude and refined, as a food for men and animals, and as a source of soda and other sodium compounds. Also largely used as a source of chlorine and hydrochloric acid, as a preservative of meat, skins, etc.; as a glazing material for pottery-ware; in the metallurgy of gold and silver, etc. The value of the mineral depends upon its purity and freedom from admixed sand and compounds of lime, magnesium, and iron.

Natronitrite, Chili Nitre.—Nitrate of sodium, NaNO_2 . Soda, 36 per cent.; nitrogen pentoxide, 64 per cent. Sometimes crystallised, usually massive. White or tinted, transparent. Very soft, somewhat sectile. G., 2.3. Occurs in desert regions in the soil and in beds of dry lakes.

Uses.—Chiefly used as a fertiliser and as a source of nitric acid, the percentage of nitrogen pentoxide governing its value for both purposes. Also used in the manufacture of nitre.

STRONTIUM.

Strontium is a somewhat rare metal, which has been known for about a century. It is a soft, yellowish-white metal, of the same weight as aluminium. It is malleable, melts readily, oxidises rapidly in the air, and decomposes water with violence.

Strontium occurs in small quantities in most limestones and other mineral substances containing calcium. Its only ores are the carbonate (strontianite) and the sulphate (celestite).

The metal finds no application in the arts. The hydrate is used in the extraction of sugar from molasses, the nitrate in pyrotechny as a constituent of all red fires, and various compounds in medicine.

Strontianite.—Carbonate of strontium, SrCO_3 . Strontia (strontium oxide), 63 to 70 per cent. Crystallised, fibrous, or granular. Pale green, white, yellow; transparent to translucent. Soft, brittle. G., 3.7. Occurs in veins in granite or limestone.

Uses.—A source of strontium salts.

Celestite.—Sulphate of strontium, SrSO_4 .—Strontia, 50 to 56 per cent. Crystallised, fibrous, globular, or granular. White, pale blue, pale red; transparent to opaque. Soft, brittle. G., 4.0. Occurs in veins, etc., in limestone and sandstone.

Use.—A source of strontium salts.

SULPHUR.

Sulphur is one of the commonest of the non-metallic elements, and has been known from time immemorial. In its ordinary form it is a bright yellow crystalline substance, which melts readily and burns with the production of pungent fumes.

Sulphur occurs to a considerable extent in the free state in all volcanic districts. Its commonest compound is pyrites, sulphide of iron; whilst sulphides of lead, copper, and other metals are of frequent occurrence. Sulphates of lime and other metals are also common, but do not constitute a source of sulphur.

The most important use of sulphur is in the manufacture of sulphuric acid, but it is also largely used for making gun and blasting powder, sulphurous acid, for vulcanising rubber, as an insecticide, for fumigating, and for the preparation of various sulphur compounds. By far the most important compound of sulphur is sulphuric acid, used in the manufacture of sodium carbonate (soda), hydrochloric, nitric, stearic, and other acids, alum, nitro-glycerine, superphosphate, etc. Sulphurous acid, metallic sulphides, and sulphates are used for a variety of purposes.

Sulphur (Native).—Pure sulphur mixed with various quantities of clay and other accidental impurities. Crystallised, massive, or earthy. Yellow, transparent to translucent. Very soft, brittle. *G.*, 2.0. Occurs in beds, veins, and irregular deposits, especially in the vicinity of volcanoes and hot springs, and of gypsum deposits.

Uses.—An important source of refined sulphur and sulphuric acid. Value depends upon its purity.

Pyrites.—Sulphide of iron, FeS_2 . Sulphur, 53 per cent. Metallic, massive, or crystalline. White or yellow, opaque. Hard, brittle. *G.*, 5.0.

Uses.—Largely used as a source of sulphur in sulphuric acid manufacture. For this purpose the ore should be free from arsenic, and should be dressed up to at least 30 per cent. of sulphur.

Marcasite.—Sulphide of iron, FeS_2 . Differs from pyrites only in crystalline form. Used for the same purpose as pyrites.

TANTALUM.

Tantalum is a rare metal, which has only been produced in a pure state and found useful application in the arts during the present century. It is a very heavy grey metal, with considerable ductility and strength, and not easily affected by the atmosphere or by chemical agents.

A very little metallic tantalum has been found native in one locality. The chief ores are compounds of the oxide with iron, manganese, and the rarer earth metals. In all cases oxide of niobium (a metal at present of no value) displaces to a greater or less extent an equivalent amount of oxide of tantalum in its ores.

The ores are usually found in or near granite masses in quartz or pegmatite veins, or in the alluvial deposits derived from them. Tin ore is a common associate.

Metallic tantalum has chiefly been used in the form of thin wire in the tantalum electric lamp. A small percentage added to steel is said to render it much harder and more resistant to corrosion. No compounds of tantalum have as yet been applied to any useful purpose.

The most important ores, which are sold on the basis of their contents in tantalum oxide, Ta_2O_5 , are:—

Tantalite (Ferrotantalite), tantalate of iron. Tantalum oxide, 45 to 85 per cent.

Tapiolite, tantalate of iron. Tantalum oxide, 45 to 85 per cent.

Manganotantalite, tantalate of manganese. Tantalum oxide, 45 to 85 per cent.

Fergusonite, tantalate of yttrium, etc. Tantalum oxide, 30 to 60 per cent.

These all occur in pegmatite veins or alluvial deposits derived from them, usually in association with tin ore. Ferrotantalite, tapiolite, and manganotantalite are hard, black, crystalline or massive minerals with high specific gravity. Fergusonite is brownish-black, hard, and possessing an unusual resinous lustre.

TIN.

Tin has been known for many centuries, the ancient Romans drawing supplies from Cornwall. It is a bright white metal, which does not tarnish in the air. It is ductile, and very malleable. Its specific gravity is 7.2, or the same as zinc. It melts below a red heat.

Occasional grains of metallic tin have been found in various parts of the world, but they are very rare. The chief ore is the dioxide, cassiterite, or tinstone. Small amounts of the metal have also been obtained from stannite, a sulphide of tin, copper, and iron.

The chief use for metallic tin is as a coating to sheet iron, the so-called tin-plate, by which the surface of the iron is prevented from rusting or from contaminating articles of food, etc., stored or cooked in them. Pure tin (block tin) is used also for various domestic and other appliances, such as still-worms, etc. Thin sheet tin, or tin-foil, is used in backing mirrors, wrapping up soaps, sweetmeats, etc. Large quantities of tin are used in making various alloys, the most important of which are the following: solder and pewter (tin and lead); britannia metal (tin, lead, copper, and bismuth); gun-metal, bell-metal, and bronze (tin and copper); triple bronzes (tin, copper, and zinc or lead), etc.

Several compounds of tin are used extensively in dyeing and calico-printing, viz., stannous chloride, stannic chloride, stannic ammonium chloride, and sodium stannate. The artificial dioxide (putty powder) is largely used for polishing metals, glass, stones, and gems, and as a constituent of enamel.

Cassiterite (Tinstone).—Oxide of tin, SnO_2 . Tin, 68 to 78 per cent. Crystallised, massive, or in rolled grains. Brown, black, red, or grey; translucent to opaque. Hard, brittle. *G.*, 7.0.

Occurs in veins or altered bands in granite, or in veins in sedimentary rocks close to their contact with granite; also largely in alluvial deposits derived from their denudation.

Uses.—The main source of tin and its compounds. The value of tin ores depend upon their richness in tin, and upon the nature and amount of associated minerals. For smelting, tin ores should be dressed up to at least 55 per cent. metal, as, otherwise, a large loss is experienced in smelting. Where the tinstone is accompanied by zircon, tantalite, ilmenite, or other minerals of the same or higher specific gravity, the ordinary methods of water concentration are unable to remove these impurities completely, and the concentrated ore is consequently low in grade and loses greatly in value. Such constituents are, therefore, a considerable drawback to the ore. The most valuable tin ores are those entirely free from all other metallic minerals.

TITANIUM.

This metal in small quantities is very widely distributed, being found in all igneous rocks and most sedimentary ones. It was first discovered at the end of the eighteenth century, and in its purest form is a dark grey powder, lighter than iron, which burns brightly on being heated in the air. It dissolves readily in dilute acids.

Titanium never occurs native. Its most common compound is ilmenite, the titanate of iron, which occurs as a constituent of many rocks, and is often found as "black sand" along rivers and seacoasts. The only other mineral which constitutes a source of titanium is the oxide, rutile.

Metallic titanium is not used in the arts, but alloys with iron, known as ferrotitanium, are at times added to cast iron and steel, with the effect of increasing their strength and hardness. Titanium oxide is used in porcelain painting, and enters into the composition of artificial teeth, and several titanium salts are used in dyeing.

Rutile.—Oxide of titanium, TiO_2 . Titanium oxide, 90 to 100 per cent.; titanium, 54 to 60 per cent. Crystallised or compact, massive. Brown, red, yellow, or black; transparent to opaque. Hard, brittle. *G.*, 4.2.

Uses.—A source of titanium alloys and compounds. When very pure, used for same purposes as artificial titanium oxide.

TUNGSTEN.

This metal was discovered in 1782. It is as heavy as gold, but of grey colour, and is practically unaffected by the atmosphere.

Metallic tungsten does not occur in nature, its chief ores being the tungstates of iron, manganese, and lime. These ores usually occur in quartz veins in granite, greenstone, or slate.

Pure tungsten is used as a filament in electric lamps, but the chief use of the metal is in hardening steel, for which purpose it is put on the market either as the impure metal or as ferrotungsten,

an alloy of iron and tungsten obtained by smelting wolfram. Tungsten-steel, containing from 2 to 12 per cent. of the metal, is largely employed for guns, armour plate, and machine tools, and to a less extent for rails.

The only compound of tungsten which is used in the arts is sodium tungstate, used as a mordant and for saturating inflammable materials to render them non-inflammable.

Wolfram or Wolframite.—Tungstate of iron and manganese, $(Fe,Mn)WO_4$. Tungsten, 60 per cent.; tungstic oxide, 76 per cent.; massive or crystallised. Somewhat hard, black or dark brown, opaque, brilliant lustre, well-marked cleavage. G., 7.4. When the mineral contains very little manganese it is known as **Ferberite**; when very little iron, as **Huebnerite**.

Uses.—Used solely as a source of tungsten, ferro-tungsten, and sodium tungstate. Its commercial value depends almost entirely upon the percentage of tungstic oxide present, but, other things being equal, an ore containing traces only of phosphorus and sulphur is worth more than one containing appreciable quantities of those substances. Ores containing wolfram are readily concentrated by hand or by machinery, and for export such concentrate should assay not less than 60 per cent. of tungstic oxide. Ore over 65 per cent. is worth considerably more per unit than ore under that grade. Any admixture of tin ore or bismuth lowers the value of the product.

Scheelite.—Tungstate of lime, $CaWO_4$. Tungsten, 64 per cent.; tungstic oxide, 80 per cent. Massive or crystallised. White or slightly tinted yellow, etc., brilliant lustre. Hard, brittle. G., 6.0.

Uses, etc.—See remarks under Wolfram.

URANIUM AND RADIUM.

These two rare metals occur together in nature in the same minerals, and will therefore conveniently be dealt with together.

Uranium compounds were known and recognised as early as 1789, but it was not till 1842 that the metal was isolated. It is white in colour, malleable, moderately hard and as heavy as gold. It tarnishes readily in the air. Both the metal and its compounds are radio-active, that is, give out energy spontaneously and continuously.

Radium, the newest and most wonderful of all the metallic elements, is best known in combination with other elements, the metal itself not having been prepared until 1910. It is a soft, white metal, rapidly attacked by air or water. The most interesting and valuable property of radium salts, and of the metal, is their extreme radio-activity, which is something like a million times as great as that of uranium.

The chief ores of uranium are uraninite (pitch-blende), an impure oxide of uranium; and carnotite, vanadate of uranium and potassium. These carry minute amounts of radium, varying from one-tenth-millionth to one-millionth part of the whole, to which they owe their chief value. These ores occur principally in quartz veins and as impregnations in sandstone, sometimes also in pegmatite veins.

Metallurgical uranium is only of scientific interest; a little of it added to steel in the form of uranium carbide is said, however, to improve it for many purposes. The acetate and nitrate are used for analytical work and in medicine and photography. Uranium compounds are also used in enamel painting and for staining glass.

The most important radium salts are the chloride and bromide, which are being largely experimented with for various purposes, principally therapeutic, particularly in the treatment of malignant growths.

Uraninite (Pitch-blende).—Oxide of uranium, lead thorium, etc. Uranium, 50 to 75 per cent.; radium, 15 to 25 centigrams per ton. Usually massive botryoidal, sometimes crystallised or granular. Grey, green, brown, or black, with lustre varying from sub-metallic to greasy or dull. Opaque, brittle, hard. G., 7 to 9.5.

Uses.—Used solely as a source of uranium and radium, its value depending on the proportion of these metals present. The

relative proportion of radium present may be roughly gauged by the radio-activity of the mineral.

Carnotite.—Hydrous vanadate of potassium and uranium. Uranium, 50 per cent.; vanadium, 11 per cent.; radium, 10 to 15 centigrams per ton. Occurs usually in sandstone in bright yellow disseminated grains and granular masses, the rocks being treated with nitric acid to obtain the valuable metals. The lowest grade of ore at present marketable is one containing 2 per cent. of uranium oxide.

Other far less important sources of uranium and radium are:

Torbernite (Copper Uranite).—Hydrous phosphate of uranium and copper. Uranium, 45 to 50 per cent.; radium, as in carnotite.

Autunite (Lime Uranite).—Hydrous phosphate of uranium and calcium. Uranium, 44 to 50 per cent.; radium, as in carnotite.

Pilbarite.—Hydrous silicate of uranium, thorium and lead. Uranium, 25 per cent.; radium, 5 to 7 centigrams per ton.

VANADIUM.

Until recently vanadium, which was discovered in 1801, was thought to be a very rare metal, and, in consequence, commanded a price altogether out of proportion to its usefulness in the arts. It is now known to be widely distributed over the globe in small quantities.

Vanadium is a very infusible metal which is but little affected by the air at ordinary temperatures, or by contact with many mineral acids. It is grey in colour, and has a specific gravity about one-half that of silver.

Vanadium occurs commonly in small proportions in most iron ores (especially titaniferous magnetites and laterite ores) and in traces in volcanic rocks, as well as in many coals, clays, sandstones, and limestones. In spite of this wide distribution of the metal in traces, workable ores of it are very rare. The most important of these are carnotite, a vanadate of uranium and potash; patronite, a sulphide of vanadium; roscoelite, a silicate of potash aluminium and vanadium; and vanadinite, a vanadate and chloride of lead.

The pure metal is not used for any but experimental purposes. An alloy of vanadium and iron, ferro-vanadium, is added to steel to improve its qualities for many purposes. Steel thus prepared is eminently suited for armour plate, projectiles and machine tools, since not only is it extremely tough and hard but it does not lose this hardness by being heated to a bright red heat and slowly cooled. Vanadic acid is largely used for the production of indelible black dyes and inks. Various pigments used in colouring porcelain and glass also contain vanadic acid.

Carnotite.—See above under "Uranium."

Uses.—One of the chief sources of vanadium and uranium and their salts.

Roscoelite.—Silicate of potassium, vanadium, and aluminium. Vanadium, 15 per cent.; vanadium pentoxide, 28 per cent. In mica-like scales, brown or green. Translucent, soft. G., 2.9.

Uses.—Used as a source of vanadium compounds.

Vanadinite.—Vanadate and chloride of lead. Vanadium, 4 to 11 per cent.; vanadium pentoxide, 8 to 20 per cent. In red or yellow crystals or incrustations. Brittle, soft, opaque. G., 6.8.

Uses.—Used as a source of vanadium compounds, and of metallic lead.

Patronite.—Sulphide of vanadium. Vanadium, about 20 per cent. Occurs in veins in porphyry.

Uses.—A most important source of vanadium compounds.

ZINC.

Zinc, or spelter, is a common metal which has been known to civilised man for several centuries. It is a bluish-white crystalline metal, brittle at ordinary temperature, but malleable and ductile at a little above the temperature of boiling water. It takes a good polish and is unaffected by perfectly dry air, but is rapidly coated in moist air with a greyish-white tarnish, which protects the metal from further corrosion. It is readily soluble in dilute acids, and has a specific gravity of 7.1.

Native zinc has been reported to occur in very small quantities, but its occurrence needs confirmation. The sulphide, blende, is a common constituent of veins, whilst the oxide (zinkite), the carbonates (smithsonite and hydrozinkite), and the silicates (willemite and hemimorphite) are less common ores.

Metallic zinc is chiefly used for making brass and for building purposes, either in sheets or as a surface coating upon iron, which is then said to be galvanised. Sheet zinc is also used for various internal ornamental work, lining packing cases, making water tanks and pipes, etc. In plates it is used to prevent corrosion of boilers, also in galvanic batteries, in photo-engraving, etc. Fine shavings of zinc are used to precipitate gold from cyanide solutions; whilst zinc powder is used as a reducing agent in manufacturing organic compounds, as a paint, and in the preparation of zinc salts. Spelter is used also for desilverising lead, and for making alloys, of which the most important are brass and bronze, in the preparation of which large quantities of zinc are consumed.

Oxide of zinc (zinc white), obtained from the metal or direct from the ore, is a very valuable pigment which has largely replaced white lead. It is also used as a constituent of many rubber goods. Zinc chloride is used as a disinfectant, and preservative of wood, in refining oils, and in making stearic acid, ether, and parchment paper. Zinc sulphate is used in dyeing, in the manufacture of glue, and the pigment known as lithopone, and as a dryer in oil paints and varnishes. Zinc chromate is used as a pigment. Several zinc salts are used in medicine.

Blende (Sphalerite).—Sulphide of zinc, ZnS . Zinc, 57 to 67 per cent. Crystallised or massive cleavable, granular to compact. Yellow, brown, black; transparent to opaque. Soft, brittle. G., 4.0. Occurs in veins in crystalline and other rocks, also in irregular masses and veins in limestone.

Uses.—The commonest source of zinc and its compounds. Value of this and other zinc ores depends upon percentage of zinc present, and on freedom from lead ores. Ores or concentrates containing over 2 per cent. of lead need special plant for their treatment.

Smithsonite.—Carbonate of zinc, $ZnCO_3$. Zinc, 42 to 52 per cent. Crystallised or massive granular or earthy, also stalactitic. White or tinted, translucent. Hard, brittle. G., 4.4. Occurs usually in veins and irregular masses in limestones.

Uses.—See Blende.

Hemimorphite.—Hydrous silicate of zinc. Zinc, 50 to 54 per cent. Crystallised, stalactitic, fibrous, massive, granular. White or tinted, transparent to translucent. Hard, brittle. G., 3.5.

Uses.—See Blende.

Other ores of rarer occurrence and less general importance are:—

Zinkite.—Oxide of zinc, ZnO . Zinc, 74 to 80 per cent.

Hydrozinkite.—Hydrous carbonate of zinc. Zinc, 55 to 60 per cent.

Willemite.—Silicate of zinc, Zn_2SiO_4 . Zinc, 48 to 58 per cent.

ZIRCONIUM.

This rare element was discovered at the close of the eighteenth century. It is a crystalline metal resembling antimony in appearance and oxidising but slowly in the air. It is soluble in warm acids and has a specific gravity of 4.1.

Zirconium does not occur free in nature; its commonest compounds are the oxide (baddeleyite) and the silicate (zircon), which occur in small quantities in granite and other crystalline rocks, and in the sands resulting from their denudation, from which they are obtained in commercial quantities by concentration. Zirconium also occurs in several rare silicates, tantalates, etc.

The metal is not applied to any useful purpose, but the oxide (zirconia) is employed in the glowers of Nernst and other lamps, having the property of yielding an intense light at comparatively low temperatures. It enters into the composition of certain glasses and glass substitutes, is used in Röntgen-therapy, and as refractory material for lining electric furnaces, etc.

Zircon.—Silicate of zirconium, $ZrSiO_4$. Zirconia, 61 to 67 per cent. Usually crystallised, also in rolled grains. Colourless or tinted, transparent to opaque. Very hard, brittle. G., 4.7.

Uses.—Used as a source of zirconia. Some varieties used as a gem (see page 21).

Baddeleyite.—Oxide of zirconium, ZrO_2 . Zirconia, 80 to 95 per cent. Usually found in pebbles in streams. Yellow, brown, or black, translucent to opaque. Hard, brittle. G., 5.7.

Uses.—An important source of zirconia. Also used as a high-class refractory for steel furnaces, etc.

SILICA AND SILICATES.

Silica, the oxide of the non-metallic element silicon, is widely and abundantly distributed in the form of quartz (free silica) and various silicates of the metals. It is a colourless, transparent, crystallised substance, which is very hard and infusible and resists the action of most acids.

By far the most important artificial substance containing silica is glass, which is a silicate of sodium and calcium or other metallic base. Hydraulic cement is a silicate and aluminate of calcium. Carborundum, a valuable abrasive, is a carbide of silicon.

Quartz.—Silica, SiO_2 , with more or less admixed oxide of iron, etc. Crystallised or massive, compact or granular. Colourless, white, or tinted; transparent to opaque. Hard, brittle to tough. G., 2.6.

Uses.—Largely used as a refractory material and in the manufacture of glass and porcelain. For these purposes and for making carborundum it should be very pure, and especially free from iron compounds. For glass making the maximum amount of iron oxide permissible in sand is for lead flint, 0.02 per cent.; for mirror plate, 0.10 per cent.; for ordinary plate, 0.20 per cent.; for window glass, 0.50 per cent. For this purpose the size of grain is also important, at least 70 per cent. should be of one grade, preferably between 0.25 and 0.50 millimetre. Less pure varieties are used as an abrasive, for making mortar, for filters, and for a multitude of other purposes. Perfectly transparent, flawless crystals or masses are used for making lenses and ornaments, and are of considerable value.

Diatomaceous Earth (Infusorial Earth).—Hydrous silica with more or less admixed organic matter, clay, etc. Consists of the accumulated remains of minute water plants. Massive, tough, or earthy and friable. White, grey, or black; opaque. Very soft and porous. G., 1.2; in bulk and dry, 0.2 up to 0.8. Occurs in surface or buried beds. Often occurs in beds of lakes and swamps.

Uses.—When calcined so as to remove all organic matter and moisture, is used for a great variety of purposes. It is employed as an abrasive, especially as a constituent of polishing powders and soaps, for which purpose it should be as free as possible from admixed sand or grit. Owing to its great porosity it is used as an absorbent, especially for nitro-glycerine, forming dynamite; for disinfectants, etc. Its utility for these purposes depends upon its absorbent capacity, and in the case of dynamite upon the presence of many closed spaces in the individual diatom skeletons, and its practical freedom from alumina or lime. Its porosity, lightness, infusibility, and low conductivity for heat, make it a valuable heat insulator for refrigerating chambers and wagons, for safes, boiler and steam-pipe coverings, "refrigerating" paints; and as a constituent of fire-resisting cements and bricks. The purest varieties are used also for making soluble glass and other glasses; and as an adulterant of rubber. For most purposes diatomaceous earth should be as free as possible from alumina, lime, iron oxide, and alkalis; and should be highly porous and absorbent.

Asbestos.—This is a name applied both in commerce and science to several silicates characterised by a finely fibrous structure. The chief varieties are Chrysotile and Pierolite, which are fibrous varieties of Serpentine; fibrous Actinolite and Tremolite, which are very closely related; fibrous Anthophyllite; fibrous Riebeckite (Crocidolite); and fibrous Talc.

Chrysotile.—Hydrous silicate of magnesium with a little iron. Sometimes known as *Amianthus*, especially when the fibres are unusually long. Occurs in veins in serpentine rock. The mineral in the veins is in compact masses which possess a fibrous structure running across the vein. It is easily separated by hand into very fine fibres of uniform diameter, very flexible, tough and silky. The length of the fibres may be the full width of the vein, but more usually are interrupted by a break near the centre of the vein. The colour in mass is oil-green or olive-yellow to almost white. Soft. G., 2.4.

Uses.—This forms the great bulk of the world's commercial asbestos, the demand for it being based on the toughness, flexibility evenness and length of the fibres, their great resistance to heat and poor conductivity when teased out into a woolly mass. Chrysotile is made into fire-proof ropes, cloths and felts. It is used for piston packing, for covering steam pipes and boilers, for lining safes, as a toughening constituent of cement sheets for walls and roofs, and for many other purposes.

Picrotite.—A name originally applied to a fibrous actinolite found in Sweden, but at the Canadian asbestos mines applied to any variety of asbestos so deficient in strength or flexibility as to be valueless.

Actinolite and Tremolite.—Silicates of calcium, magnesium and iron. In tremolite the total iron oxides amount to less than 4 per cent.; in actinolite they vary from 4 to 12 per cent. The fibrous varieties are of two distinct types. In one the fibres are very soft and brittle and are readily separated from one another. In the other the fibres are very hard and splintery and only separated with some difficulty into coarse uneven bundles. Both are light green or greenish-yellow to white in colour, and have a density of 3.0.

Uses.—The hard splintery variety is valueless. The soft, easily disintegrated kind, which is common in the State, can be used for boiler and steam pipe lagging, and recently has been used as a filler for rubber that is to stand hard wear.

Anthophyllite.—Silicate of magnesium and iron. Usually in hard splintery fibres like the corresponding type of actinolite. This is valueless. Rarely in fine tough flexible fibres like chrysotile; white or yellow in colour, and of almost equal value to chrysotile. G., 3.0.

Riebeckite.—Silicate of iron and sodium. The fibrous variety is known as *Crocidolite*, and is easily recognised by its dark grey-blue colour. Like chrysotile, it occurs in veins, and is readily separated into fine, soft, flexible fibres with a tensile strength exceeding that of chrysotile. G., 3.2.

Uses.—Owing to its comparatively low melting point (under 1,000 deg. C.), this mineral cannot be used for fire-resisting cloth, felt, etc. It is, however, well suited for insulating steam pipes and for reinforcing cement.

Talc.—Hydrous silicate of magnesium. In very brittle and soft fibres, either short or long. G., 2.7. When pure white this is of value to paper makers as a filler.

The market value of asbestos depends primarily upon the tensile strength of the fibres, their flexibility, fineness, and infusibility, and the ease with which they can be separated from one another. Of minor importance is their length, any fibre over one-eighth inch long being saleable and fibre over one inch being considered long.

Mica.—Like asbestos, this name is applied both commercially and scientifically to several distinct silicate minerals, all of which are characterised by a very perfect cleavage which enables them to be split into thin elastic plates. The most important species are *Muscovite* and *Phlogopite*.

Muscovite.—Common or white mica. Silicate of aluminium, potassium, and hydrogen. Crystallised or foliated massive. Colourless or tinted; transparent. Soft. G., 2.8. Laminæ flexible, elastic, tough, and very infusible. Occurs in pockets in pegmatite veins.

Uses.—This is the most useful variety of mica. In sheets at least two inches square, is used for windows of stoves, furnaces, and vehicles, for funnels for lamps and gaslights, for sky-lights, and compass-covers. Large quantities of sheet mica are used for electrical insulations. The scrap mica left after trimming the mineral into sheets is used for a variety of purposes. It is cemented into sheets and used for electrical insulation, under the name of "micanite." When ground, it is used as a lubricant, as a constituent of some brands of dynamite, of various piston packings, fire-resisting paints, and insulating compounds, and mixed with plaster of paris for moulds for castings. It is also used to a certain extent in decorative work, both in sheets and powder.

Phlogopite.—Amber mica. Fluo-silicate of aluminium, magnesium, and potassium. Crystallised or foliated massive. Usually amber, sometimes colourless or tinted variously; transparent to translucent. Soft. G., 2.8. Laminæ flexible, elastic, tough, and infusible. Occurs in veins or pockets in serpentine, crystalline limestone, or dolomite.

Uses.—See *Muscovite*.

Mica is marketed in two forms, viz., "sheet," consisting of thin rectangular blocks of certain standard sizes, varying from 2 inches by 1½ inches up to 8 inches by 10 inches or more; and "scrap," the small pieces left after punching out the sheets from the crude mineral. The latter is of very little value, something like 1d. a pound. The value of sheet mica depends upon the size of the sheet (varying from 3s. per lb. to £2 10s. per lb.), the ease with which it can be split up, its softness, flexibility, and freedom from wrinkles and blemishes. When used as a substitute for glass its transparency and colour are important points. For electrical purposes its resistance to heat and electricity are of importance.

Talc (Steatite, Soapstone).—Hydrous silicate of magnesium. Rarely in tabular crystals, usually massive, foliated, granular, compact, or fibrous. White or green; translucent. Very soft, sectile. G., 2.7. Occurs as rock masses and in veins and beds.

Uses.—When powdered, is largely used as a filling for paper; for this purpose the fibrous form is the best. Also for fire-proof paints, electric insulators, steam-pipe and boiler coverings, foundry facings, toilet powders, lubricants, and as a base for dynamite and cheap soap. Compact talc is cut into pencils, fire-bricks, hearth-stones, etc.

Felspar.—This name is applied to a group of minerals closely related to one another in occurrence, properties, and composition; being silicates of aluminium with potassium, sodium, or calcium. The chief varieties from a commercial point of view are orthoclase, microcline, and albite, the two first-named being identical in every-thing but optical properties.

Orthoclase and Microcline.—Silicate of aluminium and potassium. Crystallised with a perfect cleavage or massive. Colourless, white, or tinted; transparent to opaque. Hard, brittle. Occur in workable deposits chiefly in pegmatite veins.

Uses.—Chiefly used as a constituent of china, porcelain, tiles, and certain varieties of glass. Also used as an abrasive especially in polishing-soaps. Has been proposed to utilise it as a source of potash salts.

Albite.—Silicate of aluminium and sodium. Crystallised with perfect cleavage, massive, granular or lamellar. White or tinted; transparent to opaque. Hard; brittle. Occurs in workable deposits chiefly in pegmatite veins.

Uses.—See *Orthoclase*.

Other varieties of felspar could be utilised for a similar purpose were workable deposits of them available. For market the ore must be carefully hand-picked to remove all associated minerals, especially those containing iron. Felspar containing more than a trace of iron is not suited for making porcelain or glass. A small unavoidable admixture of clean, colourless quartz is no great drawback to the mineral.

Clay.—This is not a simple mineral in the scientific sense, but essentially a mixture of two minerals—one crystalline, usually quartz; the other colloidal, usually halloysite (hydrated silicate of aluminium), or some related mineral. The quartz may be replaced more or less completely by feldspar, mica, and kaolinite; whilst other colloids, such as ferric hydrate, are often associated with the halloysite. The result of this association of crystalline granules with a colloid, which becomes slimy on wetting, is the development of the essential property of plasticity upon which the economic value of clays mainly depends.

Clays vary largely in the relative proportions of their constituents, in colour, plasticity, and behaviour under heat, and according to the variations in these properties are found suitable for varying purposes. An actual manufacturing test is the most satisfactory, and, in some cases, the only way of determining their utility. At the present time, clays are not as a rule, except in making common brick, used singly for manufacturing purposes, mixtures of two or more clays being usually more satisfactory.

There is no universally accepted classification of clays, but for present purposes they may conveniently be considered under the headings of china clay, ball clay, fire clay, stoneware clay, and brick clay.

China Clay.—This is essentially a pure white clay, composed mainly of kaolinite and halloysite, with small quantities of finely divided quartz and mica, its components are thus almost solely alumina, silica, and water. It must be sufficiently free from iron compounds to remain white after burning. It is usually somewhat deficient in plasticity, but is highly infusible, and moderate in shrinkage.

China clay is used in the manufacture of porcelain and white china ware, also to a less extent as a filling for paper and as an adulterant of white pigments. Workable deposits are usually in the form of irregular surface masses resulting from the decomposition *in situ* of a granitic rock, or in sedimentary beds.

Ball Clay.—A fine-grained sedimentary clay characterised by a very high plasticity, accompanied by great shrinkage both in drying and burning. Such a clay must be added to china clay to raise its plasticity in making fine pottery of all kinds. It should contain so little iron as to burn pure white or almost so, and the greater its plasticity the higher will be its value.

Fire Clay.—The clays used for making refractory bricks, etc., are not as pure as china clay, but should not contain more than 4 per cent. of impurities other than quartz and organic matter. The best clays for this purpose are found in the coal measures immediately below the seams of coal, though they are also found under similar conditions to china clay. The best fire clays will stand intense heat (from 1500° to 1800° C.) without fusion or great shrinkage, will resist to a large extent the corroding action of fused mineral substances, and are not affected by sudden and great changes of temperature.

The finest grades of fire clay are employed in the manufacture of gas retorts, crucibles for melting glass, etc., but by far the largest proportion of the total production is converted into fire bricks and fire lumps. The refractoriness of a fire clay depends almost entirely upon its chemical composition, more than 5 per cent. of fluxes (oxides of iron, etc.) reducing the melting point considerably. The more plastic a fire clay, the denser and stronger will be the resultant fire brick, but the greater will be the shrinkage and warping on burning.

Stoneware Clay.—Clays which, without admixture of other clays, yield good stoneware are rare. They should be very plastic and give, on burning at 1200° to 1300°C., a tough, well vitrified body without extensive shrinking or cracking. This implies the presence of certain quantities, within very narrow limits, of the fluxing oxides of iron, alkalis, and lime. Most stoneware is now made from a mixture of good fire clay with a high-quality red brick clay of low fusion point.

Stoneware clays occur either as sedimentary beds or as a decomposition product of rocks *in situ*.

Brick Clay.—This is the commonest and least pure of all useful clays. Any ordinary clay or clay-shale can be made into house bricks, but the best are made from clays containing not less than 60 per cent. of "clay substance," only a very small proportion of coarse sand, and free from pyrites and from concretions of iron oxide or carbonate of lime.

Red clays of fine even grain, which burn at a comparatively low temperature to a pleasing salmon tint, with a body which is tough and not very porous, are used to produce roofing tile and terra cotta ware.

GEMS AND ORNAMENTAL STONES.

Gems, which include the most valuable of all minerals, may be defined as those varieties of mineral species which possess such striking and permanent beauty as to make them desirable articles of personal adornment. The value of gems depends upon their freedom from flaws or blemishes, the shade of colour they possess, and the permanency of that colour when exposed for long periods to light and air; their brilliancy and degree of transparency (except in the case of perfectly opaque gems such as turquoise); their hardness; and finally their rarity. The following is the approximate order of value of precious stones:—Pearl, Ruby, Diamond, Emerald, Sapphire, Oriental Cat's Eye, Opal, Turquoise, Alexandrite.* Other ornamental stones, such as Tourmaline and Jade, are classified as "semi-precious," owing to their inferior rarity and value. In the following pages the order followed under the headings of "Precious Stones" and "Semi-precious Stones" has been determined by the chemical and mineral nature of the gems. In each case the general description given is that of the most valued type.

PRECIOUS STONES.

Diamond.—Pure carbon, C. Crystallised in octahedra and other forms of the isometric system; also in water-worn pebbles. Transparent. Most valuable are colourless, red, or blue; of less value those that are yellow, green, or brown. Hardness, 10; G., 3.5. Occurs in basic igneous rocks and in alluvial deposits.

Ruby.—Variety of Corundum. Oxide of aluminium, Al_2O_3 . Crystallised in hexagonal pyramids, more or less modified; also in water-worn pebbles. Transparent, anisotropic, pigeon-blood red; less valued gems are of other shades of red. H., 9; G., 4.0. Occurs in crystalline limestone and in alluvial deposits.

Sapphire.—Variety of Corundum. Oxide of aluminium Al_2O_3 . Form and other characters, except colour, as for Ruby. Colour, corn-flower blue; other shades of blue are less admired. Occurs in crystalline limestone, basic igneous rocks, and mica-schist; also in alluvial deposits.

Emerald.—Variety of Beryl. Silicate of beryllium and aluminium, $3BeO \cdot Al_2O_3 \cdot 6SiO_2$. Crystallised in hexagonal prisms. Transparent; rich green in colour. H., 7.5. G., 2.7. The chief source of the emerald is Colombia, where it occurs in pockets in a limestone. Elsewhere it is found in mica-schist, talc-schist, pegmatite, and topaz rock.

Oriental Cat's-eye.—Variety of Chrysoberyl. Oxide of beryllium and aluminium, $BeO \cdot Al_2O_3$. Crystallised in complex forms of the orthorhombic system; more usually in water-worn pebbles. Translucent; colour from pale yellow to dark brown, and pale green to deep olive. Chatoyant; characterised by a movable internal opalescent band of white or rarely yellow light. H., 8.5. G., 3.8.

Alexandrite.—Variety of Chrysoberyl. Oxide of beryllium and aluminium, $BeO \cdot Al_2O_3$. Crystallised usually in twins of the orthorhombic system; also in rolled pebbles. Transparent. Colour, emerald green, changing in artificial light to raspberry red. Very rarely chatoyant. H., 8.5. G., 3.7. Occurs in mica-schist and in river gravels.

*E. W. Streeter, Precious Stones and Gems.

Opal.—Precious opal is a variety of common Opal. Hydrated silica, $5\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. No crystalline form; occurs massive, filling small veins and hollows in the parent rock. Translucent. Colour, milky white, exhibiting a magnificent play of prismatic colours on turning through a small angle. Rich red tints are most highly prized. Some opals lose their colour after exposure for some little time, and are therefore of very little value. H., 5.5 to 6. G., 2.1. Opals occur as the filling of small veins in sandstone and trachyte and steam holes in the latter.

Turquoise.—Hydrated phosphate of aluminium, copper, and iron, $\text{CuO} \cdot 3\text{Al}_2\text{O}_3 \cdot 2\text{P}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$. Triclinic, but usually in microcrystalline veins or nodules. Opaque. Colour, sky-blue, greenish-blue, or green, the first-named being the most valued. Many turquoises fade so easily as to be practically valueless. H., 6. G., 2.7. It occurs in veins and nodules in porphyry, trachyte, slate, and sandstone.

Spinel.—Oxide of aluminium and magnesium. Crystallised in octahedra and other forms of the isometric system. Gem variety is transparent, and deep red to rose red in colour. H., 8; G., 3.6. Isotropic. Occurs in crystalline limestone and other rocks, and in stream beds. Largely substituted for true ruby in commerce.

SEMI-PRECIOUS STONES.

Zircon or Hyacinth.—Silicate of zirconium, $\text{ZrO}_2 \cdot \text{SiO}_2$. Crystallised in combinations of pyramid and prism of the tetragonal system, also in water-worn pebbles. Transparent; crimson, yellowish-red, amber yellow. H., 7.5. G., 4.4 to 4.8. It occurs in river gravels or *in situ* in syenite, granite, and other crystalline rocks.

Peridot (Precious Olivine).—A variety of Chrysolite. Silicate of iron and magnesium, $2(\text{Mg}, \text{Fe})\text{O} \cdot \text{SiO}_2$. Occasionally crystallised in combination of orthorhombic prism and pyramid; usually in water-worn pebbles. Transparent; yellowish-green in colour, the deeper the tint the more valuable the stone. H., 6.5. G., 3.4. Occurs chiefly in river gravels.

Tourmaline.—Transparent variety of ordinary tourmaline. Composition very complex; a silicate of aluminium, boron, iron, etc. Crystallised in combinations of prism and pyramid of hexagonal system; also in water-worn pebbles. Transparent; colour red, pink (*Rubellite*), green of various shades, blue (*Indicolite*), yellow. H., 7.5. G., 3.1. Occurs chiefly in pegmatites carrying lithia mica; also in river gravels.

Topaz.—Precious variety of ordinary Topaz. Fluosilicate of aluminium, $\text{Al}_2\text{O}_3(\text{OH}, \text{F})_2 \cdot \text{SiO}_2$. Crystallised in combinations of orthorhombic prism and pyramid, with perfect basal cleavage; also in water-worn pebbles. Transparent, usually wine-yellow, but also light and dark red, pale blue, pale violet, or colourless. H., 8. G., 3.5. Occurs usually in gneiss, granite, or pegmatite, and in river gravels.

Aquamarine and Beryl are transparent varieties of common Beryl, the former of a pale green or pale blue colour, the latter yellow or pink. Except in colour they are identical with Emerald, *q.v.*

Garnet.—Gem varieties of several mineral species belonging to the Garnet Group. Three species are used as gems:—*Almandine* (*Carbuncle*), silicate of aluminium and ferrous iron, $\text{Al}_2\text{O}_3 \cdot 3\text{FeO} \cdot 3\text{SiO}_2$. Claret-coloured and most valuable of garnets. Pyrope, silicate of aluminium, magnesium and iron; $\text{Al}_2\text{O}_3(\text{Mg}, \text{Fe})\text{O} \cdot 3\text{SiO}_2$. Blood red. *Essexite* (sometimes called *Hyacinth*). Silicate of aluminium and calcium. $\text{Al}_2\text{O}_3 \cdot 3\text{CaO} \cdot 3\text{SiO}_2$. Yellow, orange, or brown.

Garnets are found crystallised in forms of the isometric system, the commonest form being the dodecahedron; also in water-worn pebbles. Transparent or semi-transparent; colours as above.

H., 7 to 8. G., 3.5 to 4.1. Occur usually in granite, gneiss, mica schist, or chlorite schist, or in river gravels. Very widely distributed.

Spodumene.—Transparent variety of ordinary spodumene. Silicate of aluminium and lithium $\text{Al}_2\text{O}_3 \cdot \text{Li}_2\text{O} \cdot 4\text{SiO}_2$. Crystallised in combinations of prism and pyramid of monoclinic system, with strong prismatic cleavage. Transparent. Colour greenish yellow, rich green (*Hiddenite*), amethyst (*Kunzite*). H., 7. G., 3.1. Occurs usually in granite, pegmatite, or gneiss.

Jade (Greenstone).—Partly a variety of Jadeite, which is a silicate of aluminium, sodium, and calcium, $\text{Al}_2\text{O}_3(\text{Na}, \text{Ca})\text{O} \cdot 4\text{SiO}_2$. Partly a variety of Actinolite, a silicate of calcium, magnesium, and iron, $\text{CaO} \cdot 3(\text{Mg}, \text{Fe})\text{O} \cdot 4\text{SiO}_2$. Occurs massive with internal crystalline structure. Translucent; dark or light green, yellowish green. H., 6 to 7. G., 3.0 to 3.3. Occurs usually in rounded masses in river beds, or in weathered serpentine rock masses.

Crocidolite.—A mixture of anhydrous and hydrous silica with more or less silicate of iron, resulting from the partial or complete alteration of true Crocidolite, which is a silicate of iron and sodium, or of Asbestos. Compact massive with greater or less fibrous structure. Translucent to opaque, chatoyant. Colours, indigo with light blue ray (*Hawk's Eye*); brown with yellow ray (*Tiger's Eye*); yellow with pale yellow ray; pale green with white ray. H., 6 to 7. G., 2.7 to 3.1. Occurs in veins in basic igneous rocks.

Chalcedony.—Massive crypto-crystalline variety of quartz, SiO_2 . Appearance subject to wide variation from the presence of small proportions of impurities. The chief ornamental varieties are: *Carnelian*, translucent of various shades of red, often striated. *Agate*, translucent and variegated, various shades of yellow, red, brown, purple etc. *Onyx*, translucent, in plain parallel bands of white and black, or brown. *Heliotrope* or *Bloodstone*, translucent, green, with blood red spots. *Jasper*, opaque, in bands of bright red, yellow, brown, white, and black. The hardness of the various varieties of chalcedony is 7, specific gravity 2.6. Chalcedony occurs in nodules in ancient lavas, in veins in various rocks, and in pebbles in streams, etc.

Moonstone.—Variety of Orthoclase, Silicate of aluminium and potassium, $\text{Al}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot 6\text{SiO}_2$. Crystallised in monoclinic prisms; usually in water-worn pebbles. Semi-transparent, opalescent. Colourless or faintly blue. H., 6. G., 2.6. Usually found in pebbles in streams in granite country.

MINERAL WATERS.

Mineral waters may be described as those natural spring waters which contain in solution either constituents rarely found in surface waters, or else exceptionally large proportions of mineral matter of any kind. They are of value either for medicinal purposes or else, owing to their pleasing taste, for table use.

Medicinal waters are chiefly characterised by the presence of magnesium salts, iron salts (Chalybeate waters), lithium salts, sulphides, or sulphates of soda and potash. Of these probably those containing lithium or iron would be found the most valuable commercially. Magnesian waters are common everywhere, especially in the interior of Western Australia. They are unmarketable except when they bear the name of some well known European spring such as Friedrichshall, Kissingen, etc.

Table waters of good quality are in considerable demand. They should be sparkling and of good flavour and should therefore contain free carbonic acid and alkaline carbonates, with comparatively little salt, magnesium compounds or alkaline sulphates. It is essential that they be quite free from sulphuretted hydrogen or sulphides, whilst the presence of some lithium is a decided advantage. The following tables give the composition of some of the Australian

mineral waters at present utilised, and will serve to show what composition is desirable in a water for the Australian market:—

TABLE WATERS.

Source.	Helidon Spa, Helidon, Q.	Zetse Spa, Ballimore, N.S.W.	Koomah Spa, Cooma, N.S.W.	Blackwood, Vic.
Sodium chloride	·0428	·0988	·072	·1293
Magnesium chloride .. ..	..	..	..	·0154
Calcium chloride .. ..	..	..	..	trace
Potassium sulphate .. ..	..	..	..	trace
Sodium sulphate .. ..	..	..	..	·0221
Potassium bicarbonate .. ..	..	·1833	·245	..
Sodium bicarbonate	4·7883	2·6157	·647	1·0977
Lithium bicarbonate	·0704	·0007	Nil	..
Magnesium bicarbonate	·0837	·1337	·320	·0209
Strontium bicarbonate .. ..	..	trace	str. tr.	..
Calcium bicarbonate	·1701	·1625	·774	·4213
Iron bicarbonate .. ..	..	·0100	Nil	trace
Silica	·0041	·0040	·008	..
Alumina .. ..	..	..	trace	..
Free carbonic acid	abundant	abundant	abundant	abundant
Total, Solids	5·1594	3·2087	2·066	1·7067

MEDICINAL WATERS.

Source.	Mittagong, N.S.W.	Clifton, No. 1, Vic.	Clifton, No. 6, Vic.	Hepburn, Vic.
Potassium chloride	·0291	..	..	..
Sodium chloride	·0308	5·5407	4·2634	·0147
Magnesium chloride	·0185	·6494	·8947	..
Calcium chloride .. ..	..	trace	trace	·0196
Potassium sulphate .. ..	..	..	..	·1580
Magnesium sulphate .. ..	..	1·0336	·2824	·0594
Sodium bicarbonate .. ..	..	·0420	·0414	·0594
Magnesium bicarbonate	·0320	·2927	·6257	·3067
Calcium bicarbonate	·0291	1·0133	·6056	·6633
Iron bicarbonate	·0855	·0820	trace	·0090
Silica .. ..	..	·0250	·0823	·0247
Free carbonic acid	present	present	present	abundant
Total, Solids	0·2250	8·6767	6·7955	2·2454

All results expressed in parts per thousand.

III.—PREPARATION OF MINERALS FOR THE MARKET.

The primary object of all preparation or dressing of minerals at the point of production is the elimination of worthless material and the concentration of the valuable portion of the deposit in the smallest possible bulk. Mineral deposits in Australia are apt to be far from railroads and invariably many hundreds, or even thousands of miles away from the points of final smelting or manufacture. Under such circumstances to pay freight, handling, insurance, wharfage, etc., on any large quantity of valueless material is to court financial disaster, hence the general necessity of some form of dressing or concentration at the mine.

In many instances similar methods of preparation are adopted for all minerals of one class, particularly for all metallic ores. In some rare instances, such as mica for example, special methods of treatment are essential. An outline will first be given of general methods, and then of such special methods as are already in use

or likely to be adopted in this State. For complete details reference must be made to such works as

The Mineral Industry,
R. H. Richards, Ore Dressing,
G. W. Lock, Mining and Ore Dressing Machinery,
G. P. Merrill, The Non-metallic Minerals,
D. C. Davies, Earthy Minerals and Mining,
H. Louis, The Dressing of Minerals.

and various monographs on individual minerals.

HANDPICKING.—This is the simplest and most universal of all methods of preparation. It is practised on such widely different materials as gold ores, copper ores and other metallic ores, as well as coal, mica, felspar and other non-metallic minerals.

In its most primitive form, handpicking is practised at the working face by the men actually breaking out ore, or removing it to the surface, being merely an almost automatic rejection of the most obviously worthless fragments of wall rock or gangue. Such treatment is universal in application and means an economy in handling from the very outset, besides yielding, at the point where it is wanted, material suitable for slope filling.

This process is frequently supplemented at the surface by more careful handpicking after hand breaking (cobbing) or machine breaking of the larger fragments which contain both valuable and valueless minerals. Where an ore is subjected to immediate local metallurgical treatment, as for example, when a gold ore is to be put through a near-by battery, or a copper ore is to be smelted on the spot, there is no saving of freight to be considered and this second more careful hand dressing is either done away with altogether or gives place to a machine concentration which is essentially part of the metallurgical treatment. In many places in America and in some parts of Australia gold ores are however carefully hand picked at the surface, only the more valuable portions, which will stand high freights, etc., being despatched to distant smelters or other works. In the case of most small mines of the base metals, not in a condition to justify the erection of machine concentrators, such careful hand-picking is not only justified but absolutely essential, before despatching the richer material to distant crushing plants. Similar treatment is usually the only necessary preparation before selling to central machine dressing plants such non-metallic minerals as felspar, asbestos, etc. In the case of gemstones careful hand-picking is *par excellence* the method of treatment at the point of production.

GRAVITY CONCENTRATION BY HAND.—The most important methods of concentration by machinery depend upon the difference in specific gravity between the valuable and valueless portions of a mineral deposit. The same principle is applied by hand in some cases and there are gradations between purely hand treatment and purely mechanical treatment on these lines.

In the preparation of alluvial ores of gold, tin, and some other metals, and precious stones, hand concentration with water is a world-wide method of removing all or almost all of the valueless associates preparatory to the marketing of the relatively small quantity of valuable mineral. Sluicing of such materials with water, dry-blowing, and hand jigging may be looked upon as transition methods applied to the same materials.

GRAVITY CONCENTRATION BY MACHINERY.—In dealing with crude ores on a large scale this is by far the most important method of removing valueless gangue. It involves a preliminary crushing to uniform size, or sorting out into grades of similar size, of crushed stone of varying sizes.

The type of machinery used will vary with the size of the ore particles. Jigs are commonly used for coarse particles, whilst concentrating tables or various modifications of settling vats (such as puddling machines, upward current separators, etc.) are in use for fine material. Details of the process will vary according as the valuable constituent is lighter or heavier than its valueless associates.

Typical cases of such methods of preparation are:

Coal.—This is jigged and the heavier masses of shale thus removed from the lighter coal.

Phuabago, ochre, china clay.—These are crushed or puddled and the lighter portion which is the valuable product is floated off in water and allowed to settle, or collected on fine screens.

Tin ores are puddled and the light gangue is washed away from the heavy tinstone, or they are crushed fine and the tinstone collected on concentrating tables.

Ores of copper, lead, tungsten and other similar ores are jigged in a coarse state to remove quartz, etc., or are crushed fine and concentrated on suitable tables.

OTHER MECHANICAL METHODS OF WIDE APPLICATION.—In addition to simple gravity methods there are several other methods of effecting a preliminary separation of the valuable mineral from its gangue. Such methods are more suited to the central works, where they form part of a scheme of metallurgical treatment, than to the mine where the less expensive methods already outlined must necessarily take precedence of them. A brief reference to them, therefore, is all that is necessary.

MAGNETIC SEPARATION.—An electro magnet is often employed to pick out a magnetic mineral of value from a non-magnetic or less magnetic gangue, or *vice versa*. This process is applied to crude iron ores and to tin ores and other materials which have already been partly concentrated with water.

OIL FLOTATION.—By stirring certain oils into crushed and wetted ores, many of the metallic minerals become coated with a thin film of oil, pickup gas bubbles, and thereafter float and can be drawn off from the gangue. This process is especially applicable to the concentration of sulphide ores of copper, lead, and molybdenum.

MUREX PROCESS.—This is a combination of magnetic separation and oil adhesion. By mixing a little magnetite with, for example, a copper carbonate ore and then stirring in oil, the magnetite and copper minerals become adherent to one another and are separated from the gangue by an electro-magnet.

SPECIAL METHODS OF PREPARATION FOR THE MARKET.—Many minerals require special methods of preparation which are not applicable to other minerals. The most important of these will be briefly dealt with.

Asbestos.—This mineral, which is strongly fibrous, forms narrow veins in a non-fibrous rock. Hand breaking and picking to remove rock containing no fibre are the most that are done at many mines. This may be supplemented by a sorting into grades according to length of fibre, the medium grade being $\frac{1}{4}$ to $\frac{5}{8}$ inch in length. Mechanical treatment consists in crushing the mineral bearing rock between rolls, and sifting, the fibrous asbestos refusing to pass the sieves whilst the granular dust of its non-fibrous associates readily passes through.

Mica.—Hand picking to remove all associated felspar and quartz is the first process in preparing this mineral for market. At the same time all mica is rejected which will not yield clean flat rectangular sheets at least two inches square. Mica so prepared is marketable, but there is still a lot of waste weight in it which it is better to get rid of if the mica has to stand long transport. This extra treatment consists in splitting the masses into plates not more than one-eighth of an inch in thickness, and trimming off the ragged edges with shears, or, better still, cutting the mica into the largest possible rectangular sheets of standard dimensions by means of dies or shears.

Graphite.—This mineral in nature is usually associated with a large amount of valueless clay, quartz, etc. In the rare instances, when the graphite occurs in lumps of pure mineral, hand picking is the only dressing required. More commonly, however, the mineral is distributed throughout the gangue in flakes of various sizes and in powder. As the value of graphite depends upon the size of the individual flakes and their freedom from earthy matter, a special scheme of dressing is called for. This consists in crush-

ing the rock by rolls, which powder the gangue, but have little effect upon the flakes of graphite. The crushed rock is sifted through a series of screens, which retain the valuable flakes whilst allowing most of the valueless gangue and powdery graphite to pass through. Finally, each grade of flake is winnowed or floated on water to remove the few remaining quartz grains, etc.

Salt.—Crude salt contains insoluble dust and sand as well as soluble impurities. It is usually purified at the site of the deposit by dissolving the crude mineral in water, allowing the insoluble substances to settle, then siphoning off the clear solution and evaporating it. As crystals of pure salt form they are lifted out with a perforated ladle and set to drain and dry on wicker baskets. The last few gallons of brine which contain most of the soluble impurities are rejected from time to time.

IV.—NOTES ON SALE OF ORES AND MINERALS OF WESTERN AUSTRALIA.

By

A. MONTGOMERY, M.A., F.G.S.

The extraction of gold from alluvial material containing it by means of processes of dry-blowing, puddling, sluicing, and so on, and also from its ores by milling and cyanide treatment, is well understood by most producers of ore on the Western Australian goldfields, and machinery capable of extracting the gold is well distributed throughout the country, so that generally it is possible to obtain the gold from such materials by local treatment.

Similarly, the washing of alluvial material for separation of tin ore, and the crushing and concentration of tin-bearing rock, are commonly well known, and the dressed "black tin" is readily saleable to storekeepers and merchants in the State for export to smelting works. But there are some minerals carrying gold which cannot be treated successfully by milling processes alone, and require smelting or chemical treatment for recovery of their values. Some mills also recover a good deal of sulphide concentrates, some of which can be treated locally by roasting, regrounding and cyaniding, while other parcels may require smelting with lead or copper ores. There is also produced at various batteries a considerable quantity of slags from the melting of gold slimes from the cyanide process, "magnet-drawings" of iron from amalgamation processes, "sweepings" from melting rooms, and old copper plates from batteries, all usually fairly rich in gold, which are best dealt with by being sold to smelting works. The selling of such products to best advantage is commonly not very well understood by the men who are producing gold ores on a small scale only.

When we come to the export for sale of the less common minerals, and the ores requiring smelting, it has been found that prospectors and miners raising such minerals on a small scale are often much perplexed as to what they have to do in order to be able to get fairly paid for their produce, and it is to assist such men that the following notes have been written.

SUITABILITY FOR MARKET.—It is not sufficient that an ore should contain enough of a valuable mineral to appear to be of payable value, unless the ore as sent to the market is in a condition in which buyers are ready to accept it. For example, molybdenite containing 90 per cent. or over of pure sulphide of molybdenum is at present worth 93/10d. per unit, *i.e.*, for each one per cent. of molybdenum sulphide) delivered at Melbourne or Sydney to the Commonwealth Government agents, but the price falls off about 2/6d. a unit down to 85 per cent. purity, and then 5s. a unit down to 80 per cent. Below 80 per cent. it is difficult to get a purchaser at all. The buyers of this mineral want nearly pure sulphide of molybdenum, and expect the producers to concentrate it up to their requirements before sending it to market. Thus, though an ore containing 10 per cent. of molybdenite would have in it enough of the mineral to return £46 18s 4d. per ton, if dressed up to the requisite degree of purity, such ore while still unconcentrated would not be saleable on

the market. It would have to be crushed and dressed so as to separate the molybdenite from the worthless rock associated with it. A person possessing plant suitable for concentrating it might purchase the crude ore, but the ordinary consumers of the dressed material would not consider it at all until dressed up to their standard of purity. In preparing an ore for sale, therefore, the first thing to be done by the mine owner is to ascertain the form in which the market demands that his ores shall be offered to it. In the notes hereunder relating to each mineral some information will be given as to the condition in which each must be presented to the market, and how such condition may be obtained.

UNIFORMITY OF PARCELS.—Nearly all ores and minerals are sold on their assay value, ascertained by drawing a fair sample from the whole bulk and analysing such sample. It follows from this that the accuracy of the sampling is of very great importance. To facilitate and ensure correct sampling, it is very necessary for the producer himself to make each parcel sent for sale as uniform in quality as possible. The more thoroughly this is done the more he protects himself against imperfect methods of sampling. Instead, therefore, of bagging the ore as it comes to hand from day to day at the mine, it is best to accumulate it in "beds" or "paddocks," making a separate bed for each separate grade of ore intended to be shipped. All big lumps of ore should be broken to a size to be determined as the best for each particular sort of mineral. For example, ordinary ores of copper, lead, and antimony should be broken to pass a 3in. ring. The ore, so broken, to hand from each day's work should be spread out in a thin layer evenly over the whole area of the ore-bed, so that when this is ready to be bagged it will consist of layer upon layer of ore obtained from time to time. If then the bags are filled by shovelling from the bed, each bag will contain some of each layer from top to bottom of the bed, and the bags should be fairly uniform in value.

SAMPLING AND ASSAY.—It is always advisable to have the ore properly sampled at the mine before it is sent away, and to do this a sample is best taken during the process of bagging. This may be done by putting one shovelful of ore out of every six, ten, fifteen, or other number which may seem most suitable for the size of the whole parcel, into a small separate heap on a hard clean floor, best covered with sheet-iron. The proportion to be taken for sample must depend on the degree of uniformity of value of the ore and the certainty with which it can be estimated that the sample will be fairly representative of the whole bulk. For parcels over ten tons in weight a first sample of one in twenty is usually sufficient, but the proportion taken for sample must be increased for smaller lots. When the material is very valuable and the parcel is only a small one, it is best to put the whole of it on the sampling floor.

This first quantity having been drawn and put on the sampling floor, all larger lumps have to be broken up until there are none left which will not pass through a ring of about half the diameter of that adopted in the first place for the main heap of crude ore. If the latter was all broken to pass a ring three inches in diameter, the sample should be broken so as all to pass one of 1½in. diameter. The principle underlying the sampling is to take such an amount and crush to such gauge that no single lump of the ore, even though pure metal or mineral, will be large enough to affect the value of the portion drawn for analysis to such an extent as to make it appreciably higher than the true average of the whole bulk of the ore parcel. Want of recognition of this principle, and consequent neglect to crush the sample sufficiently finely, is the most common reason for discrepancies in assays.

The first sample drawn having been reduced as above is next very thoroughly mixed by shovelling and formed into a conical heap, the top of which is then flattened out with a shovel so that the heap becomes a rounded bed with flat top and sloping sides. It is then marked across the top with the shovel so as to divide it into four approximately equal parts, and three of these are then shovelled up and put into bags to go with the rest of the ore from

which the sample was drawn. The floor should be swept clean after removing these portions, taking care to remove all the sweepings into the bags belonging to that part of the sample and *not* to mix them with the remaining quarter. This remaining quarter is now further crushed so that the largest stones left in it will pass through a coarse sieve with meshes not more than about a third of the diameter of the gauge used for the previous reduction. If the latter were 1½in. the sieve meshes should not be more than ½in. The whole of the sample should be made to pass through this sieve. The sifted material is then mixed thoroughly once more, made into a cone, flattened, and again divided into four portions, three of which are carefully removed, with clean sweeping up of the floor where they have been, and put into bags with the main parcel for shipment. The remaining fourth is now again crushed still more finely, and passed through a sieve with meshes not more than one-fourth of the size of the previous sieve, and the same process is repeated of mixing and quartering. At about this stage the work is best done on a sheet of canvas or American cloth. If the original sample drawn from the ore heap were one ton, we should now have about 35lbs. of sample, crushed to pass a sieve with not more than ¼in. meshes. This sample must be again more finely crushed till the whole of it can be passed through a sieve of about 40 holes to the linear inch, after which a further sample is drawn as before of 8 to 9lbs. weight. This should be ground to pass a sieve of 60 holes to the linear inch, which is fine enough for most of the metallic ores not containing gold, and the quarter drawn from the sifted product constitutes the final sample. In the case of ores and materials containing gold, it is best to put about half the 60-sieve sample through one of not less than 80 and preferably 90 or 100 holes to the linear inch, and use this very finely ground material for the final sample. It is often necessary to make the ground material perfectly dry by warming it for a time at about the temperature of boiling water before it will pass satisfactorily through the fine sieves without clogging. The final sample should now be assayed at the mine, if facilities exist for doing so, or sealed up and posted to a reliable assayer for him to make assays of it.

The assay of a sample taken at the mine, if carefully drawn as shown above, should agree very closely with the result obtained at the Smelting Works to which the ore is sent for sale, and at which the sampling is usually done with aid of machinery in a sampling mill. The assay at the mine, however, is only for the owner's own guidance, and to enable him to put a value on the ore for railway freight, Customs declarations, and insurance purposes, as the sale at the Smelting Works, or to merchants who purchase ores, is always made upon sampling and assays performed under the buyer's own supervision. The seller always has the right to be present himself or have someone to represent him at such final samplings, and when he sends away ores for sale to works at a distance, he should always arrange with some reliable person to see the ore weighed and sampled. The final sample drawn in such cases is usually divided into three, one-third being taken by the buyer for his own assay, one-third given to the seller, and the third sealed up in the presence of the representatives of both parties and held by the buyer for umpire assay if required. Buyer and seller then each have assays made of their samples and arrange to compare them. If the difference in the results is small, they usually take the mean of both assays, or, as it is termed, "split" the difference, and the mean assay is then known as the "agreed" assay, on which settlement is made. If the assay, however, disagrees to any serious amount, and the parties do not meet one another by mutual concessions, the umpire sample is sent to an umpire, who has been mutually agreed upon at the time of the sampling. The umpire fees are usually paid by the party whose result is furthest from that of the umpire. The umpire's assay having been received, the "agreed" assay is obtained according to a method arranged between the parties at the time of sampling. Sometimes they agree that the umpire's result must be taken as final, for better or worse, disregarding the buyer's and seller's assay, but more usually the mean of the two results

nearest to one another is taken. Sometimes the mean of all three results is taken. The customs in this respect differ at different works, and the seller should satisfy himself at time of sampling as to which method of adjusting assays is to be adopted, and whether he can agree to it.

In sampling auriferous concentrates and cyanide slags of high value in gold great care must be taken to grind the final sample to very fine powder, and to make allowance in the assay for any fine series of metal which will not pass through the sieves "Magnet-drawings" and smelting house sweepings are somewhat difficult to sample and assay satisfactorily, as they often contain metal too large to pass through sieves. Special methods, both of sampling and assay, have often to be devised to meet such cases. So also with the sampling of old copper plates carrying gold, which is material of very variable value in different parts of the same piece of copper. Clippings, borings, or punchings are cut plentifully from the pieces of old plate in such a way that the sample is taken as evenly as possible from all over the area of each piece, and the sample is commonly then melted in a crucible and thoroughly stirred before being poured into a mould to form a small bar. This is then bored through from side to side in two opposite corners, and the borings are assayed for gold by like methods of assay to those used in determining the gold in blister copper bars. Other methods of determining the gold in the crude sample of borings or punchings, however, are often also employed, the choice of a method depending greatly on the weight of the sample to be dealt with. Not infrequently the old plates are cut up and melted into ingots first of all, and these are then sampled by boring through them, the borings being used for the assay sample. As far as possible, it is always best to use the same methods of sampling and assay at the mine, for all sorts of ores and minerals, as will be adopted at the final sampling and assays for sale.

BAGGING.—The size and quality of bags to be used in forwarding ore are a matter of much importance. Crude ores are often very heavy and the stones may have sharp edges liable to cut through the bags. Very finely divided ores, like fine tin ore from a crushing plant, may require special lined bags, or canvas bags, to avoid loss of mineral through fine ore sitting through the material of the bags. If crude ores have to be carried long distances in carts or on camels the bags often become much chafed and worn and may have to be renewed before the ore can be shipped safely for export. Some sorts of ore, especially sulphides, become acid on standing for a time exposed to the air, and rot the bags containing them very quickly, rendering them weak and very liable to burst. Bags should not be too large, as not only are large bags relatively weaker than smaller ones and so more liable to loss of contents by rupture, but they are also apt to be unhandy for lifting by one man, and are very liable to be torn by lumpers' hooks while being loaded and unloaded at ports. Jute bags about 23in. x 15in. weighing 16ozs. each and carrying 80 to 90lbs. of heavy metallic ores are satisfactory for most crude ores, and loaded bags are best not allowed to exceed 100lbs. in weight. Lighter ones may be put in jute bags 27in. x 19in. weighing 20ozs. each, but which should not exceed 100 lbs. weight when filled. For very finely divided valuable ores, the bags are best kept smaller and lined with duck. Canvas bags are also used for valuable ores, but are too expensive for poorer ones. Such bags, when filled, should not weigh more than 80lbs.

The loss of material through rotting, chafing, tearing, and other breakages of bags is frequently very serious and annoying, especially when the parcels have to be transhipped more than once during their voyage to their destination. The shipping companies will accept no liability for loss by bursting of bags, and it frequently is quite difficult to learn at what stage of the journey the ore has been lost. In some cases of shipments of copper ores from Fremantle to England, the loss of weight between weighings at each end of the journey has been quite serious, amounting in one instance to nearly 5 per cent. of the net quantity of ore shipped, or say one cwt. in every ton. As the ore was worth nearly £30 per ton, the loss was

serious, and it would have been profitable to have re-bagged the whole parcel before sending it from Fremantle if any such loss had been anticipated. It is very bad economy to use old bags or bags of too large size in order to save cost of bagging as the loss of the contents of broken bags is likely to be far more than any saving effected in the first cost of these.

Comparisons of the net dry weight of ore delivered at smelting works in England with the gross weight of bagged ore shipped, taken over a large number of shipments, have shown that the difference ranges from about 3 up to 8 or 9 per cent. of the gross weight, and averages between 4 and 5 per cent. The difference is due to tare of bags, moisture in the ore, and loss of ore through dusting through the bags and from bursting of bags. In estimating the return likely to be received from any parcel of ore shipped to England, therefore, it is well to allow a discount of 5 per cent. from the gross weight shipped before taking the reduced amount as the weight of ore on which payment may be expected to be made. The loss is usually less in shipping to smelters within Australia.

All ore bags should be sewn up firmly and should be very distinctly and distinctively marked. If letters are used it is best to use not less than two, and preferably three, so as to minimise the probability of two lots belonging to different owners becoming confused and mixed in delivery. All old marks should be snudged out. Forwarding agents recommend the use of leather tags, sewn to the bags, with the brand repeated on them, in addition to the marks on the body of the bags. Metal tags are objected to by wharf lumpers.

Bags sent to Australian smelters are generally returned to senders, at their cost, if so desired. Those sent to England are sold by the smelters and the proceeds usually credited in the account sales. Sellers of ore should always give distinct instructions as to what is to be done with their bags.

MOISTURE DETERMINATION.—Most ores contain a certain amount of moisture, even if they have been well dried under a hot sun, so this has to be determined at the time of making assays, in order to ascertain the net dry weight of the ore sold. The assay samples should also be dried before being assayed, so as to have the assay made on thoroughly dry ore. As shipments of ore are liable to become wet in course of transport, the amount of moisture in them when they reach the buyers' sampling floor may be quite different from that found at the mine at time of despatch, but if the assays are made in each case on the weight of the dry ore, after deducting the moisture present, they are dealing with identical material and should agree. Moisture determinations at the buyer's works are necessarily made at the time of weighing the ore there. The bags are counted and weighed, and the contents emptied out on to the smelters' ore heaps or ore bins, samples being taken from them for determination of moisture during this process. These samples are placed in tins with close-fitting lids, to avoid evaporation of the moisture, and are taken as quickly as possible to the assay office where they are weighed in their moist condition. They are then dried, best by steam heat, until all moisture has been driven off which can be removed by heating to a temperature a few degrees only above that of boiling water, and again weighed in the dry condition. The loss of weight is due to water and the percentage of moisture is thus ascertained. It is rarely less than $\frac{1}{2}$ per cent., and often goes up to 4 or 5 per cent., while ore fresh from a mine may contain 10 per cent. of moisture. Earthy soft ores are apt to hold more moisture than hard solid material. In determining moisture great care must be taken not to overheat the ore, as this may set up changes which alter its weight in a very variable manner. Brown oxide of iron, for example, may lose a very varying amount of the water of combination contained in it, and which is part of the mineral even when perfectly dried at steam heat. Determination of moisture is simply to ascertain the amount of free or as it is called "hygroscopic" water in the sample.

WEIGHING.—The weight of ore sold is determined by weighing at the buyer's sampling floor, which is usually furnished with weighing machines much superior to those in ordinary use, and often self-

recording. The accuracy of such machines is guaranteed by the buyers, and at many works the weighing is done by a sworn weigher appointed by the Government, who gives a certificate of the exact weight found. After the full bags have been weighed and the contents emptied out of them, the empty bags are placed on the scales and weighed. The gross weight of the full bags less the weight of the bags, and less the amount of deduction for moisture, gives the net dry weight of ore sold.

SUPERVISION OF WEIGHING AND SAMPLING.—When ore is sent to a distant buyer, it is always best for the seller to arrange for someone to represent him at the weighing and sampling, and to have the seller's assay made. There is usually no difficulty in getting reliable men for this work, who make it their business to attend to it. Their fees usually are from £2 2s. to £3 3s. per parcel of ore sampled, but vary according to the size of the lots, and whether they themselves make the seller's assays or have them made by someone else. The assay fees are different for different sorts of minerals, according to the amount of difficulty of the assays and the number of constituent elements to be determined.

SIZE OF PARCELS.—The expenses of Agency, Assay, Supervision of Sampling, and also Railway freight are liable to amount to a relatively larger amount per ton on small than on large parcels of ore. It is usual for ore carried on the railways in quantities under five tons to be charged with freight as for five tons, and in sea-going freights a minimum of one ton is commonly charged for parcels under that weight. At the smelting works it is usual for lots of ore less than five, or in some works, less than ten tons to be charged with a sampling fee of £1 1s. in addition to usual other charges. It will be seen, therefore, that the expenses are not in all cases proportionate to the tonnage, but are much higher per ton on small parcels than on large ones. It is rather a common practice for people to send away small parcels of ore of less than a ton in weight as "trial parcels," with the idea that the information thereby gained will enable them to see what return they would get from larger lots. The extra expenses on small lots are quite likely to make such trials quite misleading. A properly drawn assay sample, one pound in weight, will serve quite as well to obtain all necessary information as, say, 10 to 15 cwt. of the ore. Speaking generally, it is not advisable to ship lead, copper, or antimony ores in lots of less than five tons in weight, and preferably there should be over 10 tons in each parcel. The more valuable ores, such as black tin, bismuth, and telluride of gold, naturally have to be shipped in smaller lots as available.

PAYMENT.—payment for ores sold is made in many different ways as arranged between buyer and seller. Often the buyers purchase the ore outright for prompt cash, but frequently they only make an advance payment on the price of the ore at the time of the sampling, and do not settle the deal until, say, three months later, this course being taken in order to enable them to smelt the ore and get the resulting metal to market. The actual final sale is then on the market price of the metal at the agreed date after the sampling. When prospectors send ore for sale, therefore, they should ascertain the terms on which the purchaser will make payment. Some ore agents sell ore parcels on a commission basis, making advances when they receive the ore and then forwarding it to the actual market and returning the net proceeds, after payment of all expenses, advances, interest on moneys laid out, and commission, to the persons who sent them the ore.

When ores are sent from Western Australia to England for sale there, it is generally quite five months after each parcel leaves this State before the final account sales are returned. By arranging to have the proceeds remitted by telegraph they can be obtained a month or six weeks earlier. The selling agents send "account sales" showing the weight of ore sold, its assay, the prices at which the contained metals are sold, and all charges paid by them, usually

inclusive of shipping freight collectable on delivery. Insurance should always be paid by the sender when first despatched by him, and is best made out to cover all risks from the time it leaves his mine up to time of delivery to the ultimate buyer.

It is customary with some British lead and copper smelters to undertake to pay for ore bought by them two or three months after date of sampling, but to pay cash on rendering their account sales. They then pay the amount due less interest for so many days as are between the date of payment and the due date. This discount for cash payment is often a puzzling item to prospectors when they receive their account sales.

CUSTOMS DECLARATION.—When ores are exported beyond Australia a declaration must be made to the Customs Department showing the weight of ore despatched, consignor and consignee's names, name of vessel by which shipment is made, port of delivery, and weight and value of contained metals or value of whole parcel. In order to be able to give particulars of value even approximately, the sender must have had an assay of the ore, so as to be able to estimate its value. The taking of a fair assay sample at the mine of every parcel of ore for shipment as above described, and assay thereof should never be dispensed with. It forms a basis of valuation from the start, and gives definite figures for all sorts of necessary business dealings.

LANDING CERTIFICATE.—Since the beginning of the Great War no shipments of ore have been permitted unless the sender gives an undertaking to return to the Collector of Customs a certificate from the port authorities at the port of delivery that the parcel of ore has been duly landed thereat in accordance with the bill of lading. The sender must arrange that such certificates are returned to him as early as possible and are promptly forwarded to the Collector of Customs.

BILLS OF LADING, SHIPPING, ETC.—There are so many small matters requiring skilled attention in connection with receiving ore from the railways and coastal steamers at the main ports, clearing it, storing it till there is an opportunity of shipping, arranging wharfage and handling charges, making customs declarations, obtaining space on vessels, getting and forwarding bills of lading, and effecting marine insurance, that mine owners will be well advised not to attempt to handle these themselves, but put them all into the hands of capable forwarding agents, several of whom are available at all principal ports. The rate of commission is small for the large number of small services required. Senders of ore by coastal steamers for transshipment at main ports should always be careful to consign their parcels marked "For Transshipment," as thereby they save themselves a certain amount of duplication of wharfage charges.

PROHIBITION OF EXPORT OF CERTAIN MINERALS, AND PERMISSION TO EXPORT.—Among other war precautions, the Commonwealth Government has deemed it advisable to prohibit export of certain minerals and ores and to exercise strict oversight over that of others. It has been given out as a general principle that ores which can be smelted in Australia must be so treated and will not be allowed to be exported, but in particular cases in which shipment to England of such ores can be shown to be the only means by which the sender can realise any profit on them, permission may be obtained through the Registrar of the Australian Metal Exchange, Melbourne, to have them sent to Great Britain. The same permission must be obtained for any export shipment of ores, metals, and minerals not at present treated in Australia. Applications for permission to ship must be made through a member of the Australian Metal Exchange, and must give full particulars of the shipment. Molybdenite, wolfram and scheelite are not permitted to be exported if the ore is up to the standards prescribed by the Commonwealth Government, who have undertaken to purchase such minerals outright when par-

cels are presented to their authorised agents. In some cases where such ores were not up to the required standard of purity, permission has been given through the Metal Exchange for export to Great Britain.

WESTERN AUSTRALIAN GOVERNMENT ADVANCE ON ORES.—In order to assist prospectors in getting a market for their ores, the Government of Western Australia has established a sampling floor at "J" Shed, North Wharf, Fremantle, and is willing to sample and assay ore parcels and to make ad-

vances on them in accordance with Regulations issued from time to time. Those in force at time of writing these notes are appended hereto (Appendices Nos. 1, 2, and 3). The values of the metals mentioned in the Regulations have not been adhered to very strictly since the market prices have risen greatly above those ruling at the time they were issued, and larger advances have been made where the market price and other circumstances have warranted doing so, at the discretion of the Mines Department. The balances from sales are paid over when received, less interest at five per cent. on moneys laid out by the Government.

Petrology

and its

Application in Industry,

together with an account of

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CHAPTER V.

PETROLOGY AND ITS APPLICATION IN INDUSTRY, WITH AN ACCOUNT OF THE CHIEF ROCK-MAKING MINERALS AND ROCKS.

BY

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A.—PETROLOGY AND ITS APPLICATION IN INDUSTRY.

Though petrology is taught as a branch of geology in most universities and technical schools, it is commonly considered merely as that branch of science which deals with the determination of the constituents of rocks and with the classification of the rocks themselves. The object of this article is to give, for the benefit of those engaged in any sphere of labour in which a knowledge of rocks is desirable, a short account of the development and true scope of the science and the economic uses to which it is being applied.

I.—Explanation and Scope of Petrology.

A complete study of the most trustworthy analyses of typical samples from those portions of the crust of the earth known to us has shown, that, of the seventy and more elements the presence of which has been proved in the crust, only eight occur in any but minute quantity in it. These eight are: oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, and potassium. As these have been proved to exist in the sun, it is certain that they all existed in the originally molten earth. Oxygen was, in the early stages, as it is now, the most active of the gaseous constituents, and from its

action on the other elements various chemical combinations are considered to have taken place. As the crust cooled, therefore, from its original molten condition, the following oxides were formed: silica, alumina, iron oxide, lime, magnesia, soda, and potash. Since of these silica alone acts as an acid, and the remainder as bases, it is presumed that, under the conditions prevailing, the silica united directly with the remainder to form silicates. It is these silicates, either in the pure state or more commonly in isomorphous mixtures that, on the cooling of the molten material, have given rise to what we call the rock-forming minerals.

Though most of the minerals have originated in this manner, there are, however, some important exceptions. It has frequently occurred that in the molten mass or magma the acid and basic constituents have not been equally developed. When, therefore, there has been an excess of silica above that required to form, under the prevailing conditions, all possible silicates, that excess has separated out on cooling to form quartz. Similarly, when there has been an excess of basic oxide, as is frequently the case with oxides of iron, this excess has also separated out either as the oxide or as the native element. It is in this manner that, in addition to quartz, platinum, corundum, iron, and probably gold have been formed.

The different minerals having been formed, as the molten crust gradually solidified, there appeared aggregates of silicates or "minerals" with more or less crystalline form and with certain mutual relations. These aggregates are known as igneous rocks, and they are considered to have constituted the first crust over the molten earth. As atmospheric action—weathering and denudation—still, however, continued on this crust, the rocks gradually became disintegrated, the detritus was carried away by winds and rains and either fused again into igneous rocks or in course of time deposited in layers to form masses which from their mode of origin have come to be known as sedimentary rocks.

The crust of the earth, therefore, consists of masses of matter called rocks, comprised of one or more simple minerals, having usually a variable composition with no necessarily symmetrical external form, and ranging in cohesion from mere loose debris up to the most compact stone.

Now, as long as the only methods known of differentiating rocks were those based on physical characters, such as colour, form, texture, specific gravity, on the identification of the constituent minerals by the naked eye, or on chemical composition, the study of rocks was known as lithology, and this term is used even at the present day in its original acceptation. In 1858, however, H. C. Sorby published his classic paper on "The Microscopical Structure of Crystals Indicating the Origin of Minerals and Rocks," in which he showed the immense importance of the application of microscopical methods of research to geological problems. From the publication of this paper, the study of rocks took on a new aspect; a degree of precision was introduced in the attainment of its results that has almost revolutionised it, and that, especially in view of the developments within the last few years, has virtually transformed it into a science in itself. It is safe to say that, as a result of Sorby's paper, no branch of geology has in recent times shown such great progress. This study of rocks, based on their microscopical characters, constitutes petrology.

The scope of the science embraces all aspects in which rocks may be considered. At first, the purely descriptive aspect, the treatment of rocks as concrete objects, received much the greatest amount of attention, a circumstance which gave rise to the term petrography, by which, until recently, the science was known. It was soon recognised, however, that in rock study, as Whitman

Cross has stated,¹ account must be taken not only of the material character of the rocks, but also of the laws governing their production, eruption, mode of occurrence and solidification, as well as their subsequent alteration. The investigator must classify rocks from every standpoint, and he must apply material facts, all of which cannot possibly be used in the systematic classification of petrography. Thus, with the extension of view of the domain of the science, the narrower signification of petrography has merged into the broader and more satisfactory one of petrology. Its objects have been summarised as follows²—

1. The investigation of the rock itself; its constitution, chemical, mineralogical, structural and physical.
2. The genesis of the rock; the source of materials, etc.
3. The geological occurrence which embraces the formal relationship of rock masses to the earth and to each other.
4. The genetic inter-relationship of rock types.
5. The metamorphism of rocks, atmospheric, contact, and dynamic.
6. The decay and destruction of rocks.
7. Other important lines of study, including the study of ores.

There is then no aspect of a rock from the earliest stages of its formation to its final decay that does not come within the sphere of the science. Whereas, however, strictly scientific questions, such as mineral and rock genesis, have received much attention, and there has been a strong tendency to develop the physical side of the science, it is only of very late years that its importance in economic or industrial geology has begun to be realised. Nevertheless, already in this special branch it has achieved results, which are admittedly of great value, and each year the extent of its application is enlarged.

There is little doubt that the microscopical investigation of steels and alloys which has already given such valuable results is directly due to the success of microscopical examination of rocks. Moreover, very recently, microscopical methods have been employed in the study of the opaque minerals or ores, and the results even in a short time have proved so important that a new field of fruitful economic research has undoubtedly been opened up. As in physiology, botany, bacteriology, and other studies, so in geology the microscope has become indispensable. It is at present, however, only in America and Germany that full recognition of its value in economic or industrial research has been attained.

II.—Applications in Industry.

The chief of these applications are found in four spheres of labour, viz. :—

1. In Geological Surveying.
2. (a) In The investigation of Ore Deposits.
(b) In Mining Geology and Mining Engineering.
3. In Engineering and Architecture.
4. In Investigations in Agriculture.

1. In Geological Surveying.

The objects of geological surveying in the narrow sense are first, to map the surface of a country or a district in such a way that at a glance one may see the rock formations of which the country is composed, their distribution and their mutual relations; and, second, with this information to prepare cross sections that will indicate the geological structure below the surface of the ground. Nowadays, there is a third object in most geological surveys, namely, to investigate the mineral resources or ore deposits of the country, but the significance of petrology in regard to this will be more conveniently treated in another section. It is obvious,

therefore, that the first essential in this work is to know of what rocks the country or district is composed, what is their respective origin, and what relationships in origin they bear to one another, i.e., what are distinctly different types and what are but varieties of one type. These questions it is the province of petrology to settle. Petrology, in fact, determines the classification which now forms the basis of the geological mapping. Its function, however, is by no means limited to this determination. In some countries, particularly in Western Australia, owing to the peculiar character of the physiography, outcrops in the districts in which valuable mineral deposits occur are few; the surface has been enormously weathered, metamorphism of the rocks is frequent, and even in the mines the rocks have mostly lost their original characters. The boundaries or junctions between different formations are in consequence often not ascertainable by observation. It is, in these cases, only by careful correlation of the microscopical characters of numerous specimens that different rock types can be identified and the approximate boundaries between them arrived at. This necessitates an intimate knowledge not only of rocks in their normal, more or less chemically unaltered state and of their typical structure, but of the decomposition products of rocks and the influence this decomposition has on the rock structures. Very few rocks in some of the mining fields of Western Australia, notably Kalgoorlie and Meekatharra, are in a condition that in any degree but remotely resembles their original state, and it is only by the difficult identification of remains of original structure, and the equally difficult interpretation of the alteration products of the rocks that the geological structure can be established. How economically important it is that it should be established is too well known to require elaboration, but instances can be cited from Western Australia where the expenditure of much labour and money would have been saved by earlier determinations of the origin of weathered rocks.

2. (a) Investigation of Ore-Deposits.

After the geological mapping of a district is complete (or nowadays more commonly during the course of the work), an investigation is made of the nature, distribution, mode of occurrence, extent and genesis of the ore deposits or mineral resources and their relation to the rocks in which they occur.

While combinations of eight elements make up most of the material of the earth's crust, the majority are of no practical value. Besides these eight, however, many others occur of which practical use can be made, and on which, indeed, all industrial activity ultimately depends. They are the metals, and these metals, together with their combinations with other elements, are known as ores. In general, they occur only in very small quantities in the rocks, but in places owing to various causes, they have been concentrated in sufficient quantity to enable them to be used profitably. Ore-deposits, then, may be defined as only special phases of the rock-forming process, and are simply rocks that contain metals that can be profitably extracted. The study of ore-deposit, therefore, is the investigation of the deposition, distribution and origin of these metalliferous rocks. Consequently, as we have seen in the case of iron, platinum, some gold, corundum and quartz, they differ essentially only in chemical composition but not in primary origin from the rock-forming silicates. It is, indeed, now admitted that (a) ores were originally derived from igneous rocks, and (b) present ore-deposits are closely associated with actually exposed intrusives or eruptives. As recent writers state, every deposit brings with it the evidence that it is no independent and separate mass, but that it is very closely related to the geological formations enclosing it, i.e., to the country rocks. The sum of the relations of an ore-deposit to the country in which it lies, they term its "geological position," and in regard to this, they state that in addition to the scientific interest attaching to an investigation of it in connection with ores, there is the greatest technical and economic importance for the miner. Disregard for this factor,

¹ Whitman Cross: *Journal Geol.*, Vol. VI., p. 80, et. seq.
² Loc. cit.

or adoption of the view that ore-deposits are separate and independent bodies may lead to great loss to those interested in mining; and as long as such ore-bodies are studied without reference to the country rock or to their genesis, the discovery of further occurrences is left to chance.¹

Ore-deposits being thus derived, and such a close relation existing between them and the country rocks, it is of the utmost importance that all information relating to these rocks be collected. Their original nature, their present character, the alterations they have undergone, both mineral and chemical, the disturbances that have affected them, such as shearing, brecciation and foliation, the evidence they afford as to metasomatic replacement, impregnation, and secondary deposition of minerals, all these must be ascertained if the broad principles governing the genesis, distribution and extent of the deposits are to be fully recognised. It is now realised that petrological methods afford the easiest, most accurate, and often the only means of determining these questions.

Moreover, the ores themselves should be investigated. Previous to 1906, little attention had been paid to this line of research. In that year, however, Campbell published a paper on "The Microscopic Investigation of Opaque Minerals,"² in which he showed how metallic ores may be identified and their relations to one another in a complex ore-body established by the examination of polished and etched specimens of the ores in reflected light in a manner previously applied to metals and alloys. Many of these investigations have since been carried out with results of great practical importance. By determination of the relative ages of the component minerals much light has been thrown on problems of ore-genesis, and safe conclusions have been drawn with regard to the character of many ores in depth. For instance, in copper and gold deposits it is common to find under the gossan a rich zone, which in newly discovered mining fields is often regarded as the normal character of the ore-body. An examination, however, of polished surfaces of the ore of this zone demonstrates at once its secondary character and consequently the improbability of the rich ore extending to any great distance in depth. Again, to take a concrete example, it has been shown that the platinum from the gravels of the Urals has a zonal structure similar to that in crystals formed from a molten mass, that, therefore, the platinum has originated as segregated particles in igneous rocks; and that, consequently, the best chance of finding it in payable quantities is in river gravels where the particles have been concentrated by water action.

Microscopic examination of sections of ores is of considerable importance in metallurgical practice. A recognition of all the minerals in a complex ore is necessary before the best method of dressing the ore can be adopted, and this is often most quickly and most easily brought about by an examination of sections of the ore both in transmitted and in reflected light. Moreover, the causes of difficulty in milling or of perplexing results of mechanical extraction are often revealed by this means. In some graphite deposits, the amount of graphite that can be mechanically extracted from the ore is less than the amount expected as the result of assays. Examination of this ore under the microscope has in some instances shown that the graphite scales are so minutely inter-laminated with rock material that complete mechanical separation cannot be achieved. Examination of sections of the zinc blende ores of Breitenbrunn in Saxony has proved that the difficulties in milling the ore are due to the fact that part of the sphalerite occurs as very thin layers enclosed between the cleavage plates of hornblende, which is itself intimately intergrown with magnetite. Microscopical investigation of polished surfaces of some nickeliferous pyrrhotites has shown that the nickel content is due to an intergrowth of pyrrhotite and the iron-nickel sulphide pentlandite, and that this growth is so intimate that complete mechanical separation of the two minerals is impossible.

2. (b) In Mining Geology and Mining Engineering.

In Mining Geology and Mining Engineering it has repeatedly been shown that in individual mines problems of importance frequently crop up which a knowledge of the general geological and petrological structure and composition of the district in which the mines are situated is not adequate to solve. In these cases, the use of the microscope is often of great value. A certain dyke, fault, or ore-body, for example, may be plotted and correlated through similarity in microscopic characters with another exposure at a different level. Its strike and dip can then be computed and its probable location at a desired point determined.³ By local alteration a rock may appear quite different from others in the vicinity, and yet it may be proved by the microscope to be essentially identical with them. Rocks may be encountered which appear as dykes, but which may be shown by petrological examination to be but varieties of one type. It has often happened, especially in districts where the rocks have been subjected to great dynamic stress, that doubt has existed as to whether a deposit is a replacement deposit or a fissure vein. The true character of the deposit is at once revealed under the microscope. Problems also, in regard to ground-water level in individual mines are often determinable from a knowledge of the microscopic character of the rocks and of the system of disturbances in the mines, and, since the amount of water in a mine has a great bearing on working expenses, the investigation of this ground water is commonly of great importance. Further, microscopic examination may reveal the proximity and direction of an ore-deposit. In certain graphite workings, for example, the first indication of a rich body of ore is the occurrence of thin microscopic scales of graphite in the quartz. The scales increase in number as the ore-body is approached.

In districts where no geological survey has been made, petrology serves the same function in mines that are being opened up as in geological surveying and in the investigation of ore-deposits.

Three special applications of the results of determinations of the rocks of a district and of the investigation of the mineral deposits are worthy of note. These are:

- (i.) In prospecting.
- (ii.) In alienation of lands for settlement.
- (iii.) In boring operations.

(i.) In Prospecting.—Knowledge of the rocks with which ores are most frequently or exclusively associated serves not only to indicate to prospectors those to which their attention may be directed with hopes of success, but those also which may without loss be left alone. There is no doubt that much time and money have been wasted in exploring tracts of country in which geological considerations show it highly improbable that mineral deposits of value will be found. Systematic prospecting, in fact, can only be carried out with a knowledge of the chief ore occurrences of the State, and with geological maps illustrating the petrological character and distribution of the rock formations. In Western Australia, for example, it has been shown that large areas in the north-west extending from the Mount Lofty and Hamersley Ranges to the coast near Roebourne are covered with volcanic rocks, and these areas should, therefore, be left alone by prospectors, though already both time and money have been spent on them. On the other hand, many of the payable gold deposits have been found in schistose epidiorites, and, in consequence, all areas of these rocks deserve careful prospecting.

(ii.) In alienation of lands.—In undeveloped countries like Western Australia, knowledge of the country rocks of the ore-deposits is of great value when questions in regard to alienation of lands for timber reserves and townships have to be settled. Owing to lack or faulty application of this knowledge, instances may be cited of townships being built over areas that were subsequently found to be auriferous.

¹ Ore Deposits by Beyschlag, Vogt and Krusch; translated by Truscott, pp. 3 and 4.

² Campbell, W.—The Microscopic Examination of Opaque Minerals. Econ. Geol., vol. 1, 1906, p. 751. See also paper by Campbell and Knight, loc. cit., p. 767.

³ The use of the Microscope in Mining Engineering; Trans. Amer. Instit. Mining Engineers, 1918 (3), p. 1016.

(iii.) In boring operations.—Boring has been extensively employed in prospecting both for gold and for water. Petrological examination of the cores shows in the one case the presence or absence of reefs, of impregnations, of lodes or other mineralised zones, and even of the fine shearing which frequently causes deflection of the bore hole; in the other, the character of the strata, the presence of possible water-bearing formations, and the proximity of the bed-rock. There are many instances of bores for water being driven in solid rock, until operations were stopped as the result of determination of the core.

3. Engineering and Architecture.

In these spheres, petrological investigations are of value:

- (i.) In tunnelling operations.
- (ii.) In the selection of foundations for dams and reservoirs.
- (iii.) In the selection of building stones.
- (iv.) In the selection of road-making materials.
- (i.) In tunnelling operations it is important to determine the solidity of the rock, the presence or absence of shearing and shattering, and of fault or flaw fissures or junctions which may serve as channels for the percolation of rain water.
- (ii.) In the selection of foundations for dams and reservoirs, microscopic examination of the bed-rocks, particularly of bore cores that have been driven through them, is not uncommonly undertaken to ascertain:
 - (a) The depth of the superficial material.
 - (b) The nature of the rock from point to point, i.e., whether the rock is homogeneous.
 - (c) The character, degree and depth of weathering of the rock.
 - (d) The presence or absence of faults, joints, shear planes, rock junctions or intrusive dykes, each of which is a possible source of weakness in foundations of this kind.
- (iii.) In the selection of building stones.—Stones or rocks being mineral aggregates, it is obvious that the mineral and physical characters of these are of prime importance in deciding the suitability of any stone for architectural or general building purposes. Chief among the characters on which the microscope throws light are:
 - (a) The mineral composition of the rock.—From a knowledge of this, the proneness of the stone to decomposition on exposure to the weather, or the action of water (as in breakwaters), the presence or absence of minute minerals which are of importance as the cause of possible future defects, the degree to which decomposition has already developed in the minerals, and the character and effect of the decomposition products, the hardness and brittleness of the minerals—all these characters are accurately determinable.

Moreover, in this connection, the comparative microscopic studies of rock used in building, which has resisted weathering for a long time and that which is in progress of disintegration, are particularly valuable. Two granites, for instance, of nearly identical mineralogical and chemical composition can behave quite differently. One may remain sound for years, the other may disintegrate very rapidly. The cause of break-down is the presence of minute microscopic pressure zones traversing the rock, a defect which can be discovered only by microscopic examination.

(b) The state of aggregation of the constituents.—This embraces the relation which the minerals bear to one another; whether they adhere closely or loosely; whether they are united by a cement, and, if so, the character and influence of that cement; whether the grain of the rock is coarse or fine; what is the nature of the fracture; and whether dressing of the stone is likely to be easy or difficult. Two marbles of equal beauty, for example, may show very different powers of resistance on exposure, a difference which is proved by the microscope to depend on whether the

grains of calcite in thin sections of the rocks interlock with irregular margins or lie in contact with one another along crystal edges.¹

These characters in great measure influence the amount of resistance than can be offered by a stone to changes of temperature, to the chemical action of the atmosphere and of water, to alternation of colour, to crushing and general dynamic stress, and to the abrasive action of wind—the chief disintegrating agents to which building stones are subjected.

(iv.) In the selection of road-making materials.—In the last year or two, owing to the great increase in heavy motor traffic and in the cost of the building and upkeep of railway lines, much more attention than in the past has been directed to the making and maintenance of roads, and, consequently, as rock fragments are the chief materials used in these processes, to the determination of those rocks best suited to withstand the increased wear and tear, prior to their actual use.

Hitherto, the chief method of making this determination has been the attrition test, i.e., a comparison of the power of the available rocks to resist a grinding process, both in the dry and in the wet state, and the results achieved have undoubtedly been of considerable practical value. Quite recently, however, Messrs. Lovegrove and Howe, and Dr. Flett of the English geological survey, have shown the importance of petrological examination of the rocks in addition to the attrition test. In their book² they have given the microscopic characters of all the chief stones used in road-making in England and also the attrition values both in the dry and in the wet state for each rock. From a careful consideration of these data it is evident that the power of a stone to resist grinding action depends largely on (a) its texture, (b) its mineral composition, (c) its state of freshness. Other things being equal, the finer the texture of the rock the less the pore space due to intervals between the grains and to fine cleavage cracks; and the more even the size of the component grains, the tougher and more resistant will be the rock. Moreover, in general, the greater the proportion of hard minerals, such as quartz, in the stone, and the fresher the constituent minerals, the higher will be its capacity to withstand abrasion.

The authors point out, however, that fresh unaltered original minerals are not always essential to this capacity. Much depends on the character of the alteration. Some porphyries, for instance, with feldspars altered to scaly muscovite and with a little secondary quartz, are preferable to others in which the feldspar is fresh. The scaly muscovite forms a tough resistant felt, and the secondary quartz fills up crevices in the stone which would otherwise serve as channels for the percolation of water. Rocks, too, in which original augite has been altered to fibrous uraltic hornblende are much more durable than those in which the augite has been changed to chlorite, or even those in which the augite is fresh; and sandstones in which the quartz grains have been cemented by secondary quartz are much harder than those in which this change has not taken place. The writers, indeed, have shown that there is a necessary connection between the petrological characters of the stones and the results of the attrition tests, that differences in the former produce corresponding differences in the latter, and that, therefore, solely by expert examination of thin sections of rocks it is possible to forecast their behaviour as road-making material with very fair accuracy. The methods already in vogue in England may with advantage be adopted in other countries in which road building and maintenance are becoming increasingly important.

4. Agriculture.

Soils, the investigation of which in relation to plant growth constitutes the study of agriculture, are known to be comprised in part of organic and in part of inorganic material. In regard to the latter there has been found such a close correspondence in qualitative chemical composition between the ash of plants and

¹ Microscopy in Economic Geology, by R. Beck, Engin. and Min. Journ., May 31, 1913, p. 1087.

² Road-making Stones: Attrition Tests in the Light of Petrology, by E. J. Lovegrove, J. S. Flett, and J. Allen Howe.

the soils in which they grow, that it is certain they derive their chief food from these soils. Moreover, it is known that soils are primarily the decomposed surfaces of rocks, some untransported or *in situ*, others transported by water to form alluvial flats. Consequently, in order to fully understand the formation of soils, it is necessary to study the composition and processes of alteration of those minerals which compose the principal rocks. In short, the study of soils is, fundamentally, the study of the decomposition products of the different rocks forming the crust of the earth.

Though formerly in estimating the value of a soil only chemical analysis was relied on, it was soon found in practice that to get the most reliable results other methods in addition had to be adopted by which the physical constitution of the soil, the combinations in which the bases exist, and the extent to which they are available by the plants would be indicated. These additional methods are mechanical analysis and the microscopical examination of soils. The object of mechanical analysis is to determine the proportion of the different physical constituents of the soil, or, more definitely, to determine the proportion of particles of different sizes. The microscopical or petrological examination reveals the identity of the particles (exclusive of the organic content), and the degree of alteration or decomposition in them. As a writer has stated, "the separation, identification and estimation of its (the soil) components in the same way as we inquire into the structure and composition of a rock containing several compound minerals, is the true key to unlock stores of knowledge on the nature and difference of the same."

While both these methods apply in greater or less degree to all soils, petrological examination is especially important in the evaluation of untransported or virgin soils, *i.e.*, those formed *in situ*. Its function is, as we have seen, the study of rocks in all their relations, including their alteration, decomposition and disintegration into the fundamental bases of soils. Therefore, if we know the petrological characters of the rocks from which these virgin soils were derived, we have a ready and reliable method by which the constituents of the soils, and the extent to which they are available by plants, can be made out. This fact has been recognised for a considerable time in Australia, where a Bureau of Soils has been established, whose duty it is to follow up the work of the geological survey with the preparation of accurate soil-maps embodying all information with regard to the soils of chief value to the farmers; and there is little doubt that in countries—for example, Western Australia—where there are large areas of untransported soils, similar systematic work would be attended by important results.

B.—THE CHIEF ROCK-MAKING MINERALS AND ROCKS.

(I).—The Chief Rock-making Minerals.

It has been shown that rocks are aggregates of silicate minerals with certain mutual relations, and as present-day classifications of rocks to a great extent depend on their mineralogical composition, it is essential that the chief characters be given of the more important rock-forming minerals.

It is, however, useless to the prospector to give any characters which require the use of the microscope, while it is of great importance that he should have those which will enable him to identify the commoner rock-minerals with the naked eye; and as, moreover, a fair degree of accuracy can frequently be obtained in the determination of rocks by their macroscopic as distinguished from their microscopic characters, and, as this determination is largely based on the mineral constitution, only those properties will be described which can be noted in the field.

These are:—

- (a.) Hardness.
- (b.) Cleavage.

- (c.) Colour.
- (d.) Lustre.
- (e.) Feel.

(a.) *Hardness*.—While it is true that the majority of the rock-making minerals and of rocks themselves have a hardness which varies only within rather narrow limits, there are a few minerals such as the micas, and some rocks such as talc schists, chlorite schists, and serpentine, which have a hardness quite outside these limits. A reference, therefore, to the following scale of hardness drawn up by Mohs will often prove of service in identification:—

- | | | |
|------------------------|---|---|
| 1. Talc | } | Scratched by the finger nail. |
| 2. Gypsum | | |
| 3. Calcite | } | Scratched by a knife. |
| 4. Fluorite | | |
| 5. Apatite. | | |
| 6. Orthoclase felspar. | | Scratched by a knife with great difficulty. |
| 7. Quartz | } | Scratch glass and each other in descending order from No. 10. |
| 8. Topaz. | | |
| 9. Sapphire | | |
| 10. Diamond. | | |

Minerals of Grade 1 can be very easily scratched by the finger nail, and have a greasy or soapy feel.

Those of Grade 2 are easily scratched by the finger nail.

Of Grade 3, cannot be scratched by the finger nail but are rather easily cut by a pen-knife.

Of Grade 4, are fairly easily scratched by a knife.

Of Grade 5, scratched with difficulty by a knife.

Of Grade 6, hardly scratched at all by a knife but distinctly by a file.

Above Grade 6, the mineral scratches glass and is untouched by a file.

(b.) *Cleavage*.—By this is meant the capability of being more or less readily split along definite plane directions which are usually parallel to certain of the principal faces on the mineral. This is an exceedingly important property of many minerals, and by its means, as we shall see, quite a number of minerals rather similar in appearance can easily be distinguished, such as quartz and felspar, augite and hornblende, etc.

(c.) *Colour*.—Serves in many cases as a broad guide to minerals and as a means of distinguishing them but is not in all cases reliable.

(d.) *Lustre*.—This is the power possessed by a mineral of reflecting light from its surfaces. The more common kinds met with among rock-making minerals are:—

- (i.) *Vitreous*: the lustre of broken glass, possessed in eminent degree by quartz.
- (ii.) *Adamantine*: that of the diamond and possessed to some extent by rutile and zircon.
- (iii.) *Pearly*: seen in talc and brucite.
- (iv.) *Silky*: the result of fibrous structure and found in some cases in hornblende as well as in calcite.

There are also certain degrees of intensity such as:—

- (v.) *Splendent*: reflecting with brilliancy.
- (vi.) *Glistening*: giving a general reflection from the surface.

A mineral is dull when there is a total absence of lustre, as in the case of kaolin.

(e.) *Feel*.—A soapy or greasy feel is possessed by talc, kaolinite, and steatite.

THE MINERALS.

Having thus briefly outlined the broad general or physical characters of minerals, we proceed in the light of them to a brief account of the more important rock-forming species. These can be arranged conveniently in the following groups:—

1. Quartz.
2. The Felspathic minerals: orthoclase, microcline, the plagioclase felspars.

3. The Felspathoids: nepheline, leucite, analcite, melilite, sodalite, nosean.
4. The Ferromagnesian: olivine, rhombic pyroxenes, augite, aegirine, hornblende, biotite, muscovite.
5. A number specially characteristic of altered or metamorphic rocks; chlorite, talc, serpentine.

The rarer species which have been called accessory minerals, such as apatite, zircon, sphene, garnet, etc., it is unnecessary to describe.

1.—QUARTZ.

Quartz is to be identified with comparative ease by the following properties:—Its hardness (=7) renders it unscratchable by a knife. It has an uneven fracture, due to the absence of well-defined cleavage; a vitreous lustre. It is translucent, often in rounded crystals or grains and usually water clear. In some rhyolites, however, it may appear almost black, but its other characters render it unmistakable.

2.—THE FELSPARS.

These are the most interesting of all the groups of minerals from the fact that they are the most important of all rock constituents. Indeed, at the present time, the classification of most rocks is based to a large extent on the particular variety of felspar they contain. As a general rule, the rock-forming felspars occur only as comparatively small crystals, but potash felspar (orthoclase), an essential constituent of granite, occurs in quite large forms even in igneous rocks. Owing to the remarkably close resemblance between the various members of the family in cleavage, crystalline form, hardness, lustre, and specific gravity, their discrimination is attended with some difficulty, but there are characters which, if carefully noted, allow of a fairly accurate determination even in hand specimens of rock.

First with regard to *Orthoclase*: In chemical composition it is a silicate of potash and alumina. It is usually pale yellow or flesh red and turbid from alteration to kaolin; has a hardness of 6 and a vitreous lustre which sometimes appears almost pearly. Most characteristic, however, especially when, as is frequently the case, the mineral is associated with quartz, is the presence of uninterrupted bright reflecting surfaces. These are due to the occurrence of definite cleavages—directions, as has already been stated, along which the mineral has a tendency to split when pressed or struck. It is the planes of separation along these cleavages which give the reflecting surfaces. The two sets of cracks are inclined at a right angle and they can almost always be distinguished by the naked eye or with the help of a pocket lens. Further, the lustre on one face will often be found to be more nearly pearly than on others.

Now with regard to the *Plagioclases*: The species grouped under this name are so called from the fact that the two cleavages instead of being at right angles as in orthoclase are oblique to each other: i.e., do not intersect exactly at 90 degrees.

The minerals of the group are:—

- (a.) Albite.
- (b.) Oligoclase.
- (c.) Andesine.
- (d.) Labradorite.
- (e.) Bytownite.
- (f.) Anorthite.

These form a most interesting series. Albite is a silicate of soda and alumina; anorthite, one of lime and alumina. If a molecule of albite is represented as Ab and one of anorthite as An, it has been found that the intermediate species can all be represented as mixtures of these two molecules in fairly definite proportions. For instance, oligoclase can be represented in composition as a mixture of albite and anorthite in the varying proportions of Ab_xAn_y to Ab_yAn_x , i.e., a mixture of from 6 to 3 molecules of albite with 1 of anorthite.

Ab_xAn_y is an acid oligoclase, Ab_yAn_x a basic oligoclase. Labradorite has been found in the same way to have the composition Ab_xAn_y to Ab_yAn_x , the former being an acid variety, the latter a basic. Similarly with the other intermediate forms.

Further, it has been found that as the proportion of anorthite in the mixture increases from nothing in albite to 100 per cent. in anorthite, there is a regular variation in many of the optical and physical properties of the minerals, and, consequently, by a determination of some of these properties it is possible to identify the particular variety of plagioclase with some degree of precision. It is on these determinations that much of the classification of rocks now depends.

The two varieties of most importance from this point of view are oligoclase, which is a soda-lime felspar, and labradorite, a lime-soda felspar, the former with soda in excess of lime, the latter with lime in excess of soda.

However, for our present purpose, it is enough to give the names of the varieties, and to show the general relationship between them. It is usually quite sufficient in the field to determine whether the particular felspar is a plagioclase or not.

The mineralogical characters of the group closely resemble those of orthoclase, but whereas the latter is generally yellow or reddish, the plagioclases as rock constituents are usually white; further, the cleavage angles are not quite 90deg., and, in nearly all cases, by careful examination, in addition to the cleavages and sometimes even obscuring them, a series of very fine and very closely aggregated straight lines can be seen on the face with the brighter lustre. These lines are the "twin striation" of plagioclase, are very characteristic, and are clearly seen even on broken surfaces.

Microcline, in chemical composition, hardness, specific gravity, and general characters is indistinguishable from orthoclase, but the presence of the striations places it at once among the plagioclases. Its chemical composition is the same as orthoclase—and its peculiar optical properties, as shown by polarised light, render its determination by the microscope not difficult. One other variety is deserving of note, viz., *Anorthoclase*: this is a soda-potash felspar, resembling microcline in cleavage angle, and to some extent in optical properties.

3.—THE FELSPATHOIDS.

These include two important and closely related minerals, nepheline and leucite, as well as some others of less importance, analcite, melilite, sodalite, and nosean. Nepheline is a soda alumina silicate, leucite a potash alumina silicate. Both, as will be seen, are rather characteristic of certain groups of alkaline rocks, but as these are of limited distribution and have not yet been observed in Western Australia, a description of them is unnecessary.

Melilite, a constituent of some alkaline basalts, is an extremely basic lime alumina silicate. Sodalite and nosean usually accompany nepheline.

4.—THE FERROMAGNESIANS.

For descriptive purposes these can be grouped as follows:—

- (a.) Olivine.
- (b.) The Micas: muscovite and biotite.
- (c.) The Pyroxenes and Amphiboles: represented chiefly by augite and hornblende.

(a) *Olivine*: A silicate of iron and magnesia, with unimportant cleavage, a hardness = 7, a vitreous lustre, and a yellowish-green colour. In rock specimens, it is generally visible to the eye as yellowish-green glassy patches or grains of small size. It is an essential constituent of what are called the basic and ultra-basic rocks, such as olivine-gabbros, basalts, and some dolerites.

(b.) *The Micas* include quite a number of different species, but the two most important from a rock-forming point of view are *muscovite*, a silicate of alumina and potash, and *biotite*, a silicate of magnesia, iron, potash, and alumina, with a variable amount of iron and

some water (as hydroxyl). Both species have a hardness = $2\frac{1}{2}$; occur in nests, flakes, or hexagonal crystals, with a perfect cleavage which yields very thin, tough, and more or less elastic laminae. The laminae are translucent, in the case of the muscovite often quite transparent. The latter, which is the species usually contained in granites and mica schists, is a pale-coloured or colourless mineral with a pearly lustre on the cleavage surface.

The former, occurring also in granites and schists, but to a great extent as well in the more basic rocks, is usually green to black, often deep black in thick crystals; sometimes pale yellow to dark brown; the lustre is very similar to that of muscovite.

Both minerals, when in plates of appreciable size, are easily identified in rocks by the simple application of the point of a knife to the flakes; not only are these very easily scratched, but their flaky nature and the lustre become at once visible.

There is another species or variety met with occasionally in rocks that have undergone chemical and dynamical alteration, viz., *sericite*, a silvery white form closely allied to muscovite, occurring in small fine scales, aggregates of scales, twisted fibres or rosettes. It is largely due to the alteration of feldspars, and much of what has been described as kaolin and talc is in reality *sericite*.

(c.) *The Pyroxenes and Amphibolites*: As typical minerals of these families we may take augite of the pyroxenes and hornblende of the amphiboles. Both families are very similar in chemical composition and crystalline form, the different members varying from pure magnesia or magnesia-iron silicates, such as the rhombic pyroxenes, *enstatite* and *hypersthene*, and the amphibole *anthophyllite* to complex lime-magnesia-iron-alumina silicates, such as typical augite and hornblende. As the rhombic forms are of comparatively rare occurrence, and their identification largely depends on microscopic examination, no attention need here be paid them. So far as the other members that are of interest at present are concerned, their relationships to each other and the resemblances of both families in general will be clear from the following classification:—

PYROXENES.

i. Non-aluminous varieties—

Diopside, including diallage; which are respectively lime-magnesia and lime-magnesia-iron silicates.

ii. Aluminous—

Augite: Including augite and aegerine; lime-magnesia-iron-alumina silicates without and with soda.

AMPHIBOLES.

i. Non-aluminous—

(a.) Tremolite: lime-magnesia silicate.

(b.) Actinolite: nephrite, asbestos, etc.; lime-magnesia-iron silicate.

ii. Aluminous—

Common hornblende: lime-magnesia-iron-alumina silicate.

Of the Pyroxenes:—

Diopside: is white or yellow, but usually pale green or dark green, and occurs in columnar crystals.

Diallage: is grayish-green, bright grass green, or deep green with sometimes a pearly lustre, often with a peculiar sheen or schiller due to inclusions.

Augite: is greenish, or brownish-black or black, in short, thick and stout crystals; usually in igneous rocks.

Aegerine: is usually in fibrous or tufted forms, bright green to dark green in colour; as a rule it is hardly distinguishable as a rock constituent in hand specimens.

Of the Amphiboles:—

Tremolite: is white to dark grey, in crystals either long-bladed or short and stout. Occasionally in fibrous or tufted aggregates. Common as a product of the metamorphism of some sedimentary rocks.

Actinolite: has a colour bright green and greyish green.

Usually in crystals, which are short or long-bladed, columnar or fibrous, in tufts or divergent groups. In some cases the colour extends only half-way along a crystal.

Hornblende is green, dark green, or black, in rounded or hexagonal crystals, with a very bright vitreous lustre.

The characteristic differences between the two families—excluding the rhombic forms—as shown especially by typical augite and hornblende are:—

Augite: which contains a greater percentage of lime, is usually black or greenish black in colour in squarish prisms, and with cleavage traces which, when visible, are seen to be inclined almost at a right angle (87° and 93°): It is rare in fibrous forms.

Hornblende: occurs much more commonly in fibrous and tufted forms, which in the aggregate appear black or dark green: when massive it has a brilliant vitreous lustre, and the cleavage cracks are inclined at angles of 56° and 124° .

A crystal, therefore, of either mineral need only be broken across for its determination to be fairly easily made.

Hornblende varieties, too, sometimes form aggregates of fine, needle-shaped crystals, giving the rock a silky lustre.

The specific gravity and hardness of both minerals are nearly the same, as also is the colour. The cleavage, however, is sufficiently characteristic.

Uralite.—There is a peculiar variety of hornblende of which a little must be said. This mineral is, briefly, pyroxene altered to amphibole. The crystals when distinct retain the form of the pyroxene, but have the cleavage, and to a small extent the optical properties of the amphibole. The change results in the formation of a bundle of actinolitic fibres, or needles. The colour varies from white to pale and deep green, the last being most common.

5. The only other minerals which call for notice are:—talc, serpentine, and chlorite.

Talc: which is a decomposition product of non-aluminous pyroxenes and amphiboles, and in composition is a hydrated silicate of magnesia, is a very soft ($H=1$) sealy micaceous mineral, usually of some shade of green, and with a pearly lustre on the surface of the scales. Occasionally it is compact and massive: it may also possess a somewhat schistose structure. It can in nearly all cases be scratched with the finger nail, gives a white powder, and is soapy or greasy to the feel.

Serpentine: which is also a hydrated silicate of magnesia is a decomposition product largely of olivine, but occasionally of non-aluminous pyroxenes and amphiboles. It is rather soft ($H=2\frac{1}{2}$ –4), can sometimes be scratched with the finger nail, always with the knife; is yellow, siskin-green, dark green, or even black in colour; usually massive, and has a resinous to greasy lustre.

Chlorite: a hydrated silicate of iron, magnesia, and alumina, with combined water. It is usually green in colour with a micaceous cleavage, but the laminae are tough and inelastic. It may be in scales, fibres, or needles, and occurs also massive. $H=2$. The lustre is pearly, vitreous, or feeble. The chlorite usually found is a secondary mineral formed from the alteration of ferro-magnesian silicates, especially aluminous augites and hornblendes.

(II).—Classification of Rocks.

Broadly speaking, and from the point of view of origin, the rocks of the crust have already been grouped in three classes:—

1. Igneous.
2. Sedimentary.
3. Metamorphic.

Further, because it is from igneous rocks, as has previously been shown, that all others have ultimately been derived, the divisions will be considered in the above order.

1.—IGNEOUS ROCKS.

The sequence of events from the molten stage of the crust to the formation of the silicates, which form the basis of rocks, has already been briefly outlined. For a better comprehension, however, of rocks of igneous origin, it is advisable to proceed a little further in the consideration of the magma. Assuming the various combinations formed, how is the molten mass to be regarded? Is it to be considered as a molten metal, as a substance which, when heated to a certain temperature under fixed pressure, will pass into the molten condition and, on cooling below that temperature, will again become solid? If this were true, it would follow that a definite order of crystallisation of the different minerals might be expected. As a matter of fact, a certain general order of consolidation does exist in one family of rocks, an order of decreasing basicity, but it is by no means rigidly adhered to. In the case of some granites, for instance, quartz which has a fusion point above that of felspar or mica is evidently the last mineral to crystallise. From this fact, together with others which have recently been discovered, the conclusion has been arrived at that a molten magma is not to be looked on as a fused substance, such as a metal, but rather as a solution of one compound, such as a silicate, in another, or of several compounds in one. The function of a high temperature is to cause the fusion of one constituent which then dissolves the others.

With regard, now, to the solidification of the magma and crystallisation of the constituents, it has been found that three factors play a most important part: the composition of the magma, the rate of cooling, and the pressure exerted on the molten material during solidification. The composition is to a certain degree indicated by the essential minerals of the rocks, so that these become of great importance in classification. It is found, however, that magmas with very similar composition give rise, under different conditions of consolidation, to widely different mineral aggregates. To these differences are referred differences in coarseness and fineness of texture, the evidence of one, or more than one, stage in the solidification, and those peculiarities in the relation of the constituents which are spoken of as the structure of the rock.

Since, further, it has been found impossible to base any detailed classification on structure alone, or on mineral composition alone, and since that founded on chemical composition is far too unwieldy to be of general service, a classification of igneous rocks has been adopted, which is based partly on the field occurrence of the rocks, partly on structure, and partly on mineral and chemical composition. This one, which has met with general acceptance, groups rocks of igneous origin according to field occurrence into three main divisions. The characters on which the grouping is based will be given under the respective heads. A subdivision into families of the rocks belonging to these three groups according to mineral composition and structure will also be given with a description of each, and, further, the varieties of each family will be mentioned and briefly described. With the rocks of each division the general order will be observed of beginning with the most acid and ending with the most basic. At the end, too, a broad classification, based on the chemical grounds of the percentage of silica in the rocks, will also be given.

The three main groups or divisions are:—

- (A.) Plutonic.
- (B.) Hypabyssal.
- (C.) Volcanic.

It must be understood that this classification is far from being perfect. No hard and fast line can be drawn between the members of these divisions. It is found, for instance, that rocks which are, from structural peculiarities, to be placed amongst the volcanics, actually occur in dykes, and should, therefore, on field relations appear among the Hypabyssals. There are also several cases in which it is practically impossible to assign a rock positively to any one particular family or group. It may have characters which ally it to two or three, but few which are distinctive of any one group. Further, rocks of different types are often found to pass by insensible gradations into one another, so that no rigid boundary lines are admissible if the facts as presented to the observer are to be truly represented.

(A.)—PLUTONIC ROCKS.

The rocks which are placed under this head have consolidated as large rock-masses at considerable depths beneath the crust. As a consequence, the features presented by them are those which point to slow cooling under great pressure. The rocks are all crystalline, and of coarse grain, *i.e.*, the minerals are usually of appreciable size, sufficient to be fairly easily identified by the naked eye. Moreover, their structure is "hypidiomorphic," which means that only a few of the crystals have developed crystal boundaries, the majority occurring as plates with irregular outlines.

From the point of view of mineralogical and chemical composition, plutonic rocks are divisible into the following families:—

- (1.) Granites.
- (2.) Syenites.
- (3.) Diorites.
- (4.) Gabbros.
- (5.) Peridotites or Olivine rocks.

(1.) Granites:

These are as a rule light-coloured rocks varying in shade from red or pink through yellow and grey to almost white. The essential minerals are quartz, felspar, and mica. The quartz is translucent and without noticeable cleavage. The felspar, which may sometimes be in large crystals, is either orthoclase alone, or orthoclase with oligoclase, albite, or microcline. The mica may be either muscovite or biotite. Hornblende or augite with or without mica may occur, giving rise to the varieties hornblende-granite and augite-granite.

The chief varieties are:—

- (a.) Muscovite granite.
- (b.) Biotite granite, with biotite as the ferro-magnesian.
- (c.) Hornblende granite: in which hornblende is the chief ferro-magnesian.
- (d.) Pegmatite granite: consisting of microcline or orthoclase and quartz, often with white mica, and with a tendency to graphic structure, *i.e.*, the felspar and quartz are so intergrown as to simulate Hebrew characters.
- (e.) Greisen: essentially of quartz and white mica. A translucent quartz rock with scales or nests of mica. Felspar practically absent. It is associated frequently with cassiterite and topaz.
- (f.) Aplite: a fine-textured rock composed of orthoclase and quartz, with a little mica, the minerals forming a fine-grained mosaic. It occurs as veins in granite.
- (g.) Soda-granite: an augite granite, with anorthoclase as the dominant felspar, and with a strong tendency to graphic structures.

- (h.) Tourmaline granite: a rock in which the felspar and mica may be partially or completely replaced by quartz and tourmaline, so that the rock may, like the luxullianite of Cornwall, be composed wholly of quartz with radiate groups of tourmaline needles.
- (i.) Alaskite: is a granitic rock, with muscovite or only a trace of biotite, and with only a small to inappreciable amount of a plagioclase felspar.* It is regarded as the most acid phase of a granite magma, and is held to pass into granite-quartz veins.

The term *Granite* has fallen into disuse, its place being taken by biotite granite.

(2.) Syenites:

These are generally pink or yellow with dark green patches or crystals, due to the presence of orthoclase and hornblende. They consist essentially of alkali-felspars (orthoclase, microcline, oligoclase) and a ferro-magnesian mineral, which is commonly hornblende, but may be augite or mica. In some varieties a feldspathoid mineral, nepheline, is found, showing that the original magma was rich in soda—a fact which is also evidenced by the presence of aegerine and occasionally sodalite. The soda varieties have been separated as a sub-family under the name of Nepheline-syenites, but as they are of limited distribution, it is unnecessary to give them here.

Varieties:

- (a.) Syenite proper: alkali-felspar and hornblende.
- (b.) Quartz syenite: with platy quartz in addition to the above.
- (c.) Mica syenite: with biotite predominant over hornblende.
- (d.) Augite syenite: Augite and alkali felspar, with some hornblende and biotite.
- (e.) Monzonite: an augite syenite, with a notable amount of plagioclase felspar enclosed by orthoclase. A little biotite is also present.
- (f.) Nepheline Syenite: consists of orthoclase, nepheline, sodalite, aegerine, hornblende. In some, leucite, zircon, mica also occur.

(3) Diorites:

These are usually medium to fine-grained rocks, green and white in colour, *i.e.*, with white spots or small crystals of plagioclase felspar in a dark green mass of hornblende. At times the felspar may be in excess. They consist essentially of a soda-lime felspar—oligoclase, andesine, or labradorite—and hornblende. The family is, however, but ill-defined, for in composition it frequently approaches the succeeding family of the gabbros, characterised by the presence of augite instead of hornblende. Of late, too, it has been shown that augite has a very strong tendency to pass over into hornblende, and, as cases have been established in which the hornblende has been derived from the augite, it is considered that a similar origin may apply to nearly all, if not all, so-called diorites. The latter are, therefore, to be regarded at least in the main as gabbros in which the pyroxene has been changed to hornblende. While, however, their probable original derivation from gabbros is not lost sight of, they may be considered with their mineralogical composition as it stands, and under these circumstances the following varieties are found to occur:—

- (a.) Diorite proper: hornblende and labradorite.
- (b.) Quartz diorite: labradorite, abundant biotite, and hornblende and much interstitial quartz.
- (c.) Quartz mica diorite; also called *Tonalite*: a striated plagioclase with a little orthoclase, much biotite and hornblende, with abundant interstitial quartz. It approaches rather closely in characters to some hornblende granites as well as to monzonites.

* Alkali felspar is usually observed.

- (d.) Granodiorite: a type with subordinate potash felspar; consists of green hornblende and acid labradorite with some biotite, orthoclase and quartz.
- (e.) Augitediorite, with colourless augite as well as brown hornblende.
- (f.) Micadiorite: a rare type; reddish brown mica, felspar, and quite subordinate green hornblende.

(4.) Gabbros:

In hand specimens these are medium to coarse-grained dark grey or black rocks, with usually a greasy lustre.

The essential constituents are a lime-soda felspar—from labradorite to anorthite—and a pyroxene, which is usually diallage. Some of the rocks contain olivine, others hypersthene, and some others both of these, in addition to the essential minerals.

At times one or other of the chief constituents may completely fail, so that there may arise either a pure labradorite felspar rock or a pure pyroxene rock. The felspars are in hand specimens usually dark-coloured and translucent and in columnar crystals. In polarised light they show very marked lamellation. The diallage is characterised by a bronzy sheen on the crystal faces, known as "schiller."

Varieties:—

- (a.) Typical gabbro: with labradorite or anorthite and diallage.
- (b.) Quartz gabbro: with basic plagioclase, diallage, and quartz.
- (c.) Olivine gabbro: with diallage, labradorite, and olivine.
- (d.) Norite: with labradorite and a rhombic pyroxene.
- (e.) Olivine norite: the above with olivine in addition.
- (f.) Anorthosite: with labradorite alone from failure of the diallage. This rock is often black and shows a beautiful iridescence on the surface of the felspar.
- (g.) Pyroxenite: with pyroxene alone from failure of the felspar.
- (h.) Troctolite: with labradorite and olivine from failure of the pyroxene.
- (i.) Saussurite gabbro: in which the lime-soda felspars have by pressure been partially or wholly altered to a granular mixture of albite, zoisite, epidote, actinolite, etc., while the original pyroxene has also been more or less altered to urallite.

(5.) Peridotites:

Crystalline rocks, of which olivine is the chief constituent and from which felspar is typically absent. In many cases they are only local varieties of olivine gabbros and norites, as is shown by the gradual transitions which can be seen from one type to the other. In hand specimens they may be coarse-grained, dense black, heavy rocks; dark-greyish black, with the appearance of typical gabbros; or, when largely composed of olivine, yellowish green and more or less translucent.

Varieties.—Though many names have been suggested to describe rocks showing slight variations from the type, it will be sufficient to separate two modifications only:—

- (a.) Peridotites: consisting almost wholly of olivine without felspar.
- (b.) Pierites: with olivine and a basic felspar and one or more of the ferro-magnesian, such as—hornblende, augite, hypersthene, enstatite, mica.

The varieties of (a) and (b) can usually be sufficiently described by prefixing the name of the ferro-magnesian which occur in addition to the olivine and plagioclase: *e.g.*, hornblende-peridotite, hornblende-pierite, augite-pierite, etc. One variety, however, deserves special mention,

Dunite: a rock consisting entirely of olivine with occasional grains of chromite.

Especially worthy of note at this point is the fact that, when these highly basic or magnesian rocks are acted on for a long period by atmospheric agents, a chemical alteration takes place in the olivine and sometimes in the hornblende and augite. This results in the formation of Serpentine, which are therefore to be regarded largely as the alteration products of peridotites and allied rocks.

(B.)—HYPABYSSAL ROCKS.

Also sometimes called Intrusives):

Some petrologists, as Harker remarks, are content to divide the igneous rocks into two great groups according as their structural characters indicate consolidation under deep-seated or under superficial conditions. The former are the Plutonics, the latter are termed Volcanics. Others, however, recognise another group with characters more or less intermediate between these two, and to this group the name Hypabyssal is given.

The rocks belonging to this group are generally regarded as having been injected from below through cracks and pipes in the overlying material—whether sedimentary or not—or of having flowed as a magma between the strata of stratified formations. In consequence of their position, they have solidified under considerable pressure and through cooling from contact with colder surfaces. Owing, further, to these conditions of consolidation, a porphyritic structure has been produced in the rocks, *i.e.*, some of the constituents have separated out, while the remainder of the magma was in a fluid state, with the result that, when, later on, the residues under stable conditions crystallised in small more or less equidimensional forms, the first minerals to separate stand out usually as large well-formed crystals in a mass of small polygonal plates or needles. These well-shaped crystals are known as phenocrysts, and the material in which they lie embedded is spoken of as the ground mass. It frequently occurs, however, that the porphyritic character is not pronounced, in which case the rocks approach in structure those of plutonic character. In other cases there is a residue of glassy, non-crystalline, material which links the rocks then with the volcanics. As moreover, the latter also have the porphyritic character typically developed, it will be evident that in the absence of any well-defined set of characters peculiarly their own, the hypabyssal rocks cannot be separated rigidly from those of either plutonic or volcanic origin.

Families:—

- (1.) Acid Hypabyssals or Intrusives.
- (2.) Porphyries and Porphyrites
- (3.) Dolerites.
- (4.) Lamprophyres.

(1) Acid Intrusives:

These are generally white, greyish, or pink-coloured rocks. They are characterised by phenocrysts of orthoclase and oligoclase in columnar or square forms. Quartz phenocrysts may or may not be present. Brown biotite also occurs, sometimes a green hornblende or augite, or rarely and only in rocks rich in soda, aegerine may be found. The ground-mass is usually a fine-textured mosaic of quartz and felspar, which may be so fine as to be irresolvable under the microscope. It may be partly or wholly glassy.

Varieties:—

- (a.) Quartz-porphyry: phenocrysts of quartz and felspar in a ground mass of varying degree of fineness, and composed of the same two minerals. Flakes of biotite are also usually found.
- (b.) Felspar-porphyry: phenocrysts of quartz absent.*

* This term has now fallen into disuse, except, perhaps, as a field term. If the rock has no quartz phenocrysts but contains quartz in the ground-mass, it is still a quartz porphyry. If it has no quartz in the ground-mass, it is an albite, an anorthosite, or one of the varieties of porphyry described later.

- (c.) Granite-porphyry: quartz wanting amongst the phenocrysts, which are mostly of oligoclase; a ground mass of irregular plates of quartz and crystals of felspar. Biotite or augite may also be present. The distinction from quartz porphyry is very slight, and probably the latter term could be used for most rocks of this variety.
- (d.) Elvan: a very fine-grained to irresolvable ground-mass with large phenocrysts of felspar and quartz and often two micas.
- (e.) Granophyre: The variety with phenocrysts of felspar and with micrographic intergrowths of felspar and quartz and regular radiate aggregates of felspar fibres. These structures indicate a transition to the volcanic rhyolites. This is a term which, according to some petrologists, should be changed to granophyre quartz porphyry. It has, however, been so sanctioned by usage that it has acquired a rather definite structural as well as mineralogical meaning, and while the leading English authorities are content to use it there seems no need for a change.
- (f.) Felsite: a term which has been applied indiscriminately to any very fine-grained rock not obviously of sedimentary origin. It has been defined as a quartz porphyry in which the phenocrysts are absent, or in very small quantities, and in which the grain is very fine. It is more accurately defined as an acid rock containing no phenocrysts, but composed entirely of a small mosaic of quartz and felspar, whose individual grains cannot as a rule be distinguished. This base has been held to result from the devitrification of glassy material, and consequently a felsite may have been originally either a hypabyssal or a volcanic rock. If phenocrysts of quartz are distinguishable, the rock is called a quartz-felsite.†
- (g.) Microgranite: a quartz porphyry, with a microscopically fine-grained ground mass, and hence hardly worthy of separate notice.
- (h.) Pitchstones: phenocrysts of glassy orthoclase (sanidine), quartz, oligoclase, and augite in a glassy ground mass. The phenocrysts may, however, be almost all absent.
- (i.) Quartz Keratophyre: an acid intrusive, rich in soda, with predominating felspar and quartz, and with or without porphyritic structure. The felspar is albite or anorthoclase.

(2.) Porphyries and Porphyrites:

These range in colour from white to green or dark green and black; nearly all, however, show phenocrysts of felspar.

The *Porphyries* are characterised by phenocrysts of alkali felspar, brown biotite, or a pale or colourless augite. The ground mass is of fine texture and consists essentially of felspar. The rocks, therefore, correspond more or less to the syenites of the Plutonic group, and, as in the case of the latter, varieties occur rich in soda and distinguished by the presence of nepheline.

Varieties:—

- (a.) Porphyry or Syenite-porphyry: with an alkali felspar in felspar intergrowths, with hornblende, and with or without biotite: sometimes with augite.
- (b.) Orthoclase-porphyry or orthophyre: with a soda pyroxene or amphibole.
- (c.) Rhomb-porphyry: rhomb-shaped phenocrysts of anorthoclase in a ground-mass of short prisms of alkali-felspar, and grains of augite.
- (d.) Bostonite: composed almost wholly of felspar (a soda variety) with or without phenocrysts; ferro-magnesian absent.

† In the writer's opinion, the term "felsite" for this variety should be abandoned in favour of "felsic quartz porphyry."

- (e.) Tinguaitite: with the composition of nepheline syenites and phonolites; tabular phenocrysts of orthoclase in a fine ground-mass of orthoclase, nepheline, and aegerine.

The *Porphyrites*: correspond in general to the diorites of Plutonic rocks, and are characterised by a lime-soda felspar (labradorite), with hornblende, augite or mica. Usually there are felspars and ferro-magnesian in large or small phenocrysts in a ground mass of felspar and ferro-magnesian needles.

The varieties depend on the presence of one or other of the ferromagnesian, *e.g.*, hornblende-porphyrityte, augite-porphyrityte, etc. etc.

(3.) Dolerites:

Greyish black or black rocks generally of medium to coarse grain.

The term is now used to embrace hypabyssal rocks with affinities to the gabbros but with finer texture, with an absence of diallagic augite, and with a characteristic relation between the felspar and augite, which are the two chief constituents. Formerly, the term diabase was applied to them and signified either rocks more or less weathered and of comparatively old age, or weathered dolerites.

The term *Dolerite* was restricted to rocks of volcanic origin and of Tertiary or later age. It has been shown, however, that there is no essential difference in the rocks either in composition or in structure corresponding to a difference in age, and the term diabase has now been abandoned by English petrologists in favour of "dolerite" for all rocks with certain peculiarities irrespective of age.

The essential minerals are a plagioclase felspar—from oligoclase to anorthite but usually labradorite—in well-outlined columnar crystals, and augite either brownish or colourless and without crystal boundaries. An important characteristic is the almost invariable presence of ophitic structure, *i.e.*, the shapeless plates of augite mould or partly wrap round or occupy the spaces between the well crystallised felspars.

Varieties:—

- (a.) Dolerite proper: with plagioclase, augite, and ophitic structure.
- (b.) Olivine-Dolerite: with grains or crystals of olivine as well.
- (c.) Quartz-Dolerite: with quartz, often original.
- (d.) Teschenite: with purple augite, brown mica, altered felspars and analcite.

(4.) Lamprophyres:

Characterised by an abundance of brown mica, hornblende, or augite in thin flakes or needles, a low silica percentage, and a considerable amount of alkalis, especially potash. Decomposition is very prevalent in these rocks. The felspars are not usually in phenocrysts and are very much weathered.

Varieties:—

- (a.) Minette: with orthoclase and an abundance of flakes of biotite.
- (b.) Kersantite: with plagioclase instead of orthoclase.
- (c.) Vogesite: with orthoclase and either hornblende or augite instead of mica.
- (d.) Camptonite: with plagioclase instead of orthoclase, and with hornblende or augite.
- (e.) Monchiquite: devoid of felspars; with olivine, purple augite and analcite.

(C.)—VOLCANIC ROCKS.

The rocks of this division are those which, extruded from the earth's interior, have consolidated from the molten state under the atmospheric conditions of comparatively rapid cooling and low pressure, *i.e.*, as lavas. Many of them have no doubt originated from

submarine eruptions, and in these cases when the depth of water above the vents has been great and the pressure consequently considerable, they have acquired characters similar to those of hypabyssal rocks. The majority, however, have solidified on the surface of the earth, and in all cases have characters arising from the circumstances of cooling which mark them off clearly from Plutonic rocks. The characters more or less peculiar to this division are as follow:—

- (a.) The presence of a glassy residue. There are, it is to be observed, not only hypabyssal rocks which also have this, but volcanics in which it is not found. These exceptions are, however, so rare that the character may still be regarded as distinctive.
- (b.) A porphyritic structure with evidence of two distinct periods in the crystallisation of the minerals. Thus we find, say, in basalts large phenocrysts of augite in a ground mass comprised of well-shaped or granular crystals of the same mineral. The difference in time of the respective crystallisations is shown by the size of the phenocrysts; those which have formed before or in the early stages of extrusion, being under conditions of slow cooling, are larger than those of the ground mass which, solidifying on the surface, have cooled very rapidly.

It will be obvious, however, that there is no great difference between the phenomena presented by the hypabyssals and by the volcanics, in some cases hardly any. It is for this reason that some petrologists, taking no account of field occurrences, have, as previously mentioned, been in favour of making only two divisions of igneous rocks, *viz.*, plutonics and volcanics.

The families of the division generally recognised are:—

- (1.) Rhyolites.
- (2.) Trachytes and Phonolites.
- (3.) Andesites.
- (4.) Basalts.
- (5.) Alkaline Basalts.

(1.) Rhyolites:

Among these are placed the lavas of acid composition. The family, therefore, corresponds generally in chemical composition to the granite family of the plutonic rocks, but differs from it widely in structure.

The rocks, which are usually white, yellow, or grey, and may have a banding due to layers of slightly different composition, have usually a porphyritic or a glassy structure, with quartz and alkali-felspars as the chief constituents. Phenocrysts may, however, quite fail. Usually, but not abundantly, there also occurs a ferro-magnesian, generally biotite. In the case of only one group, rich in soda, there is a pyroxene, aegerine.

Characteristic of the group, though not always present, are spherulitic structures—small circular or radial aggregates of fibres of felspar separated by the forms of silica, tridymite, or rarely quartz.

Varieties:—

- (a.) Rhyolite: with phenocrysts of orthoclase, microcline, or oligoclase, with or without some of quartz and with or without biotite, in a ground mass of quartz and felspar, which may be coarse or fine-grained or partly glassy.
- (b.) Spherulitic rhyolite: with spherulitic structures, large or small.
- (c.) Obsidian: a term which has been applied both to the glassy varieties of rhyolites and to those of the less common trachytes and dacites. The term "rhyolite glass" has been proposed for the very acid varieties, but has not met with general acceptance. It is difficult to restrict obsidian to the glassy forms of rhyolites

alone, because the distinction from trachyte and dacite glasses is very difficult. At present, therefore, the term is rather loosely applied. Some pitchstones of acid composition should also really come under obsidian.

- (d.) Pantellarite: with anorthoclase feldspar, and the soda pyroxene aegerine, or a soda amphibole.

(2.) *Trachytes and Phonolites:*

Trachytes are lavas with a lower percentage of SiO_2 than rhyolites, are usually greyish white or pinkish and sometimes brownish, vesicular and often with a rough surface. The essential minerals are alkali-feldspars and ferro-magnesian in small amount. Quartz is generally absent. The feldspars are sanidine, orthoclase, or oligoclase. The ferro-magnesian is usually biotite, but may be hornblende or augite.

In contrast with the rhyolites the rocks are rarely at all glassy or spherulitic. The ground-mass consists of very small thin feldspars with a more or less parallel disposition in consequence of flow, the "trachytic" structure.

Varieties:—These are based on the ferro-magnesian present—

- (a.) Trachyte: with biotite.
- (b.) Hornblende Trachyte.
- (c.) Augite Trachyte.
- (d.) Tridymite Trachyte with tridymite, a rare form of silica.

Phonolites:

Corresponding to the nepheline syenites of the plutonic rocks and the tinguaites of the hypabyssals, there is a family of volcanics similarly rich in soda—the *Phonolites*. These may be regarded as trachytes richer in alkalis than the normal type, due to the presence of feldspathoid minerals as well as alkali feldspars. The name was originally given owing to a supposedly characteristic property of emitting a ringing sound when struck. Not only, however, do some phonolites not do this, but other rocks of quite different composition also possess this property. The feldspathoids present are nepheline and leucite, with sodalite and nosean. In addition a soda pyroxene, aegerine, also occurs.

Varieties:—

- (a.) Trachytoid Phonolite: with trachytic structure in the ground mass and little nepheline.
- (b.) Nephelinitoid: with ground mass of many small squares of sanidine and nepheline and grains of aegerine.
- (c.) Leucitophyre: with leucite, nepheline, sanidine, aegerine, and nosean.

(3.) *Andesites:*

The characteristic minerals are a lime-soda feldspar and one or more ferro-magnesian minerals. Usually quartz and alkali feldspars are absent.

The feldspars most commonly found are andesine and labradorite, both in phenocrysts and in the ground mass. The coloured constituents are mica, hornblende, augite, and hypersthene.

The structure of the ground mass may be trachytic or partly glassy; the feldspars may be in abundance in it as short columns, while the ferro-magnesian minerals may occur in grains as well as crystals. In one variety, quartz occurs as phenocrysts.

Varieties:—These are classified according to the dominant coloured constituents:—

- (a.) Hornblende-andesite: with phenocrysts or grains of hornblende.
- (b.) Augite-andesite: numerous phenocrysts of plagioclase and augite with both minerals in the ground mass.
- (c.) Hypersthene-andesite: with the rhombic pyroxene hypersthene present.
- (d.) Mica-andesite: commonly with biotite in flakes.

- (e.) Dacite: an andesite with original quartz, sometimes as well-shaped squarish phenocrysts, sometimes as grains and sometimes in the ground-mass. Feldspar, hornblende, and biotite may also be present in well-shaped forms. The ground-mass is sometimes glassy.

(4.) *Basalts:*

Rocks with a low percentage of silica, a feldspar rich in lime, augite, and olivine. The feldspar is usually bytownite or anorthite as phenocrysts, and labradorite in the ground-mass.

Augite occurs both as phenocrysts, and in grains as a constituent of the ground. Olivine appears in rounded crystals or patches. The feldspar of the ground is in thin lath-shaped forms of varied orientation. The ground mass may be wholly, partly, or not at all glassy.

The rocks are generally dense black, fine-grained, and show yellowish-green patches of olivine. Occasionally, vesicles are to be seen partly filled with calcite or zeolites.

Varieties:—

- (a.) Olivine-Basalt: olivine, plagioclase, and augite.
- (b.) Basalt without olivine.
- (c.) Tachylite: Basaltic glass, a purely glassy type.
- (d.) Variolite: vitreous with an imperfect spherulitic structure.

(5.) *Alkaline Basalts:*

These are marked off in general by the fact that, while having the structure, constituents, and low acidity of ordinary basalt, they have in addition, or replacing the feldspar, one or more of the feldspathoid minerals leucite, nepheline, melilite, or well as occasionally anorthoclase and sanidine. They are, therefore, rich in alkalis. In appearance they are very similar to ordinary basalts.

Varieties:—

- (a.) Leucite and Nepheline-tephrites: in which the feldspathoid only partly takes the place of the feldspar and olivine is absent.
- (b.) Leucite and Nepheline-basanites: in which the same is true while olivine is present.
- (c.) Leucitite or Nephelinitite: in which the feldspathoid completely takes the place of the feldspar and olivine is absent.
- (d.) Leucite or Nepheline-basalt; in which the same is true and olivine is present.
- (e.) Trachydolerite: olivine, augite, leucite, anorthoclase, nepheline.

2.—SEDIMENTARY ROCKS.

By the mechanical action of wind and water as well as by the chemical action of the gases in the atmosphere and substances gaseous and solid dissolved in streams and rivers, igneous rocks are gradually broken down and the comminuted fragments are distributed on the surface of the earth, or more commonly under bodies of water in various forms characterised, in general, by some sort of stratified arrangement. The rocks formed by pressure or cementation or by the action of animals from this varied distribution of materials are spoken of as *Sedimentary Rocks*. They are generally characterised by a fragmental structure, and, in the rounded or angular forms of the constituents, in the relation of the constituents to one another and in the nature of the constituents, usually bear evidence of their detrital or fragmental origin. They have been classified as follows:—

- (A.) Arenaceous Rocks—coarse detrital deposits.
- (B.) Argillaceous—fine-grained.
- (C.) Calcareous—consisting largely of carbonates of lime and magnesia.
- (D.) Fragmental—composed of angular fragments of other, usually volcanic, rocks.

(A.) Arenaceous.—The varieties of note are:—

- (a.) Sandstone: mostly of rounded grains of quartz with a cementing material which may be siliceous, ferruginous, or calcareous.
- (b.) Grit: very similar but the original grains are angular.
- (c.) Greywacke: a complex rock of quartz, felspar, and other minerals and rocks united by a cement usually siliceous.
- (d.) Arkose: a deposit formed directly from the destruction of granite or gneiss and with abundant felspar. The surface of some weathered granites may appear like a gritty sandstone, but the angular nature of the material, together with the large amount of felspar present, is more or less distinctive.
- (e.) Quartzite: That of sedimentary origin consists of quartz grains with a quartz cement.

(B.) Argillaceous:

- (a.) Clay: when enough water is retained for the deposit to be plastic.
- (b.) Mudstone: a rock with no marked fissile character and not plastic.
- (c.) Shale: a rock that will split along the original laminae of deposition.
- (d.) Argillite: a compact massive sort of shale that has been baked, with incipient recrystallisation.
- (e.) Slate: when the original lamination due to stratification has been superseded by a new structure due to pressure and called cleavage. (See later.) This is usually inclined at a high angle to the planes of deposition.
- (f.) Phyllite: a clay-slate in which by dynamic metamorphism there has been a development of mica along the cleavage planes. (See later.)

(C.) Calcareous:

Various limestones, which may be partly siliceous, dolomitic, oolitic, shelly, chalky, not markedly crystalline, or wholly crystalline as marble. This group is not detrital, but derived generally from the precipitation of lime dissolved in water, or from its extraction by organisms.

(D.) Fragmental:

- (a.) Tuffs: more or less compacted deposits of volcanic ejectamenta, such as bombs, lapilli, and rock fragments. Some have evidently been laid down under water. They may be of various compositions depending on the lava with which they are connected; *e.g.*, Rhyolite tuffs, andesitic tuffs, etc.
- (b.) Breccia: compacted aggregations of angular rock fragments of igneous origin. If the fragments are rounded, the rocks are volcanic conglomerates.

3.—METAMORPHIC ROCKS.

By the term "metamorphism" is meant the change in previously existing rock masses which results in the production in them of new minerals, or new structures, or both. It was formerly applied only to those stratified rocks which, from deep burial in the earth and the consequent pressure and influence of the earth's internal heat, have by partial or complete fusion assumed structures and compositions resembling those of plutonic rocks. Of late years, however, it has been shown that, not only are there to be found more or less superficial sedimentary rocks which have been partially or completely altered by the action of heat alone, or by heat and pressure, but there are igneous rocks themselves the structure, and to some extent the mineral composition, of which can be shown beyond doubt

to have been altered by earth movements of considerable magnitude after the consolidation of the original rock. These movements are those associated in some cases with the intrusions of very large dykes, but chiefly with the formation of folds and with mountain building.

Further, the term has lately been extended even to include those cases in which alteration of the rocks has been largely chemical and due to such atmospheric agencies as extremes of heat and cold, wind and percolating meteoric water in which carbonic acid and various salts have usually been dissolved. It has been found—for instance in the Iron-bearing Series of Lake Superior—that, owing solely to the action of weathering and to that replacement of minerals by others known as metasomatism, what were originally felspathic grits, sandstones, and greywackes are now represented by fine-grained mica schists, while former cherty carbonates have been converted into magnetite-schists, actinolite-schists, and so on.

These rocks have not received anything approaching the amount of study that has been bestowed on those directly of igneous origin and consequently no very satisfactory classification of them has yet been evolved. That at present in use regards the rocks largely from the point of view of origin and is as follows:—

(A.) Rocks produced by Atmospheric Metamorphism.

(B.) Those due to Contact Metamorphism.

(C.) Those due to Regional Metamorphism.

Under Atmospheric Metamorphism are included those rocks due to the weathering action of water with dissolved material and the gases of the atmosphere.

Under Contact Metamorphism are included not only those rocks whose characters are due in part to the heat of deep burial and to pressure, but also and much more commonly those chiefly sedimentary rocks which have been so affected by molten igneous intrusions in the form of dykes, sills, or laccolites, as to have their original characters modified or obliterated by the development, at times, of a different structure and of new minerals.

By Regional Metamorphism is meant the changes produced in rocks of wide areas by the heat and pressure of deep burial, by folding and mountain-making movements. Formerly applied as already stated only to sedimentary rocks, the term has been shown to have in no less degree an application to those of igneous origin; and indeed the resulting rocks in both cases are often distinguishable only with great difficulty.

Before going on to outline the chief varieties under the three divisions already mentioned, as the products generally, though not invariably, have a foliated, leaved, or banded structure and are commonly known as slates, schists, and gneisses, it will be as well to make as clear as possible the meaning and extent of application of these terms.

Slate:

This is a term which has been used and is even now being used with two distinct significations—a structural and a mineralogical. Strictly speaking, a slate is a rock of sedimentary origin in which, besides the parallel lamination caused by a deposition in still water, there is a second series of planes of parting called slaty cleavage, due to the fact that, subsequent to consolidation, the rock has been subjected to pressure. This second series may or may not be parallel to the first, and is usually at a high angle to it. It is, moreover, due to the production of new minerals and to the flattening and parallel orientation of them and of some of the original minerals at right angles to the maximum compression by which the rock has been affected. Formerly, a clay slate signified a rock in which the material was supposed to be almost wholly detrital matter; but it has now become evident that in clay slates and even in shales there has been a considerable amount of mineral change.

No sharp line can therefore be drawn between true slates and phyllites; perhaps the only noteworthy difference is that in the latter there has been a development of mica along the cleavage planes

which is in general noticeable to the eye, as a glossy sheen on the surface. They are, therefore, to be considered as mica schists on a small scale, and the intermediate link in a series from slate to mica schist.

The term slate, with a purely structural signification, has also been applied to rocks which are in reality hornblende schists or similar rocks with a slaty structure. These are to be described more accurately as slaty hornblende schists, slaty chlorite schists, and so on.

Schists and Gneisses.

In the use of these terms also a considerable amount of confusion prevails owing to their being used both in a structural and in a mineralogical sense. Broadly defined, Schists are those cleavable rocks, the cleavage pieces of which are like one another and the mineral particles are for the most part so large as to be visible to the naked eye. The thin plates which resemble one another are called folia, and a rock is sometimes spoken of as foliated. This definition is based purely on structural characters.

As, however, the first schists to be frequently noted were those of which the constituents were always quartz and mica, and because quartz was soon shown to be equally as important as the mica, if not more so, its presence was assumed to be invariable and the rocks were termed simply mica schists. Later on, it was found that other minerals instead of mica also formed part of schists, e.g., hornblende, chlorite, etc.; these were accordingly described as hornblende schists, chlorite schists, and so on, the assumption being again made that quartz was the other constituent.

A little study of these latter rocks, however, soon made it obvious that quartz was often only sparingly, if at all, represented, its place being frequently taken partly or almost wholly by felspar. Such terms as hornblende schist then came to mean rocks with schistose structure in which the constituents were hornblende and other unidentified minerals. The mineralogical definition of schist therefore lost its significance. The German petrologists then stepped in and, in the case of those schistose rocks in which the presence of felspar as an important mineral could be proved in addition to that of quartz, proposed to apply the term "Gneiss." The latter, therefore, amongst German petrologists signifies a rock of schistose or foliated structure in which the alternate folia are generally composed of one or more ferro-magnesian minerals and a mixture of quartz and felspar. The presence of a ferro-magnesian mineral, however, is not invariable, its place being frequently taken, especially among those gneisses which have arisen from the metamorphism of sediments, by sillimanite, cordierite, etc.

"Gneiss" has a considerable currency on a structural basis as a banded rock, the bands of which are petrologically unlike one another and consist of interlocking mineral particles. It is further defined as possessing a banded and streaky character due to the association of different lithological types in one rock mass, or to the occurrence of bands or lentils particularly rich in some particular constituent of the rock.

To clear up the confusion between the terms, Van Hise has suggested that the term schist should be restricted to its structural meaning as already described; that gneiss should also be applied in its structural sense and should include all finely crystalline rocks whether of igneous or of aqueous origin. Where the individual minerals are recognisable to the naked eye, and where the different lithological types are clearly enough defined, as in coarse-grained gneisses, this distinction would no doubt prove of service, but where it is a question of fine-grained rocks, the discrimination becomes difficult. It appears to the writer that it would be of greater service to adopt the German definition of gneiss and to make the distinction between gneiss and schist rest partly on structure but largely on the amount of felspar and quartz developed in the rock.

A Schist would, therefore, mean a rock with a foliated structure, the foliation being due either to thin banding in one mineral alone—usually a ferro-magnesian—or to thin platy alternations of a ferro-magnesian and quartz or felspar.

A Gneiss would signify a rock also with a foliated structure, the foliation, however, in all cases being due to bands of different minerals or of a mixture of minerals, and both quartz and felspar in sensibly equal and in important quantities being present either in bands or as a mixture.

Even these definitions admit of considerable latitude, and it will be sometimes difficult to say whether a given rock is strictly a gneiss or a schist.

The varieties produced by different metamorphic agencies will now be considered.

(A.) ATMOSPHERIC METAMORPHISM.

The sedimentary rocks as a whole are examples of this process, i.e., the formation of quartzites, the recrystallisation of some limestones, the formation of many dolomites, slates, etc. More noteworthy, however, is the production, according to Van Hise, by chemical changes alone of crystalline schists on a large scale from feldspathic sandstones, greywackes, etc.

We may include here also those rocks due more obviously to the action of the atmosphere and percolating waters, such as:—

Kaolin: from the decomposition of the more acid rocks, such as granites, quartz porphyries, etc.

Laterite: from superficial decomposition by the leaching out of the alkalies from the felspars, the oxidation of the ferro-magnesian mineral, etc.

Serpentine: from the chemical alteration of highly magnesian rocks such as those rich in olivine.

Talc Rocks: due in part to chemical alteration of non-aluminous hornblende and pyroxenes.

Some Chlorite Rocks: due to alteration (largely chemical) of aluminous hornblendes and pyroxenes.

(B.) CONTACT METAMORPHISM.

The most common examples of this action are those in connection with igneous intrusions through sedimentary material, and it will be sufficient here to consider these. The changes produced lie more in the production of new minerals than of new structures. The variations in the minerals formed from the outermost limit of the action of the molten mass to its actual border have been carefully studied and definite results have been obtained, but for our present purpose a general account is all that is necessary. The chief new minerals produced are:—muscovite, cyanite, sillimanite, staurolite, rutile, chiastolite, diopside, garnets, actinolite, and tourmaline.

The results of the action can best be seen by considering the effects of heat on the different kinds of sedimentary material:—

- (i.) On Arenaceous Rocks: In this case are produced quartzites or gneisses and schists of various sorts, such as sillimanite gneiss, cordierite gneiss, garnet schist, etc.
- (ii.) On Argillaceous Rocks: Those with carbonaceous material with advancing metamorphism give rise to spotted slates, chiastolite slates, staurolite and cyanite slates, and finally perhaps mica-schists.
- (iii.) On Calcareous Rocks: These when pure may become crystallised as marbles. When impure, they may become filled with garnets, with amphiboles such as tremolite, actinolite, etc.; also by sphene, scapolite, felspar, etc. When very impure, they may give rise wholly to a lime-silicate rock.

The results of the thermal metamorphism of igneous rocks, though interesting, need not be described here.

(C.) REGIONAL METAMORPHISM.

The rocks which come under this head are all more or less crystalline and generally decidedly foliated, though some amphibolites and marbles are often quite massive. The foliations are due to the arrangement of the constituents in parallel lines. The terms, bedded and stratified, are, correctly speaking, inapplicable to them, since the banding is due to dynamic processes and there is no necessary connection with original sedimentation.

Let it be supposed that, in a more or less confined space, there is a large mass of rocks, originally plutonic or igneous, buried beneath a great thickness of overlying strata, and so deep that the limits of resistance of the rocks are exceeded, yet they are prevented from flying apart. The rocks must yield by internal crushing and if movement is possible laterally or vertically, they will flow as a mass. It is to this flow, accompanied by shearing, that the foliation of metamorphic rocks is largely due, though it must be noted that the foliations do at times correspond to original bedding.

During the shearing and flow movements, it may happen that some crystals withstand the strain better than others, so that while the latter flow, the former are merely drawn out into eye-shaped or lenticular forms and give rise to such rocks as "augen-gneiss," etc.

In general, too, a mineralogical as well as a structural change takes place. The commonest example is the production of the fibrous hornblende—uralite—at the expense of a pyroxene. Sedimentary rocks, also, subjected to previously described conditions of deep burial are entirely recrystallised and usually so far lose their original characters as to afford no clue to their origin.

The rocks due to Regional Metamorphism may be classed as follow:—

(i.) Slates, Limestones, and Dolomites.

(ii.) Gneisses and Schists.

(i.) *Slates, etc.*—These, as has already been pointed out, may be produced by thermal or contact metamorphism of argillaceous and calcareous materials. The change is due partly to heat and partly to pressure so that the rocks may be placed amongst the results of either contact metamorphism or regional metamorphism.

(ii.) *Gneisses and Schists:*

Gneisses:—These may be rocks resulting from the thermal metamorphism of sedimentary rocks and characterised by the presence of particular minerals, such as cordierite gneiss, sillimanite gneiss, etc., or they may arise from the bodily deformation of plutonic rocks.

From the definition of gneiss as employed here, those of igneous origin may have the chemical and mineralogical composition of acid, intermediate, or basic rocks, *i.e.*, they may be derived from granites, syenites, diorites, or gabbros.

Varieties:—

(a.) Sillimanite, cordierite, etc., gneisses, derived from sediments by thermal metamorphism.

(b.) Granite gneiss: with the constituents of granite and the characteristic structure.

(c.) Hornblende and pyroxene gneisses, resulting from the deformation of rather basic igneous rocks.

In this division, too, may be included:—

(d.) The Porphyroids: quartz porphyries with a roughly schistose structure and a development of sericitic mica.

(e.) Granulites: fine textured rocks consisting of a granular aggregate of quartz, feldspars, etc., and highly characteristic garnet, which gives them a pinkish tinge. They are due to the crushing of various igneous rocks.

(f.) Eclogites: consist of grass green augite and red garnet, with various other minerals. Their affinities are held to be with the gabbros.

Schists.—The general structure and composition of these have probably been sufficiently described already. There are several noteworthy varieties:—

(a.) Mica-schist.

Quartz-schist.

(b.) Chlorite-schist.

(c.) Tale schist.

(d.) Epidiorite.

(e.) Amphibolite.

(f.) Hornblende-schist.

(g.) Hornblendite.

(a.) Mica Schist: muscovite or biotite or both in bands or films with alternate bands of quartz.

Quartz-schist: quartz rocks with more or less of a parallel and cleavable structure and with parallel flakes of silver-white sericite. With increase in the amount of mica, they pass into mica schists. The colour is white, yellowish-white or yellow.

(b.) Chlorite-schist: marked by the presence of the green micaceous mineral in large amount. Some quartz often present and, at times, plagioclase, tale, and epidote. Schistose structure fairly distinct.

(c.) Tale-schist: characterised by a large amount of tale and some quartz with or without a little feldspar; frequently calcite, dolomite, or chlorite is present.

(d), (e), (f), and (g) can best be considered together. They are marked by the presence of hornblende in large amount.

Under the action of dynamic metamorphism, those basic igneous rocks whose chief ferro-magnesian is pyroxene, such as the gabbros and dolerites, pass readily into hornblende rocks with the development of a greater or less degree of schistosity. Following on the demonstration by Teall of the passage of a dolerite into a hornblende schist, it has been found in several other localities that all gradations can be traced between an augite-plagioclase rock such as dolerite and a more or less pure hornblende rock. Since some of these transition forms possess a fairly distinctive character, special names have been given to them, but it must be remembered that it is often difficult to say with certainty to which variety a particular rock belongs. In accordance with the interpretations of the Geological Survey of Great Britain, we may describe these varieties as follows:—

Epidiorites: Intermediate between the basic igneous rock and an amphibolite.

Plagioclase-hornblende rocks with or without a mineral of the epidote group, some quartz, and iron ores. According to structure, there has been a division of these rocks into two types:—

(i.) With lath-shaped feldspars and hornblende compact green or in aggregates with sometimes original cores of augite.

(ii.) Devoid of normal igneous structure, with feldspar in grains and the hornblende pale or dark green in spongy or raggedly outlined fibrous aggregates. A foliation may be noticeable.

Amphibolites: are hornblende-feldspar rocks either massive or more or less markedly schistose in which hornblende is the dominant mineral. The feldspar is frequently replaced by epidote, albite, zoisite, etc.

Hornblende-schists: hornblende abundant together often with a little biotite, augite, a plagioclase and iron ores. Quartz, except in veins, is rare. The hornblende is in prismatic, acicular, or platy forms.

Hornblendite: Rocks consisting almost entirely of hornblende to the exclusion of feldspar and quartz.

(III).—Classification of Rocks based on the percentage of Silica.*

Only the main families are here considered and correlated.

Class.	Plutonic.	Hypabyssal.	Volcanic.
Acid: over 65 per cent. SiO_2	Granite ...	Quartz-porphry	Rhyolite.
Intermediate acid: 60-65 per cent. SiO_2	Syenite ...	Porphyry ...	Trachyte.
Intermediate-basic: 55-60 per cent. SiO_2	Diorite ...	Porphyrite ...	Andesite.
Basic: 45-55 per cent. SiO_2	Gabbro ...	Dolerite ...	Basalt.
Ultrabasic: under 45 per cent. SiO_2	Pierite, Peridotite	... ..	**

* See Mennell, Introduction to Petrology, p. 84. ** The rare "Lamprophyte" has been regarded as the correlative.

The Physiography

of

Western Australia

In its Relation to Prospecting and Mining.

by

J. T. Jutson.

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Introduction.

Relation of the Topography to Prospecting and Mining.

Relation of the Topography to Water Supply.

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CHAPTER III.

THE PHYSIOGRAPHY OF WESTERN AUSTRALIA IN ITS RELATION TO PROSPECTING AND MINING.

By J. T. Jutson.

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I.—INTRODUCTION.

The physiography of Western Australia has been described by the writer in Bulletin 61 of the Geological Survey of the State, to which reference may be made. As the idea of the present article is to show, as briefly as possible, the relations between the physiographic features of the State and prospecting, mining and certain questions of water supply, space does not permit of any general account of the physiography other than the short one following.

The main physical features comprise a vast plateau, which occupies almost the whole of the State, except for narrow coastal plains. In the interior, the plateau-character still subsists, but nearer the coasts, as in the Kimberley, North-West, and South-West divisions, this plateau has been so much cut into by rivers that it is now largely composed of hills and valleys. Inland, a series of "dry" or salt lakes occurs. These are very shallow depressions which receive the surface drainage after heavy rains. The water, however, quickly disappears; part evaporates and part soaks into the ground, leaving a smooth, bare surface, which often is covered by a film of salt; hence the term "dry" or salt lakes. Chiefly inland, some old drainage systems have been found buried beneath surface deposits. These are known as "deep leads," and they have, in places, been proved to be very auriferous.

Few mountains diversify the surface of the State. Ranges of high hills occur in the Kimberley division, but they are merely the remains of the great plateau. The most mountain-like group of hills in the State is the Stirling Range in the south, which rises sharply and to a considerable height above the surrounding country.

The coast line varies from a broken to a very smooth one. The coasts are often bordered by sand dunes, behind which lie lakes and lagoons usually parallel to the coast.

The coastal plains are low-lying, narrow belts. The Swan Coastal Plain to the north and south of Perth is one of the best known coastal plains and its strata provide abundant artesian water.

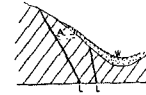
II.—RELATION OF THE TOPOGRAPHY TO PROSPECTING AND MINING.

(1) DISCOVERY OF METALLIFEROUS LODS.

The shape of the ground, the nature and thickness of the soil or other superficial covering, and the denseness or sparseness of the vegetation—all of which are largely influenced by the rainfall—have each an important effect on the outcrop and consequent discovery of metalliferous lodes.

(a) *Hills and valleys in good rainfall areas.*—In the South-West and Kimberley divisions, and to a less extent in the North-West, the ground is cut up into hills and valleys; there is, in places, a thick mantle of soil, and the vegetation is abundant. The result is that lodes tend to be hidden (Fig. 1). On the tops of the hills

Fig. 1.



Section showing two lodes (1), one outcropping on high ground, the other hidden by wash W. A=adit.

the soil may be stripped off, in this way showing the nature of the underlying rocks and any lodes contained in them (Fig. 1). Hard rocks frequently project even on soil-covered hillsides, and as lodes are often largely or chiefly composed of the hard substance, quartz, they may be found outcropping in such situations; or loose fragments may be observed, which may be traced to the parent lode. Similarly, the iron cap of some lodes may also there occur. Lodes may also actually crop out in stream beds, but the importance of the latter is the possibility of valuable minerals being found in alluvial deposits there, which, even if not payable in themselves, may lead to the discovery of a payable lode, if the mineral deposits be traced up-stream to a point above which no more can be found. The position of the lode is then limited to a certain area—unless the alluvial has been re-concentrated—and careful search by mere observation or by loaming up the hillsides, may enable the lode to be found on one side or other of the stream.* On the other hand, the non-discovery of certain minerals in stream-beds does not prove that lodes do not exist, as some metals are easily removed in solution.

(b) *Ridges and flats in dry areas.*—In the dry inland areas of Western Australia, in which is situated the great gold-bearing belt of the State, the country is a slightly undulating plateau, with various hills and ridges. The latter exist because they have been able to largely resist the weathering agencies, and such resistance has been often brought about by the toughening of the rocks, owing to the intrusion of other rocks and the formation of lodes (Fig. 2). The latter may therefore be expected to be frequently

Fig. 2.

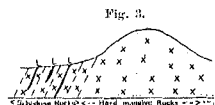


Section showing ridge of schistose rocks, toughened by lodes and dykes. (L) quartz lodes.

found in ridges—especially those of varied and changed rocks—and certainly many of the discovered Western Australian lodes so occur. Contrariwise, some hills, composed of rocks usually regarded as favourable for lodes, such as greenstones, have few or no lodes, although the latter may be fairly numerous in the lower country

* It, however, the minerals came from flat lodes, the latter may have been all worn away.

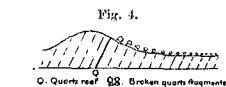
near by. The causes of this appear to be (1) the absence of cracks and fissures to contain the lodes in the higher rocks, and their presence in the lower ones; schistose rocks* are favourable for such fissures; (2) the easy wearing away of schistose rocks, unless they are specially strengthened by the introduction of much lode and other material, as pointed out above (Fig. 2); and (3) the resistance to wearing away of some non-schistose rocks even without lodes (Fig. 3). Schistose rocks are generally favourable for lodes, but because the rocks are schistose it does not necessarily follow that they will carry lodes.



Section showing low lying soft schistose rocks with lodes (L) and ridge of hard massive rocks without lodes.

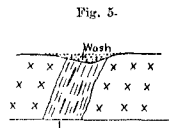
Dykes are often prominent features, and, as they may be gold or tin-bearing, or carry other minerals of value, such as topaz, amethyst and beryl, they should be sought for. Large quartz "blows" are usually barren, but may contain a gold-bearing band. "Jasper bars" form steep ridges with abundance of iron, and may contain quartz reefs and fault-lodes. Ironstone "blows" and ridges may carry gold-bearing quartz veins, and may yet be exploited for iron ores. The rock waste at the foot of ironstone hills and outcrops may conceal lodes.

(c) *Widespread occurrence of quartz fragments in dry areas.*—In the inland gold belt of Western Australia the scantiness of rain neither permits the formation of true river-valleys, nor the carrying away of the quartz fragments, which result from the breaking down of the reefs. This quartz, however, by slow movement, due largely to gravity, becomes very widespread over the surface of the ground (Fig. 4), and as the rain and the wind remove the fine soil on the surface, comparatively few of these quartz fragments become buried; but on the contrary, they are exposed to observation. Gold-bearing fragments ("floaters") may, as a result, be picked up, and perhaps be traced to the parent reef (Fig. 4).



Section showing how quartz fragments broken from a reef spread on to flats.

(d) *Floaters and loaming.*—The tracing of "floaters" and the practice of loaming are particularly valuable in Western Australia for the discovery of lode formations, and of the fault-lodes or "breaks," of which those at Boogardie are the type forms. A lode-formation is a band of altered country rock carrying gold (and perhaps pyrites and other minerals), and usually quartz veins and leaders. The lode-formation may, however, in some cases decay faster than the country itself, and may thus tend to be hidden under soil or wash (Fig. 5); but the quartz veins break down, and the frag-



Section showing a soft lode formation (L) (with quartz leaders) slightly hollowed out from the harder country and covered with wash.

ments may be found as "floaters" on the surface, leading to the discovery of the quartz veins, and also of the lode-formation itself, if it be

* Schistose rocks are those which possess thin parallel bands like leaves of a book, such bands being due to pressure since the original rocks were formed.

† Dykes were originally molten masses which have entered generally more or less vertical irregular fissures and there solidified into hard rock.

borne in mind that any band of country rock may possibly carry gold. Loaming might also lead to the same result. Similarly, with some of the small fault-lodes or "breaks," observation of the same rules may bring about the discovery of the "breaks." These "breaks" are short fractures crossing "jasper bars," which have usually been moved along the line of break, thus forming a fault. It is in the fissure caused by the break that the lode occurs. The lode usually consists of one or more thin quartz veins or "leaders," together with altered country rock, both of which may carry gold. Such lodes are, however, easily overlooked, especially where superficial deposits occur; hence the value of floaters and loaming. It may be remarked that within the last few years the latter process has had marked success in the Boogardie district.

(e) *Costeaning.*—Costeaning, that is, the cutting of a trench at right angles to the direction of a supposed or possible lode, is another method for discovering lodes. The object of costeaning is to find a new lode, or a continuation of a known one. This requires to be intelligently applied, as the labour is considerable. Thus, where there is no soil or "wash" a costean would not, as a rule, be cut. Similarly, on wide flats, away from known lodes, and where no alluvial gold has been won, costeaning would be merely "blind stabbing." It must usually be near some known lodes. Before commencing work, the general direction or strike of the known auriferous lodes of a district should be learnt. In some districts, different sets of quartz reefs, with different strikes, may occur; and one set, having a particular direction, may comprise almost all the gold-bearing reefs. Having this information, the most suitable course for the costean can be easily determined.

(f) *Use of geological maps.*—The mention of costeaning suggests the advantage of having a geological map of the district (when one has been made), and learning to use it intelligently. The more detailed maps of the mining districts show the direction or strike of the reefs, their underlie, the kind of rocks in which they occur, and whether many of the reefs are at or close to the junction of different kinds of rocks (often an important point), the nature and trend of any dykes, and the principal shafts sunk. A stranger to the district, using such a map, would see at once where the chief workings occurred, and, consequently, the position, direction and underlie of the chief lines of reef, the rocks in which they occurred, and whether any dykes that were mapped appeared to be specially associated with the reefs. With this information he could rapidly go over the ground. In the small scale maps of large areas, detail has to be omitted, but the boundaries of the different rock-formations are set out.

(g) *Drainage channels, etc.*—Any of the shallow drainage channels—whether natural or artificial—in the dry areas may have outcrops of the bed-rock, or of lodes, or may contain alluvial deposits that would lead to the discovery of a lode. Moreover, as no points, however apparently trifling, should be omitted that help to discover new lodes, mention might be made of the value of cart-wheel ruts in certain areas as aids in this direction. In portions of the chief goldfields there are extensive flats covered with soil, and so smooth and unbroken that they look as if the soil were of some thickness. A natural or an artificial cut may, however, show that the soil is not more than a few inches thick, and yet this film is in places sufficient to cover up lodes. Cart-wheel ruts often show the nature of the bed-rock, and may even disclose a lode. They are therefore worth examining.

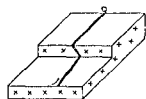
(h) *Determination of the bed-rocks.*—It is often of value to know the nature of the bed-rock. Thus, on the Western Australian goldfields most lodes have either been found right in the greenstone (the "diorite" of miners), or at or close to the junction of greenstone and granite. It is therefore important to distinguish these rocks and the belts of country which they occupy. In fresh rocks there is no difficulty as a rule, the colour (light gray or nearly white), with generally numerous quartz grains, indicating the granite, and the greenish-gray colour, often finer grain, and general absence (but not in all these rocks) of quartz grains, in-

dicating the greenstone. Where, however, the rocks are much decayed they are not so easy to settle, but here, again, the numerous quartz grains, with the tendency of the rocks to weather into white or mottled red and white, are usually signs of granite, while the absence of quartz grains and a brown colouration may show the greenstone. Over wide areas, however, there are few outcrops, and it is sometimes difficult to say what the underlying rocks are. The geological maps cover many of these areas, but when maps are not available the following points may help to decide the question, so far as the interior is concerned. Granite areas often have, at the surface, sand or sandy loam, although in places, as at Comet Vale, sand may drift from granite areas over greenstone rocks. On the sand, mallee and spinifex may grow, and the sandy loam may be covered with a thick growth of mulga. The surfaces of granitic areas are often free from ironstone pebbles. Greenstone areas often have an abundance of ironstone pebbles, are often free from sand, have somewhat clayey soils, have fairly open country, an absence of mallee and spinifex, and a variety of, but not close-set shrubby vegetation.

(i) *Effect of ironstone caps on tablelands.*—Tablelands inland may possess a cap of ironstone, which at times hides the underlying rocks and some lodes. The rocks can sometimes, but not always, be known from the nature of this cap, and where they cannot, the cliffs, locally known as "breakaways," which bound the tableland, forming the connection between the latter and the lower plateau, should be examined. The rocks, although as a rule much weathered, are there exposed, and from these the tableland ones may usually be learnt. The edges of the breakaways may have their ironstone cap stripped off by the weather, and quartz reefs may thus become exposed. Moreover, quartz reefs resist breaking up, and, in consequence, form, in places, low walls at the breakaways.

If lines of reefs run towards a tableland, are absent on the latter, but re-appear on the other side in the same direction, it may be inferred that the tableland cap is hiding reefs, and search should accordingly be made for them between the two known lines of the lower country; but if the tableland is of any height and the reef is not vertical, the reef on the tableland would not be in the same line as on the lower level, but would be to one side or the other of it, according to the underlie; and this applies to all lodes in hilly country, the actual outcrop varying according to the different levels of the surface (Fig. 6).

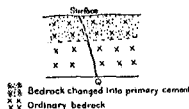
Fig. 6.



Block diagram showing difference in position of a quartz reef at different levels.

(j) *Cement and laterite.*—"Cement" is the bugbear of prospectors. It is very widespread in the main goldfields of Western Australia, and is found on the tablelands as well as on the lower country. It may be divided into two classes, "primary cement" and "secondary cement." Primary cement (Fig. 7) has been formed

Fig. 7.

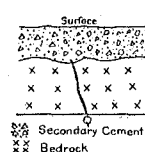


Section through primary cement and ordinary bedrock with quartz reef.

by the bed-rock having decayed for some depth below the surface, and by solutions containing (usually) iron having passed through

such rock and deposited iron near the surface, thus forming the cement cap. Recognition of this would save prospectors sinking through this type of cement in the belief that it was "wash" (Fig. 7). The secondary cement represents true "wash" or broken rock fragments, which have been cemented into a tough material usually by iron; and this cement probably hides many reefs (Fig. 8). It

Fig. 8.



Section showing secondary cement (true "wash") resting on ordinary bedrock with quartz reef.

varies in thickness from a few inches up to 10 feet (perhaps more), and this variation often takes place within a few yards, so that the finding of a moderately thick deposit at one spot does not mean that such thickness is everywhere maintained. This is important to remember in costeaning or sinking trial holes, although, unfortunately, an inspection of the ground will not show the thick and thin sheets of cement.

Laterite is the name given to much of the hard ironstone capping of the hills. It may hide lodes, but search on the slopes beneath the cap may show the softer rocks and traces of quartz reefs, if the latter exist. This is the primary laterite. One form consists of small, rounded pebbles, which break down into an ironstone gravel, which may be thought to be due to water action, and hence carry alluvial gold; but this is not the case. The pebbles are due to what is called "concretionary action." Another form is termed secondary laterite, and is largely identical with the secondary cement described above.

(2) WORKING OF METALLIFEROUS LODS BY PROSPECTORS.

Few remarks require to be made under this head, as the influence of the topography is soon understood. The principal methods are by open cut, vertical and underlay shafts, and adits. In the level country of the Western Australian goldfields adits cannot often be employed, and the working by any of the other methods mentioned is almost always determined by reasons other than the nature of the surface of the ground.

In the more broken country near the coast an adit driven in from the hillside would be a cheap and expeditious way of reaching a lode at some distance from the surface outcrop (Fig. 1).

The level of the ground water has a very material effect on the development of lodes by prospectors. Unless very rich, the lodes are generally abandoned by prospectors on reaching the water level in consequence of the expense which must be incurred to keep the water out of the workings. Hence, the depth of the ground water below the surface is important. The greater the depth the greater will be the chance of the prospector keeping up the output of the gold. The water level varies in Western Australia, being within 20 feet of the surface in places, and considerably over 100 feet in others. The average on the goldfields is, perhaps, about 70 or 80 feet.

(3) TRANSPORTATION.

The topography of a country has an important bearing on the question of transportation. The relations between topography and transportation will be here restricted to the facilities or difficulties afforded by the topography to prospecting and to the opening up and working of mines.

(a) *Affecting prospecting in the dry areas.*—Conditions of prospecting in Western Australia vary according to the nature of

the country. In the drier parts, which form the great gold-bearing belt, the country is, broadly speaking, usually level, has mostly fairly open timber, no permanent streams, no large, deep valleys, and comparatively few hills. It is, therefore, easily traversed by man and beast. The chief difficulties are the sand plains and dunes, the "dry" lakes, the absence, at times, of natural feed for horses, the close-set character of certain "mulga" vegetation areas, and the scarcity of water. The sand and close-set mulga areas can only be improved by the cutting of roads and tracks; the "dry" lakes may be crossed in certain places, but in other parts men and horses become bogged. In order to avoid this, long detours are necessary, but these have been saved to some extent by the Government having constructed corduroy crossings over certain narrow portions of the lakes. Camels, eating as they do almost any of the vegetation and thriving better on the natural feed than horses, have largely replaced the latter. The scarcity of water was one of the most serious drawbacks to the early explorers and prospectors, but the Government has, in a great measure, overcome this by constructing numerous tanks and dams, and by sinking many wells.

Natural water conservation takes place, especially in granite country, as will be shown below. In the far out parts, however, much of the same scarcity still exists, but the use of the camel has reduced this difficulty. The general opening up of the country by railways, roads, tracks, and mining settlement has also immensely facilitated the journeyings of the prospector, the more settled portions forming bases of operations for testing the country beyond. A serious but still minor (in view of their not wide distribution) risk is the occurrence of natural poison plants, which will destroy horses and camels. The absence of water also necessitated a new method for sorting out the alluvial gold, namely, "dry-blowing."

(b) *Affecting prospecting in the wetter areas.*—Prospecting in the wetter areas of the State, such as the South-West and Kimberley divisions, has the advantage of sufficient water, but the more broken character of the country makes the work in some ways more arduous, and vehicles frequently cannot be used. The North-West division is somewhat intermediate in character between the two types—wet and dry—just described.

(c) *Affecting mines.*—In the actual working of mines in the main gold belt, the generally level surface of the country enables railways, roads, and tracks to be easily and cheaply built and cut, thereby facilitating rapid and relatively cheap transportation. The immense distances, however, that machinery and stores have to be brought, make the transportation actually expensive, but transportation for the same distances over broken country would necessitate much more cost, and therefore, relatively speaking, the transportation is cheap. The ironstone gravel country that occurs so abundantly in various parts furnishes excellent natural roads and bicycle pads. In the carriage of machinery and stores by road, the camel, the donkey, and the mule have displaced the horse, as they can subside and pull heavy loads on the natural feed, while the horse cannot do so. Timber has usually been in abundance both for actual mining and for firewood; salmon gum, ginlet, morrell, and "mulga" serve these purposes well. Around Kalgoorlie and other large mining centres, the timber has been cut out, so that it must be brought from an ever lengthening distance. But here, again, the level nature of the country facilitates the building of light rail or tram lines for the carriage of the wood. Similarly the conveyance of water by pipes, whether on a great scale like the Mundaring Weir scheme, or for short distances, is much helped by the evenness of the country.

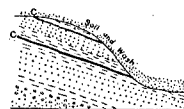
As regards mining in the more broken coastal country, the building of railways, roads, tram tracks, etc., is much more expensive than further inland. If, however, there are broad, open, well-graded valleys, the difficulty is lightened, but in an area cut into by narrow steep valleys, the cost becomes high. In certain places in Australia, as at Mt. Lyell, an aerial ropeway is used to carry ore to the treatment plant.

(4) COAL.

In the dry inland parts of Western Australia coal, on account of the nature and age of the rocks, has not been, nor is it expected that it will be, found. It is in the areas nearer the coasts, such as that containing the Collie coalfield of the South-West, that more coal may ultimately be found. We are, however, only here concerned with the relation of coal to the topography of the country.

In prospecting for coal, it should be remembered that coal seams are only found in what are known as the stratified or sedimentary rocks*, and that most of the seams hitherto discovered lie at but a moderate angle from the horizontal. This fact makes the discovery of a coal seam in a more or less broken country more likely than if the seam were vertical or nearly so. This is easily understood when one reflects that an outcrop appearing at the highest portion of the ground or even at a moderate height above the bottom of a valley, and lying rather flatly, must re-appear at various points around the main and tributary valleys (Figs. 9 and 10); but unless the sides of these valleys are steep the outcrop is easily hidden by surface wash (Fig. 9). Sea cliffs may also show

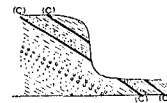
Fig. 9.



Section showing two coal seams (C) in sedimentary rocks covered by wash.

beds of coal (Fig. 10). Outcrops of coal may occur in stream beds, and where the latter are at times swept clean, a discovery might be made. But where much *debris* accumulates in the river bed, the coal outcrop is likely to be obscured, as coal breaks down rapidly, and tends more to form a hollow than a bar. Fragments of coal may be washed down the river bed, and would give an indication of a coal seam. On rock-floored sea-coasts, where swept bare by strong tides, coal may outcrop (Fig. 10). Where the country is

Fig. 10.



Steep river or coast cliff section with river or sea floor showing favourable conditions for discovery of coal (C).

flat or gently undulating, coal seams may be so hidden by superficial deposits, that frequently only the closest examination gives a chance of discovery.

The topography often influences the working of a coal seam. Thus, in flat country a shaft must be sunk to cut the seam, whereas when the seam crops out on a hillside, it may be more advantageous to put in an adit.

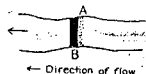
(5) ALLUVIAL DEPOSITS.

(a) *Shallow.*—In areas where there are definite river valleys, as in most places of normal rainfall, examples of which in Western Australia are the North-West, South-West, and Kimberley divisions, the beds of streams may contain payable alluvial deposits of gold, tin, platinum, tantalum, osmiridium, monazite, gemstones (diamonds, sapphires, etc.), and other valuable minerals. On account of the weight of some and the hardness of others, these minerals tend to collect along the river bed, and in pockets, cracks and

* These rocks have been chiefly formed by gravel, sand, and mud being laid down in water in regular layers or "strata."

crevices of the bed-rocks—particularly where the latter have become soft and decomposed (Figs. 11 and 12). (In Tasmania the

Fig. 11.



Plan of a river with a hard projecting bar (B) behind which alluvial mineral deposits (A) have collected.

Fig. 12.



Section down river of Fig. 11, showing hard projecting bar (B) with alluvial mineral deposits (A) behind.

bed-rock of streams has had to be broken up for a foot or more to obtain the valuable mineral osmiridium, which had settled in the crevices of the rock.*) The lighter material of no value is largely carried down the stream. Where hard bands of rock cross the river bed and project above its general surface, they act as natural riffles, and are places that should be carefully examined on the up-stream side (Figs. 11 and 12). Stratified rocks are more likely to form natural riffles than more massive rocks like granite.

Streams of moderate or large size often have pronounced bends. The current is much stronger on the outer portion of the curve than on the inner; hence detritus—which may contain valuable minerals—collects on the inner side, which is thus more likely to be productive of results than the outer (Fig. 13). Old bends of

Fig. 13.



Plan showing sandy bars at inner curves of rivers where alluvial mineral deposits may be.

rivers in alluvial ground are sometimes broken through by floods, and the cut-offs may then be tried for mineral deposits (Fig. 14).

Fig. 14.



Plan showing cut-off of a river. Cut-off may contain alluvial mineral deposits.

In gullies, wash may gather until it reaches a thickness of a fair number of feet; but it is below this wash that the heavy metals are usually found concentrated. Trial holes may therefore require sinking in country of this nature, and in doing so, it must be remembered that "false bottoms" may occur. Old alluvial terraces are found on the sides of valleys, showing the former positions of the river, and these terraces may be gold-bearing (Fig. 15). Similarly

Fig. 15.



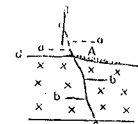
Cross section of a river valley with old alluvial terraces (A).

some present as well as older more elevated sea beaches have been payably gold- and tin-bearing.

Alluvial deposits of generally rather poor character are treated on a large scale by dredging, hydraulic sluicing, and other methods, but these hardly come within the scope of this article. The value of alluvial mineral deposits in stream beds as indicators of lodes has already been pointed out.

In the dry areas of Western Australia, the gold (which is practically the only metal of value yet found) while tending to collect in any shallow drainage lines, is much more widespread than in areas of greater rainfall, by reason of water action being too weak to cut normal river channels and to concentrate the gold. The latter frequently lies close to the surface, and for this reason after a good shower of rain, gold may at times be picked up or "speeked" from mere observation. Almost any ground in alluvial belts may contain alluvial gold, the discovery of which may lead to the location of a lode. Rich flat quartz-leaders may be removed by the weathering agents, leaving portion of the contained gold on the surface, the origin of which cannot then be definitely traced (Figs. 16 and 17).

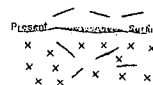
Fig. 16.



(a), (b) rich flat leaders
(c) barren quartz reef
(d) present surface
(A) alluvial gold deposits.

Section showing how rich flat leaders of a barren quartz reef may be removed leaving alluvial gold deposits, while other rich flat leaders may be below present surface.

Fig. 17.



Section showing small irregular quartz leaders, some removed leaving alluvial gold, and some below present surface.

Both in mines (in the softer rocks) and on the surface, some greenstones break up into rounded stones and pebbles, which are sometimes incorrectly thought to be due to water action, and hence to belong to an alluvial deposit. This mistake may result in useless work being done.

(b) *Deep leads.*—The deep leads in Western Australia comprise the old buried gold-bearing channels or narrow basins that have been rather extensively found in the great gold-bearing belt; and the old tin-bearing channels of Greenbushes in the South-West, and of Moolyella in the North-West. None of these old channels so far found, has been buried by lava-flows, as commonly occurs in Victoria, and this is a great advantage to Western Australia, as these lava-flows have solidified into very hard rocks, through which the deep leads must be reached at great expense. The leads of this State are buried under "wash," such as clays, sands, and gravels, which are usually easily cut through, although the water is often a source of much difficulty.

Treating first of the gold-bearing leads of the drier country, the depth of the "gutters" of the leads from the surface varies from a few feet to over 100 feet. In some localities (for example, at Kanowna, where the leads were extremely rich) different leads have been traced until they joined one another (Fig. 18), showing that here at least they formed part of an old stream system. But neither at Kanowna nor elsewhere has any lead been traced more than two to three miles. Attempts at boring have been made at Kanowna to follow the main lead beyond its known course, but hitherto they have met with little success. These leads are in places fairly close to and run towards some of the "dry" lakes; they have thus given the impression that they were directly connected with the lakes, but in no case (so far as the writer is aware) has a lead been traced into a lake. On the contrary, the shores of the lakes, where apparently the leads should enter, have in places been proved to be bed-rock. These facts, therefore, appear to show, concerning at least

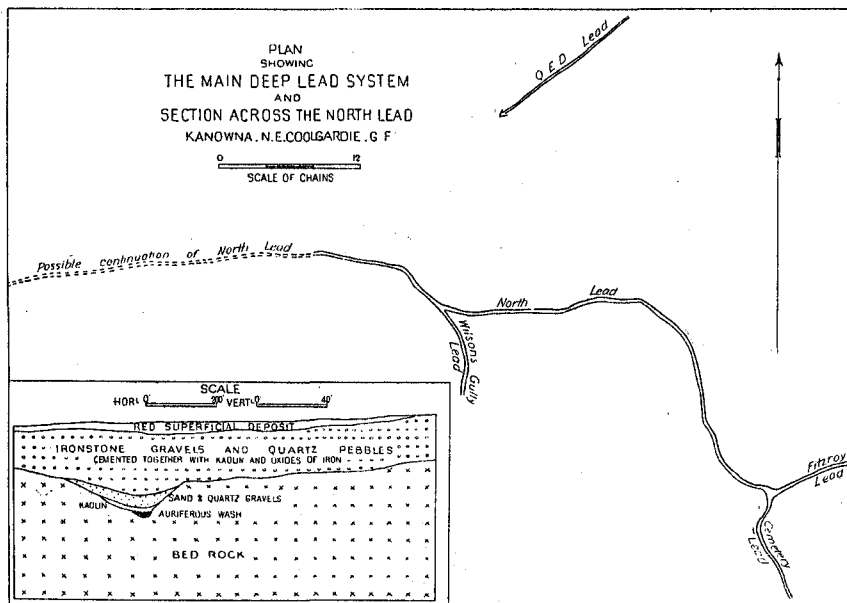
* As osmiridium has been discovered in the parent rock, serpentine, in Tasmania a lookout should be kept in this State, as serpentine occurs here.

some of the leads, that the latter have no defined outlets, and that they may be closed narrow basins; but others may possibly be connected with some deep hollows now filled with detritus, the surface of which is now a "dry" lake. Further information is required on these doubtful points. Our deficient knowledge of the leads generally suggests that caution should be used in the ex-

penditure of capital with the idea of tracing a lead, and that such expenditure should be very limited until all possible information has been obtained from an examination of the surrounding country.

From the fact that these leads are old channels or basins, water will flow into them and will cause some trouble in their working. Heavy pumping is necessary in places, and special precautions as

Fig. 18.

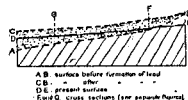


Plan showing main deep lead system at Kanowna. Section across North Lead.

to timbering the workings must be taken in order to safely hold up a mass of material, often very loose and saturated with water. In the deposits of some leads, however, there is much compacted clay, almost free from water, which stands well until exposed for some time to the air.

No principle can be laid down for the discovery of these leads. They do not always follow the present surface contours, and the soft nature of the filling material may be masked by "cement"* or other superficial substances; but if bed-rock outcrops on both sides of an apparently softer area between, then a deep lead may exist; a rapid test could be made to show the nature of the supposed soft ground above the possible lead. In some cases a lead has been found beneath an existing gully. If alluvial gold be found on the surface, the ground beneath might be tested, and if it shows undoubted wash, a further test might be made. This might lead to the discovery of a lead. The reason for this is that the higher portions of some of the leads have been worn away by the weathering agents, and the gold that was originally at the bottom of this worn down lead, may now lie on the present surface; but the lower part of the lead might still be buried and contain gold (Figs. 19, 20, and

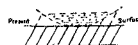
Fig. 19.



Section along the channel of a deep lead.

* It may be noted that cement sometimes contains gold.

Fig. 20.



Cross section at F (Fig. 19) showing deep lead entirely removed.

Fig. 21.

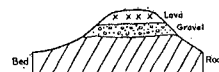


Cross section at G (Fig. 19) showing unmoved portion of deep lead.

21). Some of the gold of the Kanowna leads is of chemical origin, and has penetrated into the decomposed bed-rock.

The tin-bearing deep leads at Greenbushes and Moolyella do not always follow the lines of the present drainage. In the case of the deep leads generally, no fixed rule as to this can be laid down. Where, however, much time has elapsed between the formation of the old and new drainage channels, lava-capped hills may possess, beneath the lava, old mineral-bearing gravels which have no relation to the present drainage lines.* In these cases, sections of the gravels may be exposed on the hillsides, or some debris from their waste may be found which would give the clue to their occurrence (Fig. 22). Where leads are suspected below present watercourses,

Fig. 22.



Lava-capped hill with possibly gold or tin-bearing gravel below.

* No such lava-capped, mineral-bearing gravels have, however, so far as the writer is aware, yet been discovered in Western Australia.

a few trial holes can be sunk after careful study of the ground to show the most likely position of the possible lead.

(6) OTHER DEPOSITS.

On the floors of the "dry" lakes various mineral deposits may be formed on the evaporation of the lake water. Such deposits include common salt and gypsum. Somewhat similar material may be found away from the lakes, capping solid rocks, from which they have been derived owing to water, charged with the material, being drawn from below to the surface, and there evaporating, the contained salts being thrown down. By this means, deposits of some thickness may be formed. In wetter areas in swamps, and in partly or wholly silted up lakes, diatomaceous earth is sometimes found; and coastal lakes and lagoons may contain lime and salt deposits of value.

Phosphate rocks have been found in the State, and a sedimentary rock, if coloured green, may be an indication of their occurrence.

Caves may contain guano, bone deposits, and other substances of value. Such caves occur in limestone country, and, where hidden, may be found by the disappearance of streams, and by the occurrence of small surface holes; the reason for such caves is the extreme solubility of the limestone. Small dunes, formed by the wind like ordinary sand dunes, may be composed almost entirely of gypsum.

Hills and tablelands, especially inland, are frequently capped with iron. Other hills and ridges may be almost entirely composed of the same substance, and the jasper ridges also contain much iron. This metal is very widespread in Western Australia. Bauxite, a source of aluminium, may be associated with the iron.

Rocky river bars consist of hard rocks which may be of value for ornamental purposes, although their inaccessibility may prevent their present use. Such are the rocks at Marble Bar.

Coastal plains are usually made up of loose or friable sands, clays, marls and limestones, some of which may be used for various purposes, such as brickmaking.

Islands may contain deposits of guano, resulting from the excreta of sea birds.

Petroleum has not been touched upon in this article, as its discovery is more affected by geological structure than topography.

III.—RELATION OF THE TOPOGRAPHY TO WATER SUPPLY.

The question of water supply cannot be here fully treated. Some remarks only will be made which bear on the actual configuration of the surface to the questions in hand.

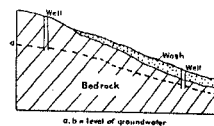
(1) ARTESIAN AND SUB-ARTESIAN WATER.

Sedimentary rocks, which may possess artesian or sub-artesian water, sometimes form sunken blocks in the earth's surface, and these blocks may be bounded on one or more sides by harder rocks of what is termed igneous origin. Thus a basin-like area might result, which would at once suggest the possibility of natural water conservation in these depressed rocks, and about which closer geological examination would then perhaps have something more definite to say. The junctions between such a depressed block and the more elevated areas might be fault lines (that is lines of fissures, along which one block has sunk below another). If that were so, these fault lines might prove important channels for the passage of water from the surface to suitable layers of rock underground. The occurrence of one group of rocks abutting another different group, and separated by a sharp fairly straight cliff or a scarp, like the Darling Fault Scarp east of Perth, would suggest the idea at once of a fault, and this could probably be verified or disproved by a geological examination.

(2) WELLS.

The contour of the country bears on the depth of sinking required to strike water. Thus the rule, the higher the country the greater the depth required to reach the water, and the lower the country the less the depth, usually holds good. This is because the level of ground water approaches the surface level in the lower areas, but recedes from it in the higher. Moreover, the waste from the rocks is apt to be stripped off from the higher ground, and to be accumulated on the lower; and the higher rocks will often be actually harder than the lower; so that for these two reasons sinking in the lower ground will probably be easier than in the higher (Fig. 23).*

Fig. 23.



Section showing advantages usually of sinking wells in lower country.

(3) GNAMMA HOLES, SOAKS, AND POOLS.

These remarks relate only to the dry areas of the goldfields, the main rocks of which are granite and greenstone. Granite is the better conservator of surface water, and its method of conservation may be briefly described. The granite crops out in many places as low-rounded hills or as more precipitous knobs of varying height and area. As the rocks decay the rain and the wind sweep away the waste and the rocks are left bare. Some portions decay faster than others and hollows are formed, which may be flat and saucer-shaped, or more like a cylinder, according to their age and conditions of formation. These are known as gnamma holes (Fig. 24).

Fig. 24.



Section showing formation of gnamma holes in granite, and conditions for soaks.

Water collects in these, and if they be some feet deep, the supply may last some time. At the foot of the granite hills there is often sand covering an irregular and hollowed out surface. The rain runs off the bare rocks, percolates through the sand and collects in the hollow beneath, thus forming soaks. The water is easily obtained by digging through the sand (Fig. 24). The Government has utilised many of the natural holes and soaks, and has increased the storage by deepening and widening.

Gnamma holes and soaks are absent from greenstone country, the texture and mode of weathering of the rocks preventing their formation, so that for surface water these rocks are of little value except along some watercourses, where fair-sized pools of water may collect after heavy rain and remain for some time. Evaporation is somewhat prevented if they are shaded to some extent from the sun and sheltered from the wind by vegetation; and soakage is prevented by their occurrence in hollows in the waste that has gathered in the creek bed, and which has been subsequently hardened by the introduction of iron, thereby rendering the surface impermeable.

* Two points must, however, be remembered, which may affect the selection of a well site. Water is generally more abundant in fractured rocks than in non-fractured ones; and in dry countries the water in the lowest lying ground tends to be more salt or brackish than in the higher ground.

(4) DRY LAKES.

The "dry" lakes, by reason of their low levels, receive considerable rain water, which soaks through and saturates the detritus. A supply of water may often be obtained from this source, but the water is usually salt and requires condensing before use.

(5) SUPPLIES FOR MINES.

In country of heavy rainfall and where the streams have a rapid fall, their water is often deflected by races to the mines, thus

furnishing a comparatively cheap supply. Where waterfalls exist these may be used to generate electricity.

In arid areas water may have to be carried great distances, as in the main water supply for the goldfields of Western Australia; but the often level character of the ground has some compensation for this. The abundance of underground water in many of the mines of Western Australia has, however, saved much surface carriage of water.

Glossary of some Common Terms

used in

Mining, Field,

and

Physiographical Geology.

Extract from

The Mining Handbook.

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Chapter VIII.

1919.

Issued under the Authority of the Hon. J. Scaddan, M.L.A., Minister for Mines.

Glossary of some Common Terms used in Mining, Field, etc.

CHAPTER VIII.

GLOSSARY OF SOME COMMON TERMS USED IN MINING, FIELD, AND PHYSIOGRAPHICAL GEOLOGY.

INTRODUCTORY NOTE.

The following glossary of terms has been prepared as an aid to the understanding of the Bulletins and other reports issued by the Geological Survey. The list of terms is restricted to those most commonly used in mining, field, and physiographical geology (including structural and stratigraphical geology). Space has not permitted a complete list of rocks to be given, but the main types are defined. A list of common minerals would have unduly lengthened the list of terms, so that they have been omitted. Similarly, purely mining terms such as stope, winze, etc., have been excluded as beyond the scope of the glossary, although common terms used in mining geology have been included.

The aim in preparing the glossary has been to combine conciseness with accuracy, a combination that is very difficult to obtain. It has therefore been necessary in some terms to sacrifice conciseness to accuracy, and in others, minute accuracy to conciseness. General accuracy has been, however, as it should be, the guiding principle of the work.

A perusal of the glossary will show the impossibility of writing geological reports without using technical terms, although it is the aim of the Geological Survey, where possible, to avoid the usage of such terms where the idea meant to be conveyed to the mind of the reader can be so conveyed in non-technical language. It must be remembered, however, that in all branches of knowledge, and in all professions, trades and occupations, technical terms are and must be constantly used. Thus the miner has his set of technical terms, such as "leading stope," "winze," etc., which, to the uninitiated, are quite incomprehensible.

GLOSSARY.

Abrasion.—The wearing down or rubbing off of rock surfaces by material such as sand, gravel, and boulders, driven or carried along by ice, rain, streams, waves, or wind. See also Denudation, Corrasion, Marine Abrasion, and Glaciation.

Abysmal.—Relating to profound depths, such as the deep portions of the sea beyond the continental shelf. Also applied to great depths below the earth's surface.

Accessory Mineral.—A mineral the presence of which is not essential to the mineral composition of an igneous rock type, e.g., tourmaline in a granite.

Acicular.—Needle-shaped.

Acid Rocks.—Rocks containing a high percentage of silica.

Aeolian.—A term applied to the erosive action of the wind, and to deposits which are due to the transporting action of the wind.

Aeolian Corrasion.—The wearing away by the wind of rock surfaces. The term is used in contradistinction to "deflation," which see.

Aeolian Erosion.—The combined effect of aeolian corrasion and deflation.

Aerolite.—A meteorite composed wholly or almost wholly of ordinary rock-forming minerals, chiefly silicates.

Agglomerate.—A rock composed of angular fragments of rocks thrown up by volcanic eruptions.

Aggradation.—The raising of a land surface by the deposition upon it of material derived from the waste of the land, such as the alluvial deposits of rivers.

Air Gap.—Equivalent to Wind Gap, which see.

Algonkian (Proterozoic).—The great dominantly sedimentary rock group between the Archaean and the Cambrian geological systems. "Proterozoic" is more commonly used than "Algonkian."

Alluvial Cones and Fans.—Masses of rock-waste brought down by rivers and deposited in the shape of flat cones and fans respectively, at the foot of hills or in the bed of a main river.

Alluvial Plain.—A plain the surface of which is made up of the rock waste from higher country brought down by rain and rivers.

Alluvium.—A deposit formed by streams and deposited on their beds or along their sides or in estuaries. See also Flood Plain.

Amphibolite.—A rock usually more or less markedly schistose, in which hornblende is the chief constituent, but in which feldspar is always present.

Amygdaloid.—A volcanic igneous rock in which round or almond-shaped gas or steam vesicles have been filled with some mineral such as calcite, agate, etc.

Analysis.—The determination of the simple substances of which a compound or mixture is made up.

Andesite.—A volcanic igneous rock of intermediate composition, consisting of plagioclase feldspar with hornblende, augite, or mica.

Anhydrous.—Without water either mechanically admixed or chemically combined.

Antecedent River.—A river which existed prior or antecedent to the uplift of a portion of its valley, but which notwithstanding such uplift has been able to maintain its course. The uplift in this case must therefore be regarded as very slow.

Anthracite.—The most mature variety of coal containing not more than 20 per cent. of volatile matter, and at least 90 per cent. of carbon (fixed and volatile).

Anticline.—An arch-like fold of strata, having a long axis so as to form a ridge instead of a dome.

Aphanite.—A rock, usually igneous, the constituents of which are so minute as to be indistinguishable to the naked eye.

Apfite.—A medium or fine-grained granite composed of quartz and feldspar.

Aqueous.—Applied to rocks which have been formed by the deposition of mud, gravel, lime, etc., under water.

Archaean.—The oldest-known group of rocks in the world. See also Algonkian and Proterozoic.

Arenaceous.—Sandy.

Argillaceous.—Clayey.

Argillite.—A hard clay slate.

Arid Erosion.—That form of erosion or general wearing away of rocks which takes place in arid countries, such erosion being largely due to the wind. Distinct land forms result from such erosion. The term is equivalent to "Desert Erosion," and is in contradistinction to normal, glacial, and marine erosion.

Arkose.—A rock formed of mineral fragments derived from granite or gneiss and containing abundant feldspar.

Artesian.—A term used in relation to water which when tapped by a bore at a considerable depth in the earth's crust will rise to or above the surface.

Asphalt.—An artificial or natural mixture of asphaltum with earth or rock.

Asphaltum.—A pure natural mixture of solid or semi-solid black carbon compounds, all of which are completely soluble in carbon bisulphide. It results from the exposure of petroleum to the weather.

Atmospheric Erosion.—A phase of erosion restricted to the breaking down and removal of rocks by the chemical and mechanical agencies of rain, frost, and changes of temperature. It does not include "corrasion" by rivers, by wind, or by ice.

Auriferous.—Containing gold.

Australite.—A term denoting the black pellets composed of volcanic glass which are found scattered over a considerable portion of the surface of Australia.

Azoic.—A term applied to a series of metamorphosed rocks, such as gneiss, mica schist, etc., in which there are no organic remains, and of which the age therefore, is unknown.

Banket.—Applied in South Africa to gold-bearing conglomerates, the pebbles of which are cemented together by silica.

Bar.—A hard band of rock, often a dyke, crossing a lode or stream bed. The term is also applied to accumulations of sand at the mouth of an estuary or bay.

Basalt.—A fine-grained, generally black, basic igneous rock consisting of plagioclase (labradorite) feldspar, augite, and frequently olivine. It occurs either as a sill or a flow. Sometimes called "bluestone."

Base-level.—As generally understood, this means the lowest level to which the land can be worn down by normal erosion without further uplift. This level tends toward that of the sea.

Base-levelling.—The reduction by normal erosion of a portion of the earth's surface to base-level.

Basset.—Outcrop of a lode or of strata.

Basic Rocks.—Rocks containing less than 52 per cent. of silica by analysis.

Basin.—Structurally, a mass of strata which dip evenly on all sides to a lowest point. In physiography it is used to indicate a hollow surrounded by a rim on all sides, and also the area drained by a river system.

Batholith or Batholite.—An intrusive mass of deep-seated origin which occupies an irregular cavity. It consists usually of plutonic rock. See Laccolith or Laccolite.

Bauxite.—Hydrous oxide of aluminium, usually occurring as a yellowish-white or reddish granular mass; an important ore of aluminium.

Bedded Vein.—A vein lying between the strata of a rock.

Bed Rock.—A term generally applied to the "solid" rock on which alluvium or "wash dirt"—whether mineral-bearing or not—rests.

Bedding Planes.—The divisions separating the various beds or layers in stratified rocks.

Beheaded River.—A river whose upper portion has been cut off or "captured" by another river.

Bench.—An approximately level rock floor on the side of a hill, valley, or sea cliff.

Betrunked River.—A river, some of the tributaries of which have been changed into separate rivers by the drowning or sinking beneath the sea of the lower part of the main trunk stream.

Bitumen.—A term sometimes used as synonymous with asphaltum (which see) but often applied to other similar looking natural carbon compounds not completely soluble in carbon bisulphide.

Black Sand.—Heavy sand composed mainly of ilmenite, with some magnetite, zircon, etc., and occasionally oxide of tin.

Block Faulting.—The breaking and moving of large portions of the earth's crust, by which distinct blocks of varying height are formed.

"Blow."—A vernacular term applied to a large outcrop of quartz or of iron ore.

Bomb.—An elliptical or pear-shaped fragment ejected from a volcano, usually vesicular or hollow.

Bottom.—A term used by miners to indicate the "solid" or bed rock on which the gold, tin, or other mineral wash-dirt rests below the surface wash or alluvium.

Breakaways.—In Western Australia, lines of usually hard-capped cliffs bounding tablelands.

Breccia.—A rock composed of angular fragments of rocks and minerals cemented together.

Brick-Earth.—A clay found in river valleys and flats suitable for making bricks.

Brown Coal.—A coal of modern formation characterised by a higher content of water and volatile matter than older and blacker coals.

Buck.—A name given to large quartz reefs in which there is no gold.

Butte.—A small mesa, which see.

Cainozoic or Kainozoic or Tertiary.—One of the great divisions of the geological record. In geological time, it succeeds the Mesozoic or Secondary division.

Calcareous.—Containing lime.

Cambrian.—The oldest system of the Palaeozoic division of the geological record.

Cannel Coal.—A highly bituminous coal used for making gas; it is compact with little or no lustre, and dull black or grayish black.

Canyon.—A Spanish name for a valley with steep and relatively high sides.

Cap.—The highest part of a lode. Such part may or may not be decomposed, and may or may not outcrop at the surface.

Carboniferous.—The second youngest system of the Palaeozoic division of the geological record.

Cataclastic.—Applied to structures produced by the internal fracture and crushing of a rock-mass.

Casing.—The clayey matter on the walls of a lode between it and the country rock.

Cement.—A tough rock, being sometimes "wash" which has been cemented together by other material such as silica, and sometimes bedrock which has decayed at the surface and has been later hardened or cemented by other material as just mentioned.

Chalk.—A fine-grained soft white limestone rock of marine origin.

Chalybeate Springs.—Springs, the water of which contains iron in solution.

Chert.—An impure flinty or massive chalcedony rock, frequently formed by the replacement of limestone by silica.

China Clay.—A fine-grained pure white clay composed almost wholly of kaolin, and used in the manufacture of china and porcelain.

Clastic.—Applied to rocks composed of fragments of pre-existing rocks.

Clay.—A soft plastic rock composed largely of hydrous aluminium silicates.

Cleavage.—The property possessed by some minerals and rocks of splitting along definite directions.

Coastal Plain.—A plain usually composed of unconsolidated material (such as sands, gravels, and clays) which has been laid down beneath the sea and then uplifted to form a plain abutting the coast.

Conchoidal.—Shell-like. Applied to the mode of fracture of various minerals, and of some rocks.

Concretions.—More or less elliptical or oval portions of rock masses, such portions being formed by accretion of mineral matter around a central substance or nucleus.

Conformable.—Applied to formations which succeed each other without a distinct break.

Conglomerate.—A rock composed of pebbles rounded by water action or by movement, and cemented by ferruginous, calcareous, siliceous, or some other material.

Consequent River.—A river the course of which is determined by the contour of the land on its uplift.

Contact Metamorphism.—The alteration in the mineral composition of a rock chiefly by heat in the vicinity of an intrusive igneous body; also called thermal metamorphism.

Continental Shelf or Platform.—The shallow portion of the sea bottom around a coast line, usually extending to the 100 fathom line or to a point from which the bottom suddenly plunges to abyssal depths.

Contortion.—The intense crumpling and folding of rock masses.

Cop.—A powdery form of gypsum used in agriculture.

Corrasion.—As applied to a stream, the action of the latter in cutting its own channel either vertically or laterally. See also Denudation, Abrasion, and Aolian Corrasion.

Country.—The name given by miners to the rock through which a lode passes.

Cross-course.—A lode crossing a main lode.

Cretaceous.—The youngest system of the Mesozoic division of the geological record.

Crustal Deformation.—A term denoting the movements within the earth's crust by which such crust or any portion of it is raised, sunk, bent, or broken. The term is generally applied to those movements which influence wide areas.

Crust of the Earth.—The outer shell of the earth comprising chiefly the sedimentary rocks and the igneous and metamorphic rocks associated with them.

Cuesta.—A hill of gently inclined stratified rocks having a steep gradient on one side and a gentle one, which accords with the inclination of the rocks, on the other.

Cycle of Normal Erosion.—The time taken in the uninterrupted reduction by erosion of a land surface to base level.

Debouchure.—The mouth of a river or channel; the point from which a spring bursts.

Decomposition.—A term applied to the decay of rocks, mainly by chemical action.

Deep Lead.—An old stream channel which is so covered by the waste of the land or by a lava flow that the existence of the channel may be unknown. Valuable minerals may have been deposited in such channel.

Deflation.—The transportation by the wind of sand and dust.

Deflation Lakes.—Lakes the basins of which have been formed by deflation.

Deformation.—The effect produced by movements in the earth's crust such as faulting, fracture, and warping.

Deformation Basins.—Basins due to movements in the earth's crust.

Deformation Lakes.—Lakes in basins formed by earth movements.

Degradation.—Equivalent to denudation, which see.

Dendrite.—The mossy or fern-like appearance on the surface of fissures and joints in rocks, usually due to a deposit of oxide of manganese.

Denudation.—The wearing away of any portion of the earth's surface, whether above or below the sea, by the action of the atmosphere, rain, rivers, ice, sea, and wind. Equivalent to Erosion.

Desert Erosion.—See Arid Erosion.

Detritus.—An accumulation of material arising from the disintegration or wearing away of rocks.

Devil's Dice.—Cubes of brown iron ore, pseudomorphs after pyrites, found in alluvial workings, or weathered rocks.

Devonian.—The fourth oldest system in the Palaeozoic division of the geological record.

Diabase.—A dark coloured basic igneous rock, frequently occurring in sheets or dykes; one of the greenstones. The term is applied to dolerites that have been more or less altered by chemical agencies.

Differential Erosion.—The more rapid erosion of one portion of the earth's surface as compared with another.

Diatomite.—Diatomaceous earth, infusorial earth, or Kieselguhr.—A soft siliceous deposit, consisting of microscopic shells of diatoms. After roasting it consists of almost pure silica in a very porous state of aggregation.

Diastrophism.—A term applied to all movements of the earth's crust whether slow or rapid.

Diorite.—A plutonic rock of intermediate composition, often called greenstone, consisting of hornblende and lime-soda felspar.

Dip.—The angle of inclination of stratified rocks, schists, or lodes from the horizontal, a vertical lode being said to dip at an angle of 90 degrees. See also Underlie or Underlay. A lode is also said to dip or underlie so many feet horizontally in so many feet vertical.

Dirt.—The auriferous, tin and other mineral bearing gravel, wash, or "pay dirt."

Disintegration.—The breaking up of rocks by atmospheric or other agents of erosion. Applied more to the results obtained by mechanical than by chemical agents of erosion.

Dissected.—A term applied to a land surface, denoting that such surface has been cut into hills and valleys by erosion.

Division Planes.—As used in geology, the planes which separate layers, bands or blocks of rocks. Budding planes separate the strata in the sedimentary rocks; planes of schistosity separate the fine layers in schists; and foliation planes separate the mineral bands in foliated rocks such as gneiss.

Division planes also include joint planes and fault planes.

Dolerite.—A generally dark-coloured, basic igneous rock consisting largely of augite and felspar. One of the "greenstones." It may be regarded as the intrusive or dyke-equivalent of a gabbro or basalt. In some cases, it is a coarse-grained basalt.

Dolomite.—Magnesian limestone, in which the molecular ratio of magnesia to lime is 1 : 1.

Dome.—A term used to indicate the shape of strata which have been bent up so evenly that they dip away from the crown on all sides. The term is in contrast to "anticline," and to "basin."

Drowned Valleys.—Valleys the lower end of which have been submerged beneath the sea. They frequently form deep winding gulfs or sounds.

"Dry" Lakes.—See "Playas."

Dry Blown.—Applied to the process, mostly in use in Western Australia, by which, on account of the absence of water, alluvial gold, tinstone, and tantalite are separated from surface detritus.

Dunes.—Sand, gypsum or clay hills formed by the wind.

Dyke.—An intruded vein of igneous rock.

Dynamic Metamorphism.—The pronounced structural and mineral change effected in rocks by the exercise of physical force such as tension, compression, shearing, etc.

Effusive.—Applied to rocks which have been poured out at the surface in a molten state and there solidified.

Embouchure.—Opening. Mouth of a river, chasm, channel, or passage.

Engrafted River.—A river which has resulted from the union, by uplift or tilting up of the land, of two or more rivers formerly entering the sea separately.

Enrichment, Secondary.—This is usually met with in lodes near the water level, being due to the downward percolation of meteoric water which in its passage through the oxidised zone dissolves portion of the metallic contents which are re-deposited upon contact with the sulphides.

Entrenched Meander.—An old river meander or wide curve which has become a deep winding trench or channel owing to the revival of the stream, generally by uplift.

Eocene.—The oldest geological system in the Tertiary division.

Eolian or Aeolian Deposits.—Applied to sand-dunes or other deposits which have been accumulated by the wind.

Epeirogenic.—Denoting slow earth movements by which great areas may be elevated or submerged as practically horizontal blocks, i.e., without folding. Compare "Orogenic."

Epidiorite.—A greenstone rock consisting essentially of hornblende and felspar, which has been derived from a gabbro or diorite by alteration of the augite to hornblende; also a rock consisting of hornblende and felspar, in which all trace of igneous structure has been destroyed by dynamic metamorphism.

Epigene.—Applied to the action of all geological agents acting upon the surface of the earth. See Hypogene.

Erosion.—Equivalent to denudation, which see. (See also Abrasion and Corrasion.)

Erratics.—Masses of ice-transported rock often of a different nature to the rocks of the district in which such masses are found.

Eruptives.—Rocks which have been ejected from volcanoes, or injected amongst other rocks in a molten state. This term, by reason of its vagueness, is becoming obsolete.

Escarpment.—A cliff or abrupt face of a hill or tableland.

Essential Minerals.—Those which are essential to the composition of an igneous rock, e.g., the quartz, felspar, and mica of a granite.

Estuary.—The tidal portion of a river.

Exfoliation.—The peeling off of rock layers in successive rounded coats.

Extrusive.—Denoting a force which drives out or expels, such as that which propels lava from a volcano. The term is applied to rocks which reach the surface of the land in a molten state.

Fault.—A fracture and subsequent movement of rocks, the result of which is that one group of rocks abuts against another group with which the first group was not formerly in contact. The plane along which such movement takes place is called a fault-plane.

Fault-lode.—A band of crushed and broken rock along a fault line, carrying minerals of economic value.

Fault Plane.—See Fault.

Fault-Rock.—A term applied to a band or zone of rock crushed and broken during the formation of a fault.

Fault Scarp.—A usually steep rock face (along a comparatively straight line) which has been produced by faulting.

Feeder or Loader.—A small vein carrying ore, usually running into a larger one.

Felsite or Felstone.—A rock having a fine granular structure, and composed chiefly of felspar and quartz; a quartz-porphry in which the constituents cannot be made out by the naked eye.

Ferruginous.—Containing iron.

Fjord or Fjord.—A deep narrow valley now forming an inlet of the sea but which has its bottom deeper towards the centre than at its mouth. See Ria.

Fissure Vein.—A fissure filled with mineral matter usually extending for a considerable distance both vertically and horizontally. It may show a banded structure, indicating successive depositions.

Flexure.—A bending of rocks of the earth's crust.

Floater.—A term applied to loose pieces of quartz, which may be gold-bearing, and which have broken away from the lode. They are often of value in finding a lode.

Float-Gold.—Gold in such thin scales or fine dust that it will float on water.

Floating Reef.—A large loose mass of auriferous quartz found in the alluvium.

Flood Plains.—The plains on each side of a river, the materials of such plains being the alluvium brought down and spread over the adjacent land by the river.

Fluvialite.—A term relating to rivers and river action.

Folding.—The bending by forces within the earth's crust, of rocks and lodes into arches and troughs, domes and basins.

Foliated.—Composed of thin leaf-like layers; applied to rocks composed of alternating bands of different minerals.

Footwall.—The wall on the lower or "foot" side of a lode.

Formation.—A series of rocks which have been deposited successively over the same area, and have characters in common; e.g., the strata which make up the Carboniferous formation.

Fossils.—Any remains, casts, or impressions of animals or plants imbedded in the earth's surface.

Fragmental.—Applied to rocks that are formed of fragments of pre-existing rocks. Equivalent to "clastic."

Freestone.—A term applied to any stone that will work freely or easily with the mallet and chisel.

Fumarole.—A volcanic vent up which pass sulphur and other fumes and gases.

Gabbro.—A basic, plutonic, igneous rock, composed chiefly of labradorite felspar and diorite.

Gash Vein.—A mineral vein filling an irregular crack in the rocks.

Gang or Gangue.—Mineral matter of no economic value occurring with valuable minerals in veins or lodes.

Geodes.—Cavities, usually in igneous rocks into which project well-formed crystals.

Geanticline.—A great arch-like fold of portion of the crust of the earth.

Geological Record.—The evidence obtained from the rocks of the crust of the earth of the physical changes (such as alternation of sea and land, and variations of climate) on the surface of the earth; of the mode of formation, succession, and present position of the various rock groups; and of the kind of animals and plants that have lived upon the earth during successive geological periods. The geological record is divided into great main divisions, such as the Mesozoic division, and the divisions are divided into systems, such as the Carboniferous system.

Geomorphology.—The science relating to the various forms assumed by the surface of the earth and the causes which have produced them.

Geosyncline.—A great trough-like fold of portion of the crust of the earth.

Geotectonics.—The major architecture of the earth's crust. It is comprised in Structural Geology.

Glaciation.—The effect produced on rocks by glaciers.

Glassy.—Applied to rocks consisting wholly or in part of volcanic glass, particularly as regards the ground-mass.

Gnamma Holes.—Shallow and deep holes in the interior of Western Australia formed in rocks, the chief of which is granite. They frequently contain water, and form almost the only natural surface supplies.

Gneiss.—A compact metamorphic rock, having a banded or foliated appearance and structure, due to a parallel arrangement of the constituent minerals.

Gossan.—Vein stuff containing much oxide of iron, found in the cap of a lode.

Gradation.—The act of bringing portions of the earth's surface to a common level by any natural process or agency.

Grade.—In physiography when a river has reached the condition that it is neither cutting down nor building up its channel, it is said to be "at grade."

Granite.—A crystalline, acid plutonic rock composed typically of quartz, felspar, and mica.

Granodiorite.—A rock intermediate in mineral and chemical composition between a hornblende granite and a quartz-diorite. A quartz-diorite with subordinate potash felspar.

Graphic Granite.—A variety of granite with quartz and felspar so intergrown as to produce the appearance of Hobrow characters.

Greywacke.—A complex rock composed of grains of quartz, felspar, and other minerals and rocks united by a cement usually siliceous.

Greenstones.—A comprehensive term used to designate basic igneous and metamorphic crystalline rocks of a green or dark-green colour.

Greisen.—A variety of granite consisting of quartz and mica with little or no felspar.

Grit.—Coarse sandstone composed mostly of angular quartz fragments cemented together.

Ground-mass.—The generally fine-grained mass of a porphyritic rock in which the phenocrysts are embedded.

Gully.—A small valley.

Gutter.—A buried stream channel in which gold or other valuable mineral is found below the material which has obliterated the channel.

Hade.—The inclination of a fault measured from the vertical.

Hanging Wall.—The upper or "head" wall of a lode.

Heave.—The apparently horizontal displacement of a faulted lode.

Holocrystalline.—Wholly or perfectly crystalline; applied to a rock composed of crystalline minerals.

Hogback.—A ridge-like band of hard rock with a steep dip, projecting well above softer rocks on each side.

Horizon.—The stratigraphical position of a bed or series of beds of rock.

Hornstone.—A hard flinty rock of very fine grain and of yellow, brown or black colour, produced by contact, or by intense dynamic, metamorphism.

Hornblende.—A rock consisting almost wholly of hornblende plates or prisms, and containing no felspar.

Horse.—Generally a lens-shaped mass of country rock in a lode and dividing such lode into two branches; also termed a "horse of mullock."

Horst.—A great upstanding earth block from which the originally continuous adjacent rock masses have subsided along powerful fractures of the earth's crust.

Hydrogenesis.—A process of ore deposition in which the ore body has been deposited from solution.

Hydraulic Cement.—A cement that will set under water.

Hydro-thermal.—A term applied to the combined action of heat and water in altering the structure and composition of minerals and rocks in the crust of the earth.

Hydrous.—Minerals which contain water chemically combined.

Hypabyssal.—Applied to rocks of igneous origin that have been rather rapidly cooled by being intruded as dykes or sills; i.e., under conditions intermediate between those causing the formation of plutonic and of volcanic rocks.

Hypogene.—Applied to the geological forces acting beneath the surface of the earth. See *Epigene*.

Igneous Rocks.—Rocks which have been consolidated from a molten condition and have cooled either on or within the earth's crust. Those which have overflowed the surface in a molten state are termed volcanic or effusive, and those which have cooled below the crust are plutonic, or hypabyssal.

Incrustation.—As used in geology, a coating of mineral matter usually different from the substance coated.

Indurated.—Applied to rocks that have been hardened by the action of heat or introduction of foreign matter.

Infusorial Earth.—See *Diatomite*.

Inselsberge.—"Island hills"—Isolated hills or ridges—the result of long continued arid erosion.

In Situ.—In the place where formed.

Insolation.—The influence of changes of temperature in the surface weathering of rocks.

Intrusive.—Applied to rocks which have been thrust up into the outer portions of the earth's crust in a molten state, and have solidified without flowing over the surface.

Ironstone.—Iron ore, or a rock consisting chiefly of iron compounds.

Isoclinal Folding.—Folding of strata of so intense a character that along certain sections the rocks all dip one way and do not disclose the folding.

Jasper.—A red or yellow chalcodonic quartz rock generally stained yellow or red by oxide of iron.

Jet.—A compact, black, highly lustrous variety of brown coal.

Joints.—Cracks or partings in a rock, distinct from bedding or cleavage planes.

Jurassic.—The middle system of the Mesozoic division of the geological record.

Kainozoic.—See *Cainozoic*.

Kaolin.—China clay. Decomposed felspar. Hydrous aluminium silicate of a white or yellowish colour, and either mealy or compact.

Kerosene.—A mineral oil, suitable for illuminating purposes and distilled from crude petroleum or from a bituminous shale.

Kidney Iron-ore.—A variety of limonite or goethite named from its resemblance in shape to a kidney.

Kieselguhr.—See *Diatomite*.

Kopi.—See *Copi*.

Laccolith or Laccolite.—A mass of igneous rock thrust in a molten state between the division planes of stratified rocks, so as to cause the strata to be bent into a dome. On cooling the igneous rock itself is in the form of a dome with a flat base. See *Batholith* or *Batholite*.

Lacustrine.—Applied to deposits which have been laid down in fresh water lakes or marshes.

Lapilli.—Small fragments of volcanic matter, rounded, angular, or indefinite in shape, too large to be borne far by the wind; usually about the size of a pea.

Laminae.—Thin layers.

Laterite.—A generally dark-red rock which generally forms in warm climates as a cap on the surface of other rocks; usually composed of iron, silica, and alumina. Some varieties are siliceous, others ferruginous, others kaolinic, and the colour depends on the composition.

Lava.—A volcanic rock which issues in a molten state from vents and fissures, and generally solidifies on the surface of the earth.

Lead.—(Pronounced *Lead*).—See *Deep Lead*.

Leader.—A small vein usually connected with a larger lode.

Lenticular.—Lens-shaped.

Ligneous.—Having a woody structure.

Lignite.—Brown coal. Modern coal showing a woody structure.

Lime.—Oxide of calcium. Commercial lime is produced by roasting limestone or chalk.

Lime Sand.—A sand composed largely of calcium carbonate, and usually found in dunes along the coast.

Limestone.—A granular rock composed chiefly of calcium carbonate. When crystalline, it is known as marble.

Lime Sinks.—Hollows in limestone country due to the collapse of roofs of caverns which have been leached out by water.

Littoral.—Applied to deposits which have been laid down along the shore line of either a sea or a lake.

Lode.—A vein or band of rock containing metallic minerals of economic value; but excluding an alluvial deposit.

Lode Formation.—A belt of rock carrying metallic minerals of economic value. Distinct veins may traverse the lode rock.

Loess.—A fine-grained, somewhat calcareous clayey deposit probably of wind origin.

Longitudinal Valley.—A valley whose course is parallel to the strike of the rocks.

Lydian Stone.—A black flinty jasper used for testing the quality of gold; also called *touchstone*.

Magma.—A large mass of molten igneous rock.

Magmatic Segregations.—Concentrations of certain portions of a magma. These usually shade off gradually into the typical magma.

Marble.—A crystalline form of limestone.

Marine Abrasion.—The action of sea waves, either armed with material such as pebbles and sand, as is usually the case, or alone, in wearing away the rocks of a sea coast.

Marl.—A soft earthy form of limestone which may contain clay, lime, and magnesian carbonate, quartz, mica, etc.

Massive.—Without close-set planes of separation.

Matrix.—The rock or that portion of a lode which contains minerals of economic value. Also applied to the finer material around the fragments of a clastic rock.

Mature Rivers.—Rivers which have well-defined valleys with strong but not very steep sides. Such rivers are at "grade."

Mesa.—A flat-topped table mountain or hill representing a remnant of a plateau now largely removed by sub-aerial erosion. See *Butte*.

Mesozoic or Secondary.—One of the great geological divisions of time. It is between the *Cainozoic* and *Palaeozoic* divisions.

Metamorphic.—Applied to a rock, the term means changed or altered by deep-seated processes. Applied to a mineral, it means resulting from or generated by such deep-seated processes.

Metamorphism.—The alteration of rock masses in structure or in mineral composition, or in both, by deep seated processes, particularly by physical forces, as distinct from surface alteration (weathering).

Metasomatic.—Applied to an alteration in a mineral or rock involving a chemical change by which the complete or partial replacement of the original mineral or rock takes place.

Metasomatism.—The alteration of rock masses in chemical composition by deep seated processes.

Meteorite.—A mineral mass that has fallen from beyond the earth.

Micaceous.—Consisting largely of mica, or having the scaly appearance and structure of mica, e.g., micaceous hematite.

Miocene.—The third oldest and the second youngest system of the Tertiary division of the geological record.

Monadnocks.—Isolated hills and ridges which are the remains of a once higher continuous belt of land, which has been reduced by normal erosion to a peneplain.

Monocline.—A single downward bend in horizontal strata. The strata are bent down but after some distance become horizontal again.

Moraine.—Rock debris which has been removed and piled up by glaciers.

Mudstone.—Dry, compact mud or silt, generally not finely stratified or laminated.

Mullock.—Portions of the country rock in a lode. The term is also used by miners to describe any rock debris used for filling stopes, etc., in a mine.

Natural Bridge.—Formed in the interior of Western Australia by a hole being made by erosion through a narrow ridge, leaving a continuous hard cap above.

Nodule.—A small concretionary mass of rock.

Norite.—A gabbro, with hypersthene more common than diaspore.

Obsidian.—Acid volcanic glass; often resembling black, dark-green or dark-brown bottle-glass.

Obsequent River.—That portion of a consequent river the flow of which has been reversed by capture by a subsequent stream.

Ochre.—Any coloured clay or earthy oxide of iron suitable for use as a pigment.

Oil Shales.—Highly bituminous shales from which mineral oils are distilled.

Old Rivers.—Rivers possessing wide shallow valleys with gently sloping sides.

Oligocene.—The second oldest system of the Tertiary division of the geological record.

Oolite.—Consisting of little spheroidal grains built up of successive coats of calcareous material.

Ooze.—A calcareous or siliceous mud of organic origin occurring as a deep sea deposit.

Ordovician.—The second oldest system of the Palaeozoic division of the geological record.

Orogenic.—Denoting the action of forces within the earth by which portions of the earth's crust are folded and puckered up into mountain ranges. See *Epigeogenic*.

Outcrop.—That portion of any rock or lode which is actually exposed at the surface.

Paint Gold.—A very thin coating of gold on the faces of quartz or other gangue.

Palaeontology.—The science which treats of fossils or evidence of life in former ages.

Palaeozoic (Ancient Life).—The name given to the strata which contain the oldest known undoubted fossil remains; formerly called *Primary*.

Planation.—The act of reducing to a level or nearly level surface a portion of the earth's surface by erosion.

Peat.—A form of cannel or gas coal that burns with a crackling noise.

Peat.—A dark-brown fuel resulting from the partial decomposition of vegetable tissues in wet places; it is vegetable matter only partially altered to coal.

Pegmatite.—A crystalline acid igneous rock of coarse texture which may consist of quartz and mica, quartz and felspar, or quartz, felspar, and mica; a very coarse variety of granite, usually occurring as a dyke.

Peneplain.—A gently rolling lowland, forming an almost plain surface which is due to long-continued sub-aerial erosion. Sometimes also spelt "peneplano."

Peridotite.—An ultra-basic igneous rock characterised usually by much olivine, and a very low percentage of silica.

Permian.—The youngest system of the Palaeozoic division of the geological record.

Permian-Carboniferous.—A series of strata intermediate between the Permian and Carboniferous systems of the geological record.

Petroleum.—Any naturally occurring oil which is not of immediate animal or vegetable origin.

Petrology.—The science of rocks in all their relations.

Phenocrysts.—Crystals, generally recognisable by the naked eye, occurring in a fine-grained mass in rocks of igneous origin, *i.e.*, crystals of quartz and felspar in a quartz porphyry.

Phonolite.—A volcanic rock of intermediate composition, rich in soda and generally containing nepheline.

Phosphatic.—Containing phosphoric acid.

Phyllite.—An indurated and partially metamorphosed clay slate, often micaceous; intermediate between a slate and a mica-schist, and often with a sheen on the platy surfaces due to a development of mica scales.

Physiography.—The science which treats of the forms and origin of the physical features of the earth's surface, such as mountains, valleys, lakes, plains and sea coasts. The term is sometimes used in a wider sense to include the relation of such physical features to meteorology, vegetation, animal life, and man.

Pipe.—A narrow highly inclined portion of rich ore in a lode.

Pipe Clay.—A white or white-burning clay suitable for making tobacco pipes.

Pisolitic.—Formed of spherical grains larger than a pea, the internal structure of which is usually radiating and concentric, with a central nucleus of some foreign body.

Pitch.—In structural geology, the inclination from the horizontal of the axis of an anticline or syncline, and also the inclination of an ore shoot in a lode.

Pitchstone.—A dark-coloured vitreous, volcanic igneous rock; chiefly a blackish or greenish glass with a dull pitchy lustre.

Placer.—An alluvial deposit which may contain gold, tin, platinum, or other valuable mineral.

Plains.—Plains are divided into plains of erosion, being rock masses worn down to a general level, and plains of deposition, being level accumulations of transported material.

Plain of Marine Abrasion.—A rock plain formed at shallow depths beneath the sea by the erosive powers of the latter.

Plaster of Paris.—Roasted gypsum.

Playas.—Extensive bare level areas in arid countries the surface materials of which are usually fine silts which may be impregnated with salts. Such surfaces are occasionally covered with thin sheets of water which rapidly evaporate. In Western Australia playas are called "dry lakes." See also *Salinas*.

Pleistocene.—The geological epoch which immediately precedes the present or Recent period. Included in the term Post Tertiary.

Pliocene.—The latest member of the Tertiary division of the geological record.

Plutonic.—Applied to igneous rocks possessing a coarsely crystalline structure which were cooled and consolidated slowly under great pressure at some depth beneath the surface.

Pneumatolysis.—A process of ore deposition brought about by the agency of heated gases and vapours.

Pocket.—A highly concentrated but usually small accumulation of a mineral in a lode.

Porphyry.—An intermediate igneous rock containing phenocrysts, usually of felspar, enclosed in a ground-mass chiefly of felspar.

Porphyritic.—A porphyritic rock of intermediate composition, composed chiefly of plagioclase phenocrysts in a fine-grained feldspathic ground-mass.

Porphyritic.—Applied to igneous rocks which consist of crystals recognisable by the naked eye, in a fine-grained mass.

Post Tertiary or Quaternary.—A term applied to a division of all rocks younger than the youngest system of the Tertiary division. Pleistocene and Recent are included in this division.

Pre-Cambrian.—A term applied to all rocks older than the oldest system of the Palaeozoic division.

Primary Minerals.—(1) Those minerals which are essential to the constitution of a certain rock and have crystallised from the molten magma; *e.g.*, quartz, felspar, and mica in granite. (2) Those minerals originally formed in a lode or other mineral aggregate.

Proterozoic.—See *Algonkian*.

Pug.—A soft moist tenacious clay. It occurs in "deep lead" deposits in Western Australia, notably at Kanowna.

Pumice.—A cellular acid volcanic rock which is so light that it will float on water.

Pyroclastic Rocks.—Fragmental or clastic rocks, such as tuffs, ashes, and agglomerates, produced by volcanic agencies.

Quartzite.—An altered sandstone in which the grains of sand have been cemented by silica.

Quartz porphyry.—An acid igneous rock related to granite, but usually found in dykes or small masses, and composed of crystals of quartz or felspar or both, distinct from the ground-mass.

Recent.—A term applied to all rocks now forming or which have formed since the Pleistocene period.

Reef.—A quartz lode or vein, also a submerged ledge of rock in the sea.

Regional Metamorphism.—A term applied to great alterations in rocks over wide areas. These changes have usually taken place at considerable depth and are mainly due to the exercise of great physical force.

Rejuvenated or Revived River.—A river which has begun to further deepen its channel by reason usually of an uplift of the land.

Reniform.—Kidney-shaped.

Reversed Fault.—A fault by which one mass of rock has moved over another with which it was originally continuous in such a direction that a vertical line would cut the two portions of the now dislocated rock.

Residual.—A hill or ridge which projects above the general surface of a plain of erosion, being that portion of a more extensive formation which has escaped the erosion which formed the plain.

Revived Fault Scarp.—A scarp which has been re-formed by renewed faulting along an old fault line.

Revived River.—See *Rejuvenated or Revived River*.

Rhyolite.—An acid volcanic igneous rock generally exhibiting flow structure and usually carrying sporadic crystals of quartz and felspar as phenocrysts in a generally fine-grained ground-mass.

Ria.—A narrow inlet forming an old drowned valley whose bottom slopes continuously seaward. See *Fjord*.

Rift Valley.—A narrow and comparatively straight valley bounded by fault scarps.

Roches Moutonnees.—Striated and polished rock surfaces resembling sheep's backs, caused by the passage of ice over such surfaces.

Rock.—A geological term for the materials—compacted or uncompacted—which compose the earth's crust. Thus, geologically speaking, beds or other accumulations of sand, gravel and clay are "rocks."

Rubble.—Loose stones, generally fragments of rock broken off from a main mass.

Saddle Reefs.—Lodes (usually quartz) bent into arches or "saddles."

Salinas.—Extensive level areas in arid countries which are occasionally covered with thin sheets of water. The surfaces of such areas are covered with sheets of salt of varying thickness. See *Playas*.

Scarp.—The face forming a sharp transition from a higher to a lower belt of country along a comparatively straight line often of considerable length. A scarp may be due to faulting or to erosion.

Schist.—A rock with a foliated structure due to the minerals being arranged in layers, and produced by dynamic stress. According to the chief constituent mineral or minerals, the rock may be a hornblende schist, a mica schist, a quartz-mica schist, and so on.

Scoria or Cinders.—Rough fragments of a clinkorlike nature ejected by volcanoes.

Seepage.—The percolation of water through a porous rock.

Sedimentary Rocks.—All rocks that have not directly formed from a molten state or that have not been much altered by great heat or pressure. They embrace those formed by running water, marine action, wind action, chemical means, and the decay of plants and animals.

Septaria.—Concretions in the interior of which are cracks due to shrinkage, and sometimes filled with secondary calcite.

Serpentine.—A hydrous magnesium silicate rock of plutonic origin, generally of a black, greenish-black or green tint.

Shale.—A sedimentary clayey rock which splits along the laminae of original deposition.

Shearing.—A change in rock structure induced by two opposite forces acting in parallel or closely adjacent planes, and tending to slide some of the particles over the others.

Shoot.—The portion of the lode, of greater or less length, which carries the payable ore and which generally dips at an angle along the line of lode. Sometimes restricted to the richest part of the ore. The term also includes a plankend incline used for passing ore, coal, or stone into trucks, but this is more properly termed a "chute."

Siliceous.—Containing silica. Applied to rocks or minerals which contain silica in greater or less amount. The commonest form of silica is quartz.

Sills.—Shoots of volcanic rock injected between layers of other rock.

Silt.—A very fine-grained deposit which has been laid down under water and which has not become compacted into a hard rock.

Silurian.—The third oldest system in the Palaeozoic division of the geological record.

Slack.—Small coal.

Slate.—An argillaceous rock which splits into plates at various angles to the bedding; a shale which is cleaved at an angle to the bedding or lamination.

Slickenside.—A striated surface upon the face of a rock or lode, such striated surface being frequently due to a fault.

Slide.—A term used in mining to indicate a small fault or dislocation in a lode.

Soak.—The name given in Western Australia to the small but not always permanent supply of fresh water often met in sinking at the base of granite outcrops.

Spheroidal.—As applied to weathering, the peeling off of rocks as shells or surface layers leaving a rounded core.

Stalactites.—Hanging icicles, columns, or sheets of carbonate of lime deposited from water dripping from the roof of a limestone cave.

Stalagmites.—Columns or ridges of carbonate of lime rising from a limestone cave floor, and formed by water charged with carbonate of lime dripping from the stalactites above. Stalactites and stalagmites often meet, and then form a column from floor to roof.

Stockworks.—Masses of rock impregnated by numerous small mineral veins.

Stratified.—Applied to deposits which consist of a series of beds or layers of different character.

Stratigraphy.—That branch of geology which treats of the age and succession of rocks.

Stratum.—When rocks lie in layers one above another, each layer forms a stratum in the series.

Streaming.—The act of separating ore from gravel by the aid of running water.

Stream Tin.—Tin ore occurring in stream beds in the same way as alluvial gold; the term is used to distinguish it from lode tin.

Striae.—Lines or furrows occasionally seen on the walls of a lode or fault. Also the furrows or "scratches" on glaciated rock floors and pebbles.

Striated.—Streaked, or with lines or grooves running more or less parallel to each other.

Strike.—The horizontal direction, expressed as a magnetic bearing, of an outcrop of a lode or rock, or of a foliation plane or fault.

Sub-Aerial.—A term applied to that form of erosion which takes place "under the air," i.e., on the surface of the land as distinct from that beneath the shallow water of the ocean. It includes the erosive action of rivers.

Sub-Artesian.—A term applied to a water supply encountered at a considerable depth below the earth's surface but which has not sufficient pressure to cause such water to overflow at the surface.

Subsequent River.—A tributary of a consequent river, which has mostly developed "subsequently" to the latter, and is parallel to the strike of the rocks.

Sunkland.—A block of country which has sunk relatively to the surrounding areas, such sinking being due to movements within the earth's crust. A sunkland may or may not be bounded by fault scarps. Equivalent to the German "Senkungsfeld."

Syenite.—A sub-acid plutonic igneous rock, composed chiefly of hornblende and acid feldspar.

Syncline.—A trough-shaped curve of strata having one long axis, which distinguishes it from a basin.

Tachylite.—A glassy black variety of basalt usually found as a thin crust or solvage on basalt flows or dykes.

Talus.—The sloping mounds of detritus which accumulates at the base of cliffs.

Tectonic.—Pertaining to the structure of the crust of the earth and the movements that occur in such crust.

Tektite.—An aeorlite composed of volcanic glass.

Tertiary.—Cainozoic. One of the great divisions of the geological record. In geological time it succeeds the Mesozoic or Secondary division.

Terraces.—Platforms or benches along the sides of valleys, lakes, or sea-coasts. They may be either of rock or of detritus.

Thalweg.—The lowest line along the course of a valley.

Throw.—The amount of vertical displacement of a rock mass caused by a fault.

Thrust.—A term generally used to indicate a push of a great dislocated rock-mass along a somewhat flat plane. Also termed an overthrust.

Tile Ore.—An intimate mixture of red oxide of copper and oxide or hydrated oxide of iron.

Tilted Block.—A block of the earth's crust which has, owing to fracture or bending, been tilted in a different direction or angle to that of the surrounding country.

Till.—A glacial deposit consisting of boulders, pebbles, and clay.

Topography.—The shape which the physical surface features of the earth give to any particular land surface, or to the bed of the oceans.

Tors.—Monoliths, or piles of rock masses often resembling ruins, and generally resulting from the decay of granite.

Trachyte.—An intermediate volcanic igneous rock, consisting of phenocrysts of felspar set in a ground-mass of lath-shaped crystals of the same mineral, and generally with a residuum of glass.

Transverse Valley.—A valley which cuts across the strike of the rocks.

Trap or Trappean.—A somewhat obsolete general term applied to basic igneous rocks, which from their occurrence in sheets resemble steps.

Travertine.—A massive limestone formed by the deposit of calcareous matter from springs and streams carrying carbonate of lime in solution. Also a deposit composed principally of carbonate of lime laid down on the surface of the ground by evaporating water containing that substance.

Trenched Valley.—A valley possessing a definite comparatively deeply cut channel or trench.

Trend.—The course of a vein or defined belt or band of rock.

Triassic.—The oldest system of the Mesozoic division of the geological record.

Trough Faulting.—A movement of the earth's crust by which two or more faults are formed in such a way that a block or blocks of rock is or are lowered into such crust.

Tufa.—A soft limestone rock full of cavities deposited by water often on grass and sticks as incrustations; very similar to travertine.

Tuff.—The term applied to a rock composed of small fragments of glass or rock thrown out by a volcano.

Ultra-Basic.—Applied to a small group of igneous rocks containing less than 45 per cent. of silica, and usually much olivine.

Underlie or Underlay.—The angle measured from the vertical at which a vein dips from the surface. See Dip.

Vein.—A fissure in the earth's crust filled with mineral matter.

Vesicular.—Containing numbers of rounded or elliptical cavities.

Volcanic.—Applied to igneous rocks which have been ejected from volcanoes either as lava flows or in innumerable fragments.

Vugh.—A hollow or cavity in a rock or lode often lined with crystals.

Walls.—The boundaries between the country rock and the lode, the upper being the "hanging," and the lower the "foot" wall.

Warping.—A gentle bending of the earth's crust without the formation of pronounced folds or dislocations.

Water Gap.—A gap or notch cut by a river through a ridge of hard rock.

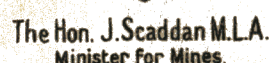
Water Shed or Water Parting or Divide.—The line which separates the catchment area or basin of one stream from another, or of one group of streams from another group.

Weathering.—The decomposition, disintegration and breaking up of the upper surface of the earth's crust by the action of the atmosphere, changes of temperature, rain, and frost.

Wind Gap.—A gap in a ridge without any stream. Formerly a stream flowed through the gap but the course of the stream has been diverted. Equivalent to Air Gap.

Young River.—A stream having a valley with steep and little dissected sides.

Zone.—A name given to a series of strata distinguished by similar organic remains. Also applied to the various belts of rock from the surface downwards, as zones of oxidation and of fracture, sulphide zone, etc.



BASED ON THE WORK OF THE GEOLOGICAL SURVEY.

A. GIBB MAITLAND

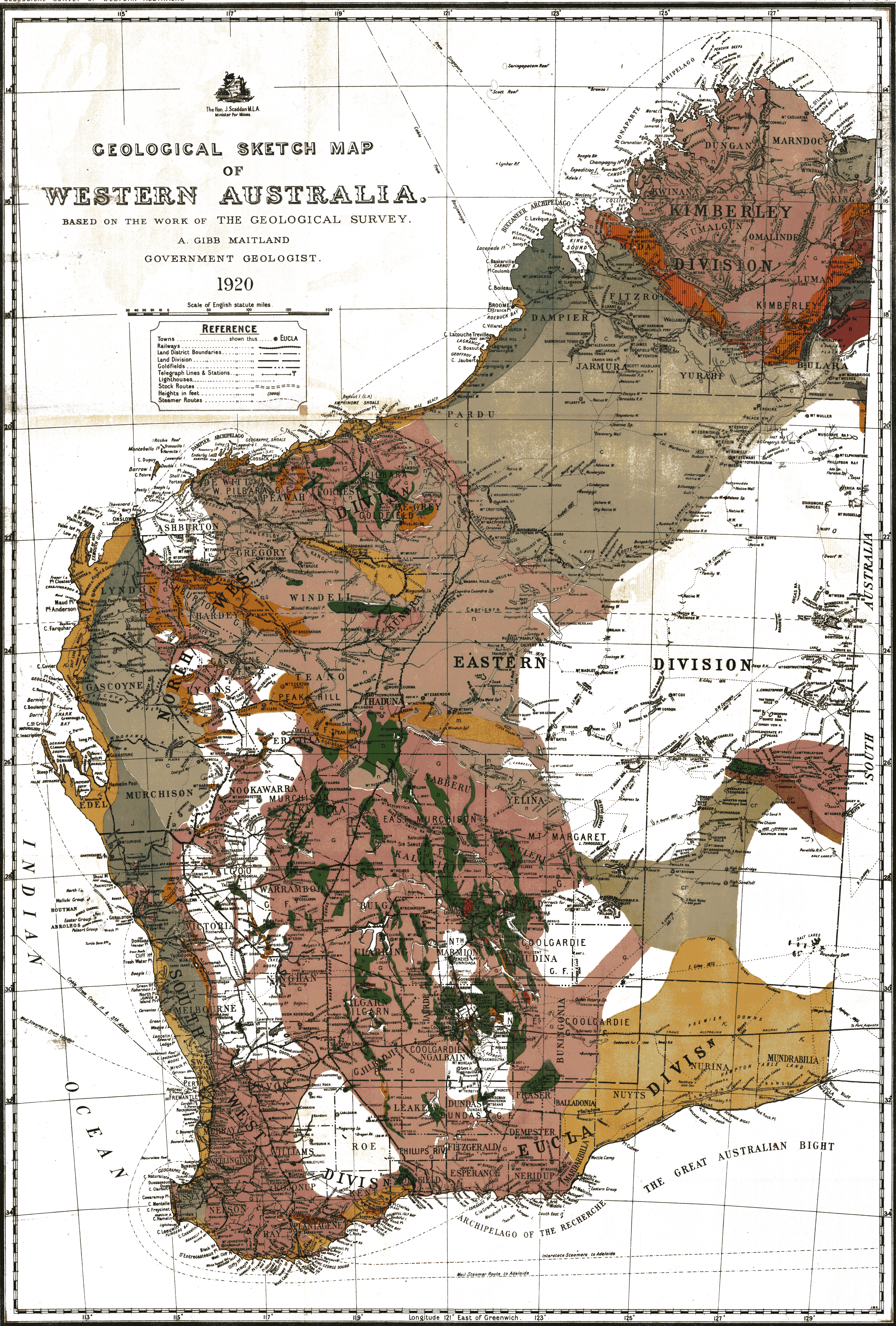
GOVERNMENT GEOLOGIST.

1920

Scale of English statute miles.

REFERENCE

Towns	shown thus	●	EUCLA
Railways	—		
Land District Boundaries	—		
Land Division	—		
Goldfields	—		
Telegraph Lines & Stations	—		
Lighthouses	—		
Stock Routes	—		
Heights in feet	—		
Steamer Routes	—		



LEGEND.

(Possibly Upper Proterozoic)

PROTEROZOIC ARCHÆOZOIC

ARCHÆOZOIC

IGNEOUS

By Authority: FRED. WM. SIMPSON, Government Printer, Perth.

D₁ D

Dolerite dykes Gab bro. dolerite, ex

and sills diorite, serpentine.
(Post-gold "greenstones") (Pre-gold "greenstones")

C. B. Kidson, del



The Hon. J. Scaddan M.L.A.
Minister for Mines

MAP OF WESTERN AUSTRALIA.

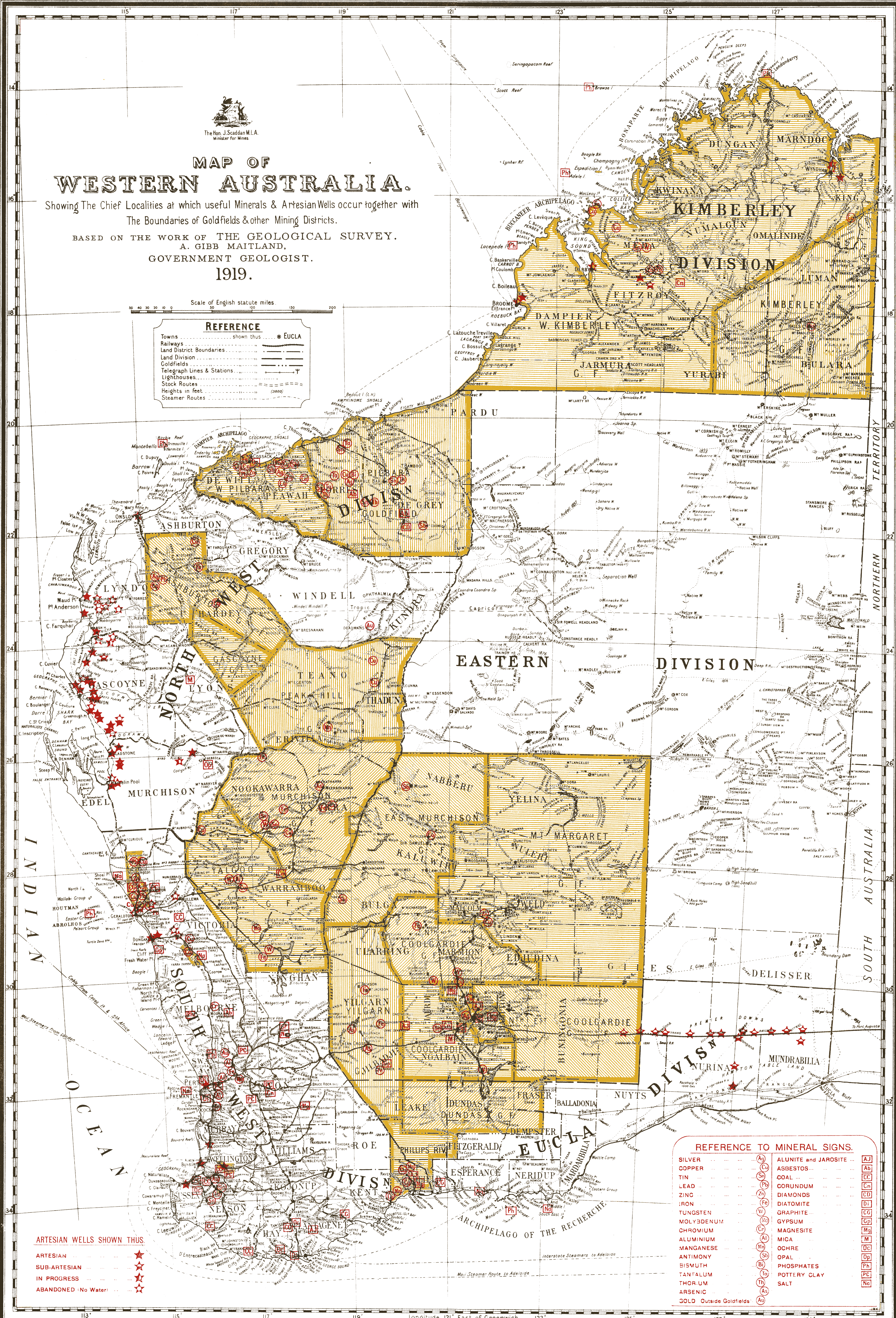
Showing The Chief Localities at which useful Minerals & Artesian Wells occur together with
The Boundaries of Goldfields & other Mining Districts.

BASED ON THE WORK OF THE GEOLOGICAL SURVEY.
A. GIBB MAITLAND,
GOVERNMENT GEOLOGIST.
1919.

Scale of English statute miles.

REFERENCE

- Towns shown thus ● EUCLA
Railways ————
Land District Boundaries ————
Land Division ————
Goldfields ————
Telegraph Lines & Stations ————
Lighthouses ————
Stock Routes ————
Heights in feet (3800)
Steamer Routes ————



ARTESIAN WELLS SHOWN THUS

- ARTESIAN ★
SUB-ARTESIAN ★
IN PROGRESS ★
ABANDONED (No Water) ★

REFERENCE TO MINERAL SIGNS.

- | | | | |
|-------------------------|----|----------------------|----|
| SILVER | Ag | ALUNITE and JAROSITE | AJ |
| COPPER | Cu | ASBESTOS | AS |
| TIN | Sn | COAL | CO |
| LEAD | Pb | CORUNDUM | CR |
| ZINC | Zn | DIAMONDS | DI |
| IRON | Fe | DIATOMITE | DT |
| TUNGSTEN | W | GRAPHITE | GR |
| MOLYBDENUM | Mo | GYPSUM | GP |
| CHROMIUM | Cr | MAGNESITE | MG |
| ALUMINIUM | Al | MICA | MI |
| MANGANESE | Mn | OPAL | OP |
| ANTIMONY | Sb | PHOSPHATES | PH |
| BISMUTH | Bi | POTTERY CLAY | PC |
| TANTALUM | Ta | SALT | SA |
| THORIUM | Th | | |
| ARSENIC | As | | |
| GOLD Outside Goldfields | Au | | |



MAP OF WESTERN AUSTRALIA.

Showing 4 Miles to 1 Inch Series of Geological Sketch Maps
& other Geological Maps issued since 1896.

BASED ON THE WORK OF THE GEOLOGICAL SURVEY.

A. GIBB MAITLAND,
GOVERNMENT GEOLOGIST.

1920.

Scale of English statute miles.
50 40 30 20 10 0 50 100 150 200

LEGEND.

Standard 4 Miles to 1 Inch, Published.

Surveys completed, printing authorised, small scale map published.

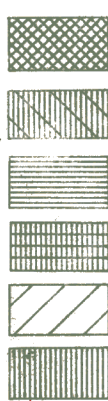
Surveys completed.

small scale map published.

Surveys in hand but incomplete.

District maps published on various scales.

Maps of individual Centres on various scales. (See list on margin).



30



NOTE:—The numbers in green correspond with those of the 300 chains per inch series issued by the Department of Lands & Surveys.

Map.	ANNUAL REPORT.			BULLETIN.		
	Year.	Plate.	Scale.	No.	Plate.	Scale.
3. Coolgardie	1897	VII.	20 chains per inch	3	II.	40 chains per inch
4. Northampton	I.	40	"	9	"	40
5. Peak Hill	III.	10	"	"	"	"
6. Horebush	IV.	8	"	"	"	"
7. Baulby	IV.	8	"	"	"	"
8. Kanowna	VI.	20	"	64	I.	95
9. Collier Coal Field	IV.	10	"	"	"	"
10. Wongah Hills	VI.	20	"	"	"	"
11. Lake Way (Wiluna)	IV.	10	"	"	"	"
12. Greenbushes	VI.	20	"	"	"	"
13. Lindsay's and Hayes' New Find	III.	25	"	32	"	20
14. Mulga	IV.	10	"	"	"	"
15. Donnybrook Goldfield	VI.	20	"	"	"	"
16. Kanowna	V.	37	"	"	"	"
17. Menzies	VII.	37	"	21	III.	40
18. Arrows (2 sheets)	"	40	"	"	"	"
19. Warreroo	"	11 miles per inch	"	"	"	"
20. Canning River Valley	"	20 chains per inch	"	"	"	"
21. Helena River Valley	"	20	"	"	"	"
22. Kalgoorlie (separately) (6 sheets)	"	10	"	42	II.	30
Do.	"	30	"	42	II.	26-6
Do. (North-End) (Sheets 1, 2, 5, 6, 7, 10-11)	"	"	"	51	XII.	2
Do.	"	"	"	69	XII.	10
Do. (Sheets 10-21)	"	"	"	69	XIV.	2
27. Boulder Basin (2 sheets)	"	"	4 chains per inch	7	I.	20
28. Auriferous Reefs, Cue and Day Dawn	"	"	"	8	I.	15
29. Leonora	"	"	"	11	I.	40
30. Horebush and Mt. Magnet	"	"	"	12	I.	40
31. Edgell and Yarr	"	"	"	12	XVI.	40
32. Mulline	"	"	"	12	II.	40
32A. Mulwarrie and Davyhurst	"	"	"	13	"	30
33. Leconora	"	"	"	14	II.	20
34. The Island, Lake Austin	"	"	"	14	III.	20
35. The Mainland, Lake Austin	"	"	"	14	IV.	20
36. Tuckanarra	"	"	"	14	V.	20
37. Quilns	"	"	"	14	VI.	20
37A. Gabanintha	"	"	"	14	VII.	20
38. Nannine	"	"	"	14	VIII.	20
39. Meekatharra	"	"	"	14	IX.	20
Do. (Sheets A and B)	"	"	"	68	IV.	40
Do. (Sheets 1-9)	"	"	"	68	XIII.	182 feet per inch
40. Abbots	"	"	"	68	XII.	80 chains per inch
41. Lalla Rookh	"	"	"	14	XI.	21
42. Bamboo	"	"	"	15	II.	20
43. Yandicoogina	"	"	"	15	IV.	40
44. Mosquito Creek	"	"	"	15	V.	40
45. Moolyella Tinfield	"	"	"	15	VI.	40
46. Auriferous Reefs, Taiga Taiga	"	"	"	15	VII.	20
47. Southern Cross	"	"	"	15	VIII.	20
48. Mt. Morgans	"	"	"	15	IX.	20
49. Mulga	"	"	"	15	X.	20
50. Nulagine	"	"	"	15	XI.	20
51. Warramunga	"	"	"	15	XII.	20
52. Marble Bar	"	"	"	15	XIII.	20
53. Norseman (2 sheets)	"	"	"	15	XIV.	20
54. Tambourah	"	"	"	15	XV.	20
55. Western Shaw	"	"	"	15	XVI.	20
56. Tanbourn and Western Shaw	"	"	"	15	XVII.	20
57. Just in Time	"	"	"	15	XVIII.	20
58. Wodgina Tinfield	"	"	"	15	XIX.	20
59. Stannum	"	"	"	15	XX.	20
60. Laverton	"	"	"	15	XXI.	20
61. Laneville	"	"	"	15	XXII.	20
62. Hopy's Find (Ida H.)	"	"	"	15	XXIII.	20
63. Burville	"	"	"	15	XXIV.	20
64. Auriferous Reefs, Duketon	"	"	"	15	XXV.	20
65. Dunderburg	"	"	"	15	XXVI.	20
66. Princes Royal Harbour	"	"	"	15	XXVII.	20
67. Lawlers	"	"	"	15	XXVIII.	20
68. Sir Samuel	"	"	"	15	XXIX.	20
69. Cue	"	"	"	15	XXX.	20
70. Cuddingwarra	"	"	"	15	XXXI.	20
71. Day Dawn	"	"	"	15	XXXII.	20
72. Bonnievale	"	"	"	15	XXXIII.	20
73. Sandstone and Nungarra	"	"	"	15	XXXIV.	20
74. Birrigin	"	"	"	15	XXXV.	20
75. Christmas Island	"	"	"	15	XXXVI.	20
76. Koolan Island, Yampi Sound	"	"	"	15	XXXVII.	20
77. Bengerall	"	"	"	15	XXXVIII.	20
78. Uro	"	"	"	15	XXXIX.	20
79. Red Hill	"	"	"	15	XL.	20
80. Roebourne	"	"	"	15	XLI.	20
81. Station Peak	"	"	"	15	XLII.	20
82. Barmah	"	"	"	15	XLIII.	20
83. Auriferous Reefs, Wiluna	"	"	"	15	XLIV.	20
84. Warramunga	"	"	"	15	XLV.	20
85. Diamond and Kundip	"	"	"	15	XLVI.	20
86. Gingin	"	"	"	15	XLVII.	20
87. Geraldine	"	"	"	15	XLVIII.	20
88. Wilma Creek	"	"	"	15	XLIX.	20
89. Ghera	"	"	"	15	XLX.	20
90. Weeriana	"	"	"	15	LI.	20
91. Kanowna	"	"	"	15	LII.	20
92. Moora	"	"	"	15	LIII.	20
93. Kalamit Clay Deposit	"	"	"	15	LIV.	20
94. Pinjarra Limestone Deposit	"	"	"	15	LV.	20
95. Payne's Find	"	"	"	15	LVI.	20
96. Soanville Asbestos Deposit	"	"	"	15	LVII.	20
97. Tindale and Londonderry	"	"	"	15	LVIII.	20
98. Ora Banda	"	"	"	15	LIX.	20
99. Coodard	"	"	"	15	LI.	20
100. Pooma	"	"	"	15	LII.	20
101. Kurnalpi	"	"	"	15	LIII.	20
102. Ruby Well	"	"	"	15	LIV.	20
103. Mithaburn (Holden's Find)	"	"	"	15	LV.	20
104. Mt. Keith	"	"	"	15	LVI.	20
105. Leonnville, Mt. Magnet, & Boogardie	"	"	"	15	LVII.	20
106. Woodliffe Rush	"	"	"	15	LVIII.	20
107. Golden Ridge	"	"	"	15	LIX.	20
108. Ilgarve	"	"	"	15	LI.	20
109. Narra Tarr	"	"	"	15	LII.	20
110. Marvel Loch	"	"	"	15	LIII.	20
111. Great Victoria and Parker's Range	"	"	"	15	LIV.	20
112. Olga, Duke, and Chertona's	"	"	"	15	LV.	20
113. Yerrilla	"	"	"	15	LVI.	20
114. Speekana	"	"	"	15	LVII.	20
115. Valgrids (Sheets 1-4)	"	"	"	15	LVIII.	20
116. Karungahaki (Sheets 1-3)	"	"	"	15	LIX.	20
117. Erenin	"	"	"	15	LI.	20
118. Bullfinch	"	"	"	15	LII.	20
119. Corntian	"	"	"	15	LIII.	20
120. Westonia	"	"	"	15	LIV.	20
121. Jackson	"	"	"	15	LV.	20
122. Marla	"	"	"	15	LVI.	20
123. Linden	"	"	"	15	LVII.	20
124. Yundandind, Pennyweight Point, Pike's Hollow and Escalante	"	"	"	15	LVIII.	20
125. Vilgapt	"	"	"	15	LIX.	20
126. Field's Find (Duketon)	"	"	"	15	LI.	20
127. Munglump	"	"	"	15	LII.	20
128. Bulong and Lake Yindardiga, the Country between	"	"	"	15	LIII.	20
129. Bulong Magnesian Area	"	"	"	15	LIV.	20
130. Kimberley District	1898	III.	20 miles per inch	2	IV.	80 miles per inch
131. Pilbara Goldfield (Part of)	"	"	"	2	V.	20
132. South-Western Districts	"	"	"	"	"	"
133. Murchison and Sandford Rivers	"	"	"	"	"	"
134. Irwin River Coalfield	1903	"	"	"	"	"
135. Pilbara Goldfield	"	"	"	38	I.	3
136. Kimberley District	"	"	"	38	II.	10
137. Artesian Area North of Northampton	"	"	"	38	III.	10
138. Artesian Area between the Minilya and Ashburton Rivers	"	"	"	38	IV.	10
139. Greenough River District	"	"	"	38	V.	10
140. Ashburton and Gascoyne Goldfields	"	"	"	38	VI.	10
141. West Pilbara Goldfield	"	"	"	38	VII.	10
142. Country along Transcontinental Railway	"	"	"	38	VIII.	10
143. Country between Arrows and Northampton (2 sheets)	"	"	"	38	IX.	10
144. Country between Carnamah and Moora to the Coast	"	"	"	38	X.	10
145. Wilma to Hall's Creek (2 sheets)	"	"	"	38	XI.	10
146. Hall's Creek to Tanami	"	"	"	38	XII.	10
147. Country North of Southern Cross	"	"	"	38	XIII.	10
148. South-West Division (Portion of)	"	"	"	38	XIV.	10
149. Lake Hume, Country in the neighbourhood of	"	"	"	38	XV.	10
150. Yilgarn Goldfield (Part of)	"	"	"	38	XVI.	10
151. Peak Hill Goldfield and Parts of Ashburton and Gascoyne Goldfields	"	"	"	38	XVII.	10
152. Coolgardie and Londonderry, the Country between	"	"	"	38	XVIII.	10
153. Coolgardie and Boulder, the Country between	"	"	"	38	XIX.	10
154. Murchison Goldfield (Part of)	"	"	"	38	XX.	10
155. Bremer Range	"	"	"	38	XXI.	10
156. Yilgarn Goldfield (South Part)	"	"	"	38	XXII.	10
157. Kalgoorlie and Mulline, the Country between	"	"	"	38	XXIII.	10
158. Extreme South-Western Portion of Western Australia	"	"	"	38	XXIV.	10
159. Coolgardie and East Coolgardie Goldfields, Part of	"	"	"	38	XXV.	10
160. Meekatharra District	"	"	"	38	XXVI.	10
161. Yilgarn Goldfield	"	"	"	38	XXVII.	10
162. Lake Barlee and Jackson, the Country between	"	"	"	38	XXVIII.	10
163. Lake Curragong and Southern Cross, the Country between	"	"	"	38	XXIX.	10
164. Marvel Loch and North Iron Cap, the Country between	"	"	"	38	XXX.	10
165. Middle Mt. Ironsop and Ravensthorpe Range, the Country between	"	"	"	38	XXXI.	10
166. North Coolgardie Goldfield (Part of)	"	"	"	38	XXXII.	10
167. Yerrilla District	"	"	"	38	XXXIII.	10
168. Laverton through Warburton Range to South Australian Border	"	"	"	38	XXXIV.	10
169. North-West, Central, and Eastern Divisions between long. 119° and 129° 47' E. and lat. 21° 30' and 27° S.	"	"	"	38	XXXV.	10