

1912.  
WESTERN AUSTRALIA.

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# GEOLOGICAL SURVEY.

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BULLETIN No. 42.

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## CONTRIBUTIONS

TO THE STUDY OF

### THE GEOLOGY AND ORE DEPOSITS OF KALGOORLIE.

#### East Coolgardie Goldfield.

#### PART I.

BY

E. S. SIMPSON & C. G. GIBSON.

*Issued under the Authority of the Hon. P. Collier, M.L.A.,  
Minister for Mines.*

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WITH TWO MAPS AND 50 FIGURES.

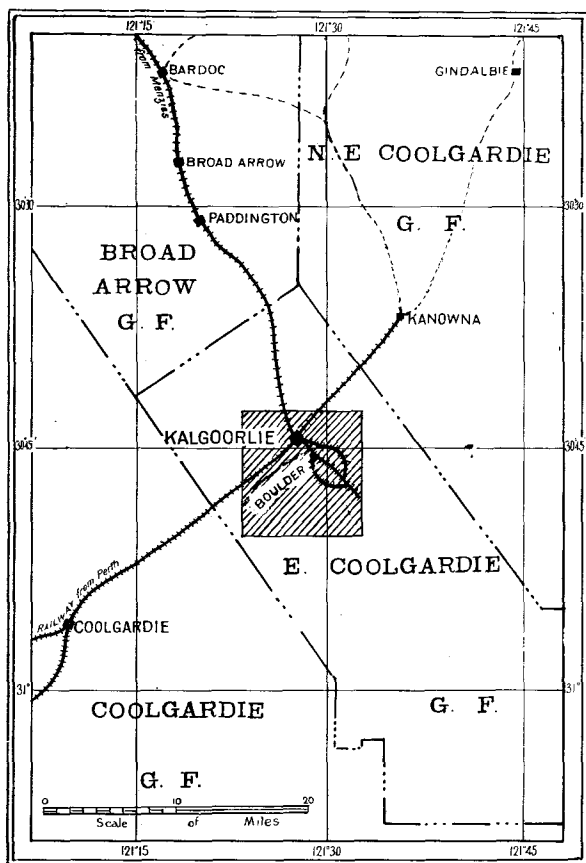


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1912.

Frontispiece.



Map showing the Area described in this Bulletin.



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#### AUTHORS' NOTE.

No reference will be found in the following pages to Mr. C. O. G. Larcombe's extensive monograph on the "Geology of Kalgoorlie" (Transactions of the Australasian Institute of Mining Engineers, Vol. V.) owing to the fact that this Bulletin was in the Printer's hands some time before the first copy of Mr. Larcombe's paper reached Perth.

The numbers in heavy type, thus [8763], are catalogue numbers of specimens in the Geological Survey collection now on exhibit in the Mineral Gallery of the West Australian Museum.

E. S. SIMPSON,  
C. G. GIBSON.

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## PREFATORY NOTE.

THE contributions by two officers of the Geological Staff upon the Kalgoorlie Field have been deemed of sufficient public interest to warrant their issue as a separate bulletin in advance of the completion of the more or less detailed work underground which is at present in progress.

The latter work had been taken in hand by one of the authors, Mr. Gibson, but his sudden resignation, together with the re-organisation and augmentation of the Geological Staff, has rendered it absolutely impossible for the detailed investigations to be brought to a close as early as would have been the case under other circumstances. An early completion of the work has also been rendered difficult owing to the fact that the energies of the field staff have now of necessity to be directed to the mapping of the districts lying between known mining centres with the view to meeting the demand for authentic geological information regarding outside and lesser known districts, and directing the prospecting phase of mining operations into legitimate channels.

As the underground survey proceeds, the issue of a further bulletin, containing an account of the structural relations of the ore deposits and the general tectonics of the field, as well as its petrography, aspects which it has been found impossible to touch upon in the present publication, is contemplated.

The results of such scientific researches as have at present been carried out at Kalgoorlie seem to indicate that there is little or no fear that on the whole the ore deposits will not persist to the greatest depth to which mining becomes possible and that the grade of ore below a depth of 2,000 feet may be expected to be just as variable below that level as it has been above it.



GOVERNMENT GEOLOGIST.

Geological Survey Office,  
14th November, 1911.

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NOTE *re* MICROPHOTOGRAPHS.

The scale of enlargement shown thus—x 15.

The lighting indicated by the following initials :—

O.L.—Ordinary transmitted light.

P.L.—Plane-polarised transmitted light.

X.N.—Between crossed nicols.

R.L.—Ordinary reflected light.

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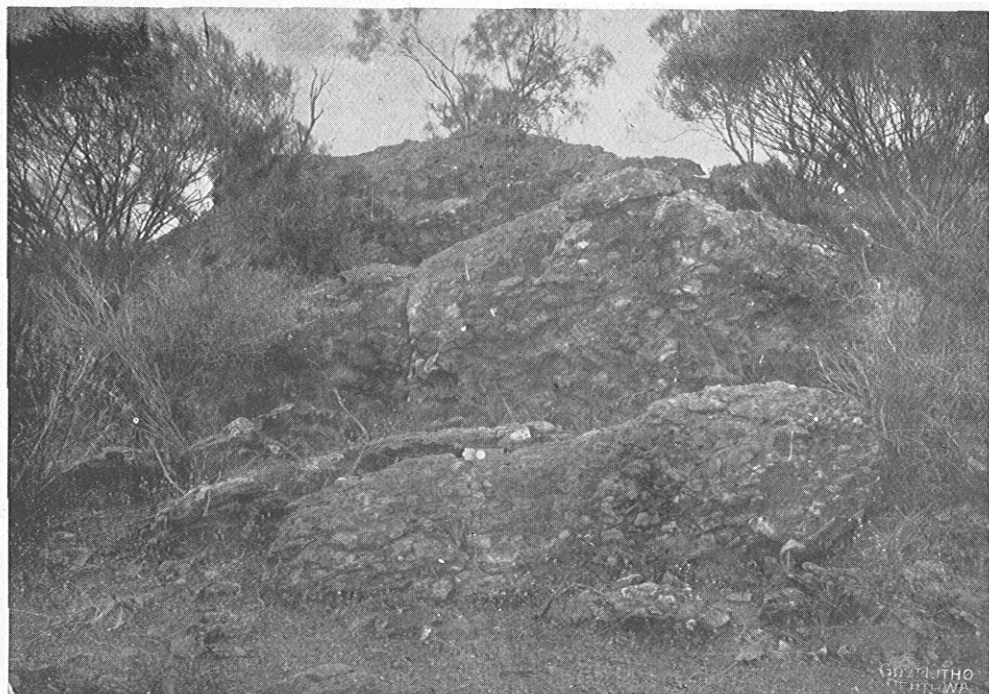


Photo: C. G. Gibson.

Sheared Conglomerate, 7½ miles South-West of Boulder.



# Contributions to the Study of the Geology and Ore Deposits of Kalgoorlie, East Coolgardie Goldfield.

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## PART I.

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### I—GEOLOGY OF KALGOORLIE AND BOULDER.

By Chas. G. Gibson.

#### GENERAL TOPOGRAPHY.

The chief topographical feature of the Kalgoorlie district is a main central ridge of hills trending roughly north-north-west and south-south-east, and reaching its maximum altitude in Mt. Gledden, better known as Maritana Hill, which rises to a height of one hundred and fifty feet; this ridge has a length of about four miles, and dies out in a southerly direction just beyond the south end of the Boulder mines. On each side of this central ridge are wide flats draining southerly and extending laterally on the east side for, say, five miles, and on the western for about three. On the east side of the eastern valley is another rather more conspicuous ridge of hills also trending roughly north-west and south-east and having a maximum altitude of possibly a couple of hundred feet; along this ridge of hills are situated the mining centres of Boorara and Waterfall (Golden Ridge). The western flats are also in their turn flanked by a low ridge of hills less conspicuous at their northern end but well defined at their southern. Both the eastern and western valleys, if they may be termed such, drain, as before stated, southerly into the extensive salt lake, or marsh, known as Gnumballa or Hannans Lake, which starts but a short distance south of the Boulder mines, and trends away in a south and south-westerly direction for many miles.

This extensive salt marsh known as Hannans Lake represents, in common with the other so-called salt lakes of Western Australia, what is, in the writer's opinion, the remains of a large inland river-lake system having at one time a natural outlet to the sea. The majority of these "lakes," when carefully followed up, are found to belong to certain definite systems and to be connected by more or less well-defined valleys, all having their fall in the one general

direction. In a report on the "Country lying along the Route of the proposed Transcontinental Railway in Western Australia,"\* reference was made to the Mulgabbie lakes and the long narrow lake system known as the Pantom River, as representing the remains of a large inland river flowing into the sea in Tertiary or pre-Tertiary time. Probably at this time the climatic conditions of Western Australia changed, the rainfall became less, and the rivers ceased to run; they then gradually dried up and their courses became more or less obliterated by the accumulation of wind-driven surface debris, sands, loam, etc., resulting from the gradual weathering of the country rocks. The smaller rivers and lakes in this way possibly completely disappeared, while the present salt marshes, and their occasionally connecting valleys, represent the remains of the larger lakes and deeper river valleys.

On the western side of this salt marsh, and some three miles south of Boulder, is a small conspicuous clump of hills having their highest point in Mt. Hunt, the most prominent landmark in the district, which rises to a height of from three to four hundred feet. These hills are more or less connected by a westerly extension to the main western ridge.

The town of Kalgoorlie is situated on the western fall of the main central ridge northwards from its middle point, and the mines are along the line of the ridge, the "Golden Mile" being at its southern end, the underlying rocks of the valleys being, as will be explained later, non-auriferous or practically so.

#### GENERAL GEOLOGY.

The original rocks of the Kalgoorlie district were of sedimentary origin, viz., shales, soft sandstones, grits, conglomerates, etc., with possibly inter-bedded lava flows, laid down horizontally in probably pre-Cambrian time on a gneissic or granite floor; these were by earth movement afterwards tilted into their present highly inclined positions and subsequently intruded by large masses of basic and ultra basic igneous rocks (gabbros, diabases, porphyrites, pyroxenites, peridotites, etc.), which in turn have been invaded by a small series of acidic rocks (quartz and felspar-porphyrates). Slight further earth movement has then taken place causing considerable shearing and faulting of the rocks, the former (the shearing) resulting in the formation of the lines along which the auriferous lodes of the field occur.

The accompanying geological map, Plate II. shows the present relative extent and position of the more important of the various classes of rocks found on the field.

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\* Geol. Surv. Bull. 37.

Fig. 2.

*Bulletin No. 42.*



Photo: C. G. Gibson.

Sheared Conglomerate,  $7\frac{1}{2}$  miles South-West of Boulder.

Neg. 619.

These may in a general way be grouped under the following nine heads :—

The Ancient Sediments	.. ..	Shales, Sandstones, Grits, Conglomerates, etc.
The Calc-schists	.. ..	} The Older Greenstones.
The Fine-grained Amphibolites	.. ..	
The Quartz-Diabases	.. ..	} The Later or Intrusive Greenstones.
The Coarse-grained Amphibolites including Amphibolite Epidiorites, Gabbros, and Pyroxenites	.. ..	
The Porphyrites	.. ..	} Newer Intrusives.
The Quartz and Felspar - Porphyries	.. ..	
The Peridotites	.. ..	Intrusive.
The Recent Deposits	.. ..	Sands, Loam, Laterites, etc.

#### THE ANCIENT SEDIMENTS.

These consist of shales, soft sandstones, mica and talc-schists, grits, and conglomerates, the shales and sandstones being of by far the greatest development. The sandstones are invariably soft and friable and generally have a somewhat banded appearance; they have a more or less fissile character, due to the shearing they have undergone. The sandstones vary in colour from dirty white through yellowish to red; the shales occur inter-bedded with them and are of considerably less extent. Mica and talc-schists are of comparatively rare occurrence; the former are found at a point of about nine miles south-west of Kalgoorlie and half a mile or so on the south side of the Coolgardie road; here there is a considerable development of a moderately hard laminated sandstone carrying a large percentage of black mica (biotite) and closely resembling in general appearance a fine-grained biotite-gneiss. Talc-schists are not seen in the main series of sedimentary rocks connected with the Kalgoorlie belt, but are found at a spot roughly five miles south of Mt. Monger townsite; these appear to be of sedimentary origin, but may equally as well be merely a highly sheared and altered form of the pyroxene rocks occurring in the locality, and the fact that they strike and dip differently to any of the known sedimentary series lends considerable strength to this latter view. Two main series of conglomerates occur, one between Binduli and Kurrawang, at a point some eight and a half miles south-west of Kalgoorlie, and the other about half way between Kalgoorlie and Kanowna. The first of these is by far the more important and better defined series; the matrix is a fairly soft micaceous sandstone practically identical with the surrounding rocks, while the pebbles and boulders, rarely more

than six inches in diameter, consist of jasperoid and hæmatite-bearing quartz, black chert, quartz, quartzite, quartz and felspar-porphyrries, felsite, granite, etc. (Figs. 1, 2, 3). The pebbles are as a rule set fairly closely together in the matrix, are well waterworn and rounded; they have, however, since their deposition been subjected to considerable pressure and shearing, and usually split fairly easily in one direction; were it not for this defect they would have probably proved of considerable local value for use as pulverisers in tube mills. The second, or Kurramia series, differ from the preceding, in that it is of considerably less extent and not so well defined; the bed is also much more weathered. The pebbles and boulders are mostly of hard blue quartz, with quartz and felspar-porphyrries, the latter being very much weathered and softened; the matrix is apparently the same as in the Kurrawang series, viz., a soft more or less micaceous sandstone.

All the rocks of the sedimentary series strike about north-north-west and south-south-east and have a prevailing underlay of about 80 degrees to the west; the conglomerate beds strike and dip with the enclosing rocks.

The close general resemblance in hand specimens of some of the sedimentary rocks to certain sheared and weathered forms of porphyrite and other igneous rocks will be referred to later when dealing with the igneous varieties in question.

*The General Extent of the Sedimentary Rocks.*—Three main belts of sedimentary rocks occur in the Kalgoorlie district; these exhibit a marked parallelism in their general trend, which is roughly north-north-west and south-south-east, or the same as the strike of the various beds forming the series. The western or Kurrawang belt starts some four miles west of Kalgoorlie and has a width of roughly twelve miles; how far northerly it runs is not known, as everything is hidden in this direction by an extensive covering of loose sand and loam; the belt probably extends, however, brokenly perhaps, to the neighbourhood of Black Flag; southerly it is known to run beyond Wollubar, some twenty miles from Kalgoorlie, but appears to be narrowing down in this direction and probably does not go much further; it thus has a probable total length of about fifty miles.

The rocks of this belt are mostly soft laminated sandstones, but they also include shales, mica-schists, grits, and conglomerates. Good natural sections of them are to be seen along the small "breakaways" forming the western edge of the lake country some six miles south-west of Boulder, while good examples, more especially of the sandstones, are also seen in some of the old mine workings near Binduli and in some old shafts on the eastern foot of the conglomerate ridge two or three miles further to the south-west.



Photo: C. G. Gibson.

Sheared Conglomerate,  $7\frac{1}{2}$  miles South-West of Boulder.

Neg. 618.

The main series of conglomerates before referred to occurs within this Kurrawang belt, and has its greatest development at a point some eight and a half miles south-west of Kalgoorlie, where it forms a well-marked ridge of hills trending roughly north-north-west and south-south-east and extending for several miles both ways ; this ridge is crossed near its northern end by the main Coolgardie road at a point a little more than seven miles from the Kalgoorlie Post Office. There are at least three main beds of conglomerate in the series, and taken together with the intervening bands of soft sandstone they have a maximum thickness of well over a thousand feet. Judging by the pebbles on the surface there appear to be one or two small narrow parallel beds half a mile or so east of the main line ; no actual outcrops of these can, however, be seen, and their occurrence is by no means certain.

One of the most interesting features in connection with the occurrence of this series of conglomerates is the presence in them of that banded jasperoid and hematite-bearing quartz which is such a distinguishing feature of the Mt. Margaret and most of the northern goldfields ; this hematite-bearing quartz is, as far as the writer is aware, only associated with greenstone country, and the presence of boulders of it in the conglomerate points to pre-existing greenstone areas, thus making these of considerably greater age than the sedimentary rocks of this series ; if a pre-Cambrian age is assumed for the latter, then the original greenstones are probably Archean ; the absence of greenstone pebbles themselves in the conglomerate can be explained by the readiness with which such weather and disintegrate. The nearest occurrence of this hematite-bearing quartz of any importance that the writer knows of is some eighty to ninety miles east-north-east of Kalgoorlie, on what is probably the southerly continuation of the Edjudina series.

The second series of conglomerates occurs in the eastern or Kurramia belt of sedimentary rocks, and will be described later.

While writing of these conglomerates mention should be made of an occurrence reported by Mr. Frank Hann from the neighbourhood of Mt. Squires, in what is commonly known as the Warburton Range district, near the South Australian border. Here from Mr. Hann's description there is a large development of apparently vertically or highly inclined conglomerates seemingly similar to those of the Kurrawang series ; the writer has seen pebbles from the "Mt. Squires" conglomerate, and they have the same characteristics as those from the Kurrawang beds. Should the two series be similar, then other rocks in the locality may also prove similar, and the district should be worth investigation, more especially as greenstone country is known to exist in the Warburton district.

The second or central belt of sedimentary rocks lies immediately on the eastern side of that complex of igneous rocks forming the main auriferous belt, and occupies the valley lying between the Kalgoorlie and Boorara ridges.

This belt, as shown on the accompanying map, Plate II., has a general width of from two to two and a half miles; its general trend is north-north-west and south-south-east, and it extends in these directions for many miles, though its exact limits are not at present known.

The rocks of the series consist of soft laminated sandstones, grits, and shales. A good section of the shales, just on the western edge of the belt, can be seen in the old Phoenix brick pits (Fig. 4), just on the south side of the Kanowna road and about two miles from the Kalgoorlie Post Office.

The sandstones and fine grits have been exposed in a couple of water shafts on old G.M.L. 3606, about a mile and a half further east along the same road, while typical examples of coarse grits are to be seen in several old shafts just to the east of the Isolation Hospital Reserve 7882; these latter grits, with their coarse quartz grains and white kaolinic binding material, very closely resemble a soft highly kaolinised coarse granite or quartz-porphry.

The third eastern or Kurramia belt lies on the eastern side of the Boorara ridge and extends easterly for some miles, or nearly to Kanowna. Like the others, it also has a north-north-west and south-south-east trend, and is of considerable extent, probably having a total length of well over twenty miles, its greatest development being to the northward.

The rocks of this belt consist, as far as known, chiefly of soft sandstones and grits, but they also include a small series of conglomerates. The general character of these conglomerates has already been referred to; they can be seen in a small cutting about a mile and a half along the Kurramia wood line, where the bed is about a hundred feet in thickness and seen to be interbedded with the sandstones; these conglomerates are of considerably less importance and magnitude than the Kurrawang series, and cannot be followed for any great distance on the surface.

The whole of the sedimentary rocks of the district, more especially referred to in this report, are non-auriferous and therefore of no economical importance.

#### THE OLDER GREENSTONES.

The rocks which have been classed under the heading of "Older Greenstones" comprise two main groups, viz.: (a) the calc schists and (b) the fine-grained amphibolites. These in places have a very close relationship and resemblance to each other and were probably of the same origin; they possibly represent





Photo: C. G. Gibson.

Shales, Phoenix Brick Pits.

Neg. 66.

an ancient basic lava flow, or intrusion, formed while the sedimentary rocks were still in their original position.

*The Calc-Schists.*—The rocks of this group are essentially fine-grained, but vary somewhat in colour and general appearance; typically they are dark grey on fresh fracture, with a somewhat blotchy appearance due to unequal carbonating, and are characterised by numerous small veins of calcite and dolomite running through them in all directions; they break readily in almost any direction, and when strongly laminated generally show a fairly good development of scaly chlorite along the cleavage planes. A less typical variety is darker, very fine-grained, harder and more compact, with at times little or no sign of schistosity; this type, in hand specimens, very closely resembles some of the fine-grained slightly carbonated chlorite diabases.

Another variety is strongly mottled in appearance, the mottling being due to the presence of more or less rounded aggregates of calcite (dolomite), these being up to half an inch in diameter and often set closely together, the balance of the rock being of the normal greyish type. Owing to the presence of comparatively large amounts of ferrous carbonates in nearly all these rocks, the surface, which on fresh fracture is grey to dark green, rapidly darkens and often becomes slightly reddish on exposure to the air owing to the oxidation of the ferrous compounds.

The calc-schists are apparently very closely allied to the fine-grained amphibolites and probably form part of an ancient basic lava flow or intrusion; owing, however, to the extreme alteration, both chemical and physical, that has gone on in them, their original structure has been almost completely obliterated, and they now consist essentially of an indefinite mixture of chlorite and carbonates, with only very occasionally traces of their original crystalline form left.

A section (108) of the dark variety microscopically examined is seen to consist of an indefinite fine-grained aggregate of chlorite carbonates and saussurite with a little clear secondary feldspar, some sericite in small flakes, and much scattered ilmenite, mostly in fine grains; no original structure is visible, and the carbonates form the greater part of the section. A section (88) of the mottled variety from the 300ft. level of the A.W.A. G.M. is also seen to consist of a somewhat indefinite fine-grained aggregate of carbonates, chlorites and saussurite, with large more or less spherical inclusions, these consisting of carbonates (probably dolomite) with a little quartz; in addition there is present a little rutile. (Rutile in needle-like crystals is a characteristic mineral of all the varieties of the calc-schists). In fine needle-like crystals, and also a good deal of scattered ilmenite, some traces of the original structure

are at times still present, and the rock appears to have been at one time a fine-grained fibrous amphibolite.

An interesting vein alteration of the calc-schists is seen some ten chains to the south of Mt. Ferrum on G.M.L. 111E; here the rock has been sheared and subsequently converted into a black and white mottled siliceous schist, which under the microscope is seen to consist essentially of tourmaline and quartz, the former being in irregular bands formed of felted aggregates of small crystals, while the quartz is mostly in large and small elongated granular "eyes"; in addition there are present a good deal of finely scattered iron ores and a small amount of carbonates. (The rock is a tourmaline-quartz-schist.) A very similar rock also occurs as an extreme alteration of the fine-grained amphibolites, and will be described later.

Another extreme alteration of the calc-schists is found in the so-called "graphitic slates"; these are found in every variety of the greenstones, and will be described when the "quartz-diabases" are being dealt with.

In their original form the interlacing and interlocking of the mineral fibres and crystals would give a certain degree of toughness to the rocks of this series, but owing to the almost total obliteration of this structure by the replacement of the original minerals by finely crystalline and non-crystalline carbonates of comparative softness, the original strength and toughness has been destroyed and the rocks fracture readily, and on this account, and also because of their general softness, mining operations in them are comparatively cheap and easy. This class also is as a general rule freer from the occurrence of joint planes and heads than much of the amphibolite diabase country, and on this account it is often found to stand better after being opened up.

The calc-schists lie immediately on the east side of the complex of igneous rocks forming the "newer greenstones" series, and their boundaries and extent are shown on the accompanying map, Plate II.

The hard dark variety already referred to occurs as irregular bands and lenses of varying size throughout the main mass; these merely represent more or less lenticular areas or "eyes" which have resisted shearing and subsequent alteration to a greater extent than the main body.

The mottled variety occurs only as a comparatively narrow fringe round the eastern side of the basic amphibolite area at the north end, and is best seen in the workings of the A.W.A. Gold Mine; its peculiar character is probably due to contact alteration brought about by the intrusive amphibolite.

In economic importance the calc-schists probably rank next to the quartz-diabases, many auriferous deposits of considerable

importance occurring within them ; these, however, have so far always been at no great distance from the newer intrusives.

The "*Fine-Grained Amphibolites*."—These are another somewhat indefinite group of rocks ; typically they are fine-grained, dark-green to grey-green in colour, and usually massive. In some of their forms they very closely resemble certain varieties of the calc-schists, this being more especially the case with the series on the eastern side of the field.

Some of the freshest and most massive varieties are undoubted amphibolites ; other types approach somewhat closely to a fine-grained quartz-diorite, whilst others again are solid carbonate-chlorite rocks, probably formerly amphibolites.

As they are undoubtedly all part of the one series these rocks have, for the sake of simplicity in mapping, been grouped under the one heading of "fine-grained amphibolites."

The type rock is fine-grained, massive, and dark green in colour, and is an undoubted fine-grained amphibolite ; an example [11033] from G.M.L. 942, Queen of the West, seen under the microscope is shown to consist essentially of pale-green hornblende arranged in fine fibrous radiating aggregates and in sheaves of small needle-shaped crystals ; the hornblende is partly converted into chlorite, and there are present in addition a little saussurite (representing the remains of small felspar crystals) and a small amount of carbonates (Fig. 5). Another example (7) of the same type from a spot twenty chains north-north-west of the New Reefers G.M. shows the radiating hornblende aggregates to be considerably more chloritised, while there is a correspondingly greater development of carbonates ; small amounts of ilmenite and rutile and a little clear secondary felspar are also present, as well as a little quartz (probably of secondary origin).

A somewhat more chloritic variety of this type is found in the railway quarry near Somerville ; originally this rock apparently consisted almost entirely of hornblende in fine radiating aggregates, but a section of it now shows most of the hornblende to have been converted to chlorite, while there are present, as subordinate minerals, carbonates (in minute veinlets and small granular aggregates), iron ores (in small scattered grains), and a little granular epidote ; the saussuritised remains of few small felspar crystals are also present as well as a small amount of quartz.

A form somewhat approaching in general character a very fine grained variety of the quartz-diorite is found on the eastern side of the field at a spot about a quarter of a mile east-north-east of the Brownhill Recreation Reserve ; in its present form, however, this rock is very much altered and carbonated and its original structure is almost completely obliterated ; a section (14) of it shows it to consist chiefly of carbonates, a little green chlorite,

some quartz, much ilmenite, largely altered to leucoxene, as well as smaller amounts of magnetite, pyrites, epidote, and saussurite ; a second section (15) from that same locality is the same as the preceding except that there is a much larger development of greenish chlorite and slightly less carbonates. A similar variety is found on the western side on W.R. 227, Boulder, and also on the Mullingar Quarry Reserve at Kalgoorlie ; the latter variety, however, is in greater part a massive chlorite carbonate rock with no traces of original structure left. A section (25) of the variety on W.R. 227 shows it to be a fairly highly carbonated rock consisting in addition to chlorite and carbonate of a little quartz, some clear felspar (probably largely secondary albite), a good deal of epidote and some ilmenite (largely altered to leucoxene) ; there is a little micropegmatitic intergrowth of the quartz and felspar and also of the quartz and chlorite ; in general character this variety is not unlike the Somerville type, except that it is slightly coarser, more carbonated, and exhibits slight micropegmatitic structure, this not being present in the latter variety.

A section (84) of the Mullingar quarry rock shows it to consist essentially of a fairly indefinite fine-grained aggregate of chlorite carbonates and quartz, the chlorite forming the bulk of the section ; there are also present some saussurite, a little clear (secondary) felspar, much granular epidote, a good deal of magnetite and much ilmenite (largely altered to leucoxene) ; a little micropegmatitic intergrowth of the quartz and chlorite is noticeable, the former being probably chiefly of secondary origin. A second section (58) shows a somewhat finer grained granular aggregate of carbonates and chlorite, with no trace whatever of original structure left ; as subordinate minerals there are present small amounts of saussurite (representing original felspar), some ilmenite (mostly altered to leucoxene), a few small grains of clear quartz, and a little granular epidote. This rock appears to have been formerly a fairly fine-grained basic amphibolite.

Owing to the probable very close relationship in their original forms of these fine-grained amphibolites with the calc-schists, some of the more extreme alteration types of the two groups are indistinguishable, more especially in their weathered forms, this being particularly the case with the highly sheared and vein-altered varieties.

One very interesting modification (vein-alteration) of the fine-grained amphibolites is seen in the eastern band at a point about fifty chains east-south-east of Brownhill Railway Station ; here on an old dump can be seen a weathered highly carbonated chloritic schist containing numerous small flakes of a dark scaly-looking mineral resembling a dark variety of siderite ; a section (219) of this schist seen under the microscope shows the scaly-looking

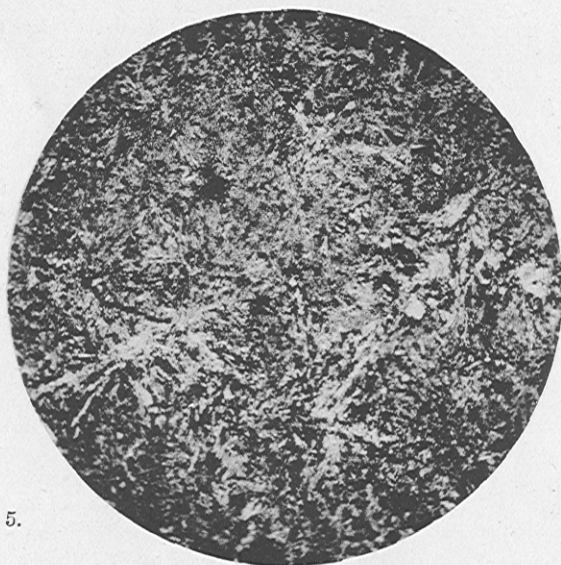


Fig. 5.

Photo. by

[11,033.] O.L.  $\times 15$ .

H. Bowley.

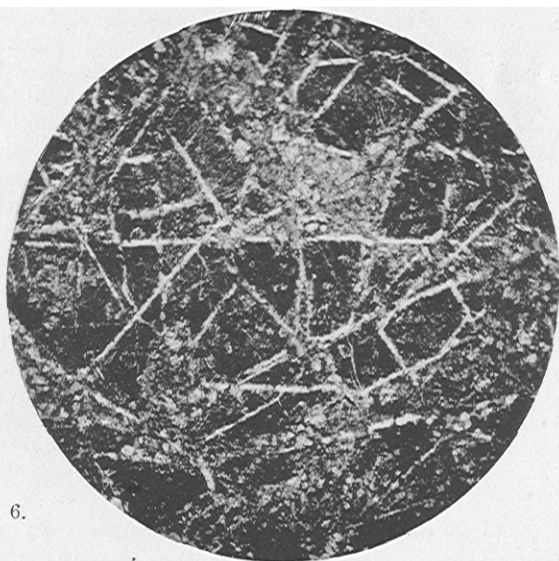


Fig. 6.

Photo. by

[11,104.] O.L.  $\times 15$ .

H. Bowley.

Fig. 5.—Fine grained Amphibolite, Queen of the West G.M.L. 942.

Fig. 6.—Quartz Diabase, showing extreme carbonating, Hidden Treasure G.M.

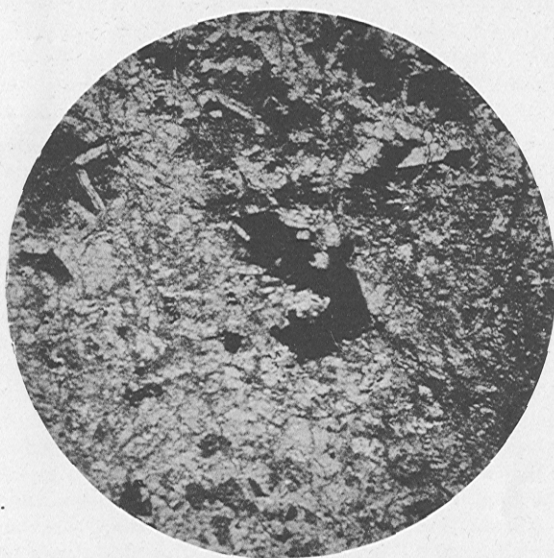


Fig 7.

Photo by

[11,041.] O.L.  $\times 15$ .

H. Bowley.



Fig. 8.

Photo. by

[11,003.] O.L.  $\times 15$ .

H. Bowley.

Fig. 7.—Quartz Diabase, showing carbonating, Oroya North Block.

Fig. 8.—Basic Amphibolite (Pyroxenite), Outridge G.M.L. 1187.

mineral to be chloritoid occurring in abundant well-formed rectangular flakes; the matrix is a fine-grained intimate mixture of finely granular quartz sericite and carbonates, with a little dirty chloritic material and some finely divided iron ores scattered through it; small veinlets of quartz and chloritic material run through the section, the latter being associated with much fine iron ores; numerous small crystals of rutile are also present.

Other less interesting but more common alteration varieties are the so-called "slate" bands; these are merely highly sheared zones which have undergone bleaching, kaolinization, secondary silicification, etc., and have at times exactly the appearance of true sedimentary slates; sometimes they become graphitic, while at others they are highly ferruginous and siliceous, then becoming the so-called "jasper lodes"; these variations are, however, characteristic of all the igneous groups of rocks, and will be discussed in more detail later on.

The extent of the fine-grained amphibolites is shown on the geological map which forms Plate II. The type rock from which the group has been named is found immediately on the western side of the main "newer intrusive" mass, and also further west towards Somerville. The main apparent differences between this rock and that forming the eastern band (and in part also the western) is due to the fact that the latter has undergone considerably greater physical and chemical alteration, the latter resulting in a greater development of chlorite, carbonates, and a certain amount of secondary quartz, whilst the two combined have resulted in the formation of the extreme alteration types mentioned above, and which, comparatively speaking, appear to be almost entirely absent from the western group—(it must be mentioned, however, that a large portion of the western area of these rocks is hidden beneath extensive recent deposits of sand, loam, etc., and as there are practically no underground workings over this area it is impossible to say what variations from the type may occur in it).

The two western bands shown on the map probably become one a little further north, owing to the porphyrite dying out, and they then probably continue onwards in this direction for a considerable distance. The eastern band also probably runs some distance in this direction, but it does not appear to continue far southerly.

The rocks of this series have so far proved of no economic value, and the result of such work as has been done within them has been to prove that they are non-auriferous.

#### THE LATER OR INTRUSIVE GREENSTONES.

The series of basic and ultrabasic igneous rocks which have been mapped as the "Later, or Intrusive Greenstones," includes



quartz-diabases, gabbros, pyroxenites, epidiorites and amphibolites ; they are all of coarse texture and are very closely allied to each other, most probably forming part of one original magma. The group referred to as "Quartz Diabase" has been separated from the others principally on economic grounds, while the remaining members of the series have been grouped together under the one main heading of "coarse grained amphibolites" chiefly for the sake of simplicity in mapping. These various groups will be referred to more in detail and their relationships more fully described when dealing with the subdivision in question.

*The Quartz-Diabases.*—The type rock of this group is in hand specimens massive and fairly coarse-grained ; it has a mottled appearance, being dark-green in general colour with abundant porphyritic white feldspars, or what were originally feldspars, and occasional fair-sized blebs of colourless quartz as well as numerous small irregular greyish patches of leucoxene. A section (157) of it seen under the microscope shows it to be a holocrystalline rock consisting of quartz, feldspar, chlorite and carbonates, with ilmenite, leucoxene, epidote, and apatite as subordinate minerals ; the quartz is mostly granular and interstitial, but also occurs in micrographic intergrowth with the feldspar and also to a less extent with the chlorite, being in the latter case probably secondary (a good deal of the granular variety probably also being of secondary origin) ; the feldspar, other than that occurring in micrographic intergrowth with the quartz, is mostly in long tabular crystals, multiple twinned, and is considerably saussuritised and carbonated ; the chlorite occurs in scaly aggregates and scattered flakes and is very abundant ; it is associated with varying amounts of carbonates, etc., and represents the remains of an abundant original ferro-magnesian mineral, probably augite ; the micrographic intergrowth of quartz and chlorite which can occasionally be noticed is probably due to the separation of secondary quartz during the alteration of the augite ; the carbonates occur in small granular patches, chiefly associated with the chlorite, but also to a less extent with the feldspars ; much ilmenite has originally been present mostly in good-sized patches, but is now very largely altered to leucoxene ; epidote is present in the form of a few very small scattered grains, generally closely associated with the chlorite, while a few small needle-shaped crystals of apatite are present as inclusions in some of the larger quartz blebs. This rock differs but little from some of the more chloritised quartzose amphibolites of the northern end of the field ; its chief difference lies in the complete change of the original ferro-magnesian mineral to scaly chlorite and the comparatively small development of epidote, this mineral being very abundant in the northern rock. (Fig. 6.)

A less typical variety is considerably finer-grained, with, in hand specimens, no sign of porphyritic feldspars and with the quartz blebs developed to a much less degree; it is, however, merely a local modification of the type rock, and is usually much more carbonated, though this is not apparent in hand specimens; under the microscope it is seen to consist of a more or less granular aggregate of chlorite and carbonates, the latter occurring at times as well-formed rhombohedrons, with a few small quartz grains and much scattered ilmenite and magnetite; there are also present a little clear feldspar (probably secondary albite), a good deal of saussurite, and a few small flakes of colourless mica (sericite); the original structure of the rock has been completely obliterated by the carbonating and a few small veins of quartz and carbonates, and quartz, chlorite, and carbonates are to be seen running through the section. (Fig. 7.)

As a general rule the "diabases" are massive, but they are also found in all degrees of foliation, schistosity, and chemical alteration; these resulting in the production of chlorite schists, carbonate chlorite schists, carbonate sericite schists, quartz carbonate sericite schists, massive carbonate rocks, etc., etc.

The chief effect of the chemical alteration is seen in the extreme carbonating that has gone on over certain areas, this, as might be expected, being greatest where the shearing of the rocks is most pronounced. As the result of it the rock has been converted into an indefinite mixture of lime, iron, and magnesian carbonates with some residual silicates and a good deal of secondary and some original quartz. In its extreme form the carbonated rock is white to pale pink on fresh fracture, but it soon changes to a dull pink owing to the oxidation of the ferrous carbonates present; in texture it varies from a fine-grained compact variety with apparently very little quartz to a coarse variety with large quartz blebs, this latter type at first glance having very much the general appearance of a pink granite or syenite. In some of its finer compact forms it is indistinguishable from the highly carbonated feldspar-porphyrries, even when examined with the aid of a microscope. This finer and more compact variety is usually found in proximity to the lodes and represents the extreme form of this alteration.

This general carbonating is extremely common, and all gradations from the normal "diabase" to the above extreme forms can be seen. A section (178) of a specimen of the partly carbonated normal rock from Chaffers G.M. shows the greater part of the original ferromagnesian minerals to have been converted to carbonates, only a little scattered chlorite being left, while there is a large development of clear interstitial quartz (probably secondary) in addition to that occurring in micropegmatitic intergrowth with the feldspar; the bulk of the feldspars have been completely

saussuritised ; in this case the original structure of the rock is still present. Another specimen (101) from the Oroya North Block shows a further stage in which the greater part of the original structure has been obliterated, though the rock as a whole is still coarsely crystalline ; in this case there is very little chlorite left and there is a correspondingly greater development of carbonates ; much of the original feldspar has also been converted to carbonates, and there is a large development of interstitial quartz ; there is a good deal of saussurite present and numerous small flakes of sericite ; the ilmenite has been almost entirely converted to leucoxene, and there is a large development of finely scattered magnetite, this being associated with the carbonate chlorite patches representing the original ferro-magnesian masses.

Another specimen (145) of the same type shows a considerable micropegmatitic intergrowth of quartz and saussurite (representing original feldspar), and quartz and chlorite, in addition to much clear quartz and the usual carbonates, chlorite, saussurite, ilmenite, etc. ; there is only a little chlorite present, most of it having been converted to carbonates with the separation of clear secondary quartz round the remains of the original ferro-magnesian masses ; the original feldspars have been converted to saussurite and carbonates, and there is a considerable development of flakey sericite ; much ilmenite, mostly in skeleton crystals, has been present, but is now largely altered to leucoxene.

A specimen (103c) in which the carbonating has gone a stage further shows the original structure to be completely obliterated, with the exception of some small patches showing micrographic intergrowth of quartz and feldspar (now completely saussuritised), the section now consisting, in addition to the micropegmatite of a fairly coarse granular aggregate of carbonates with some clear quartz, a little finely scattered chlorite, and some clear secondary feldspar, together with some saussurite and a good deal of ilmenite, the latter largely altered to leucoxene ; the carbonates are mostly in granular aggregates, but are also in more or less well-formed rhombohedrons. This rock is still fairly coarsely granular in hand specimens.

A still further stage is represented by specimen [11041] which is a fine-grained more or less massive rock apparently consisting almost entirely of carbonates ; this is seen in section to consist of a finely granular aggregate of carbonates, with patches of saussurite, throughout which are scattered a little scaly chlorite, a good deal of flakey sericite, much ilmenite (as usual, largely altered to leucoxene), and a little magnetite ; in addition to the granular aggregates of carbonates numerous minute veins of calcite (dolomite) are present.

An interesting variety of the partly carbonated type is seen in specimen (105); in hand specimens this appears as a fairly massive fine-grained chlorite rock, throughout which are scattered numerous well-formed rhombohedrons of calcite (dolomite?) up to .05 inches in diameter; a section of it shews numerous well-formed and partly-formed calcite (dolomite?) rhombohedrons set in an indefinite fine-grained ground mass consisting of granular greenish chlorite, saussurite, some clear secondary feldspar, little quartz and carbonates, and much finely scattered magnetite; there is no trace of original structure left. (A very similar type to this is also occasionally found in the calc-schist series.)

The carbonating is often of very considerable extent, frequently extending over a width of as much as well over two hundred feet; being a "vein alteration" of the original rock, and not due solely to percolation of surface waters, it is probably fairly deep-seated, and is frequently to be seen down to depths of two thousand feet and over. It is almost invariably found taking place over the more highly-sheared portions of the country, and very frequently is to be seen to a greater or less extent in the immediate neighbourhood of the lodes. In some cases it occurs as very persistent well-marked bands, and in others as more or less irregular lenticular masses, these being often of very small extent.

Good examples of large developments of it are to be seen in the Kalgurli, Associated, Perseverance, Lake View, and Ivanhoe Gold Mines, and also in the Hamilton workings of the Great Boulder, whilst smaller local developments are to be seen in almost all the mine workings within the "diabase" area; splendid examples showing the gradual change from the normal "diabase," and explaining exactly the true relationship of the two varieties, are to be seen in many of the crosscuts underground, notably in the main west crosscut on the 1,200ft. level in the South Kalgurli and near the end of the west crosscut on the 1,669ft. level in the Ivanhoe Gold Mine. Frequently the carbonating can be seen, on a small scale, proceeding in the massive rock on each side of a fault or cleavage line, being most intense immediately along the fissure and gradually dying out on both sides of it; in the case of a small cleavage it often extends for less than an inch on either side, while in the case of main fault lines it at times extends over many feet.

In many cases these carbonated rocks carry a considerable quantity of pyrites, usually fairly coarsely crystalline and non-auriferous. In the majority of cases the iron for the formation of this pyrites has been originally derived from the rock itself, and now represents merely a rearrangement of the original iron by chemical combination with introduced sulphur; in other cases, however, both the iron and the sulphur have been introduced, and are found most largely developed immediately along the cleavage

crack, out from which carbonating has taken place, the pyrites, like the carbonating, rapidly decreasing away from the cleavage.

Very commonly there is a large development of finely crystalline magnetite through some of these carbonated rocks, this often being more marked in proximity to the lodes. Very good examples of this magnetite carbonate rock are to be seen in the Lake View and Perseverance Mines.

A highly schistose variety of the carbonated rock is occasionally met with along the lode channels or where secondary shearing has taken place; this form is usually creamy white in colour, and has a somewhat greasy appearance and feel owing to the large development of sericite along the cleavage planes; this variety may be described as a quartz carbonate-sericite schist.

For exactly the same reason as in the case of the calc-schists, *i.e.*, owing to the replacement of the original interlocking and comparatively tough minerals by soft granular and crystalline carbonates, mining operations within these carbonated areas are easier and cheaper than in the normal type of country; owing to the generally softer nature of the rock, drilling is comparatively easier and quicker, and along the same crosscut can often be seen cuts that have been fired in both classes of country; in the carbonated rock the cuts will be shot out right to the extreme end of, and often slightly beyond, the drill holes, while in the tougher normal rock often as much as six or nine inches of the hole will be left in the face.

Whilst on the subject of the quartz diabases mention must be made of the bands of so-called "slates" which occur so commonly in them as well as in other classes of rock on the field. These bands are found up to well over a hundred feet in thickness, and owing to their great similarity, especially near the surface, to true shales and slates, they have commonly been assumed to have been originally of sedimentary origin. Such, however, is, in the writer's opinion, undoubtedly not the case, all the available evidence going to prove that they are merely highly-sheared and laminated bands of country rock subsequently altered by chemical agencies into their present form.

The bands vary in thickness from a few inches up to over a hundred and fifty feet, the more usual thickness being from two to six feet; the wider and better defined ones are very persistent, both longitudinally and vertically; they are known to exist to a depth of 2,600ft., and can be traced often for well over a mile in length; on the other hand some of the smaller bands are of very restricted extent, and at times do not continue for more than a hundred feet either way, being merely thin lenticular patches; these lenses, however, are usually connected by a more or less well-defined shear or fault line. Usually the strike and dip of these so-called slates is the same as the general foliation of the country,

*i.e.*, strike about 25 degrees west of north and dip steeply to the west, but there are one or two cases in which they do not do this, the most conspicuous example being the band met with along the 1,200ft. level of the Great Boulder Mine at a point some twelve hundred feet north of the main shaft; the strike of this band is normal (*i.e.*, about north-north-west), but its dip is 45 to 50 degrees to the east; it is well-defined, and can be followed for some distance along the drive, having an average thickness of only about four inches; its central line is marked by a narrow seam of calcite (dolomite?), and the band represents the line of a main easterly dipping fault.

As a general rule the bands are graphitic, the graphite being usually most largely developed along the cleavage planes and being in some cases present in considerable quantity; it has evidently been deposited subsequently to the shearing of the rock, and is in all probability formed as the result of the decomposition of hydrocarbons derived from deep-seated sources. In these graphitic bands occurrences of natural gas have at times been met with. The most important of these was in the Associated Northern, a description of which is given on page 52 of this copy, while more recently a similar occurrence was reported by the management of the Great Boulder Proprietary Gold Mine, when sinking their main shaft below the 2,500ft. level, and also in the north end of the drive at the 2,500ft. level. In the writer's opinion it is to the imperfect combustion of this gas that the graphite in the schists owes its existence; the gas itself is undoubtedly derived from deep-seated sources, possibly from the decomposition of deep-seated carbides.

Frequently nodules of pyrites up to three-quarters of an inch in diameter are found in the graphitic bands; they generally exhibit a somewhat flattened appearance, owing to their growth being restricted in the direction at right angles to the foliation of the schists.

Very often small graphitic bands, probably marking lines of secondary shearing, are found in close relationship to the lodes, usually along the walls, but occasionally in the lode channels themselves; in these cases, owing to the graphite becoming mechanically mixed with the ore, they often cause considerable trouble in the metallurgical treatment of the ore.

When seen as hand specimens or in the workings underground the change from the "slate" to the solid country can at times be seen to be a gradual one, but more often it appears to be sharp and sudden; microscopic examination, however, shows it to be always a gradual one, the apparently solid country exhibiting a strong incipient schistosity which is not visible to the naked eye. A section of a specimen (157) from the 1,850ft. level in the Hamilton

workings of the Great Boulder Mine showing both the "slate" and the apparently solid country shows the latter to be a quartz-carbonate-sericite schist with a schistose structure almost equally developed to that of the "slate," but of a coarser texture and practically free from the presence of graphite; in the "country" there is a considerable development of clear quartz blebs, these being almost entirely absent in the "slate;" they are of fair size, rounded to angular with no sign of having been sheared or drawn out, and showing no sign of movement round them; they are evidently of secondary origin, and it is in the presence of these, the absence of carbon (graphite), and the generally coarser texture that lie the only essential difference between the "country" and the "slate."

In many cases the graphite bands carry a high percentage of pyrites, sometimes in the form of nodules, but more usually as disseminated crystals and generally considerably coarser than that found in the lodes; in no case, however, have they so far proved to be auriferous. This can be accounted for by the fact that they have been formed subsequently to the deposition of the gold in the main lode channels, and their mineralisation has taken place at a later date than, and under different conditions to, that of the auriferous lodes.

Occasionally there are considerable developments of these schists which are non-graphitic; this variety at the surface, where weathered, is indistinguishable from a true shale; occasionally it has undergone secondary silicification, and has then all the appearance of a fine-grained phyllite. There are particularly fine developments of this class on the Morning Star and Forest King Leases, about half a mile south of Trafalgar Railway Station, and also in the eastern band of fine-grained amphibolite just north of Brown Hill Suburban Area.

All these so-called "slate bands," both graphitic and non-graphitic, being merely bands of sheared country, are found in all the various classes of rock on the field, except the sedimentary (they probably, in their non-graphitic form, exist here also, but are not distinguishable on account of there being no difference between them and the enclosing sheared sediments); they are particularly well developed in the calc-schists and in the "newer greenstones," and are found from one end of the district to the other.

An interesting variation of one of these bands is seen on the western slope of Slug Hill, about half a mile south-south-east of the Trafalgar Railway Station; here there is a well-defined band some four to six feet in thickness striking in the usual direction and dipping at about sixty degrees to the west; it is non-graphitic, and has been subjected to certain vein alteration, with the result that

it is now converted into a tourmaline schist. A section (198) shows it to consist in part of a fine quartz mosaic with smallish scattered crystals of tourmaline, and in part of a dense felted mass of small tourmaline crystals set in a ground mass of fine quartz mosaic; occasional small needle-shaped crystals of rutile are associated with the quartz.

The "quartz-diabases" are the most important group of rocks on the field, as it is within them that all the principal auriferous deposits at present being worked occur; their full extent is shown on the map accompanying this report (Plate I.).

The term "diabase," the writer must admit, is not a particularly sound one when applied to the rocks in their present state, but the separation has been made and the name given to them chiefly on the grounds of economic reasons in order to distinguish them from the very similar but less auriferous rocks of the north end of the field. Originally the quartz-diabases appear to have been plagioclase, augite and quartz-plagioclase-augite rocks of the diabase or perhaps gabbro type, and have been thus practically identical with the other rocks of the "newer greenstone" series, all of which were originally plagioclase-augite, quartz-plagioclase-augite, and augite rocks, viz., gabbros, quartz-gabbros, and pyroxenites, now in part epidiorites and amphibolites. In the case of the "quartz-diabases" mass alteration, probably largely assisted by the presence of the intrusive porphyries, has taken place to a much greater extent than in the "amphibolite" group, the original ferro-magnesian minerals being completely converted into chlorite, while in the latter group the alteration has not gone so far, the ferro-magnesian being in many cases unaltered, while in others they have been largely converted to uraltite and hornblende, and in a less degree, in some of the north end rocks, to chlorite.

Since those rocks in which the alteration of the original ferro-magnesian minerals has been greatest, viz., the "quartz-diabases," are the most highly auriferous, and those in which it has been partial, viz., the chloritic amphibolites of the north end, are auriferous to a slightly less degree, while those again in which practically no alteration has taken place, viz., the gabbros and allied rocks of the western band, are for all practical purposes non-auriferous, it seems reasonable to assume that the gold has originally been held in combination by the ferro-magnesian minerals; the splitting up of these to chlorite, etc., has enabled the gold to get into solution and to be subsequently deposited in the lode formations.

That this is so, or that the conditions affecting the conversion of the ferro-magnesian minerals had any connection with those affecting the deposition of the gold is of course open to argument,



but the fact remains that in the wholly chloritic rocks (the "quartz-diabases") and in these alone are the highly auriferous lodes to be found.

*The Coarse-grained Amphibolites.*—As already stated, the series of rocks which have been mapped together under the one main heading of "coarse-grained amphibolites" include amphibolites, epidiorites, gabbros, quartz-gabbros, and pyroxenites. They are all coarse-grained in texture and, with the exception of small locally sheared areas, are distinctly massive. Originally they were, as mentioned earlier in this report, all plagioclase-augite, quartz-plagioclase-augite, and augite rocks of the gabbro, quartz-gabbro and pyroxenite types; a certain amount of mass alteration has taken place in them, and large areas of the original pyroxenites and gabbros are now amphibolites and epidiorites; these two varieties, particularly the amphibolites, have their greatest development over those areas shown at the north end of the main central (Kalgoorlie) ridge and to the west and south of the Boulder mines; they also occur to a lesser extent towards the northern end of the western greenstone band.

Over the area on the northern side of Kalgoorlie they are of three distinct types, (a) quartzose (b) felspathic and (c) basic; these appear to undoubtedly represent merely differentiations from the one intrusive mass, the "quartzose" or more siliceous occupying, as would be expected, the central portion of the mass and gradually grading off both ways into the more basic varieties forming the outer margins, the "basic" being on the eastern margin and the "felspathic" on the western. The "quartzose" type is in its more chloritic form almost identical with the "quartz-diabases," the essential differences being the presence of small amounts of pale green hornblende in the "amphibolites" as well as a much larger development of granular epidote; it is the country rock of, amongst others, the Golden Zone, Hannan's Reward, and the mines on Cassidy Hill and Mt. Gledden. Typically it is a coarse, blocky, dark-greenish coloured rock, almost black in places, apparently consisting chiefly of hornblende and chlorite, with a few quartz blebs visible and occasional felspar crystals.

A section (1065) of a typical specimen from the Don (G.M.L. 225E), at the north end of the field, shows it to be a holocrystalline rock made up of the following constituents:—chlorite, in large greenish patches and scattered scales all through the section; plagioclase felspar, mostly in fair-sized imperfectly formed crystals and masses and largely altered to saussurite; quartz, plentiful in clear grains and in abundant micropegmatitic intergrowth with the felspar and also to a less extent with chlorite; hornblende, as a few small pale green patches, it has mostly been altered to chlorite; epidote, abundant in granular aggregates; magnetite and ilmenite,

both plentiful in large and small crystals ; carbonates, but not to any large extent ; biotite, as small flakes in radiating aggregates and probably of secondary origin as the result of the alteration of the original augite ; zoisite, in the form of a few small scattered crystals.

Another section (1068) from G.M.L. 248E (Hannan's North) is similar to the preceding except that the original ferro-magnesian mineral has been almost entirely altered to chlorite, there being only a few very small patches of hornblende left ; there is also a larger development of epidote, while the majority of the ilmenite has been altered to leucoxene. Except for the small amount of hornblende still remaining and the larger amount of epidote present, this rock is identical with those of the "quartz-diabase" series.

A very coarse-grained variety of this type occurs on the western fall of Maritana Hill (Mt. Gledden) on G.M.L. 3770, Eaglehawk United ; in it the original-ferromagnesian has been largely in excess, and is in irregular crystals up to half an inch or more in diameter, these being at times somewhat "barrel" shaped owing to curving of the faces ; it is merely a coarse-grained more basic segregation from the main mass, and is of only very limited extent, being seen in only one set of mine workings. A section (85) of it shows a good deal of pale green hornblende (uralite) still remaining, though most of the original ferro-magnesian has been converted into chlorite, this being present in large masses and in numerous scattered scaly flakes, the latter having largely encroached on the larger felspar crystals ; a little clear quartz is present and much micropegmatite of quartz and felspar, the latter largely converted into saussurite ; there is a fair amount of felspar, chiefly in long tabular crystals and much saussuritised ; much ilmenite and leucoxene are present and also large amounts of granular epidote, together with a few small patches of carbonates.

A variety (86) intermediate between this and the preceding type rock is found on the Sir John Forrest G.M.L. at the south-east end of Maritana Hill ; this is a coarse-grained massive rock very dark in colour and showing numerous quartz blebs and a larger development of felspar crystals than the Eaglehawk variety, while a section of it shews that it also contains more green hornblende and correspondingly less chlorite, more felspar, more micropegmatite of quartz and felspar and more unaltered ilmenite.

This type of the amphibolite is occasionally found in a highly carbonated state similar to, but not so intense as, that undergone by the "quartz-diabases" ; the areas, however, are of very limited extent ; a fairly good example is seen on G.M.L. 547 on the north side of Mt. Ferrum. Owing to the practically complete destruction of the ferro-magnesian this rock in its most highly carbonated form

is indistinguishable, both in hand specimens and microscopically, from certain of the carbonated "diabases."

It is within this area of chloritic quartzose amphibolites that most of the gold-bearing lodes of the north end of the field occur; certain auriferous deposits have certainly been worked in the basic type of rock, but most of these appear to be closely associated with certain intrusive peridotite masses; in the felspathic type lodes have been worked to a small extent but they have, however, not so far proved payably auriferous.

The felspathic variety is the type "amphibolite" of the field; it is a holocrystalline coarse-grained massive rock, in hand specimens consisting apparently of feldspar and hornblende in about equal proportions, the feldspar being in good-sized irregularly shaped crystals and giving the rock a decidedly mottled appearance. It occurs on the western side of the northern Kalgoorlie area, over practically the whole of the southern central, or Boulder area, and over most of the northern end of the main western belt. With these felspathic amphibolites are included the epidiorites.

A typical example from the northern Kalgoorlie area is represented by the rock found on the east side of Mullingar, a section (1077) of which shows it to be a holocrystalline rock consisting of the following minerals:—(1) pale hornblende and uraltite, both abundant and in part converted to chlorite; they are both apparently the result of alteration of augite, a little of which is still present in its original form, showing well-defined schiller structure, this being still visible in some of the uraltite; (2) plagioclase feldspar, very much saussuritised and arranged in clusters of smallish rectangular crystals; (3) quartz, as occasional small clear patches filling the spaces between the feldspar crystals; (4) epidote, in minute scattered grains associated with the chlorite; (5) ilmenite, in fair quantity and largely altered to leucoxene; there is no micropegmatitic intergrowth of quartz and feldspar; the derivatives from the original pyroxene are somewhat in excess of the combined other constituents of the rock. A section ( ) of another specimen (34) from an outcrop just at the back of the Warden's residence, Kalgoorlie, is similar to the foregoing except that there is no augite left but more uraltite, more chlorite and correspondingly less hornblende; traces of original schiller structure are at times still visible in the uraltite; the feldspars are much saussuritised and carbonated and are in the characteristic groups of small rectangular crystals. A typical specimen (47) of the southern central or Boulder area is from G.M.L. 1092, Hesperus North. A section ( ) of this shows the bulk of the original augite to be altered to pale hornblende and uraltite (chiefly) with some chlorite; schiller structure is at times visible in the partly uraltitised augite; the original feldspars are in groups of small rectangular crystals much saussuritised;

much ilmenite and leucoxene are present as well as a little clear secondary feldspar and some carbonates; a small amount of clear quartz and a little micropegmatite of quartz and chlorite and quartz and feldspar is also present, together with a fair amount of granular epidote; traces of an original ophitic structure can still be seen in the section. A slightly more basic variety (48) of this type is found near Recreation Reserve 6435 some fifteen chains further west than (47); this consists of a fairly fine-grained crystalline mixture of feldspar and green and brown hornblende, the latter in small flakes and plates, with large irregular masses and flakes of uraltite and a little chlorite; the original feldspars are much saussuritised, and there are present, in addition, some carbonates, a little clear quartz, a little granular epidote, and a good deal of ilmenite and leucoxene.

Another variety (187) approaching somewhat to the "acidic" type occurs on G.M.L. 1397. Alice; it is a slightly more chloritic variety of (47); a section of it shows a little hornblende, but most of the original ferro-magnesian has been converted to uraltite and chlorite, both of these being present in large amounts; the feldspars are in small crystals and slightly fresher than usual; there is a fair amount of micropegmatite of quartz and chlorite, much granular epidote and a large amount of ilmenite and leucoxene. Associated with this rock is an interesting vein breccia; this shows in hand specimens radiating bunches of tremolite set in a matrix apparently composed chiefly of carbonates; a little of it is to be found on the dump on G.M.L. 1397 (Alice).

A section of it shows the tremolite to be arranged in long sheaves and radiating bunches of needle-shaped crystals, set in a ground mass of granular and crystalline carbonates (dolomite?); associated with it are numerous small crystals of magnetite. Another variety (70) of the amphibolite practically identical with the "quartzose" variety of the north end and approaching closely to the "quartz-diabases" of the Belt series is found on G.M.L. 1112 (Pirie); a section of this shows the original ferro-magnesian to be entirely converted to uraltite and sealy chlorite, the latter being present in considerable quantity; there are also present much micropegmatite of quartz and feldspar, numerous good-sized feldspar crystals (saussuritised) together with a fair amount of ilmenite and leucoxene, some granular epidote, and a small amount of carbonate.

On G.M.L. 3337 (Ivanhoe and Boulder Junction) is coarse massive amphibolite (51) differing slightly from the type rock; in hand specimens it is not unlike the type, but is somewhat lighter coloured, with the hornblende in more needle-shaped crystals, and is probably merely a locally altered form of it. A section of it shows it to consist of—pale green hornblende, in flakes, grains

elongated prisms and long feathery and radiating aggregates; plagioclase feldspars in elongated crystals much saussuritised; much ilmenite and leucoxene; a little scattered chlorite; a few small grains of epidote; a little clear secondary feldspar and a small amount of clear quartz. At a spot some thirty chains north-west from G.M.L. 3337 is a rock (72) slightly more basic than the typical "felspathic" variety and approaching very closely to the Mt. Hunt type; it is a coarsely crystalline rock, lighter in colour than usual, and apparently consisting almost entirely of light-coloured hornblende, there being very little feldspar visible to the naked eye; examined under the microscope it is seen to be holocrystalline and to consist of pale to colourless hornblende (partly chloritised) in large masses and irregularly shaped crystals and largely in excess of the combined other constituents; feldspar, in good-sized elongated crystals largely altered to saussurite and carbonates; quartz, in small quantity, some of it being in micrographic intergrowth with the feldspar; chlorite in small patches and scattered flakes; ilmenite and leucoxene in good-sized crystals and masses; magnetite in finely divided crystals associated with the chlorite; the section shows slight traces of ophitic structure in places.

The type "basic" variety of amphibolite is found on the eastern side of the northern Kalgoorlie area as shown on the small scale plan herewith (Plate II.); it is a coarse-grained green-coloured massive rock consisting apparently entirely of pale hornblende. Typical examples [11003] and (18) are seen on G.M.L. 1187 (Out-ridge), and on G.M.L. 4088, just on the north side of the Bulong road; sections of these show the original ferro-magnesian mineral to be pale coloured augite, now largely altered to hornblende, and, to a less extent, to chlorite; it is in large flakes and masses and forms practically the whole of the section, the only other minerals present being a little scattered ilmenite, a few small patches of carbonates, and a little saussurite representing the remains of original small feldspar crystals. (Fig. 8.)

Occurring within the "basic" area is a small patch of rock (16) almost identical with the acid or quartzose variety; this is seen on the dump on G.M.L. 4054 (Euclid); it is of very limited extent, and probably represents merely an acid segregation. A section of it shows much chlorite, in large patches and scattered flakes, together with a little pale hornblende, a good deal of clear quartz, and some large patches of micropegmatite of quartz and feldspar; some feldspar in long prismatic crystals much saussuritised; much ilmenite and leucoxene; much granular epidote and a few small patches of carbonates.

These "basic" amphibolites, when subjected to local shearing, become converted into chlorite and carbonate, chlorite schists. A section of one of these from a spot about ten chains east of G.M.L.

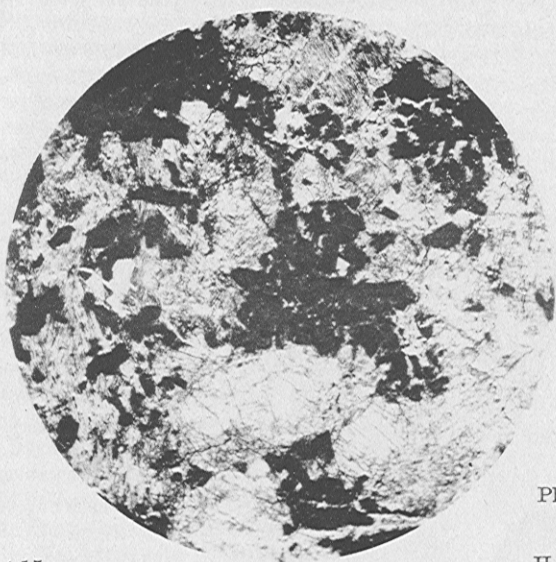


Fig. 9.

Photo. by

[10,418.] O.L.  $\times 15$ .

H. Bowley.

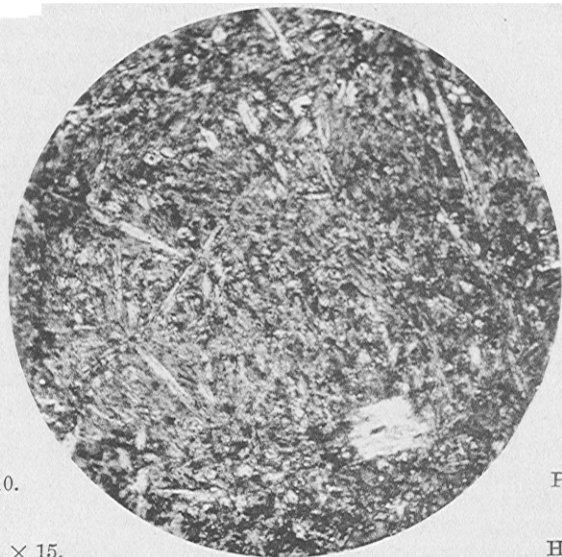


Fig. 10.

Photo. by

[10,426.] O.L.  $\times 15$ .

H. Bowley.

Fig. 9.—Gabbro, showing rectangular cleavage and schiller structure in Augite, half-mile West of Boulder Abattoirs.

Fig. 10.—Fine grained Amphibolite (contact altered with Tremolite), Monument Hill.

3880 (Devon Consols) shows it to consist of a fairly fine-grained granular aggregate of pale-coloured chlorite and carbonates, together with a little finely-divided sericite, some zoisite and numerous small scattered grains of magnetite and ilmenite.

The rocks of the main western band of "coarse-grained" amphibolites, portion of which is shown on the accompanying map, form an interesting series. Towards their southern end (*i.e.*, within the limits of the map) these rocks are typical gabbros, coarse-grained, massive, and fairly fresh; going northwards they have undergone a gradual mass alteration, the original augite being gradually converted to hornblende, till, at about the northern limit of the map, they are "felspathic" amphibolites practically identical with those of the northern Kalgoorlie area. A good example [10418] of the typical gabbro is seen about half a mile to the west of the Boulder abattoirs; a section of this rock shows it to be holocrystalline, and to consist essentially of augite and plagioclase feldspar, the former being in considerable excess and occurring in large irregular crystals and masses, showing the typical cleavage and often exhibiting good schiller structure; the feldspars are mostly in good-sized elongated prismatic crystals, and are considerably saussuritised; subordinate minerals are magnetite, ilmenite, leucoxene, and a little chlorite (Fig. 9). A slightly more basic type (36) occurs on Spion Kop Hill, some  $2\frac{1}{2}$  (?) miles west of Mt. Hunt; this consists almost entirely of pale-coloured augite in large irregular masses and flakes, a little of which has been altered to pale green uraltite; a few fair-sized clouded feldspar crystals are present, and also a little scaly chlorite, some leucoxene, some finely divided magnetite, a few small patches of carbonates, and a little sphene.

A good example of the "amphibolite" type from the northern portion of this belt is seen on the north side of the railway line, and about a mile and a quarter north of the Somerville railway quarry; in hand specimens this rock (23) is identical with those described from Mullingar and from near the Warden's Residence, Kalgoorlie; microscopically it differs from these only in that there is more pale hornblende and considerably less uraltite present, and that the feldspars are not arranged in quite such marked aggregates of rectangular crystals; in other respects the rocks are identical.

An intermediate type between this and the gabbro is found near the eastern edge of the belt immediately to the west of the Boulder abattoir's reserve; here the augite has also been partly converted to hornblende and to a less extent to uraltite and chlorite, but there is much more of the original ferromagnesian mineral remaining than in the preceding type.

Schistose areas occur within the main band as the result of local shearing; in these cases the original augite has been practically entirely converted to pale green hornblende, uraltite, and chlorite.

The rocks forming the Mt. Hunt area are as a whole slightly more basic than those of the western belt, and in their unaltered state approach more nearly to pyroxenites than to gabbros; in hand specimens they are massive and coarse-grained, and in general appearance practically identical with those of the gabbro series. Typical examples (55) and (56) from the slopes of Mt. Hunt, when examined microscopically, are seen to consist almost entirely of pale-coloured augite, partly uralitised and at times slightly chloritised; with this are associated a small amount of triclinic feldspar, a little ilmenite and leucoxene, and a few small crystals of sphene. Towards the northern end of the area the rocks are more felspathic and the pyroxene is found in a further state of alteration, being almost entirely converted to pale hornblende; it is still, however, largely in excess of the combined other constituents.

All these rocks, when subjected to local shearing and schisting, become converted into fairly coarse chlorite schists.

On the eastern margin of the main area, close to its junction with the porphyrite and at a spot some thirty chains south of Cemetery Reserve 4382, is seen an interesting variation of these rocks; in hand specimens this variety is fairly fine-grained, and consists apparently entirely of pale green hornblende in irregular aggregates of needle-shaped crystals; it has a short "blocky" fracture which also distinguishes it from the more massive normal rock; under the microscope it is seen to consist of pale hornblende arranged in irregular and radiating groups of needle-shaped crystals in elongated feathery aggregates; the hornblende is slightly chloritised in part, and a little saussurite is present representing the remains of small amounts of original feldspar; small veinlets of zoisite can at times be seen in the rock, which appears to be a contact-altered gabbro or pyroxenite.

Two rocks of rather doubtful origin have been included in the "coarse-grained amphibolites," partly because of their general similarity to certain forms of these, but more from want of any direct evidence to justify their separation into separate groups.

The first of these (50) is found about five chains south of Recreation Reserve 6435 (south-east of Boulder); it is a fairly fine-grained massive rock, very dark in colour, and when microscopically examined is seen to be composed almost entirely of augite, this being in the form of small flakes, granular aggregates, and occasional bunches of small radiating crystals; a good deal of it has been altered to greenish chlorite, with which is associated a little granular epidote; in addition there are present a little clear interstitial feldspar, some small patches of carbonates and some ilmenite, the latter being largely altered to leucoxene. This rock is seen on the dumps of two abandoned shafts; there are no surface outcrops, and



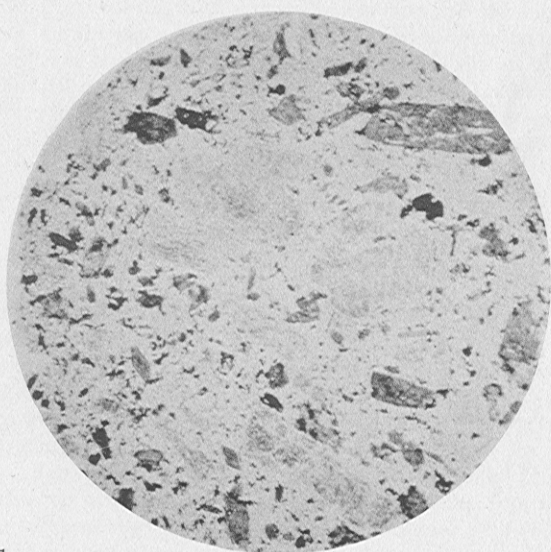


Fig. 11.

Photo. by

[10,421.] O.L.  $\times 15$ .

H. Bowley.

· Porphyrite, half-mile North of Boulder Abattoirs.

owing to the underground workings being inaccessible it is impossible to see the mode of occurrence of the rock and its possible relationship to the enclosing amphibolites ; it may possibly be a dyke rock of later age, or it may be merely a local variation of the main rock mass.

The second [10426] occurs on the west fall of Monument Hill, some three miles to the south of Boulder. This is also a fine-grained massive fairly dark-coloured rock composed of a fine intergrowth of pale green hornblende and felspar, these for the most part being arranged in fibrous aggregates ; numerous long narrow crystals of tremolite occur throughout the rock (Fig. 10), and as subordinate minerals there are also present small amounts of epidote and zoisite as well as some finely divided magnetite and ilmenite. There is only a small area of this rock, and it can be seen on the dumps of two shafts a couple of chains apart ; for the same reason as with the preceding variety its mode of occurrence cannot be seen, but it occurs entirely within the porphyrite area, and whatever its length may be its width is something less than a chain (as shown by the surrounding shafts) ; like the preceding rock, it may be an intrusive basic dyke, but more probably it represents merely a small isolated area of the main amphibolite mass which has been caught up and held by the intruding porphyrite.

#### THE PORPHYRITES.

The rocks of this series are massive, moderately fine-grained, and of intermediate composition. Typically they are of a brownish-green to dark brown ground colour, with numerous white porphyritic crystals of felspar and occasional dark porphyritic hornblende crystals ; usually the felspar phenocrysts are of fair size, giving the rock a decided mottled appearance, but at times they are so small that to the naked eye the porphyritic structure of the rock is unnoticeable. Occasionally the rock (specially the fine grained variety) exhibits a peculiar blotchy appearance, due to the presence of numerous patches, up to an inch or more in diameter, of a grey felsitic material representing small local acid segregations.

There are numerous local variations within the main mass, but these are best described individually (Fig. 11).

Examples of the typical rock are common ; it is well seen in the deep shaft on the Kalgoorlie Power Co.'s property and also on Water Reserve 3398 on the west side of the Kalgoorlie Racecourse ; fresher and better examples are, however, found further south-west in the neighbourhood of the Boulder Abattoirs Reserve 7405.

A section (219) of the rock from W.R. 3398 shows it to be considerably weathered ; the felspar phenocrysts have been

entirely converted to saussurite and carbonates ; the hornblende is represented by dirty green chlorite, which is also all through the ground mass in small scattered flakes ; some granular quartz, apparently secondary, is present, and some scattered iron ores the original ground mass is now represented by a somewhat indefinite mixture of saussurite and carbonates. A fresher example [10421] is from a spot about twenty chains north-east of the Boulder Abattoirs ; under the microscope this shows numerous well-formed feldspar and hornblende phenocrysts set in a finely crystalline felsitic ground mass ; the feldspars are in well-formed tabular and prismatic crystals, both large and small, and are multiple-twinned with occasional well-developed zone structure ; they are considerably saussuritised, this being most marked over the central portion of the phenocrysts, and there are also numerous small flakes of sericite as inclusions in them ; the hornblende phenocrysts are abundant and well-defined, but are mostly small and are considerably chloritised in places ; occasionally a little biotite occurs in parallel intergrowth with the hornblende ; magnetite is present in small scattered crystals, and there is also some finely granular quartz scattered through the ground mass. Several modifications of this type occur here, and frequently on the same dump can be seen the normal rock, a fine-grained variety of it, and also the fine-grained blotchy rock already referred to ; sections of this latter variety (160) show the bulk of the rock to be merely a fine-grained variety of the type above described, while the lighter-coloured patches, which are merely acid segregations from the main body, are seen to consist of an extremely fine-grained felsitic ground mass in which are embedded numerous small well-formed multiple-twinned feldspar and some small granular aggregates of clear quartz, as well as some minute flakes of hornblende.

From approximately the same locality as (30) a variation (612) of the type rock is found which is interesting, because of the fact that the hornblende phenocrysts have been practically entirely altered to urallite, the more usual alteration being directly to chlorite or to iron oxides, quartz, and carbonates.

A more acid variety of the type rock is seen some ten chains further south than (30) and again at a spot twenty chains still further south ; it appears to be an acid segregation on a much larger scale ; it is much coarser in texture than the main body, and at the surface weathers to a light-coloured rock closely resembling a weathered fine-grained granite. A section of a somewhat weathered specimen (31) from the northern portion of it shows it to be here an almost holocrystalline rock ; large well-formed porphyritic feldspars, both singly and multiply-twinned, are abundant, and are considerably saussuritised and carbonated, especially over their central portions ; there are numerous large blebs of quartz present



Photo: E. S. Simpson.

Sheared Porphyry, Walsh's Quarry, Kalgoorlie.

Neg. 59.

and some scattered flakes of muscovite, as well as a few small crystals of hornblende and some scattered iron ores; the usual felsitic ground mass is replaced by a granular mosaic of clear quartz and feldspar, chiefly quartz. Specimens (161) and (29) are somewhat less acid, more nearly normal, variations from a spot some twenty chains further south. These in section show a fairly coarsely crystalline feldspar ground mass with numerous small quartz blebs; in this are embedded abundant large feldspar phenocrysts, some fairly fresh and some much saussuritised, and numerous flakes and small well-formed crystals of hornblende; a few small patches of biotite occur, and one or two small crystals of sphene; magnetite is fairly plentiful, and is associated with what appears to be the remains of patches of biotite; several small flakes of sericite occur as the result of the alteration of some of the feldspars.

A variety (203) practically identical with (161) and (29) is also found on G.M.L. 3798 (Ivanhoe Gold Estates No. 5); in this case, however, alteration has gone on to a greater extent, and the bulk of the original ferro-magnesian minerals have been converted into iron oxides, quartz, and carbonates. A very fine grained modification (206) of this acid variety occurs some twenty chains to the west of G.M.L. 3798; a section of it shows a fairly fine-grained felsitic ground mass with numerous well-formed small feldspar phenocrysts and occasional patches of greenish chlorite, as well as some scattered iron ores and a little granular quartz; the specimen is much carbonated, and patches of granular carbonates are common throughout the section. This rock more closely approaches the feldspar porphyries than the true porphyrite.

On the dump of an abandoned shaft a few chains north of G.M.L. 3944 (Boulder Telluride Blue) can be seen a fine-grained almost black rock (65) carrying a large amount of biotite in small flakes and scales; owing to the mine working being inaccessible and to there being no surface outcrops, this rock cannot be seen *in situ*; it is, however, right on the line of contact of the porphyrite with the coarse-grained amphibolite, and it probably belongs to the former series, representing possibly the chilled margin of this. A section of it shows it to be finely crystalline to granular, consisting of abundant small flakes of biotite and hornblende, together with a little sericite and some magnetite set in a fairly fine granular feldspar ground mass, the latter, as well as the biotite and hornblende, being very little weathered.

Another interesting rock (52) evidently representing a contact-altered form of the porphyrite is found about sixty chains to the north-east of Mt. Hunt; it is a fairly fine-grained compact rock, very dark in colour, showing abundant small needle-shaped crystals of hornblende; it is apparently on the junction of the porphyrite with main peridotite mass, the actual junction being here not well

defined, and appears almost as if it were a small isolated area of the porphyrite which has been caught up and held in the peridotite at the time of the latter's intrusion.

A section of it shows it to have a fairly fine-grained crystalline to granular felspar ground mass, through which is scattered a good deal of quartz in small granular aggregates; numerous good-sized felspar phenocrysts occur, these showing multiple-twinning and being fairly fresh; tremolite is plentiful throughout the section in aggregates and sheaves of long acicular crystals, occasionally in fan-shaped bunches of radiating needles, and can frequently be seen penetrating the felspar crystals; a few small well-formed phenocrysts of light brown hornblende occur, these usually showing the characteristic cross cleavage; numerous small grains and crystals of magnetite are scattered through the section, while the ground mass is at times dirty, owing to the presence of small amounts of chloritic material and iron carbonates.

In addition to occurring in the typical massive form, the porphyrite is also found in a sheared state, this at times extending over considerable areas. An example (193) of this sheared variety from G.M.L. 896 (Boulder and Lake View Deposit) very closely resembles some of the coarse-grained felspar porphyries in its general characteristics; the rock is considerably weathered and carbonated, but the section shows numerous small, and several large, felspar phenocrysts set in a coarsely crystalline felspar groundmass; both the phenocrysts and the groundmass are much saussuritised and carbonated, and patches of carbonates are common throughout the section; several fair-sized patches of a mixture of scaly green chlorite carbonates and iron oxides probably represent the remains of original hornblende phenocrysts; small patches of iron ores are scattered all through the section, and there is considerable iron staining. Usually in the more highly sheared varieties there is a large development of sericite, and these forms, when slightly weathered, are practically indistinguishable from sheared felspar-porphyrines.

In its highly weathered form the sheared porphyrite at times very closely resembles certain rocks of the older sedimentary series, so much so in fact that in cases of surface outcrops it is absolutely impossible to distinguish between the two. As an example, the sheared porphyrite on the edge of the lake at Monument Hill is at the surface absolutely identical with the similarly weathered sedimentary rocks of the Kurrawang series; mine workings have, however, proved the identity of the former, while the presence of conglomerate beds places the identity of the latter beyond dispute. A series of rocks whose origin has not been so conclusively settled is that seen in Walsh's Quarry, about a mile along the Coolgardie road; as seen in the face of the quarry these rocks appear to consist

of sandstones, soft siliceous slates and shales, and may be of sedimentary origin, but the writer, after careful comparison of them with other rocks, is strongly of the opinion that they are merely sheared and weathered porphyrite.\* (Fig. 12.).

In addition to the main mass of porphyrite several small dykes of it occur; these are found traversing the "amphibolites" in any direction, and are never at any great distance from the main mass, of which they appear to be merely apophyses; being of no importance they have not been shown on the accompanying map. One of these dykes, from a spot about one and a half miles west of Mt. Hunt, is a hornblende-porphyrity very similar to the main mass, but having a greater development of hornblende phenocrysts; a section of it [11035] shows numerous well-formed phenocrysts and numerous small flakes of hornblende, with a few felspar phenocrysts set in a finely crystalline felspar ground mass; the large felspars are somewhat saussuritised, but the ground mass is fairly fresh; a little scattered magnetite is present and a few small grains of epidote, together with a little scaly chlorite. (Fig. 13.)

Half a mile or so to the west of Mt. Hunt there are shown on the map several felspar-porphyrity dykes penetrating the amphibolites; these have a close general resemblance to the porphyries further north, but at the same time have certain features in common with the porphyrites; in all probability they are merely offshoots from the main porphyrite mass, and if so they help to show that the porphyry dykes of the "Belt" series are themselves apophyses of the porphyrite; further mention will be made of these particular dykes when dealing with the felspar porphyries.

While writing on the subject of the porphyrites mention must be made of the so-called "building stone" so much used in Kalgoorlie some years ago for building purposes. This in its typical form is a light-coloured, fairly compact, somewhat fine-grained rock, closely resembling in general appearance a soft sandstone; it is soft enough to be cut with a knife, and frequently exhibits a red and white, or brown and white, banded appearance, this being due to original horizontal weathering of the rock. The greater portion of this stone used in the past in Kalgoorlie has been obtained from Button's, or White Cliff quarry, some three miles south of Boulder. The rock has been generally regarded as being of sedimentary origin, but the writer holds strongly the opinion that it is merely a weathered form of the porphyrite; in fact, this is pretty conclusively proved by a shaft a few chains east from the quarry, which has been started in the building stone and has bottomed in fairly fresh typical mottled porphyrite, all gradations between the two being seen on the dump. Other examples of undoubted por-

\*The rocks in Walsh's quarry are shown on the Geological Map issued 1902 as slates of sedimentary origin.—A.G.M., G.G.

phyrite weathering into typical "building stone" can be seen in several localities, one of the best of these being just north of the Boulder Abattoirs Reserve 7405. A very similar rock results at times from the weathering of the massive "amphibolites," but not much of this has been used for building purposes.

The greater portion of the known porphyrite area is included within the limits of the accompanying map; its extension northerly beyond these limits is apparently not far; southerly, however, it probably extends for considerably further, especially the eastern portion of it; everything, however, in this direction is hidden beneath the accumulated surface deposits of the Hannan's Lake valley, and there is no indication whatever as to what the nature of the underlying rocks may be. It forms the underlying rock of the extensive flats on the west side of the main Kalgoorlie ridge, and appears therefore to weather and disintegrate more rapidly than the surrounding "greenstones," which it is undoubtedly newer than and intrusive into.

The series as a whole is of no economic importance and is non-auriferous.

#### THE QUARTZ AND FELSPAR-PORPHYRIES.

(a.) *The Felspar-Porphyrtes.*—These are found in the form of narrow dykes traversing the older rocks of the field; they are not numerous, and as far as can be seen, appear to be chiefly confined to the "quartz-diabase" area. In some of their forms they approach very closely to certain varieties of the porphyrites, and appear to be closely connected with it, being possibly merely offshoots from the main mass, or, more probably, later effusions from the same magma that produced the original porphyrite; the dykes within the "quartz diabase" area certainly appear to be the latter, but those in the neighbourhood of Mt. Hunt, on the other hand, seem to be merely offshoots from the main body.

As a general rule the dykes vary from six to forty feet in thickness, but are of great persistency and can often be traced for considerable distances. Owing to the weathered condition of the outcrops and the accumulation of surface debris they cannot as a rule be followed on the surface, but are met with in the different underground mine workings. Typically the rock is pale pink to dirty white in colour, hard, compact, fine-grained and usually massive. Sections of average samples seen under the microscope show numerous well-formed felspar phenocrysts set in a finely crystalline felspar ground-mass, in which are also seen occasional fair-sized patches of dirty green chlorite material associated with carbonates, iron ores (usually magnetite), and a little quartz, and probably representing original hornblende phenocrysts; the felspars are both large and small, and usually exhibit multiple-twinning;



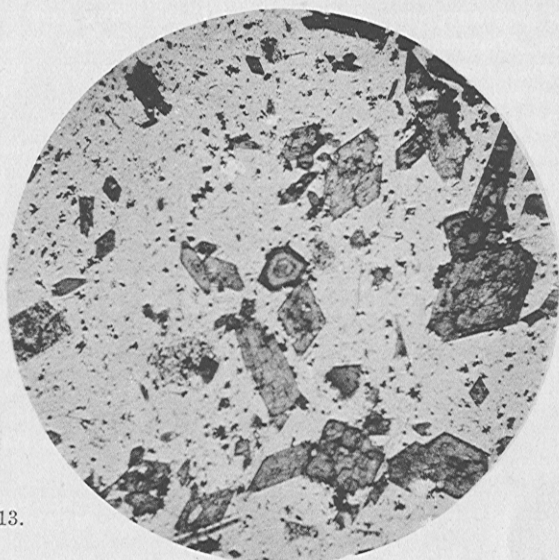


Fig. 13.

Photo. by

[11,035.] O.L.  $\times 15$ .

H. Bowley.

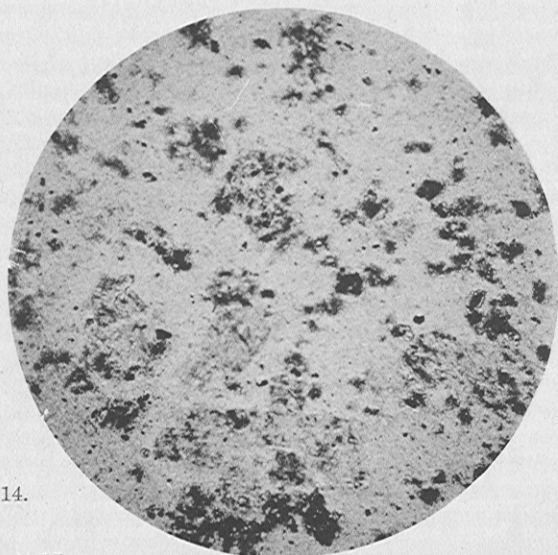


Fig. 14.

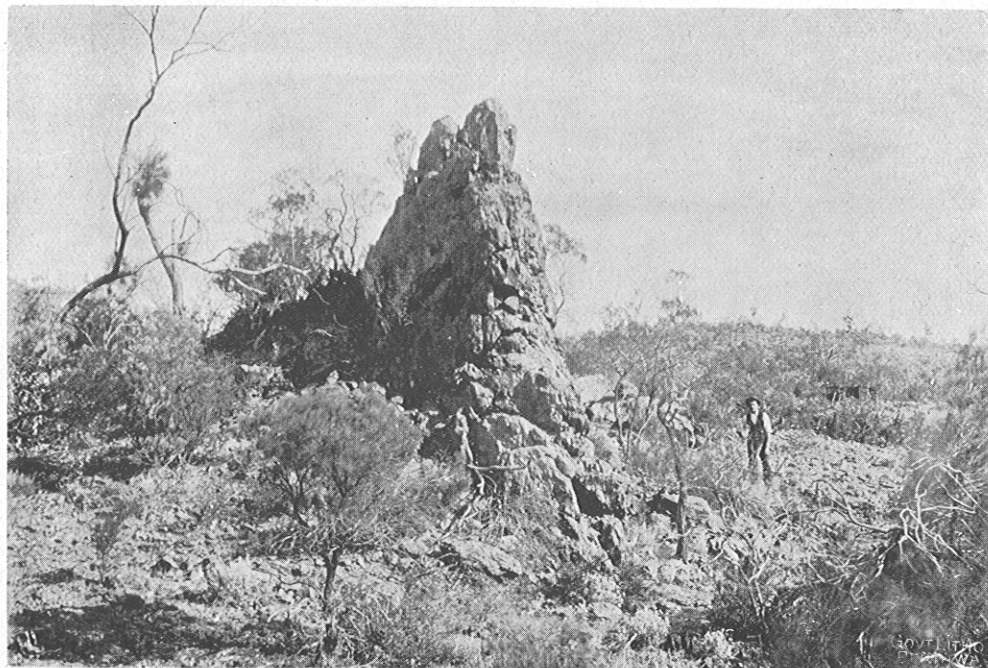
Photo. by

[11,057.] O.L.  $\times 15$ .

H. Bowley.

Fig. 13.—Hornblende Porphyrite, 1½ miles West of Mt. Hunt.

Fig. 14.—Felspar-Porphry, 1,550ft., Kalgurli G.M.



Outcrop of Hæmatite Quartzite, Mt. Hunt.

they are as a rule, however, considerably saussuritised ; the ground-mass is invariably much saussuritised and often considerably carbonated, small patches of granular carbonates being of fairly common occurrence ; in addition to the above minerals there are also present small amounts of fuchsite (chrome mica), a little clear secondary feldspar, and varying amounts of sericite, this occurring chiefly in association with the magnetite and carbonate patches and often surrounding crystals of the former. (Fig. 14.)

Slight variations from the type are occasionally met with, the chief difference being in the relative fineness of the ground-mass and in the size of the feldspar phenocrysts. An example (61) of a very fine-grained variety is seen on a dump fifteen chains south of W.R. 104, to the south of Boulder ; this specimen is considerably carbonated and weathered, but a section of it shows the feldspar phenocrysts to be more numerous than usual, well-formed, but small ; the groundmass is now highly saussuritised and carbonated, but has originally been much finer-grained than usual ; in other respects the rock is identical with the type specimen.

Another variety (215) is found towards the north end of the field about twenty chains to the north of Mt. Percy ; in this case the rock has a fairly coarsely crystalline feldspar ground-mass with a few large, and numerous small, feldspar phenocrysts, these generally showing multiple-twinning, numerous patches of carbonates and iron ores, with a little quartz and at times some dirty green chlorite, probably represent the remains of original hornblende crystals ; a good deal of scattered magnetite and sericite are present, and the whole section is much carbonated and saussuritised.

Of the dykes occurring at the southern end of the field, one some eighty chains north-north-west from Mt. Hunt is worthy of description ; it has a width varying from ten to twenty feet and can be traced on the surface for a distance of nearly half a mile ; at its southern end it appears, in hand specimens, to be almost identical with certain of the porphyrites, but at its north end it is more felsitic, and a section of it (66) from here shows a moderately fine-grained crystalline feldspar ground-mass having a well-marked "trachytic" structure in which are embedded numerous well formed feldspar phenocrysts, exhibiting both single and multiple-twinning ; numerous small patches of greenish chlorite and partly chloritised hornblende are scattered through the section, as well as a good deal of fairly finely-divided magnetite ; the rock is somewhat weathered and there are present as secondary minerals small amounts of sericite, saussurite, calcite, and hematite. Another similar dyke (113) occurring about thirty chains north-west from the mount is very much weathered, and in its present form is indistinguishable both macroscopically and microscopically from a

weathered variety of the massive porphyrite occurring further to the north-east.

The dykes within the "quartz-dabase" area appear to be newer than some of the lodes and older than others. They have in many cases been subjected to the same faulting as the lodes, and have frequently undergone considerable shearing and are often much carbonated; when both carbonated and sheared they form carbonate-sericite-schists identical with certain of those formed as the result of the same extreme alteration of the "quartz-dabase." They have had no direct effect on the local enrichment of the lodes, but possibly have had a great deal to do with the general mineralisation, etc., of many of the lodes, in so far as the presence of magmatic waters following on their intrusion has in all probability been the direct cause of, or at least has largely assisted in, such mineralisation.

*The Quartz-Porphyrries.*—Quartz porphyries occur in the neighbourhood of Binduli as shown on the map (Plate II.). The occurrence is in the form of a large dyke trending roughly north-north-west and south-south-east, and having an average width of well over a mile.

Southerly this dyke can be followed fairly continuously to the edge of the lake country some five or six miles from Binduli, where it disappears beneath the recent deposits; it probably continues a good deal farther than shown on the map, and is most likely connected with the quartz-porphyry seen at Wongi dam to the west of Wollubar; northerly its extension is not known, as it is entirely hidden in this direction beneath extensive recent deposits.

In general appearance the quartz-porphyry varies somewhat; towards its northern end, *i.e.*, at Binduli, it is of a pale pinkish colour with numerous porphyritic feldspar crystals and large quartz blebs; it varies from this to, at the south end, a variety with a dark-brownish ground-mass with large porphyritic feldspars and very little quartz; the former variety is, however, the typical one. Sections of typical specimens (165) and (166) from the northern end show numerous phenocrysts of feldspar and hornblende with occasional good-sized blebs of clear quartz set in a finely crystalline felsitic ground-mass; the feldspar phenocrysts are the most abundant, and are both large and small; they are usually well-formed, and generally exhibit multiple-twinning; the hornblende phenocrysts are mostly small and as a rule not well-formed; the quartz is in good-sized rounded blebs and also in small granular aggregates;

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In an article recently written for the Western Australian Chamber of Mines I referred to this Binduli porphyry as consisting of two separate dykes. Further petrological examination, however, has proved to me that the supposed soft sandstones and grits associated with these dykes are merely highly-sheared and weathered forms of the porphyry itself.

One or two other slight variations from the Chamber of Mines article (and map) appear in this report; these are, however, merely very slight modifications, being the result of further detailed field work, and in no way detract from the general value of the original work.—C.G.G.

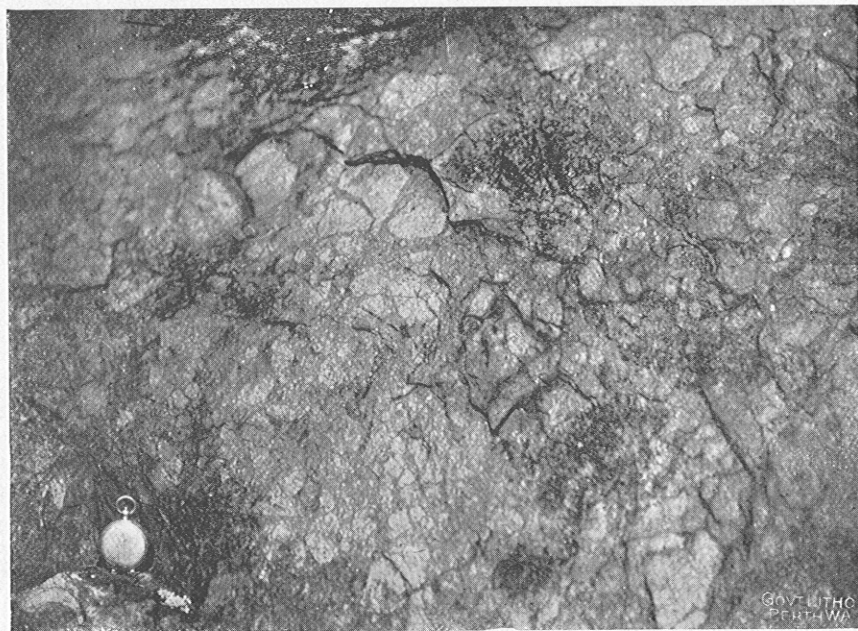


Photo: C. G. Gibson.

Neg. 611.

Brecciated Quartz Porphyry, about 5 miles South-West of Boulder.

a good deal of scattered magnetite is present and occasional small flakes of biotite; as secondary minerals carbonates, epidote, saussurite, chlorite, and iron oxides are present in varying amounts. A section of the darker, more porphyritic, variety (33) from the southern end shows a greater development of felspar phenocrysts, both single and multiple-twinned, and a less development of quartz, which in this case is present in the form of small grains and granular aggregates; biotite is more plentiful, and is in small scattered flakes; frequently it is considerably altered to chlorite, carbonates, iron ores, etc.

The porphyry occurring at Wongi, and which is probably a continuation of the Binduli belt, is somewhat coarser in texture, but in other respects is similar to the former of the above two varieties.

In their sheared and weathered forms these quartz-porphyrries exactly resemble some of the coarser and more gritty varieties of the sedimentary rocks; for example, the undoubted sheared porphyry on W.R. 334 at Binduli is, in hand specimens, indistinguishable from the soft gritty sediments of the Kurrawang series. (Fig. 15.)

One of the most interesting features in connection with the Binduli porphyry is the occurrence in it, at both the north and south ends, of large well-defined crush breccias. The best of these is at the south end, some four miles south of the Coolgardie road, where it extends over a width of from ten to twelve chains; it has in a general way much the appearance of a compact coarse boulder conglomerate, and is in every way similar to the so-called conglomerates of Kanowna which, in the writer's opinion, are nothing more or less than similar crush breccias; by following it in a north-north-westerly direction it can be seen to pass gradually into, first a slightly sheared, and finally into the unaltered porphyry. The breccia has been formed by shearing of the porphyry while it was probably still in a more or less semi-molten condition.\*

The breccia at the northern end cannot be seen on the surface owing to the covering of the recent deposits; it has, however, been cut in certain old mine workings, and specimens of it can be seen on the dump of an abandoned shaft on G.M.L. 3645 a couple of miles to the north-west of Binduli.

A similar class of breccia is found on W.R. 221, some three-quarters of a mile north of Lakeside; in this case the "boulders" are of both porphyrite and diabase, and the breccia appears to be formed along the line of contact of the two formations. No outcrops of it can be seen, but it has been opened up to a considerable extent by underground workings, which are now unfortunately inaccessible.

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\*There are conglomerates of undoubtedly sedimentary origin at Kanowna.—A.G.M., G.G.

## THE PERIDOTITES.

The rocks which have been mapped under the heading of "Peridotite and its Derivatives" have their greatest development towards the southern end of the district along the western side of Hannan's Lake, this area being shown on the accompanying map (Plate II.). The rock here is massive, extremely fine-grained, almost black in colour, and breaks with a slightly conchoidal fracture; it appears to have been originally an olivine rock, but has suffered considerable alteration and is now almost entirely converted to solid serpentine. On a small island on the west side of the lake an interesting extreme alteration of it can be seen; here it has, by the action of carbonated waters, been entirely converted into a dark-grey coarsely crystalline rock composed chiefly of carbonates of magnesia, iron and lime (Fig. 16).

Talc-schists occur as the result of local shearing of the peridotite, and are to be found at both the north and south ends of the field. The best occurrence at the south end is to be seen on old G.M.L. 3911 (Last Chance), where a well-developed band has been opened up in some old mine workings; the band is considerably carbonated and also slightly graphitic.

A little asbestos (var. picrolite) is found here and there in the serpentine area, but it is of no great value; scattered over the hills, however, are occasional patches of magnesite which might possibly be put to some use as furnace linings, etc.

The rocks at the north end, which have been mapped as a derivative of the peridotite, is a massive, greyish, fairly coarsely crystalline carbonated rock agreeing very closely in analysis with the carbonated peridotite occurring on the west edge of Hannan's Lake; it is on this latter account rather than on its petrological character that the rock has been classed as a peridotite, typical examples of it are to be seen in a small quarry near the junction of the Bulong and Parkeston roads and also in the Devon Consols Mine (G.M.L. 3880). Sections of these types (76) and (79) show them to now consist of an indefinite aggregate of carbonates with a little scattered quartz and chlorite, much magnetite and a few small patches of talc. Further north and some ten chains east of G.M.L. 1252 (Tabby Cat) there is to be seen on an old dump a fairly good example of a talc-schist which probably marks the northern extension of the Devon Consols band; it is the only occurrence of talc-schist at this end of the field that the writer knows of.

Another good talc-schist (207) is to be seen a couple of miles south of Boulder and about half a mile west of the Cemetery Reserve; no outcrop of it is to be seen, but it has been exposed in some old mine workings and probably represents the remains of a small peridotite dyke.

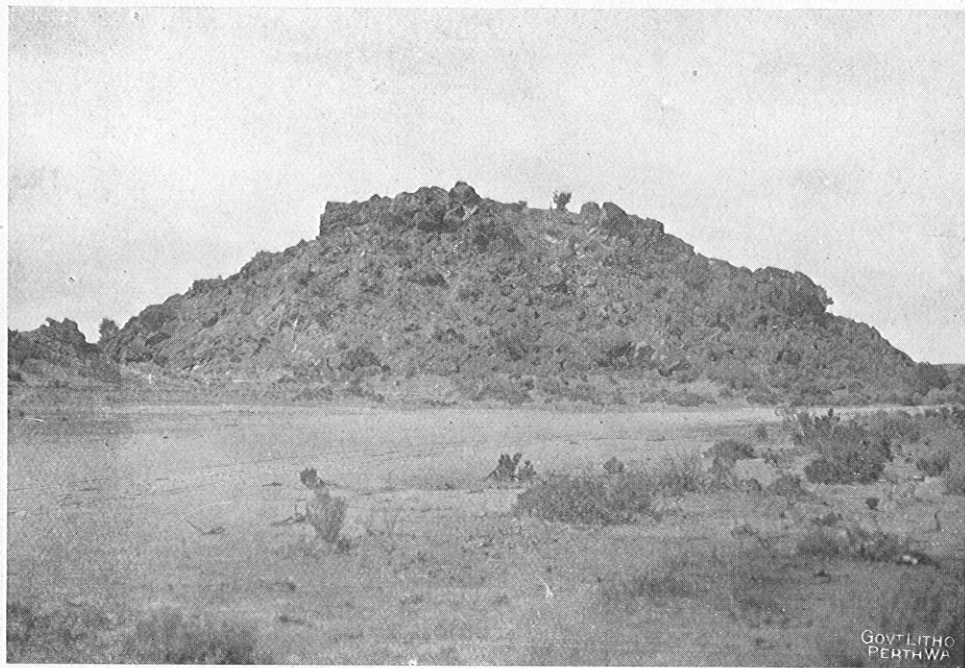


Photo: C. G. Gibson.

Outcrop of Carbonated Peridotite, Hannans Lake.

Neg. 620.



The northern areas appear to be narrow dykes which have been intruded into amphibolites ; their exact extent is, however, difficult to define with any accuracy owing to the amount of debris and recent deposits covering this portion of the district.

The main area at the south end of the field is also an intrusive mass, and the series is apparently the latest of the field. Direct evidence of this intrusive character is given by the presence of the contact-altered porphyrite, already referred to, which is found along the western boundary of the southern area.

The carbonated peridotites at the northern end are found to be invariably associated with the fuchsite-bearing lodes which are such a conspicuous feature of this end of the field, and are evidently the source from which the fuchsite has been derived, as they are found on analysis to contain, as a rule, slightly over one-half per cent. of chromic oxide.

Except for their relationship with certain gold-bearing lodes at the north end the peridotites as a whole can be classed as non-auriferous.

#### THE RECENT DEPOSITS.

These consist for the most part of loose sand, loam, iron-stone, gravels, etc., and are the result of the gradual weathering and breaking down *in situ* of the underlying rocks. They cover by far the greater part of the district, often to a considerable depth, and make accurate geological mapping at times a matter of most practical impossibility, and also render surface prospecting a matter of extreme difficulty.

Included in these recent deposits are the laterites, or ironstone conglomerates, which are such a conspicuous feature of the district. They occur for the most part as the cappings of small hills and ridges, and when they have been opened up by mine or other workings are seen to consist at the surface of almost pure iron oxide, this gradually passing downward into a more or less nodular ferruginous clay and ultimately into the weathered and bleached country rock ; the thickness of the highly ferruginous surface portion varies from one to twenty feet. As to the question of the origin of these laterites the view held by the writer is the fairly commonly accepted one that they have been formed *in situ* by the gradual concentration by atmospheric agencies of ferric oxide derived from the decomposition of the underlying rocks, which in every case have been originally rich in iron compounds.

Among the recent deposits allied to the laterites in their mode of occurrence must be mentioned two deposits found at the southern end of the field near Hannan's Lake. The first of these is found on the western edge of the lake, about half a mile south

of G. M. L. 3337 (Ivanhoe and Boulder Junction); it has been described in Geological Survey Bulletin VI., page 78 :—

“ as a siliceous sinter, varying in character from a light porous white rock composed almost wholly of silica to a dense brown rock containing a considerable proportion of iron oxide; it is studded with irregular lumps of transparent opal.”

The normal type of the rock is highly ferruginous, and it is, in the writer's opinion, merely a laterite carrying a large percentage of silica, which is present in the form of blebs of the hydrous variety opal; it is found near the edge of the main peridotite mass, and is probably formed as the result of the decomposition of a small dyke of this.

The second is found in several places towards the southern end of the main porphyrite area, the best occurrence being a few chains east of White Cliffs quarry. It is typically a fine-grained, more or less vitreous quartzite consisting almost entirely of hydrous silica, and is found as the result of the concentration on the surface of silica derived from the decomposition of the underlying rocks which originally carried a high percentage of silica. Occasionally fragments of weather-worn quartz up to an inch and a half in diameter are to be seen cemented into the quartzite, the rock then having very much the appearance of a pebble conglomerate; a good example (130) of this type is to be seen at a spot about thirty chains south of G. M. L. 3911 (Last Chance).

Another variety of the recent deposits worthy of special mention is the travertine, which in an impure state covers large areas in the form of a thin film at a depth of a few inches to several feet below the surface. The most noteworthy occurrence of it is near Binduli, where it covers an area of several acres at times to a depth of a couple of feet, and in this case is overlying the quartz porphyry. The travertine owes its origin to the lime originally contained in the underlying rocks, which has been dissolved out and subsequently deposited on the surface by evaporation. The deposit at Binduli has had a little work done on it, and some of it has in past years been burnt for lime.

Mention of the magnesite, which in places overlies the peridotites, has already been made.

The recent deposits have not been shown on the accompanying map, this claiming to show the structural features only.

#### THE ORE DEPOSITS.

In the following pages the question of the Ore Deposits is touched upon in only a general way; the subject will be fully dealt with in detail in Part II. of this report, the necessary field work in this connection being not yet completed. In Part II. it is

proposed to produce a large scale map of the "Golden Mile" showing, in addition to the geological information, the position of the principal lines of lodes, faults, etc.; it is also proposed to include numerous sections of mine workings, cross and longitudinal sections of lodes, ore shoots, etc., etc.\*

The class of deposit worked on the Kalgoorlie field is that to which the term "lode deposit" has been generally applied, for though in a few cases quartz reefs of small size have been opened out, these are always more or less intimately connected with the main class.

These lodes have in a general way been well defined as† :—

A more or less vertical zone of rock usually continuous with the surrounding rock, and of similar origin, but distinct from it in carrying metallic ores disseminated through it in payable quantities, and, as a rule, characterised by strong foliation. They probably owe their origin to a shearing action having crushed and foliated portion of a rock mass in a certain definite direction, producing a more or less well-defined band of rock through which, by virtue of the foliation, mineral-bearing solutions or vapours can have free circulation. In consequence of this, mineral deposits are formed within the rock, usually, but not necessarily, extending over the whole of the foliated zone. . . . and having no definite boundaries horizontally or vertically other than those determined by the decrease of assay value of the rock to a point at which it ceases to pay the expenses of working.

For the purposes of detailed description the ore-deposits are best grouped according to the various classes of rock in which they are found, viz. :—

- (1.) Deposits in the Quartz-Diabases.
- (2.) Deposits in the Calc-Schists.
- (3.) Deposits in the Acid Amphibolites.

(1.) *The Deposits in the Quartz-Diabases.*—These may be subdivided into :—

- (a.) The quartzose ore-bodies.
- (b.) The schistose or carbonated ore-bodies.

There is, however, no hard and fast line between the two classes, both being of the same origin and each in a part grading imperceptibly into the other. As a general rule, however, the quartzose bodies are more regular both in values and occurrence than the carbonated varieties. Typical bodies of this class are those worked in the western group of mines, viz., the Great Boulder, Horseshoe, and Ivanhoe; most of the other mines are on carbonated or schistose bodies.

The essential difference between the two classes lies in the fact that a greater amount of replacement has taken place in the former, and the original lode material has been to a large extent gradually replaced by a dark compact cherty-looking quartz, while

\*Mr. Gibson resigned his position in the service before his field work in connection with the preparation of Part II. was completed.—A.G.M., G.G.

† E. S. Simpson, G.S. W.A., Bulletin VI., p. 22.

in the latter the alteration is chiefly to carbonates ; these ore-bodies always have a more or less banded appearance, and the development of the quartzose material is always greater in the central portion of the lode. Within the limits of the lode channels are frequently found small irregular veins of white glassy quartz, usually running at right angles to the strike of the lodes ; these rarely carry any appreciable gold values, but very often contain considerable amounts of tourmaline and tennantite (sulpharsenide of copper) in addition to the usual vein minerals ; they are of very limited extent, rarely extending for more than a few feet in any one direction, and are evidently of secondary origin, probably marking shrinkage cracks in the lodes proper.

Very frequently the main lodes show signs of secondary movement and of reopening, especially along the centre line of fissuring ; in these cases the middle portion of the lode is much brecciated, the darker original quartz being broken up and re-cemented by a fine-grained intergrowth of white quartz and calcite (dolomite ?). This re-opening is also seen in the case of the carbonated lodes, though the re-cementing of the brecciated material is not so noticeable as in the darker quartzose bodies.

In the case of the carbonated lodes their general appearance varies from a more or less solid mixture of carbonates to a very slightly carbonated sericite or chlorite schist ; they are much more irregular, both in size and in the distribution of the values, than the quartzose lodes.

Almost invariably the main central line of the lodes is marked by a small well-defined seam, usually of quartz with carbonates of iron, etc., and generally not more than a quarter of an inch in width ; this represents the central line along which the original shearing has taken place, and it can be followed in many cases for long distances ; often the lode, *i.e.*, the crushed and altered rock, will die out, and this central seam then exists merely as a narrow cleavage running through the comparatively solid country.

Mineralisation of the lodes has of course taken place to the largest extent where the foliation and crushing have been most intense, while in the more solid rock it has taken place only over a very small area, extending outwards from the main fissure. As the shearing of the rocks is irregular in its intensity, so also is the extent of the mineralised lodes irregular, the occurrences being to a certain extent lenticular ; in some cases—where the shearing has been fairly general—the mineralisation has extended over a width of well over a hundred feet, and the whole of this width has carried payable gold values, while at other times along the same lode-line the shearing and mineralisation is confined to a width of a few feet ; in short, wherever the country has been highly foliated or sheared, there mineralisation has taken place, but in

these mineralised bands, though gold is invariably present up to a certain extent, it is not always there in sufficient quantity to pay for working.

Along the main lode lines in many cases the values are found to occur in irregular lenticular patches, even when there is apparently no change in the lode ; in other cases the more highly-sheared portions throughout which the ores are deposited are themselves lenticular in habit, and as these lenses are irregular both in size and occurrence they cause some slight trouble both in mining operations and in the satisfactory estimation of ore reserves ; for example, a level may be driven for some distance on good values, while one stope taken above the drive may see the end of these values ; this has actually happened on more than one occasion. Again, in prospecting for ore-bodies with the diamond drill, this lenticular habit of the lodes is apt to be very misleading owing to the fact that a bore-hole might cut an apparently fair-sized body of ore which on further development will prove to be only an isolated lens of no great length or depth ; at the same time it would be equally likely to miss a lens of ore and cut the lode where it had pinched or carried no values.

The lode channels themselves are very persistent both in strike and in depth, and have been frequently known to continue without a break through several leases ; the length and frequency of the ore-lenses along the same lode vary greatly ; while one lens may be only twenty feet in length the next one may be several hundred feet ; frequently, however, the persistence in depth of the short lenses is just as great as with the longer ones, though this is not always the case ; all the lenses as a rule show a tendency to pitch to the south. The values never cut out entirely along the main lodes, but in those portions of them connecting two ore-lenses they drop to a point at which they cease to be at present payable.

As a general rule, the majority of the main shear zones, or lodes, have a roughly parallel strike, this being approximately north-north-west and south-south-east. There is, however, another system with a more nearly north and south trend ; these are newer than the north-westerly lodes and cut through them, large " lenses " of mineralised rock being often found at the points of intersection owing to the general " shattering " of the country which has taken place at these points. The El Oro lode may be taken as a good example of these north and south lodes.

The general underlie of all lodes varies from vertical to steeply west ; it is nearly always somewhat variable in the upper levels, but below about 600ft. it is generally to the west.

As these mineralised shear-zones or lodes are fairly numerous, extensive diamond drilling or crosscutting has to be resorted to in order to prove their existence ; frequently a small or low-grade lode will be intersected in a crosscut, and a good deal of exploratory

driving has often to be done on it in the chance of meeting with a lens of payable ore, these being of possible occurrence along any lode channel.

In many cases the lodes in the "quartz-diabases" are found to run alongside porphyry dykes and occasionally to cut into them and through them. In these latter cases, *i.e.*, in the porphyry, the values are generally found to be lower and as a rule not payable. One or two odd exceptions to this rule occur, however, notably in the South Kalgurli mine, where, on the No. 6 level, a small lens of highly payable ore was worked in the middle of a large porphyry dyke.

With regard to the mineralisation of the ore bodies the principal lode minerals in addition to gold and tellurides (calaverite, petzite, sylvanite, hessite, coloradoite, altaite) are iron pyrites, marcasite, chalcopyrite, tennantite, asbolite, carbonates (of iron, lime, magnesia, etc.), sulphates (of lime and magnesia), iron ores (hæmatite, magnetite, ilmenite, etc.), tourmaline, chlorite, albite, rutile, etc. Of these the most important is, next to the gold and tellurides, the iron pyrites; this is usually present in fair quantity, and it is invariably found to be the case that the finer grained it is the higher are its gold contents; frequently a coarse more or less crystalline pyrites is present, more especially on the walls and in the carbonated lodes, and this almost invariably carries no payable values; it has apparently been deposited at a later date and certainly under different conditions from those of the finer-grained auriferous pyrites.

(2.) *The Deposits in the Calc-Schists.*—No quartzose ore-bodies occur in this series of rocks, the lodes being similar and behaving similarly in every way to the schistose and carbonated ores found in the "diabase," and the same general remarks apply almost equally well to both. As a general rule, however, they are more patchy in their contents and on the whole of lower grade than the latter class of deposits. As an example of this might be mentioned the Associated Gold Mine; here the same lode was worked in both the "diabase" and the calc-schists, and while it gave good returns in the former class of rock it was unpayable in the latter.

Special though brief mention must, however, be made of one particular ore body occurring in the calc schists, and this is the remarkable "Oroya Shoot." The ore body in this case was in the form of a pipe or chimney whose cross-section, though irregular, approximated in a general way to a more or less flattened oval, having in places a maximum diameter of roughly a hundred feet. The general pitch of the "pipe" was at a very flat angle to the south, with at the same time an underlay to the west. It has been worked from the surface down through the following leases:—Brown Hill, Iron Duke, Oroya, and Australia East, or for a total length of well over three-quarters of a mile; at the point where

it appears to have died out it had reached a vertical depth of about twelve hundred feet. Immediately on the east side of the pipe is a well-defined body of highly-sheared rock dipping at an angle of about forty-five degrees to the west; the ore appears to have lain on or close to this shear line, dipping with it and at the same time pitching away, as before stated, very flatly to the south. In several places the hanging and foot walls, if they may be termed such, of the ore body are formed by well-marked fault or fissure lines, and these, taken in conjunction with the main underlying shear plane, have probably had a good deal to do with the deposition of the values. Occasional small patches, or "droppers," of ore run out from the main body; these are of very limited extent, and are generally formed on an intersecting cleavage or fissure plane.

(3.) *The Deposits in the Acid Amphibolites.*—Lodes similar in origin and general character to those in the "diabases" and calc-schists also occur in certain of the acid amphibolites, but they have not as a general rule so far proved of any great importance.

The main point of difference between this class of rocks and the diabases and calc-schists is the occurrence within them of small rich quartz veins and leaders. These have been worked to the greatest extent in Hannan's Reward and on Cassidy Hill; they are never of any great size, rarely exceeding a foot in thickness, and more usually ranging from a mere thread up to two or three inches; they are confined to certain well-defined belts of sheared rock, and are never found beyond the limits of the sheared zone, running at right angles to the general trend of this; although consequently never of any great length they are fairly persistent in depth. In the big lode on Hannan's Reward, which near the surface exceeds a hundred feet in thickness, these leaders were especially numerous and some of them were phenomenally rich. At first the leaders themselves were taken out, but subsequently the whole lode formation, which itself carried a little gold, was worked, the high grade of the quartz veins being sufficient to bring the grade of the whole formation up to payable limits.

It is from these quartz leaders that the bulk of the alluvial gold obtained in the neighbourhood of Hannan's Hill was originally derived.

Another class of deposits found in the amphibolites of the north end are the contact bodies referred to previously as occurring alongside the peridotite dykes. These are merely mineralised zones of sheared and altered rock and must be classed as "lodes"; they are, however, irregular, following to a considerable extent the boundaries of the peridotite; they are also of comparatively small size and their gold contents are very erratic, although at times extremely high. They are characterised as a rule by their bright green colour, this being due to the presence of finely divided fuchsite,

whose occurrence has already been referred to. Lodes of this description are typically represented in the Hidden Secret and Fair Play Mines.

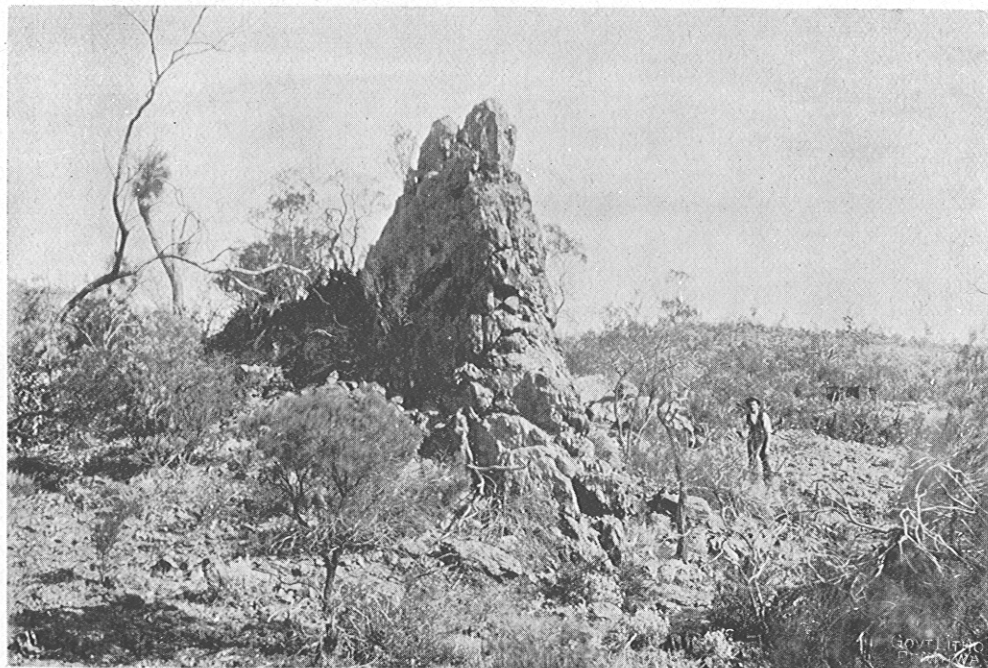
While on the subject of the lodes generally, brief mention must be made of the large banded and jasperoid quartz reefs occurring in certain portions of the field. These are found principally in the amphibolites, and especially at the south end in the neighbourhood of Mt. Hunt (Fig. 17). They are of dark banded and jasperoid quartz, often carrying a large percentage of hæmatite and sometimes magnetite, and are the result of extreme alteration and silicification of well-defined sheared bands of rock; they are very persistent in strike, sometimes extending for over a mile in length, and are of large size, occasionally reaching as much as fifty feet in thickness; near Mt. Hunt they are particularly numerous, and can be seen in places rising from the ground to a height of forty or fifty feet. Although small auriferous quartz leaders are at times associated with them, the jasperoid lodes themselves appear to be practically non-auriferous.

#### THE FAULTS.

Faulting of the lodes has been fairly common, more especially in the quartz-diorite and calc-schists areas; the main system runs approximately parallel to the general strike of the lodes, and the faults dip at an angle of 40 to 45 degrees to the west. The faults of this system are "reversed" faults, and are due to overthrusting of the western portion of the belt; contrary to the usually accepted idea of reverse faults, they do not duplicate the lodes. Occasionally, however, normal or easterly dipping faults do occur, but they are much less usual than those with a westerly dip. The displacement caused by both classes of faults varies considerably, usually, however, ranging from ten to forty feet. As a general rule the faults of the main system are very persistent not only in strike but also in dip, and can readily be followed down from level to level; they are usually marked by a seam of calcite or gypsum, or a "dig," varying from half an inch up to as much as four inches in width, and in the latter cases almost always act as water channels. Occasionally values are found along the fault lines between the two portions of the lode; these sometimes extend over a width of as much as two feet; but, as a general rule, values are not found in appreciable quantity along the fault lines.

In addition to these two main fault systems, on the subject of whose relative age the author is at present not quite clear, though he is inclined to think that those with the westerly dip are the older, there is a newer and less important system of practically vertical faults; these are as a rule smaller and not so persistent or well-defined as the main lines; they strike in about the same direction





Outcrop of Hæmatite Quartzite, Mt. Hunt.

as the larger faults, and can frequently be seen cutting across these ; the displacement caused by them is as a rule very small.

The numerous small fissures, or " heads " or " floors," which are found crossing the lodes and country in almost every direction, and often at right angles to the main lines, are evidently part of a secondary system induced by these main lines ; as a general rule they cause no displacement ; they, however, frequently affect the values of the lodes to a large extent. Often good values in a lode will be found to cut out completely on either a diagonal or flat head, although there is no apparent change in the lode ; at other times the values will be found to be entirely confined between two parallel heads ; no rule can, however, be laid down as to the behaviour of these heads ; sometimes they will, as just stated, cut the values right off, and in others they will be found to have no effect whatever on them ; the rule in one case is the exception in the other.

The chief effect of the main faults is, by their presence, to lessen the apparent amount of ore " in sight " between any two levels by causing, as a result of the over-thrusting upwards of the upper portion, the formation of a vertical, as well as horizontal, gap between the two portions of the faulted lode.

Another effect of the faulting is represented by the following occurrence which actually took place in the Great Boulder Main Reef G.M. An inclined bore-hole from the No. 14 level cut what appeared to be two separate ore bodies ; subsequent development, however, proved the supposed second body to be merely the faulted portion of the original one, the bore-hole thus having passed through the same lode twice ; equally well also might it have passed through the gap between the two portions and thus have apparently proved the non-existence of the lode below the level bored from.

#### CONCLUSION.

With regard to the permanency of the Kalgoorlie and Boulder lode it may be at once stated that they are undoubtedly deep-seated, and will in every probability live at least to the depth to which mining operations can at present be carried ; whether or not their gold contents will live with them is a matter on which it is impossible to speak with any certainty, and one which can only be proved by actual development ; the best arguments in favour of this, however, that the writer knows of, are the following deep level developments recently reported by two of the leading mines of the field :—

*Golden Horseshoe.*—Cabled report to London, May 19th, 1909, No. 3 shaft, 2,000ft. level, East branch, No. 3 lode, total width 18 feet, assays, 1oz. 2dwts. per ton ; free gold and telluride showing from wall to wall.

*Great Boulder Proprietary.*—Cabled report to London, August 25th, 1909.

Prospecting with diamond drill, Edwards' shaft, 2,600 feet level, West. At 108 feet from shaft struck ore, for the first three feet schist intermixed with quartz leaders, the ore is very rich in free gold; assay average 11ozs. per ton. The next three feet similar, but there is no visible gold, assays average 5dwts. per ton. The next eight feet consists of pyrites and quartz, assay value 5dwts. per ton; there is quartz in the end of the borehole.

Cabled report to London, November 12th, 1909.

Edwards' shaft, 2,500 feet level, West crosscut has cut the reef 98 feet from shaft; it is hard quartz; width of ore 14 feet, and assays 10½dwts. per ton.

Cable, December 11th 1909.

Edwards' shaft, 2,500 feet level, North end of drive, average assays 15 dwts. per ton; south end 44dwts. per ton.

These developments are the deepest on the field, and speak for themselves as to the permanency of, at all events, some of the most important of the lodes and their values. \*

The manager of the Great Boulder reported on Saturday having sent the following cable to the London board:—

Prospecting with diamond drill from the 2,800 feet level, West from the main shaft at an angle of 274 degrees, measuring from the western side of the shaft have struck vein of ore at 194 feet from starting point; width of ore is 19in. and assay value 170dwts. per ton. Prospecting with diamond drill horizontally from the same starting point at an angle of 190 degrees, struck ore from 226ft. to 229ft. For the first three feet assays average about 57dwts. per ton, balance not yet finished.

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\* Since the above was written recent deep level development has been reported from the Great Boulder Proprietary Gold Mine.

## II.—COMPOSITION AND INTERNAL STRUCTURE OF THE KALGOORLIE AND BOULDER ORES.

By E. S. Simpson.

Before entering into any detail as to the mineralogy of the Kalgoorlie ore deposits, it is essential to discuss the type of deposit there presented and briefly consider its origin. Broadly speaking, by far the greater number of known primary gold deposits in Western Australia fall within one of two categories, viz.—

- (1.) Quartz Reefs, *i.e.*, fissure fillings the main gangue of which is quartz accompanied by more or less pyrites and other sulphides ;
- (2.) Lode Formations, *i.e.*, impregnations of zones of previously existing rocks, which in the process of impregnation have been more or less metasomatised.

Whilst it is in almost every case an easy matter to allocate any given gold deposit in the State to one or other of these groups (the Kalgoorlie deposits belonging to the second group), a certain overlapping occurs. Thus the walls of auriferous quartz reefs are found at times to be impregnated to a payable extent with gold for a distance from the vein varying from a fraction of an inch up to many feet. On the other hand the West Australian type of impregnation is confined largely to shear zones characterised by much crushing and fracturing, wherein some of the fractures are filled with more or less solid quartz, though these quartz veins differ from the typical quartz reef in being comparatively narrow, in being discontinuous when traced for any considerable distance, in being somewhat irregular in direction, and in some cases in being themselves practically non-auriferous.

To the mining engineer or working miner the order in which the phenomena of ore deposition in any district present themselves is usually this :—

- (1.) The nature of the alluvial deposits derived from the disintegration of the primary deposits.
- (2.) The results of weathering of the latter as exhibited in the oxidised ores above water level.
- (3.) The occurrence of underground water, and any secondary enrichment associated with it.
- (4.) The structure and composition of the unweathered deposit below water-level and the nature of its enclosing rock.
- (5.) After considerable depth is attained, the problem of the origin of the deposit is forced upon the attention of the mining engineer, in view of its important bearing upon the question of the continuity of the deposit and the persistence in it of payable values.

In a scientific discussion of the ore deposits the reverse or historical order is that which will give the clearest insight into the

problem, and for this reason the matter is dealt with in these pages under the following headings in the order given :—

- (1.) The original nature of the rock now constituting the matrix of the gold, and changes in it preceding ore deposition ;
- (2.) The introduction of gold into the rock, and the action of the gold-bearing solutions upon it ;
- (3.) The ultimate mineral and chemical constitution of the unoxidised ore bodies ;
- (4.) Weathering and its results ;
- (5.) The derived alluvial deposits.

### *1.—The Original Rocks of the Ore Deposits.*

The narrow bands constituting the ore deposits occupy what is after all but a very small portion of the whole original rock mass. Except, therefore, for certain small dykes of an intrusive nature, the rock immediately adjacent to the formations was once identical with that in the deposits themselves, in many cases the latter merging by insensible gradations into the former. Both have been highly modified, the lodestuff naturally more so than the barren rock, having been subjected to the attack of ore-bearing solutions, in addition to those dynamic and other agencies which have affected the whole rock mass. It follows that evidence as to the original nature of the ore is to be obtained not only from the ore itself, but also from the adjacent less altered rock. A great deal has been written on this subject, and several theories advanced as to the origin of the auriferous rock. Göczel and Schmeisser, who were the first to critically examine it, came to the conclusion that it was an altered diabase (plagioclase-augite rock), and all the most recent work on the subject confirms their theory.

Several important criticisms of it, however, have appeared. E. F. Pittman and G. W. Card, collaborating in 1897, though recognising that lodestuff and enclosing rock were different facies of the same rock, came to the conclusion that the lodes were crushed and otherwise altered dykes of quartz porphyry. Pittman writes :—\*

“There is a gradual transition, downwards, from the talcose, schistose-looking rocks of the surface, to the bluish-green rock which is found in the lower levels, and which has the appearance to the naked eye of a characteristic quartz-felsite.”

Card writes :—†

“The country rock is of igneous origin, and belongs to the acid group ; in all probability it is a quartz felspar porphyry, but may approximate to a granite in places. . . . The lodes represent belts along which the crushing effects have been most severe, and the deposition of secondary material more abundant. They are, in fact, more highly altered portions of the country rock.”

\*Rec., Geol. Surv. N.S.W., Vol. VI., p. 10.

†Ib. p. 22.

L. J. Spencer, of the Mineral Department of the British Museum, writes \* :—

“The matrix of the telluride specimens is usually a pale greenish sericite-schist. . . . Chlorite is often present, and the rock is then of a darker green colour, and may approach a chlorite schist in character.”

And again in a footnote :—

“The matrix of the ore is often stated to be a hornblende-schist. No hornblende was detected on any of the British Museum specimens; and in published analyses (Simpson 1902), of these rocks the small amount of magnesia in the portion of the rock insoluble in hydrochloric acid indicates that not much, if any, hornblende can be present. Bands of hornblende schist are no doubt present in the sericite schist. Much confusion between observed fact and theory has been occasioned by the attempts of various authors to explain the origin of these schists.”

With regard to Spencer's statements it may be remarked that he describes the ore by the very non-committal name of “sericite-schist,” *i.e.*, a foliated rock exhibiting sericite on the cleavages. Such a rock has been observed in Western Australia to result from the alteration of a sedimentary shale (*e.g.*, at Uaroo), from the crushing of a granite (Darlington), or of a felsite or acid porphyry (Menzies), or, under extreme cases of alteration, from a basic igneous rock (Kalgoorlie and probably Cue, Peak Hill, and elsewhere in this State †). So far as I am aware no writer having any intimate knowledge of Kalgoorlie lodestuff has ever called it a hornblende schist, for the simple reason that no hornblende or other amphibole has ever been detected in it. Amphibolites however (by some incorrectly called hornblende schists, they rarely show even slight signs of foliation), occur as barren rocks in close proximity to the Kalgoorlie mines, and there is no doubt that the lodes are extremely metamorphosed bands of similar rocks, in which all traces of hornblende or other amphibole have been destroyed by conversion into chlorite and carbonates of iron and magnesia, etc.

The conclusion arrived at by Pittman and Card that the rock was of an acidic nature, was not an unnatural one to come to in the absence of comparative analyses of the material forming the lodes and the rocks on either side, and was in fact under similar conditions shared by the present writer. The appearance in hand specimens of most of the ore and much of the adjacent rock, exhibiting as they do, in a pale-coloured rock, blebs of quartz and much sericite, is decidedly that of an acid igneous rock. Even under the microscope one is liable to look upon these two minerals and the acid felspars as the predominant constituents without giving due weight to the carbonates, and to remain in ignorance of the fact that the latter only very rarely include calcite, being mainly highly ferruginous dolomite and often siderite, which puts a very

\*Mineralogical Magazine, Vol. XIII., p. 281.

†A similar alteration of a gabbro is noted by Clarke, “Data of Geochemistry,” p. 513.

different complexion on the question of origin. The gradual passage of the ore-bodies and of most of the enclosing rock into highly chloritic material should, however, have drawn attention to the possibility of both being of a more basic origin. Recent researches in the field and in the laboratory leave no doubt of the basic character of the original rock, confirming the opinion expressed in 1901, in Bulletin 6, that this must in the great majority of cases have been either a diabase or gabbro. In rare instances it was probably a peridotite. In only one case has gold been found in an altered acid porphyry (ceratophyre).

If one compares the analyses of unoxidised lodestuff from Kalgoorlie on page 68, with those of average granite or quartz-porphyry, it will be evident that the theory of Pittman and Card implies the introduction into the ore-bearing belts of rock of large quantities of carbonates of lime, magnesia, and iron, and of iron sulphide, accompanied by the removal of large amounts of silica. The alternative theory that the ores are the result of hydrothermal alteration of more basic rocks requires little or no movement of silica or iron, and only a moderate leaching out of lime and magnesia, such as would be expected on the presumption that the ore bodies owed their existence to the attack of the rock by solutions and vapours containing carbonic acid, sulphur, and potash, accompanied by actually small, but economically important quantities of gold and silver. Such effects are typical of subsiding volcanic action such as is generally accompanied by ore deposition.

The accompanying Table I. gives the composition of some typical examples of Kalgoorlie rocks, in almost all of which auriferous shear zones are known to have developed.

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The gold has been almost entirely confined to a series of genetically related rocks of which analyses A to K are typical. The rock in its original condition was an igneous intrusion or series of related intrusions, whose chief components were pyroxene and labradorite or a similar felspar. Judging by the structure of the present altered forms, this rock varied in places in the relative proportions of the two main constituents and also in the development of variable minor amounts of ilmenite and quartz. The gabbro to the west of Boulder is the nearest approach now known to the primary rock.

It is impossible to decide whether the alterations now seen in these non-auriferous rocks took place wholly or in part before the introduction of gold into the lodes, or whether they represent the preliminary steps in the series of events accompanying that important action, or finally whether they represent the contemporaneous action, at a distance from the lode channel, of the same agencies which led to the formation of the auriferous lodes. It is significant that these alterations are for the most part confined to an area in the vicinity of the lodes, and bounded by lines roughly parallel to them. Three changes almost certainly preceded ore deposition, viz., *uralitisation*, i.e., the conversion of the greater part of the pyroxene into actinolite; secondly *saussuritisation*, the conversion of most of the basic felspar into a mixture of albite, zoisite, etc.; and thirdly the development of a series of fractures along the lines of the present lodes. The first two changes resulted in the production of the rocks described as amphibolites and epidiorites.

The second stage of alteration was characterised by chloritisation, further saussuritisation and some carbonation. During this stage the amphibole of the rock was wholly converted into chlorite, and this again in part into dolomite (bitter spar), whilst the remaining primary felspar was converted into saussurite (albite plus zoisite plus quartz or calcite or both). The result was a massive propylite, or a foliated chlorite schist, such as adjoins almost all the lodes of the field. The latter at this stage were either chlorite schists, or fractured, but not foliated, propylite, which offered along the planes of foliation and fracture free passage for gases, vapours and aqueous solutions.

In the case of the acid and subacid rocks of the types L, M, and N some crushing and partial carbonation would appear at this stage. In the case of the olivine rocks, serpentinisation would probably be complete, and partial carbonation along shear zones.

## *2—Introduction of Gold and Accompanying Changes.*

The final conversion into corresponding carbonates of all compounds of ferrous iron, lime, magnesia, and manganese, in the

rocks of the diabase-gabbro type, is confined to the lodes themselves and to a small area immediately adjacent. It would appear, therefore, to be part of the ore-depositing action or to be the immediate herald of it. It resulted in the formation of the present lode material and of the barren ankerite rock (Table I., Analysis K), ottrelite schist \* and similar rocks. An immense volume of carbonic acid has been concerned in this action, and it was evidently under such pressure as to penetrate the rock for considerable distances away from the shear zones which formed the main channels for its distribution. In the latter it converted the green ferro-magnesian silicates into colourless or pale yellow carbonates, thus completely masking to the unaided eye the original basic nature of the rock. At the same time variable quantities of the carbonates so formed, especially the more soluble ones, were carried off in solution.

It is evident from analyses of the ore that sulphur and potash were introduced into the rock with the gold, silver, mercury, and tellurium. Other frequent concomitants of mineralisation, arsenic, antimony, copper, and the heavy metals are almost totally absent or confined to small sections of the lodes. The presence of a small amount of tourmaline is evidence that the mineralisation was accompanied by the introduction of quite small proportions of boron and fluorine.

There can be no doubt that the gold and its concomitants owe their ultimate derivation to a later igneous intrusion which may or may not have reached the level of the present surface. Under conditions of lowering temperature and pressure, vapours and fluids were liberated from the solidifying mass and forced under pressure through the shear zones of the surrounding rocks, and there deposited sufficient gold to convert the shear zones into auriferous lodes.

Victor Lenher considers † the deposition of gold and silver tellurides in lodes or veins to be due to the—

“intermingling of a solution of gold and silver chlorides, held in solution by an alkaline chloride, with an alkaline sulphide solution carrying tellurium.”

In view, however, of the readiness with which both gold and gold sulphide dissolve in solutions of potassium sulphides to form the sulphaurate,  $\text{KAuS}_2$ , as well as tellurium to form the sulphotellurite  $\text{K}_6\text{TeS}_5$ , there is no necessity to assume that the gold and tellurium were introduced in different solutions. Silver too is sufficiently soluble in such solutions, especially in the presence of alkaline chlorides and bicarbonates, to have been introduced with the gold and tellurium in the actually small quantities in which it occurs in the lodes.

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\* See p. 142.

† Victor Lenher: Some Observations on the Tellurides. *Economic Geology*, vol. IV., p. 564.

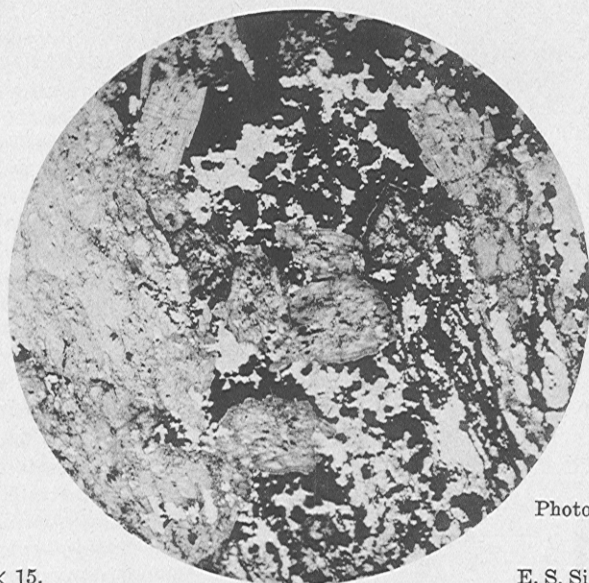


Fig. 18.

Photo. by

[10,843.] O.L.  $\times 15$ .

E. S. Simpson.

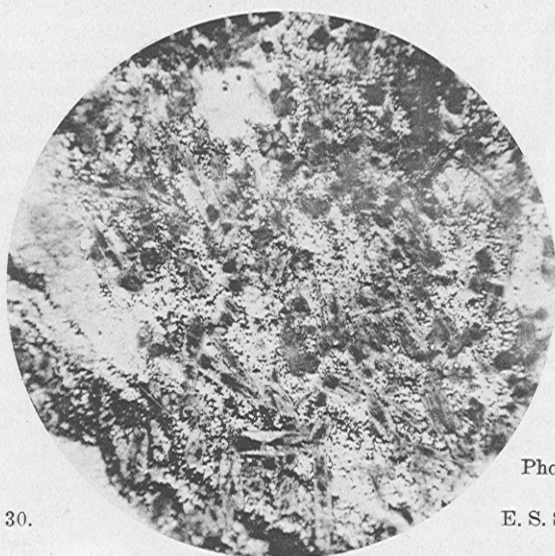


Fig. 19.

Photo. by

[10,844.] O.L.  $\times 30$ .

E. S. Simpson.

Fig. 18.—Ore with large crystals of Tourmaline, 300ft., A.W.A. United G.M. The ground mass consists of granular Pyrites, Dolomite, Quartz, Sericite, and Albite.

Fig. 19.—Ore with abundant small crystals of Tourmaline, 1,200ft., South Kalgurli G.M. The Tourmaline shows an "hour-glass" arrangement of inclusions, and is embedded in a mass of very fine grained Pyrites, Dolomite, Quartz, Sericite, and Albite.

The sulphur of the alkaline solutions attacked the silicates and carbonates of iron with the formation of pyrites, and the fluids thus were deprived of their capacity for carrying gold, tellurium, etc., and precipitated free gold and tellurides of gold and silver. Minor accompanying changes were the precipitation of sulphide of arsenic, and the formation of chalcopyrite and fahl ore at the expense of the traces of copper present in the original rocks. Under such conditions no reducing agent is required to account for the deposition of native gold and tellurides in the lodes, on the contrary any agent, such as oxygen, which would remove the sulphur from solution or affect its mode of combination, would bring about the precipitation of gold and tellurium. This fact is of prime importance in explaining and predicting the distribution of the gold within the ore channels.

Two of the most important changes in the lodestuff accompanying the process of ore deposition have already been noted, viz., the complete or almost complete conversion of silicates of iron and magnesia into carbonates, resulting in the development of dolomite, ankerite, and siderite; and secondly the formation of pyrites by the action of sulphur compounds on iron carbonates or silicates. The third important change was the development of sericite by the interaction of the potash of the ore-bearing solutions with aluminous silicates, most probably the aluminous (amesite) molecule of chlorite.

The fourth and last important change was the production of secondary silica. This would be formed during the conversion of the ferro-magnesian silicates into carbonates. In part it remained, finely granular, *in situ*, either scattered amongst the other secondary minerals or replacing them largely, with the formation of the chalcedonic ore such as that of the Golden Horseshoe and adjacent mines (see Fig. 31). In part it filled small irregular contraction fissures (see Fig. 22).

Magnetite is a somewhat common secondary constituent of some lodes. It may have been formed during the alteration of a silicate carrying both ferrous and ferric iron, such as chlorite.

### 3.—*Mineral and Chemical Constitution of the Unoxidised Lodestuff.*

The ultimate product of the combined effects of regional metamorphism and hydrothermal (ore-depositing) action is shown in the accompanying tables of analyses of ores. In Table II. are given some early and incomplete analyses, the figures of several of which are not very satisfactory since the "silica" includes all insoluble silicates, such as sericite, albite, etc.; and also in some cases the "ore" was non-auriferous, though doubtless taken from an ore channel. In Table III. are given the results of analyses of

several typical ores made recently in the Geological Survey Laboratory. They are more complete than any other analyses previously published, and special care was taken to select typical material for analysis. With the single exception of [10959] all these analyses were made on chippings from single blocks of ore ranging in weight from one to 20 pounds. In the case of [10959], from the Associated Northern Gold Mine, the analysis represents the composition of a bulk sample of about one hundredweight.

The analyses indicate three types of ore and a fourth is known.

*Ore Type "A."*—Highly siliceous, cf. [10961], Great Boulder Gold Mine (Fig. 31), characterised by a very large proportion of chalcedony and a correspondingly small proportion of carbonates, pyrites, and mica. Such ore is mainly confined to certain lodes and portions of lodes in the Golden Horseshoe and adjacent mines.\* R. Allen describes the ore of the Ivanhoe Gold Mine in these terms † :

"The ore treated contains more silica than is found in the majority of the Kalgoorlie mines. The great bulk of the gold is free, but some is combined with tellurium, the refractory ore in the mine averaging about 14 per cent. of the whole. In the lower levels the ore is harder, more siliceous, and contains less free gold than in the upper levels."

He gives the analysis quoted in Column E, Table II., as typical.

Whilst small irregular quartz veins which are true fissure fillings are common in all the Kalgoorlie mines, the evidence with regard to the larger masses of siliceous ore points to their not being the filling of open fissures with dissolved silica. They appear rather to be irregular metasomatic replacements of zones of altered diabase, as shown by the presence of much chalcedony with very minor amounts of vitreous quartz, the lack of continuous hard and fast walls between the siliceous ore and the adjacent schistose ore or rock, the indications, in some instances, of macroscopic and microscopic rock structures, and the presence of minor rock-forming minerals not usually associated with siliceous fissure fillings.

*Ore Type "B."*—The second type of ore, as exemplified in analyses of 8990c, 10962g, 10959, etc., is that specially characteristic of Kalgoorlie. It is a pale grey or greenish-gray schistose rock, the ultimate outcome of the action upon shear zones in diabase or gabbro of a long series of metamorphosing actions. The silica percentage in this ore averages about 50, of which about one-half is present as secondary chalcedony or vitreous quartz, the balance being present as silicates. In addition to quartz the characteristic gangue minerals are ankerite, sericite, albite, and pyrites. These five minerals usually account for 90 to 95 per cent. of the ore. At

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\* Great Boulder Proprietary, Ivanhoe, Chaffers.

† Monthly Journal of the Chamber of Mines, Vol. IV., p. 294, and West Australian Metallurgical Practice, p. 5.

TABLE II.—*Early Incomplete Analyses of Unoxidised Lodestuff.*

	A.	B.	C.	D.	E.	F.	G.	H.	
Depth—feet ..	230	1,100	Year's average	400	500	(?)	300	(?)	Depth—feet
Mine .. ..	Great Boulder	Great Boulder	Great Boulder	Ivanhoe	Ivanhoe	Main Reef	Lake View	Han. Paringa	Mine
Insol. .. ..	..	74·95	..	..	77·7	..	..	..	Insol. .. ..
SiO <sub>2</sub> .. ..	35·04	..	53·50	46·94	..	48·43	51·27	70·25	SiO <sub>2</sub> .. ..
TiO <sub>2</sub> .. ..	2·57	..	..	·14	..	..	·23	·34	TiO <sub>2</sub> .. ..
CO <sub>2</sub> .. ..	8·38	6·59	7·50	13·41	..	[7·75]	8·02	·02	CO <sub>2</sub> .. ..
H <sub>2</sub> O + .. ..	..	·25	..	·30	..	..	·22	1·34	H <sub>2</sub> O + .. ..
K <sub>2</sub> O .. ..	2·25	..	..	2·57	..	..	2·37	1·28	K <sub>2</sub> O .. ..
Na <sub>2</sub> O .. ..	2·93	1·40	1·79	1·84	..	..	1·78	3·46	Na <sub>2</sub> O .. ..
CaO .. ..	4·77	3·94	6·54	6·43	5·4	9·86	6·40	·14	CaO .. ..
MgO .. ..	4·97	2·48	2·96	3·56	3·4	2·03	4·18	·12	MgO .. ..
MnO .. ..	trace	..	..	·32	..	..	trace	trace	MnO .. ..
FeO .. ..	..	2·00	..	9·20	..	..	2·63	·87	FeO .. ..
Fe <sub>2</sub> O <sub>3</sub> .. ..	18·98	..	7·97	·33	7·0	..	1·54	1·00	Fe <sub>2</sub> O <sub>3</sub> .. ..
Al <sub>2</sub> O <sub>3</sub> .. ..	9·67	1·75	13·12	12·49	1·5	11·98	13·85	15·22	Al <sub>2</sub> O <sub>3</sub> .. ..
Fe .. ..	4·80	2·52	2·90	1·05	..	10·24	3·99	2·47	Fe .. ..
Cu .. ..	·14	..	..	..	..	·33	..	·50	Cu .. ..
S .. ..	5·49	2·88	3·32	1·20	3·9	3·66	4·42	2·96	S .. ..
H <sub>2</sub> O— .. ..	..	..	·10	·09	·2	..	·40	·42	H <sub>2</sub> O— .. ..
Undet. and Loss	..	..	..	..	·9	5·72	..	..	Undet. and Loss
	99·99	93·76	100·00	99·87	100·00	100·00	101·30	100·39	
Au. ozs. p.t. ..	traces	(?)	1·300	trace	(?)	6·500	9·635	1·687	Au. ozs. p.t.
Ag. ozs. p.t. ..	0·243	(?)	·950	none	(?)	2·500	6·360	·816	Ag. oz. p.t.
Authority ..	Dr. Helms	R. Allen	Roberts	Gibson	R. Allen	Skewes	Simpson	Simpson	Authority

TABLE III.—*Complete Analyses of Unoxidised Lodestuff.*

G.S.M.	10931	8990c	10952G	10959	10964L	10847A	10938B	G.S.M.
Depth—feet	2,200	820	2,200	550	1,900	200	(?)	Depth—feet
Mine ..	Great Boulder.	Oroya	Great Boulder	Assoc. North.	Lake View.	Fair Play	Hidden Sec.	Mine
SiO <sub>2</sub> ..	88.48	49.92	46.28	46.67	51.78	24.52	25.23	SiO <sub>2</sub>
TiO <sub>2</sub> ..	.22	1.10	1.19	.42	1.48	.54	trace	TiO <sub>2</sub>
ZrO <sub>2</sub> ..	(?)	.01	min. tr.	none	none	none	.01	ZrO <sub>2</sub>
CO <sub>2</sub> ..	2.81	9.09	9.52	13.02	10.44	23.32	.18	CO <sub>2</sub>
P <sub>2</sub> O <sub>5</sub> ..	.19	.16	.20	.37	.72	.29	.33	P <sub>2</sub> O <sub>5</sub>
H <sub>2</sub> O +	.11	.96	.81	1.13	.33	.80	2.25	H <sub>2</sub> O +
K <sub>2</sub> O ..	.48	2.66	3.42	1.64	3.06	1.96	2.52	K <sub>2</sub> O
Na <sub>2</sub> O ..	.20	.85	1.95	.96	.58	.50	1.72	Na <sub>2</sub> O
CaO ..	1.88	6.33	6.44	6.11	3.86	14.31	.14	CaO
BaO ..	(?)	.01	none	.04	.01	.43	.13	BaO
MgO ..	1.41	3.49	4.03	4.17	3.02	12.04	5.09	MgO
MnO ..	.32	.33	.20	.32	.30	.39	none	MnO
FeO ..	.35	2.62	2.74	9.89	9.06	.30	.33	FeO
Fe <sub>2</sub> O <sub>3</sub> ..	none	trace	.75	1.39	3.64	5.77	none	Fe <sub>2</sub> O <sub>3</sub>
Al <sub>2</sub> O <sub>3</sub> ..	1.78	10.73	12.41	6.92	8.84	5.81	15.77	Al <sub>2</sub> O <sub>3</sub>
V <sub>2</sub> O <sub>3</sub> ..	.11	.06	.12	.32	none	.32	1.21	V <sub>2</sub> O <sub>3</sub>
Cr <sub>2</sub> O <sub>3</sub> ..	none	.03	.02	min. trace	none	.22	.50	Cr <sub>2</sub> O <sub>3</sub>
Fe ..	.99	5.44	4.79	3.29	1.25	3.02	20.05	Fe
Cu ..	.03	min. tr.	.02	none	.20	.04	.38	Cu
Ni ..	(?)	(?)	(?)	.24	none	trace	.12	Ni
Pb ..	.04	.01	none	none	.01	none	trace	Pb
Zn ..	min. tr.	.20	min. tr.	none	none	1.37	.08	Zn
Sb ..	.02	.01	min. tr.	.01	.02	none	.02	Sb
As ..	.01	.03	.02	.01	.01	.02	.03	As
S ..	1.14	6.34	5.50	3.78	1.43	3.94	23.28	S
Te ..	min. tr.	min. tr.	min. tr.	min. tr.	(?)	(?)	.24	Te
Au ..	..	..	..	.01	..	..	.06	Au
Ag ..	..	..	..	..	..	..	.51	Ag
H <sub>2</sub> O —	.02	.11	.13	.09	.06	.06	.28	H <sub>2</sub> O —
	100.59	100.49	100.54	100.79	100.10	99.97	100.46	
Au. ozs. p.t. . .	2.250	1.656	1.104	3.750	0.181	0.600	19.675	Au ozs. p.t.
Ag. ozs. p.t. . .	2.596	0.525	0.800	0.594	0.144	0.218	165.450	Ag ozs. p.t.
Sp. gr. ..	..	2.95	2.95	..	2.97	3.02	..	Sp gr.



times chlorite, orthoclase, magnetite, siderite, or calcite may become prominent, and at others a vanadiferous mica is of importance. The metallic minerals (sulphides, arsenides, etc.), other than pyrites, never form more than one per cent. of the ore except in occasional selected fragments. The various tellurides, with tennantite, chalcopyrite and blende, are the most prominent metallic minerals in such cases. A similar remark applies to tourmaline, which never constitutes an appreciable portion of bulk samples of ore, though it may rarely amount to as much as 50 per cent. of isolated fragments (*see* Figs. 18, 19).

It is possible to arrive at a rough approximation to the mineralogical composition by calculation from the ultimate analyses. This has been done in a few cases with the results shown in Table IV.

TABLE IV.—*Approximate Mineral Composition of some Kalgoorlie Sulphide Ores.*

	[10962c], Great Boulder.	[10959], Associated Northern.	[206], Lake View.	[1753], Ivanhoe.	[8990c], Oroya.
Quartz .. ..	21	33	29½	25	33½
Ankerite .. ..	21	20	18	21½	20
Other Carbonates .. ..	..	10	..	10	..
Sericite .. ..	19	13½	19½	21½	22½
Orthoclase .. ..	7	..	..	..	..
Albite .. ..	16	8	15	15½	7½
Chlorite .. ..	3	5	7	3	3½
Pyrites .. ..	10	7	8½	2	11½
Apatite .. ..	½	1	(?)	(?)	½
Rutile .. ..	1	½	..	..	1
Magnetite .. ..	1	2	(?)	½	..
	99½	100	97½	99	100

Ores of this type have been described by R. Allen in these terms \*—

"Oroya Brownhill Gold Mines.—The ores from the three mines † are very similar in character, very schistose and crush freely; also they are very free from minerals harmful to the cyanide process. They contain from 50 to 65 per cent. of silica and insolubles, about 7 per cent. carbonate of lime, three to five per cent. carbonate of magnesia, about five per cent. of alumina, the balance being principally iron compounds. Tellurides of gold and silver are found throughout the ores, also coloradoite in addition; these, with a considerable amount of auriferous iron pyrites, form the great bulk of the concentrates, and contain the greater portion of the gold contents of the ores.

\* West Australian Metallurgical Practice, p. 19.

† Oroya North Lease, Oroya South Lease, Brown Hill.

The amount of free gold is small, existing in a very fine state of division disseminated throughout the mass as a rule."

"Kalgurli Gold Mine.\*—The ore is usually of a bluish-grey colour and of a fine grained schistose structure, but occasionally it is greenish in colour and massive in structure. . . . The following are the principal constituents of the ore :— $\text{SiO}_2$ , 60 per cent. ; S, 4.2 per cent. ;  $\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3$ , 16 per cent. ;  $\text{CaCO}_3 + \text{MgCO}_3$ , 11 per cent. Amongst the minerals found in the ore, besides iron pyrites, which amounts to about 8 per cent. of the ore, there are found various tellurides of gold, a telluride of mercury, also titaniferous iron, sulphate of lime and hydrous mica in the divisional planes. Quartz is distributed largely through the rock mass, but an unusual quantity of it is sometimes an indication of poorness of ore. The gold is rarely free, and the tellurides occur either in patches or very finely disseminated."

"Great Boulder Perseverance Gold Mine.†—The ore treated is either greyish or greenish in colour, schistose in structure, and contains ordinary pyrites throughout its mass. Arsenical pyrites and the tellurides common to the district, also quartz masses, occur in places. It has been noticed that the siliceousness of the ore, as well as the amount of its pyrites contents, increases with depth. The following is an analysis of a general sample of the ore going to the mill, the sampling extending over a period of six weeks, three samples having been taken daily :—

Insoluble	$\text{SiO}_2$	..	..	..	..	46.58
	$\text{Al}_2\text{O}_3$	..	..	..	..	11.51
	FeO	..	..	..	..	1.60
	MnO	..	..	..	..	.20
	CaO	..	..	..	..	.20
	MgO	..	..	..	..	.29
	Alkalis and loss	..	..	..	..	3.08
Soluble	$\text{FeS}_2$	..	..	..	..	6.80
	$\text{Fe}_3\text{O}_4$	..	..	..	..	4.38
	$\text{CaCO}_3$	..	..	..	..	13.42
	$\text{MgCO}_3$	..	..	..	..	6.93
	$\text{Al}_2\text{O}_3$	..	..	..	..	2.06
	$\text{K}_2\text{O}$	..	..	..	..	.87
	$\text{Na}_2\text{O}$	..	..	..	..	.37
	Loss and water	..	..	..	..	1.71

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100.00 "

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Detailed macroscopic and microscopic descriptions of many specimens of ore are given in Part III. of this Bulletin. Some remarks of general application to this type of ore may, however, be added here. The foliation of the ore varies from that of a typical sericite schist (*e.g.*, G.S.M. 8752, South Kalgurli Gold Mine), to a very faint only roughly parallel cleavage. In all cases it is due to thin, more or less parallel, bands of scaly sericite or vanadiferous mica. The pyrites is usually well crystallised (Fig. 21).

\* West Australian Metallurgical Practice, p. 51.

†*Ibid.*, p. 63.

but the free gold and tellurides exhibit smooth curved surfaces towards one another, whilst their external boundaries are governed by those of the surrounding minerals (Figs. 21, 28). The other constituents of the ore are granular in structure, mostly finely granular, except chlorite, which may be either disseminated as a pigment or scattered about in small scales devoid of orientation. A series of joint planes at right angles to the schistosity may be well marked (*e.g.*, G.S.M. 8990, Oroya Gold Mine).

Secondary fissure fillings are usually narrow, discontinuous, and variable in direction. The chief filling is vitreous quartz. With it there is invariably some dolomite (bitterspar) or ankerite, rarely calcite, and at times these carbonates may form the major portion of the vein, *e.g.* [10965], Ivanhoe Gold Mine, and [143], Block 45, G.M. (Fig. 29).

*Ore Type "C."*—Examples of this appear in Table III. in ores from the Hidden Secret and Fair Play Gold Mines (Figs. 20, 36, 37, 46). The leading characteristics are a very low percentage of silica and the presence of a notable amount of chromium and vanadium mica. Very few ores are known of this type, which is confined to the northern end of the field where intrusions of peridotite are known, and it is probable that these ores represent shear zones in an altered rock of that type. It is worthy of note that in the ore from the Fair Play mine there is a very high percentage of carbonate, principally normal dolomite, whilst in the Hidden Secret ore there are only traces of carbonates with an unusually high percentage of pyrites. The analysis of the latter was made on a single block of specimen ore of about five pounds weight, and the results may not be typical of the whole ore body but only represent the composition of a small mineral aggregate associated with extraordinarily large quantities of gold, silver, and tellurium. In outward appearance this ore was a dark green schistose rock.

*Ore Type "D."*—This is represented in the Perth Museum Collection by a single specimen [9385]. It is a foliated ceratophyre with free gold from the North Kalgurli Gold Mine, probably part of the same dyke whose composition is given in Table I., Column N. Mr. C. G. Gibson notes the occurrence of similar ore in the South Kalgurli Gold Mine.

*Distribution of the Precious Metals in the Ore.*—In these unoxidised ores gold and silver occur as free native gold carrying a little silver, as pure telluride of gold (calaverite) as pure telluride of silver (hessite), and as tellurides of both gold and silver (sylvanite and petzite). Very little information is available as to the relative proportions of free gold and combined gold; some statements on this point by R. Allen have already been quoted.

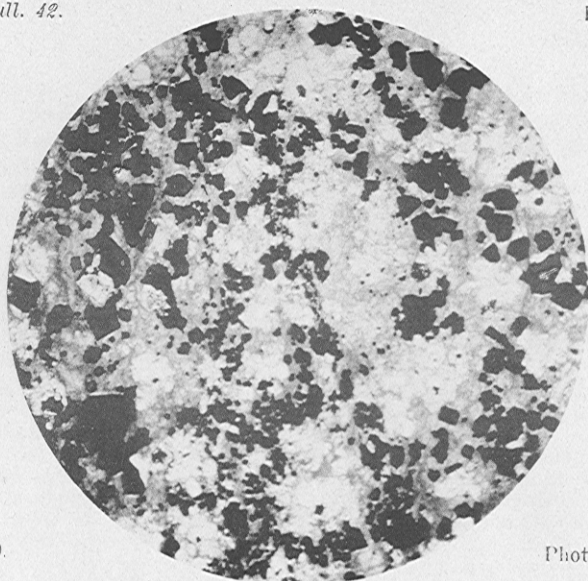


Fig. 20.

Photo. by

[10,938.] O.L.  $\times 15$ .

E. S. Simpson.

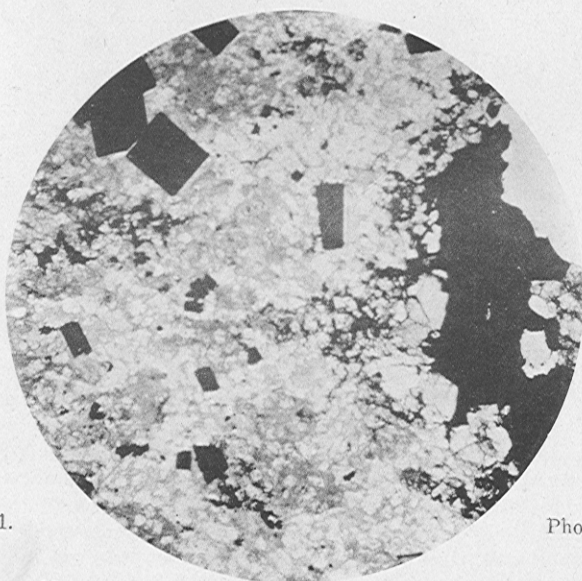


Fig. 21.

Photo. by

[10,938.] O.L.  $\times 15$ .

E. S. Simpson.

Fig. 20.—Telluride Ore, Hidden Secret G.M. Pyrites (black), Albite (white), and green Chrome-Vanadium Mica (half-tone).

Fig. 21.—Rich Telluride Ore, Hidden Secret G.M. Well crystallised Pyrites, straggling filamentous Hessite, and, on right, large mass of black Hessite intergrown with Petzite and Chalcocopyrite.

The relative proportions of gold and silver in the unoxidised ore are indicated by the following figures :—

TABLE V.—*Relative Proportions of Gold and Silver in Unoxidised Ore.*

Mine.	Depth, etc.	Gold,	Silver,
		per ton.	per ton.
		oz. dwt. gr.	oz. dwt. gr.
Kalgurli .. ..	Average, July, 1900 ..	1 12 2	0 9 0
Kalgurli .. ..	Average, July, 1902 ..	1 0 11	0 7 14
Oroya .. ..	Single block, 820ft. ..	1 13 3	0 10 12
Great Boulder ..	Single block schist, 2,200ft. ..	1 2 2	0 16 0
Great Boulder ..	Single block quartz, 2,200ft. ..	2 5 0	2 11 22
Great Boulder ..	Average ore, 1902 ..	1 6 0	0 19 0
Fair Play .. ..	Single block, 200ft. ..	0 12 0	0 4 9
Associated Northern	Bulk sample, 550ft. ..	3 15 0	0 11 21
Lake View .. ..	Single block, 300ft. ..	9 12 17	6 7 10
Lake View .. ..	Single block, 1,900ft. ..	0 3 15	0 2 21
Main Reef .. ..	Bulk sample .. ..	5 17 19	1 1 5
Main Reef .. ..	Bulk sample .. ..	4 11 11	2 4 2
Hannan's Paringa	Single block .. ..	1 13 18	0 16 8
Hidden Secret ..	Single block .. ..	19 13 12	165 9 0
South Kalgurli ..	Single block, 184ft. ..	0 8 17	0 3 9
Ivanhoe .. ..	Single block, 1,010ft. ..	0 13 9	0 6 6
Associated .. ..	Single block, 1,820ft. ..	0 5 20	0 6 4
Associated .. ..	Single block, 1,820ft. ..	25 6 12	2 12 6

It is evident from these figures, which are typical, that except in the Hidden Secret Mine the proportion of gold in the ore is usually more than twice as great as that of silver. In the rich ore from the Hidden Secret mine the silver is invariably in considerable excess, due to the large development of hessite (telluride of silver).

Platinum was looked for in several ores by Mingaye's method,\* which on the charges used should serve to detect quantities as small as a few grains to the ton. The results obtained were :—

Associated Northern, 550ft. .. ..	Platinum, none.
South Kalgurli, 1,200ft. .. ..	Platinum, none.
Golden Horseshoe, (?) ft. .. ..	Platinum, none.
Hidden Secret, (?) ft. .. ..	Platinum, none.

Whilst traces of the precious metals are detectable in all parts of the ore channel or fracture zone, the richer ore (that containing 4dwts. or more of gold per ton), which alone will pay the cost of treatment, is confined to certain shoots, lenses, or irregular masses within the ore channel. These are for the most part irregular in distribution and extent, the ore passing at times by gradual decrease of values into valueless rock, at others terminating sharply

\* Rec. Geol. Surv. N.S.W., Vol. VIII., p. 284.

against a well-defined wall. The distribution of the gold is governed not only by the extent of that portion of the fracture zone which has formed the main channel through which the ore-bearing current has passed, but by the extent of fracturing of the surrounding rock by which distribution of the solution has been facilitated, and by the presence of walls, which may or may not be lines of fault, but which have obstructed the further passage of the solutions in that direction, either by stopping movement altogether or by diverting it. If it is correct that the gold has been deposited by precipitation of alkaline sulphide solutions by ferrous compounds in the rock, the latter being of universal distribution throughout the district in excessive amounts, the present distribution of gold must be governed solely by the conditions of distribution of the gold-bearing currents. In this connection Prof. Liveing's report on the Associated Mine \* to the directors of the company is of great interest.

A series of determinations were made of gold, silver, sulphur, carbon dioxide and silica in different pieces of similar ore from the same level of the same mine, in order to see if there were any mutual relationship. The results obtained were inconclusive, as will be seen from Table VI.

TABLE VI.—*Constituents of Ore from 820ft. Level, Oroya Gold Mine.*

Mark.	Gold.			Silver.			Sulphur.	Carbon Dioxide.	Silica.
	oz.	dwt.	gr.	oz.	dwt.	gr.	%	%	%
D .. ..	0	2	13	0	1	20	5·25	9·99	52·09
A .. ..	0	3	6	Trace			5·42	9·32	53·26
E .. ..	0	4	0	0	3	6	4·93	10·92	51·73
B .. ..	0	4	9	0	1	2	5·53	9·13	51·44
F .. ..	1	8	4	0	3	4	6·32	12·02	43·85
C .. ..	1	13	3	0	10	12	6·34	9·09	49·92

It is evident that theories of ore deposition have here the most important practical application. With a limited amount of precipitating agent such as frequently occurs in gold deposits, the rich ore must be sought where the precipitant was abundant, and "indicators" (the bearers of the precipitant) must be sought and followed in an endeavour to locate fresh ore shoots and masses. With a vast excess of precipitant occurring everywhere throughout not only the ore channels but the adjacent rocks, such as appears to be the case at Kalgoorlie, the system of fractures and faults which govern the current of the ore-bearing solution must be the object of study, as governing the distribution of the gold.

\* See W.A., Min. Bldg., and Eng. Journal, 19—XI.—1910.

The same factors will furnish the answer to the all-absorbing question as to whether payable ore will be found to the greatest depth to which mining can be prosecuted, say at most 7,000 feet. Compounds of ferrous oxide are just as abundant at 2,000 feet in these mines as at 200 or 1,000 feet, and there is no doubt whatever that they will continue to be abundant to depths far greater than 7,000 feet. Precipitating agents in vast excess will therefore have been present in the ore channels at all depths to the limit stated and far beyond. The origin of the ore-bearing solutions being in some igneous intrusion doubtless very deep-seated, far below the limit of mining, the third and only doubtful factor is the nature at great depths of the fracture zones which constituted the channels for the passage of the gold-bearing solutions. There are three possible alternatives :—

(1.) The fracture zone may, with variations, remain on the average of such a moderate width as to have allowed the gold to deposit in payable amounts ;

(2.) The fracture zone may gradually narrow under increasing pressure until it becomes a mere single fracture or a series of fractures covering too narrow a zone to permit of being worked at a profit ;

(3.) The widening of the fracture zone observed by Prof. Living in the deeper levels of the Associated may continue or increase with a resulting wide distribution of low values.

Of these three the last may be rejected as impossible of continuation or extension with the increased pressure accompanying great depths. The second is quite probable, but narrowing not having been marked between the surface and 2,000 feet should not be greatly marked between 2,000 and say 7,000 feet. The first alternative would appear to be that most likely to be experienced within the limits of practical mining.

The grade of ore may be expected to be just as variable below 2,000 feet as records show it to have been above that level. Bonanzas of 10, 20, and 30-ounce ore were rare in the shallow levels, and will doubtless be equally rare at greater depths. That large bodies of high-grade ore, however, are not unknown at depths well over 1,000 feet can be seen by reference to any of the recent "Progress Reports" of the various mines as published in the Monthly Journal of the Chamber of Mines.

#### *4. -- Weathering and its Results.*

Owing to the peculiar composition of the unweathered ore an unusually great difference exists between the sulphide and oxidised ores as regards their chemical and mineral composition. In early discussions of metallurgical treatment this was not generally recognised, and hopeless confusion of ideas was the result.\*

\*See for example the discussion of Claudet's paper : "Notes on the Experimental Treatment of a Gold Ore from the Hannan's District, W.A." Trans. Inst. Min. Metall., Vol. V. 1896-7.

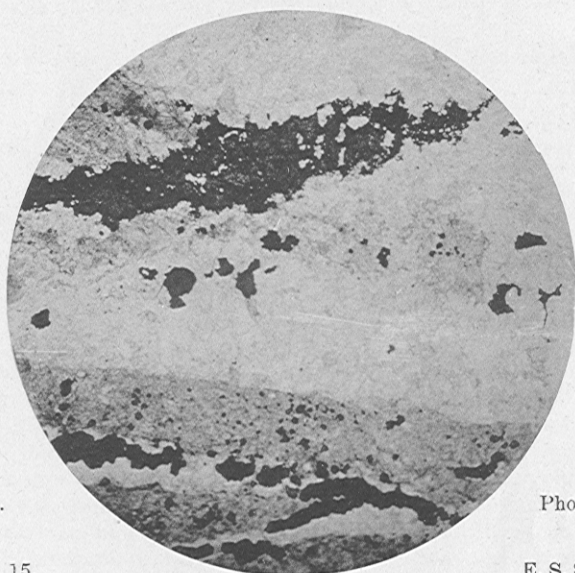


Fig. 22.

Photo. by

[8,990.] O.L.  $\times 15$ .

E. S. Simpson.

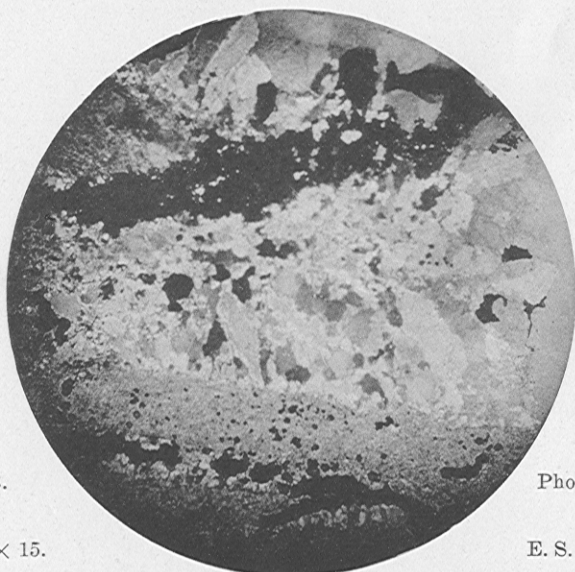


Fig. 23.

Photo. by

[8,990.] C.N.  $\times 15$ .

E. S. Simpson.

Figs. 22 and 23.—Ore with free Gold and Blende, 820ft., Oroya G.M. Blende forms dark vein-like mass across top of section; three irregular grains of Gold at middle of right side. Vein Quartz forms most of upper portion of section; Pyrites with fine grained Sericite, Albite, and Ankerite the lower portion.



A comparison of the most important differences in mineral constituents is as follows:—

Mineral.	Oxidised Ore.	Unoxidised Ore.
Native gold .. .. .	Common	Far less common
Tellurides .. .. .	None	Common
Pyrites and other sulphides ..	None	Common
Carbonates .. .. .	None	Abundant
Calcium compounds .. .. .	Very small	Abundant
Magnesium compounds .. .. .	Very small	Common
Albite .. .. .	Very small	Common
Sericite .. .. .	Abundant	Abundant
Kaolin .. .. .	Abundant	None
Limonite .. .. .	Usually much	None

The leading effects of weathering have been a complete oxidation of pyrites and other sulphides, and the oxidation of all tellurium with liberation of free gold and silver and, rarely, formation of cerargyrite (silver chloride). The earthy minerals are equally affected, the greater part of the albite is converted to kaolin, chlorite is completely decomposed with production of kaolin, limonite, etc., whilst the carbonates have been wholly destroyed by the oxidising pyrites with production of soluble sulphates of lime and magnesia, and ultimately also limonite. These changes are indicated in the few available analyses of oxidised ores given in Table VII.

TABLE VII.—*Analyses of Oxidised Lodestuff.*

	A.	B.	C.	D.
Depth—feet .. .. .	200	..	50	(?)
Mine .. .. .	Lake View.	(?)	Perseverance.	Gt. Boulder.
SiO <sub>2</sub> .. .. .	56·85	56·60	39·76	66·80
TiO <sub>2</sub> .. .. .	1·51	..	..	..
CO <sub>2</sub> .. .. .	·08	..	..	..
P <sub>2</sub> O <sub>5</sub> .. .. .	·35	..	..	..
H <sub>2</sub> O + .. .. .	4·00	[4·43]	5·95	5·15
K <sub>2</sub> O .. .. .	1·50	3·66	(?)	(?)
Na <sub>2</sub> O .. .. .	·97	..	..	..
CaO .. .. .	·47	·50	Trace	·37
MgO .. .. .	2·69	·25	Trace	·13
MnO .. .. .	None	·15	·79	..
FeO .. .. .	5·38	..	1·60	·16
Fe <sub>2</sub> O <sub>3</sub> .. .. .	11·79	15·48	36·29	17·69
Al <sub>2</sub> O <sub>3</sub> .. .. .	13·66	18·58	14·60	8·44
V <sub>2</sub> O <sub>5</sub> .. .. .	None	..	..	..
Cr <sub>2</sub> O <sub>3</sub> .. .. .	·06	..	..	..
Cu .. .. .	None	·05	..	..
SO <sub>3</sub> .. .. .	·10	·30	Trace	..
NaCl .. .. .	·10	..	..	·50
H <sub>2</sub> O — .. .. .	·58	..	·73	..
	100·09	100·00	99·71	99·24
Gold—ozs. per ton..	2·525	3·275	5·116	(?)
Silver—ozs. per ton..	0·81	..	1·733	(?)
Authority .. .. .	Simpson	Claudet	Simpson	Clarke

In outward appearance the oxidised ores are more or less schistose, porous rocks, varying in colour from almost pure white to dark brown according to the percentage of limonite in them. They may be very soft (G.S.M. 132/3, Great Boulder) or somewhat hard (G.S.M. 10446, Hannan's Reward). Their chief constituents are very finely granular quartz, sericite, kaolin, and limonite. Analyses indicate that they may also contain finely divided albite, magnetite, and ilmenite or rutile.

The gold is invariably free and often of a spongy texture, being the residue of oxidised tellurides. Silver is combined with the gold or in rare instances exists as chloride. Much of the silver must have been originally converted into chloride and carried off in solution in the strongly saline underground waters. The result of this would be partly the distribution of silver through the surrounding rocks, partly its redeposition as sulphide or sulpharsenide at water level. Of such secondary enrichment in silver at water level there is no recorded evidence.

The alkaline nature of the unoxidised ore and of the ground waters is distinctly unfavourable to the development of any secondary enrichments in gold, since it would be impossible under such conditions for chlorine, ferric sulphate, ferric chloride, or other solvent of gold to form except very locally. Movement of the ground water would soon bring it into contact with earthy carbonates which would immediately destroy it.

### *5.—Alluvial Deposits.*

The main part of the alluvial gold of the district was obtained from the thin surface covering of ferruginous clay in the immediate vicinity of the lode outcrops. These are of structural rather than mineralogical interest. They were doubtless considerably concentrated by the winnowing action of the wind upon such soft light material, almost perpetually bone-dry. The gold in these deposits appears to have been mostly rather fine-grained and of high grade. The largest nugget recorded from the district weighed 24 ounces. In the Geological Survey Collection is one [5145] from the single deep lead which was located to the west of the Hainault Gold Mine. This nugget weighs  $16\frac{1}{2}$  ounces, is flattened in form, crystalline, and ragged in outline, with no signs of being waterworn. It was found within the boundaries of the Ivanhoe Venture Gold Mine, now no longer in existence. The "wash" in this lead was the usual mixture of clay, quartz, sand, and gravel, found universally in such deposits.

### III.—DETAILED MINERALOGY OF KALGOORLIE AND BOULDER, WITH SPECIAL REFERENCE TO THE ORE DEPOSITS.

By E. S. Simpson.

The following pages contain a description of the physical properties, chemical composition, and mode of occurrence of the minerals found in the auriferous lodes, with special reference to the Geological Survey Collection of Western Australia, to which the numbered specimens belong. This collection now numbers about 300 original specimens of auriferous material from Kalgoorlie, besides many duplicates. In spite, however, of its size some minerals unfortunately are as yet but poorly represented in it, considerably better specimens having found their way to the museums of London and other European cities.

To facilitate reference, the minerals are dealt with in the order adopted by Dana in his System of Mineralogy, to which the numbers prefixed to the mineral names refer. In addition to those species whose occurrence is well authenticated, short notes are given relative to many other minerals whose presence has been announced from time to time in various publications, but not subsequently confirmed. Some notes are also included regarding minerals found in the rocks in the immediate neighbourhood of the lodes.

TABLE NO. VIII.—*List of Minerals reported to occur at Kalgoorlie.*

Reference No.	Mineral.	Auriferous Lodes.	Barren Lodes.*	Rocks.	Surface Deposits.
2	Graphite .. ..	X	X	X	..
7	Tellurium (Native) .. ..	X	..	..	..
13	Gold .. ..	X	..	..	..
17a	Gold-amalgam .. ..	(?)	..	..	..
16	Mercury .. ..	(?)	..	..	..
26	Realgar .. ..	X	..	..	..
28	Stibnite .. ..	(?)	..	..	..
31	Tetradymite .. ..	X	..	..	..
43	Hessite .. ..	X	..	..	..
44	Petzite .. ..	X	..	..	..
	Coolgardite .. ..	..	..	..	..
	Kalgoorlite .. ..	..	..	..	..
45	Galena .. ..	X	..	..	..
46	Altaite .. ..	X	..	..	..
57a	Rickardite .. ..	(?)	..	..	..
58	Blende (Sphalerite) .. ..	X	..	..	..

\* Mineral deposits containing only traces of gold, but carrying much pyrites or other secondary mineral characteristic of lodes.

TABLE NO. VIII.—*List of Minerals reported, etc.—continued.*

Reference No.	Mineral.	Auriferous Lodes.	Barren Lodes.*	Rocks.	Surface Deposits.
62	Coloradoite .. .. .	X	..	..	..
66	Cinnabar .. .. .	(?)	..	..	..
68	Greenockite .. .. .	..	..	..	..
74	Pyrrhotite .. .. .	(?)	..	X	..
77	Meloniite .. .. .	X	..	..	..
83	Chalcopyrite .. .. .	X	..	..	..
85	Pyrites .. .. .	X	X	X	..
96	Marcasite .. .. .	X	X	..	..
97	Lollingite .. .. .	(?)	..	..	..
98	Arsenopyrite (Mispickel) .. .. .	X	X	..	..
104	Sylvanite .. .. .	X	..	..	..
104a	Goldschmidtite .. .. .	..	..	..	..
105	Krennerite .. .. .	(?)	..	..	..
105a	Calaverite .. .. .	X	..	..	..
106	Nagyagite .. .. .	X	..	..	..
145	Proustite .. .. .	(?)	..	..	..
149	Tennantite .. .. .	X	..	..	..
158	Enargite .. .. .	(?)	..	..	..
166	Halite (Salt) .. .. .	X	X	X	X
169	Cerargyrite .. .. .	X	..	..	..
175	Fluorite .. .. .	(?)	..	..	..
210a	Quartz, Vitreous .. .. .	X	X	X	X
210b	Quartz, Chalcedonic .. .. .	X	X	..	..
212	Opal .. .. .	..	..	..	X
223	Water .. .. .	X	X	X	X
229	Massicot .. .. .	(?)	..	..	..
232	Haematite .. .. .	X	X	X	..
233	Ilmenite .. .. .	X	X	X	X
233a	Leucoxene .. .. .	X	(?)	X	(?)
237	Magnetite .. .. .	X	X	X	X
241	Chromite .. .. .	..	..	X	..
250	Rutile .. .. .	X	X	X	X
255	Turgite .. .. .	..	..	..	X
258	Manganite .. .. .	X	..	..	..
259	Limonite .. .. .	X	X	X	X
261	Bauxite .. .. .	..	..	..	X
269a	Asbolite .. .. .	X	..	..	..
270	Calcite .. .. .	X	X	(?)	..
270a	Travertine .. .. .	..	..	..	..
271	Dolomite .. .. .	X	X	X	..
271a	Ankerite .. .. .	X	X	X	..
272	Magnesite .. .. .	..	..	X	X
272a	Mesitite .. .. .	..	(?)	X	..
273	Siderite .. .. .	X	X	X	..
288	Malachite .. .. .	X	..	..	..
313	Orthoclase .. .. .	X	..	X	..
316	Albite .. .. .	X	X	(?)	..
319	Labradorite .. .. .	..	..	X	..

\* Mineral deposits containing only traces of gold, but carrying much pyrites or other secondary mineral characteristic of lodes.

TABLE NO. VIII.—*List of Minerals reported, etc.—continued.*

Reference No.	Mineral.	Auriferous Lodes.	Barren Lodes.*	Rocks.	Surface Deposits.
325	Pyroxene .. .. .	..	..	X	..
338 <sup>a</sup>	Amphibole, Tremolite .. .. .	..	..	X	..
338 <sup>b</sup>	Amphibole, Actinolite .. .. .	..	..	X	..
338 <sup>c</sup>	Amphibole, Hornblende .. .. .	..	..	X	..
376	Chrysolite (Olivine) .. .. .	..	..	..	X
394	Zircon .. .. .	X	X	X	..
406	Zoisite .. .. .	..	..	X	..
406 <sup>a</sup>	Clinozoisite .. .. .	..	..	X	..
407	Epidote .. .. .	..	..	X	..
409	Allanite .. .. .	..	..	X	..
410	Axinite .. .. .	..	X	..	..
426	Tourmaline .. .. .	X	X	X	..
..	Zeolite .. .. .	..	..	X	..
458	Muscovite (Sericite) .. .. .	X	X	X	X
458 <sup>a</sup>	Fuchsite .. .. .	X	X	(?)	..
462	Biotite .. .. .	..	..	..	..
462 <sup>a</sup>	Phlogopite .. .. .	X	..	..	..
463	Roscoelite .. .. .	X	..	..	..
467	Ottrelite .. .. .	..	..	X	..
468 <sup>a</sup>	Penninite .. .. .	X	X	X	..
469	Prochlorite .. .. .	X	X	X	..
481	Serpentine .. .. .	..	..	X	..
484	Talc .. .. .	..	..	X	..
492	Kaolin .. .. .	X	X	X	X
493	Halloysite .. .. .	..	..	..	..
505	Chloropal .. .. .	..	..	X	..
549	Apatite .. .. .	X	X	X	X
552	Vanadinite .. .. .	(?)	..	..	..
683	Natronitrite (Soda-nitre) .. .. .	..	..	..	X
716	Thenardite .. .. .	..	..	..	X
718	Glauberite .. .. .	..	..	..	X
719	Barite (Barytes) .. .. .	X	..	..	..
722	Anhydrite .. .. .	..	..	..	..
746	Gypsum .. .. .	X	X	..	..
748	Epsomite .. .. .	..	..	..	X
809	Emmonsitite .. .. .	(?)	..	..	..
810	Durdenite .. .. .	(?)	..	..	..
814	Scheelite .. .. .	X	..	..	..

\* Mineral deposits containing only traces of gold, but carrying much pyrites or other secondary mineral characteristic of lodes.

## 2.—GRAPHITE.

Composition, almost pure carbon. Whilst this mineral is abundant in certain shear zones of the greenstone rocks ("barren lodes"), which at times approach to within a few feet of the auriferous lodes,\* only one instance is known to the writer in which it is actually accompanied by an appreciable amount of gold. Specimen [1732] from the Forrest King (Hannan's Paringa) Gold Mine, south of the suburb of Trafalgar (Lake View), is a schistose rock carrying over  $1\frac{1}{2}$  ounces of gold per ton and sufficient finely granular graphite to give an unusually dark colour to the rock both in mass and in thin sections. In the barren shear zones it occurs as a finely disseminated powder and at times in fine scales. A large amount of pyrites in nodules and bands frequently accompanies it. The carbon in one sample examined amounted to 4 per cent.

## 7.—TELLURIUM.

Composition, almost pure tellurium. This mineral has not been detected in any of the specimens in the Survey Collection, nor could L. J. Spencer detect it in any of the British Museum specimens. A mineral occurring in small quantity in ore from the Hidden Secret Gold Mine was at first assumed to be this. It dissolved completely in strong sulphuric acid, giving a strong tellurium reaction, was wholly volatile, and yielded no mercury. The mineral was tetradymite, but the tellurium, under certain conditions, masked the usual iodide reaction with the blowpipe for bismuth.

The occurrence of native tellurium at Kalgoorlie was first announced by Holroyd in 1897, in the following words:—

"The principal forms in which tellurium occurs are calaverite, sylvanite, and native in traces."

It is probable that Holroyd's "native tellurium" was coloradoite (telluride of mercury) which was not at first identified as such. In the *Chemical News* of 7th December, 1900, R. W. E. McIvor, in a short paragraph, says:—

"While examining some specimens of telluride ore from the Hannans District, Western Australia, I found, associated with pyrites, a finely granular white metallic-looking mineral, which on analysis proved to be tellurium. Freed from foreign substances it has a specific gravity of 6.2 and contained—

Tellurium .. .. .	96.935
Gold .. .. .	2.399
	<hr/>
	99.334

Iron and sulphur were present, but I failed to detect any trace of selenium."

T. A. Rickard says † that a piece of "native tellurium" given to him in Kalgoorlie, in 1897; volatilised completely in a closed tube but yielded globules of mercury, showing that it was coloradoite.

\* See C. G. Gibson, this Volume, p. 27.

† Trans. Amer. Inst. Min. Eng., Vol. XXX., p. 715.

## 13.—GOLD.

Composition, metallic gold with more or less silver and traces of copper, etc. Free gold has been obtained from the oxidised zone of all lodes and veins at Kalgoorlie, forming in fact the sole source of the gold extracted. It has also been recorded from the unoxidised ores of practically every mine in the district. In spite of the large amount of tellurides in some of the mines, it is probable that quite half of the total output of  $11\frac{1}{2}$  millions of ounces of gold from the district originally occurred in the ore in the free state.

The size and shape of the particles of gold is very variable, and influences to some extent the metallurgical treatment, those particles which are coarse and lumpy being readily amalgamated and difficult of solution in cyanide, whilst those particles which are small and filmy are just the reverse, being readily dissolved in cyanide, but only amalgamated with difficulty.

On the basis of shape and size of particles the following varieties are generally recognised :—

- |                     |    |    |    |                               |
|---------------------|----|----|----|-------------------------------|
| A.—Crystallised     | .. | .. | .. | (1.) Coarse crystals          |
|                     |    |    |    | (2.) Fine isolated crystals   |
|                     |    |    |    | (3.) Sponge gold              |
|                     |    |    |    | (4.) Mustard gold             |
|                     |    |    |    | (5.) Dendritic gold           |
| B.—Not crystallised | .. | .. |    | (6.) Rough gold               |
|                     |    |    |    | (7.) Flake gold               |
|                     |    |    |    | (8.) Paint gold or float gold |

So far as origin is concerned (1), (6), and (7) are probably invariably primary, *i.e.*, deposited in the ore by the original mineral-bearing solutions. (2), (3), and (4) are invariably secondary, *i.e.*, formed long after the original ore deposition by the action of circulating ground water in the oxidised and oxidising zones. (5) and (8) may be either primary or secondary, being found in both oxidised and unoxidised ores.

Crystallised gold is less common than non-crystallised, group (6) embracing the majority of the free gold.

(1.) *Coarse Crystals*.—These are extremely rare and are only doubtfully represented in the collection by one specimen. Smooth faces on coarse gold, which appear at first sight as crystal faces, can usually be ascribed to growth against smooth faces of dolomite or siderite.

(2.) *Fine Isolated Crystals*.—These are found not uncommonly on fracture or cleavage faces of oxidised ore. They are either single crystals from 0.05 to 0.10 mm. in size, or small hemispherical groups of crystals up to 1 mm. in diameter. For the most part the crystals appear to be imperfect octahedra, but occasionally square faces of the cube are seen. Frequently the edges are well developed, whilst the faces are furrowed out.

(3.) *Sponge Gold*.—A most interesting and unusual form of native gold, of which excellent specimens were obtained from the Golden Horseshoe and Great Boulder Proprietary Gold Mines. The most extensive development of this form of gold ever recorded was in the stopes above the 200ft. level of the latter mine, where in a few hours on 19th March, 1897, about 70lbs. weight of pure sponge gold was taken out of a vugh. One piece alone weighed 60ozs., and altogether 250ozs. were exhibited by the management in one of the shop windows of Kalgoorlie on the following day. A small piece from this find was shown in the Western Australian Court at the Franco-British Exhibition. Holroyd \* refers to the occurrence of sponge gold also at the North Boulder Gold Mine.

Sponge gold is undoubtedly the product of oxidation of a gold telluride (probably calaverite), being found (loosely filling irregular cavities in quartz or schist) only in the surface ores of those mines which have yielded tellurides. It is a porous mass of small incompletely developed mutually adherent gold crystals, growing in arborescent form, the effect being a structure not unlike a marine, or still better vegetable sponge (lufa). The pores are of greater volume than the gold, which retains to the unaided eye its brilliant metallic lustre. Under the microscope the crystals are seen to average 0.1 mm. in diameter, and to consist of the octahedron modified by the cube and rhombic dodecahedron, and many other forms, most of the crystals being very complex.

A very good imitation of sponge gold was made artificially by dissolving calaverite in aqua regia, removing almost all nitric acid, and finally slowly precipitating the gold by oxalic acid, the precipitation taking several days to approach completion.

One specimen of sponge gold from the Golden Horseshoe Gold Mine was analysed and found to contain—

Gold	..	..	..	..	99.91
Silver	..	..	..	..	.09
Copper and Iron	..	..	..	..	Nil
					<hr/> 100.00

This shows that some at least of the Kalgoorlie sponge gold is remarkably pure, much more so than any other gold heretofore analysed.† Its purity can readily be accounted for. It originally occurred in combination with tellurium as calaverite containing on the average—

Gold	..	..	..	..	42.0
Silver	..	..	..	..	0.7

\* Trans. Aust. Inst. Min. Eng., Vol. IV., p. 192.

† In a recent article in Economic Geology (Vol. VI., p. 29), by W. J. Sharwood, it is pointed out that in many instances where native gold has been found of exceptional purity, it has been associated with tellurides.



The oxidation of this without the removal of silver would give a metal composed of—

					%
Gold	..	..	..	..	98.4
Silver	..	..	..	..	1.6

The tellurium, however, was apparently removed to a large extent, if not wholly, by sulphuric acid from decomposing pyrites, the action being practically a parting process which would remove not only the tellurium but also the greater part of the silver too. The abundance of sodium and magnesium chlorides in the ground water would further assist in purifying the spongy mass of gold by solution of silver.

(4.) *Mustard Gold*.—This is closely related in structure to sponge gold, but in outward appearance is very different, being like a mass of dull yellow ochre. Under the microscope it is seen, however, to more closely resemble a marine sponge than the so-called sponge gold. Both the strings of gold and the pores between them are much finer in texture, no crystal faces being recognisable with a  $\frac{1}{2}$ -inch objective. The whole mass is much more compact than typical sponge gold and has a far less brilliant lustre. It is found, like the latter, loosely filling irregular pockets in oxidised ore, being doubtless the result of oxidation of tellurides previously completely filling the pockets. Whilst masses of sponge gold can only be torn into fragments by the exercise of a fair amount of force, masses of mustard gold readily break up into small blocks with fairly smooth faces.

The only two really characteristic specimens in the collection are [1502] from the Lake View Consols Gold Mine, and [438] from the Kalgurli Gold Mine.

A. G. Holroyd \* speaks at some length of the occurrence of mustard gold. He says, *inter alia* :—"If this gold is pressed with the blade of a knife, its metallic lustre is at once apparent. Mustard or clay gold can be artificially obtained in the laboratory by dissolving very slowly a piece of telluride of gold in sulphuric acid, the tellurium is leached out and leaves the gold in an exactly similar form to that which is found upon this field. This among many other reasons leads the author to believe that the mustard gold in a mine in this district is an indication of the presence of telluride of gold at lower levels. The greater quantity of the (oxidised, E.S.S.) ores on the Kalgoorlie field carry mustard gold." Mr. Holroyd refers to the occurrence of mustard gold in the Block 45, Hannan's Star, North Boulder, and Great Boulder Perseverance Gold Mines.

(5.) *Dendritic Gold*.—Thin plates of gold showing a dendritic structure due to partial development of crystal faces occur rarely on joint planes in oxidised ore. Our collection shows one such [6736] from the Ivanhoe Gold Mine.

\* Loc. cit.

(6.) *Rough Gold*.—This is the commonest form of the native metal here as elsewhere. It is irregular in boundary, showing no crystal faces, and having no one dimension very markedly greater than any other. (Figs. 22, 23.) In wire gold on the other hand one dimension is much greater than the other two, in paint or flake gold two dimensions are much greater than the third. Wire gold appears to be unknown at Kalgoorlie.

Rough gold in all sizes, from microscopic specks up to fairly large slugs, has been met with in all the Kalgoorlie mines. Whilst internally of crystalline structure its rough exterior is due to the fact that in process of growth it has met on all sides with hard and insoluble minerals such as quartz, etc. It is found in quartz veins, in dolomite veins, and in the schistose rock, embedded in quartz, dolomite, coloradoite, etc. Bearing in mind the conditions of its deposition, it is natural to find that these fragments of gold have a ragged exterior. Where, however, gold and coloradoite have been deposited together (a not unusual occurrence) the surfaces of gold in contact with the coloradoite are often very smooth and curved.

The composition of a sample of rough gold from the Oroya Gold Mine was—

					%
Gold	..	..	..	..	93.93
Silver	..	..	..	..	5.85
Copper	..	..	..	..	.22
					<hr/>
					100.00

(7.) *Flake Gold*.—(Thick flake gold as distinct from paint gold). In cracks in quartz and other minerals both in the oxidised and unoxidised ore flakes of gold with a thickness varying from 0.1 to 1.0 mm. are found. In lateral extent they are variable. Such pieces being heavy in proportion to their superficial area, sink readily in water and are readily caught in an ordinary battery. They are seen in specimens from several mines.

(8.) *Paint Gold*.—This from the metallurgical point of view is the most difficult to deal with. It consists of small films or scales from 0.01 mm. downwards, much of it approaching thin gold leaf in thickness. The scales may be mere specks or may be 1 to 3 mm. in diameter. They occur either in extremely narrow cracks or on cleavage planes or slickensides intergrown with scales of sericite and chlorite between which they appear to have been deposited. Excellent examples have been obtained from Kalgoorlie, particularly from the Golden Horseshoe Gold Mine, [8953] A. and B. Specimens are also in the collection from the Lake View Consols and Cæsus North No. 1 Gold Mines. It is found in both oxidised and unoxidised ore.

Most of the varieties of gold outlined above are not shut off by any hard and fast boundaries from their fellows. Thus mustard gold by increase in coarseness of grain merges into sponge gold; paint gold by increase in thickness into flake gold; by development of dendritic boundaries into dendritic gold, etc., etc.

A point that needs investigation is the composition of the gold. With the two exceptions given no figures are available. The grade of the smelted gold produced by the mines is a very unreliable index for three reasons:—(1) The proportion of silver extracted from the ore with the gold varies; (2.) The proportion of base metals picked up during extraction is variable; (3) The extent to which refining is carried on is likewise not constant, and silver is removed as well as base metals during the process. The following figures showing the composition of bullion from four mines in 1906 are taken from "West Australian Metallurgical Practice."

TABLE IX.—*Composition of Kalgoorlie Bullion.*

	Gold.	Silver.	Base Metal.
Great Boulder Proprietary—			
Amalgamation bullion .. ..	894.1	83.8	22.1
Cyanide bullion .. .. .	804.4	174.3	21.3
Associated—			
Amalgamation bullion .. ..	941.2	40.8	18.0
Cyanide bullion, ordinary ..	890.2	84.3	25.5
Cyanide bullion, Clark's process	999.4	<i>Nil</i>	.6
Lake View Consols—			
Concentrates amalgamation ..	971.5	18.4	10.1
Cyanide bullion .. .. .	787.2	185.5	27.3
Golden Horseshoe—			
Battery .. .. .	913.2	60.4	26.4
Sands plant .. .. .	698.0	260.0	42.0
Raw slimes plant .. .. .	701.2	254.0	48.8
Concentrates pans .. .. .	954.4	40.3	5.3
Concentrates agitation .. ..	703.9	268.8	27.3

From such conflicting figures it seems impossible to obtain any information as to the original grade of the free gold.

The following are descriptions of typical specimens in the Survey Collection:—

[542], 100ft., Lake View Consols Gold Mine. Completely oxidised schist. On two fracture faces are many single crystals and small hemispherical crystal groups reaching occasionally 1 mm. in diameter.

[10395], 100ft., Great Boulder Proprietary Gold Mine. This is another excellent specimen of the same type as [542].

[1503], 200ft., Golden Horseshoe Gold Mine. Four pieces of typical sponge gold weighing in all 13 grammes (roughly  $\frac{1}{2}$ -oz.). Two of these were originally conjoined. They are typical sponge gold as described on page 82.

[1804], Golden Horseshoe Gold Mine. Two specimens of oxidised schist showing irregular hollows loosely filled with masses of typical sponge gold. In one case the gold is in a quartz veinlet, in the other in the solid schist.

[166], 200ft., Lake View Consols Gold Mine. Schist with quartz veins from water level. Many medium-sized masses of sylvanite, one wholly converted into a dull yellow mustard gold, others coated with a layer of same. In this case the mustard gold is evidently the product of oxidation of sylvanite.

[1502], Lake View Consols Gold Mine. A specimen of greenish schist in which all tellurides and sulphides are completely oxidised. Many irregular cavities up to an inch in length are loosely filled with typical mustard gold.

[438], Kalgurli Gold Mine. Water level ore oxidised for some little distance in from all cracks, but centrally unoxidised. Much coloradoite present in various sized masses. On one side of specimen a row of small irregularly-shaped masses of very dull ochreous gold. (mustard gold).

[6736], 100ft., middle lode, Ivanhoe G.M. Completely oxidised silicious ore with much gold on fracture faces. The gold is mostly in small flakes with a fairly well-defined dendritic outline.

[8954], Oroya Gold Mine. This is the finest specimen of rough gold in the collection. The specimen is a much shattered slab, 100 x 115 x 40 mm. ( $4 \times 4\frac{1}{2} \times 1\frac{1}{2}$  in.) in size, held together by coarse gold. One flat face is made up largely of a grey quartz leader, the other face is greenstone schist. Gross weight 30.6 ozs., estimated to contain about 25 ozs. gold,  $\frac{1}{2}$ -oz. coloradoite, and a little sylvanite. The gold is very ragged except where it has been in contact with coloradoite, where quite smooth, brilliant, curved faces occur. Its composition is given above, page 84.

[8342], 600ft., North Kalgurli Gold Mine. Massive grey rock with crossing veins of quartz. Rough gold in several places in rock, in quartz and in a small calcite vein. Some fine pyrites and a black mineral present.

[6363], Hidden Secret Gold Mine. Bright gold in moderately thick films or plates on fractures of petzite and hessite, forming veins and masses in pyritous greenstone.

[9200], Brown Hill Gold Mine. Gold in somewhat large flakes on cleavage surface of partly oxidised schist.

[5249], Devon Consols Gold Mine. Thin plates of gold in fractures of vitreous quartz veinlet.

[5245], Hannan's Reward Gold Mine. Thin plate of gold in fracture in scheelite from oxidised zone.

[8953] A and B, Golden Horseshoe Gold Mine. Two magnificent specimens of paint gold. The whole of the slickensided top surfaces coated thickly with very thin small scales of bright gold, mixed with scales of chlorite and sericite.

[2499], 130ft., Croesus North No. 1 Gold Mine. A block of oxidised schist, one cleavage face half covered with thin dendrites of manganese oxide. Thin scales of paint gold inclined to be dendritic are freely scattered over the face of the manganese. The effect is that of a pencil drawing of branching trees dotted with golden flowers.

#### 16.—MERCURY.

Composition, metallic mercury with at times traces of gold and silver. This mineral is not represented in the British Museum Collection nor in any collection examined by myself. T. A. Rickard, however, says \* :—"At Kalgoorlie native mercury and native amalgam have also been found." Coloradoite (telluride of mercury) is one of the commonest tellurides at Boulder, and its decomposition should lead to the production of native mercury, or, where associated with free gold (as is commonly the case), to gold amalgam.

#### 17A.—GOLD-AMALGAM.

Alloy of gold and mercury. The remarks under "Mercury" apply equally to this mineral. E. F. Pittman says † :—"It is stated that a specimen of native amalgam was found in the Boulder Perseverance Mine, Kalgoorlie, last year."

#### 26.—REALGAR.

Sulphide of arsenic, AsS. This mineral has been reported from only two mines, the Great Boulder Proprietary and Golden Horseshoe. The following notes on its occurrence in these mines were kindly supplied by the Manager of the former, Mr. Richard Hamiltor:—

"The mineral realgar has been found from the surface to the 2,500ft. level in the lode known as No. 4 in the Horseshoe Mine, but which was in the Great Boulder Mine at the 100ft. level and was then known as our Western Lode. This lode dipped into the Horseshoe and at about a thousand feet in depth it returned to the Great Boulder, and junctioned with the lode which the Great Boulder had been following in the meantime. The mineral was not at any time plentiful, one might see as much as shows in the enclosed specimen at intervals of say ten feet downwards and laterally. It was generally found

\* Trans. Amer. Inst., Min. Eng., Vol. XXX, p. 715.

† Rec. Geol. Surv. N.S.W., Vol. V., p. 204.

near the centre of the lode, and was at least twice as abundant above the 1,000ft. level as it is below that depth. The other lodes in the Great Boulder Mine, and I believe in the Horseshoe also, do not show this mineral."

The specimen referred to, [11347], consists of dark green lode-stuff with small veins of crystallised carbonates. Realgar is present in the form of numerous small crystalline masses of a bright scarlet or orange colour.

#### 28.—STIBNITE.

Sulphide of Antimony,  $\text{Sb}_2\text{S}_3$ . An anonymous note in the Monthly Report of the Chamber of Mines of W.A., Vol. I., p. 132, reads:—

"Great Boulder Mine.

The following minerals are frequently met with in the drives and stopes of the above mine below the 200ft. level. . . . Stibnite, when found, is generally in large patches. . . ."

This statement has never been confirmed, and the mineral referred to is no doubt fahl ore, which gives a strong reaction in a closed tube for antimony sulphide.

#### 31.—TETRADYMITES.

Telluride of bismuth,  $\text{Bi}_2\text{Te}_3$ . This has only recently been detected embedded in petzite in ore from the Hidden Secret Gold Mine. It occurs in small scaly masses with irregular or roughly hexagonal outlines. It has a silver-white colour and brilliant lustre equal to that of sylvanite. Flakes were found to be soft, somewhat sectile, flexible, wholly volatile and wholly soluble in sulphuric acid, giving the tellurium reaction. The iodide test for bismuth was usually masked by the volatilisation of tellurium with the bismuth iodide. Wet tests, however, gave conclusive evidence of the presence of much bismuth. Cupellation of 0.04 gramme gave no gold or silver. It occurs in quite small amounts in small crystal individuals in several of the specimens embraced under No. [10938], recently purchased from the owner of the Hidden Secret Gold Mine. These specimens show much hessite and petzite with less coloradoite, free gold and tetradymite, the tellurides forming irregular masses or filling narrow veins in a dark green schist.

#### 43.—HESSITE.

Telluride of silver,  $\text{Ag}_2\text{Te}$ . The occurrence of this mineral seems to have been first recorded in 1898 by Schmeisser, who says \* that in the telluride deposits the silver occurs at petzite, hessite,

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\* Schmeisser and Vogelsang: The Goldfields of Australasia, Louis' translation, p. 73.

and other varieties. Krusch in 1901 wrote\* :—"In the deep ground there appears a series of minerals which consist of compounds of tellurium with gold, silver, and mercury. Especially noticeable are sylvanite, calaverite, krennerite, petzite, hessite, coloradoite and kalgoorlite. . . . Hessite is a pure telluride of silver of lead-grey colour and formula  $\text{Ag}_2\text{Te}$ ." L. J. Spencer in 1902 stated that he was unable to detect this mineral amongst the excellent collection of Kalgoorlie ores in the British Museum, and it is open to question whether the above "occurrences" were not surmises to account for the presence of silver in the telluride ores of the Golden Mile. The precious metal tellurides however, in this zone are the bitellurides, petzite, sylvanite, and calaverite, the two first-named of which contain sufficient silver to account for all the silver shown by assays.

Some years later than the publication of Schmeisser and Krusch's notes, tellurides were met with for the first time in the Hidden Secret Gold Mine some distance to the north of the Golden Mile. In this mine hessite and petzite are about equally prominent, and from time to time "bonanzas" of extraordinarily rich ore have been opened in it. A fine suite of specimens illustrative of these occurrences has recently been added to the Geological Survey Collection. The lodestuff as exhibited by these is a dark green chloritic rock somewhat banded and foliated, and characterised by a large proportion of pyrites. No veins of secondary quartz are to be seen. The tellurides occur as solid veins, lenses or pipe-like masses cutting across the planes of foliation, and as branching moss-like masses of microscopic dimensions (Fig. 21). The characteristic contents of the larger masses are a somewhat intimate mixture of hessite and petzite, with which are frequently found coloradoite, fahl-ore (enargite ?), and chalcopyrite, and more rarely free gold, tetradymite, altaite, melonite, and galena. In the presence of such mixtures containing minerals closely resembling one another it is easy to account for the analyses which led to the announcement of "kalgoorlite" and "coolgardite" as new mineral species.

No evidences of crystallisation are seen on the hessite which occurs as irregular-shaped masses from the size of a pin's head up to  $50 \times 40 \times 30$  mm. ( $2 \times 1\frac{1}{2} \times 1\frac{1}{4}$  inches). Occasionally it forms the sole contents of a veinlet up to 6 mm. ( $\frac{1}{4}$ -inch) wide, besides which, as stated above, it is distributed throughout the mass of the lodestuff in minute branching filaments, and in thin coatings on cleavage planes. It is lead-grey in colour, sometimes with dull dark-grey tarnish, but usually with bright metallic lustre. It is soft (H,  $2\frac{1}{4}$ ) sectile, tough, and possesses an uneven fracture. In the closed tube it fuses readily and gives a white fusible sublimate of telluric oxide.

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\* P. Krusch: Die Telluride West Australiens, Zeit. für prakt. Geologie, 1901.

The composition of several fragments from this mine was ascertained by double cupellation with lead, and the following are typical results :—

—						A.	B.
Gold	..	..	..	..	..	.8	.1
Silver	..	..	..	..	..	61.0	61.7
Copper	..	..	..	..	..	Trace	Trace
Tellurium	..	..	..	..	..	38.2	38.2

The gold in these may be due to included petzite. *See* specimen registered under Nos. [10908] and [10938].

#### 44.—PETZITE.

Telluride of gold and silver,  $\text{Au}_2\text{Te} \cdot 3\text{Ag}_2\text{Te}$ . This mineral occurs throughout the telluride area at Kalgoorlie, but is much less abundant than either calaverite or coloradoite. By far the finest specimens come from the Hidden Secret Gold Mine, from which masses of 40 x 30 x 15 mm. ( $1\frac{1}{2} \times 1\frac{1}{4} \times \frac{3}{8}$  ins.) have been obtained. In the mines at the southern end it occurs in much smaller masses down to microscopic size. In addition to the mine already mentioned it has been recorded from the following mines :—Ivanhoe, Golden Horseshoe, Main Reef, Great Boulder Proprietary, South Kalgurli, Associated, Associated Northern, and Brown Hill.

As found at Kalgoorlie this mineral is black in colour, with bright metallic lustre, which tarnishes somewhat readily on exposure to the air. No cleavage or crystal faces have been detected on it, its outlines being governed by the boundaries of the enclosing minerals. Usually it occurs in scattered grains embedded in quartz or schistose lodestuff. In the Hidden Secret Gold Mine it forms, usually in intimate admixture with hessite, coloradoite, and chalcopyrite, the filling of small veins or lenses from 1 to 10 or more millimetres wide. These veins cut across the planes of foliation of the lodestuff almost at right angles. In appearance this mineral closely resembles coloradoite (when showing no cleavage) and fahl ore, and, to a less extent, hessite. From the last-named it is distinguished by its colour, being a pure black and not dark lead grey as is that of hessite, by being brittle, not sectile, and finally by yielding gold. From coloradoite it is distinguished by yielding no mercury when heated in the closed tube, by showing no trace of cleavage, and by yielding gold. From fahl ore or enargite it is distinguished by the very different reactions obtained in the closed tube.



In arriving at the composition of the Kalgoorlie petzite the greatest care has to be observed in selecting material for analysis so as to ensure the absence of other minerals resembling it and frequently intergrown with it. Of twelve published analyses of Kalgoorlie petzite, three show evidence of an admixture of from 0·5 to 4·0 per cen. of coloradoite; one shows 1·5 per cent. of coloradoite and some fahl ore or enargite; two show a very large admixture of calaverite or sylvanite or both; four others show such a large admixture of coloradoite and other tellurides as to have been looked upon for some time as belonging to two new mineral species.\*

The best available analyses are:—

TABLE X.—*Petzite, Kalgoorlie.*

—	1.	2.	3.	4.	5.	6.
Gold .. ..	24·33	24·64	24·62	24·16	23·42	23·58
Silver .. ..	40·70	40·47	40·55	41·22	41·37	43·31
Mercury .. ..	..	·29	..	2·00	2·26	·88
Copper .. ..	·10	..	..	·10	·16	·20
Iron .. ..	·07	..	..	..	..	Trace
Nickel .. ..	·08	..	..	..	..	..
Tellurium .. ..	32·60	34·60	34·83	32·33	33·00	31·58
Selenium .. ..	1·45	..	..	..	..	..
Sulphur .. ..	·26	..	..	..	..	..
Antimony .. ..	..	..	..	..	..	·30
Authority .. ..	99·59 Krusch	100·00 Grace	100·00 Grace	99·81 Carnot	100·21 Carnot	99·85 Carnot

Analyses 2 and 3 were of mineral from the Associated Gold Mine; no information is available as to the source of the other specimens.

The proportions of gold and silver in petzite from the Hidden Secret Gold Mine were determined by double cupellation.† The results obtained from three separate specimens were:—

*Petzite, Kalgoorlie.*

Gold .. ..	25·3	25·2	25·2
Silver .. ..	42·0	41·8	41·7
Copper .. ..	str. tr.	str. tr.	str. tr.
Tellurium .. ..	[32·7]	[33·0]	[33·1]
	100·0	100·0	100·0

\*See under Coolgardite and Kalgoorlite, p. 92

†See hereunder p. 171.

## 44A.—KALGOORLITE AND COOLGARDITE.

For some years it was not generally recognised that there were at Kalgoorlie more than two species of tellurides, one dark-coloured, the other light-coloured. It is, therefore, not to be wondered at that in selecting material for analysis what we now know to be essential precautions were not taken to ensure the homogeneity of that material. In consequence analyses were made both of single lumps of telluride, including more than one species, and of collections of fragments shed from several specimens of ore. The liability to err in this way is very evident when one views the extraordinarily complex telluride veins of the Hidden Secret Mine. In these there is a very intimate intergrowth of hessite, petzite, coloradoite, altaite, tetradyomite, and occasionally melonite, as well as fahl ore or enargite, chalcopyrite, galena, and free gold. Even when upon one's guard against such mixtures, it is not always possible to select a homogeneous sample of one mineral, as polishing and etching of these veins and masses show that what after careful scrutiny appears to be a single mineral is in reality contaminated by small deeply embedded granules of a second and often a third species.

The following table includes those published analyses of tellurides which appear with good reason to have been made on heterogeneous material:—

TABLE XI.—*Analyses of Mixed Tellurides from Kalgoorlie.*

	I.	II.	III.	IV.	V.	VI.
Gold .. ..	20·72	23·15	27·75	37·06	15·06	26·10
Silver .. ..	30·98	16·65	13·60	4·71	45·95	30·43
Mercury .. ..	10·86	3·10	3·70	3·70	..	·70
Copper .. ..	·05	·10	·25	·88	1·16	·60
Iron .. ..	..	Trace	Trace	·90	·08	·40
Nickel .. ..	..	..	..	..	·06	..
Zinc .. ..	..	..	..	..	·04	..
Tellurium .. ..	37·26	56·55	53·70	51·13	36·90	41·11
Sulphur .. ..	·13	..	..	..	·45	..
Antimony .. ..	..	·20	·15	1·20	·12	·80
	100·00	99·75	99·15	99·58	99·82	100·14
Sp. gr. .. ..	8·79	..	..	..	..	..
Name .. ..	Kalgoor- ite	Cool- gardite	Cool- gardite	Cool- gardite	Mixture	Mixture
Authority .. ..	Mingaye and Pittman	Carnot	Carnot	Carnot	Krusch	Carnot

I. Upon this analysis E. F. Pittman based his claim for the recognition of a new species "Kalgoorlite." In a valuable paper \* contributed in 1902 to the Mineralogical Society of London, L. J. Spencer gives excellent reasons for rejecting "Kalgoorlite" as a species, the material upon which the analysis was made being evidently a mixture of coloradoite and petzite.

II., III., and IV.—Upon these analyses Prof. A. Carnot founded the species "Coolgardite." On reference to the translation of his paper in the appendix it will be seen that these analyses were made indubitably upon mixtures of fragments of several minerals including coloradoite, petzite, sylvanite and calaverite. "Coolgardite" therefore has no claim to recognition as a species.

#### 45.—GALENA.

Sulphide of lead, PbS. So far as the writer is aware this has only been found in one mine at Kalgoorlie, viz., the Hidden Secret Gold Mine. A specimen of pyritous greenstone [10956] from one of the rich "patches" in this mine shows a lens of metallic minerals in which coarsely granular galena is prominent. It is lead-grey in colour with perfect cubic cleavage, gives no reaction for tellurium, but strong reactions for lead and sulphur. It is intergrown with hessite and pyrites, whilst close to it are free gold, tetradymite, and chalcopyrite.

#### 46.—ALTAITE.

Telluride of lead, PbTe. The first mention of this mineral is by L. J. Spencer, who says† :—

"It was found in small amounts on three of the British Museum specimens, all from the Great Boulder Proprietary Gold Mine. It is of a lead-grey colour, sometimes with a yellowish tarnish, and has three perfect cleavages at right angles to each other. . . . In appearance it resembles galena, but qualitative chemical tests, both before the blowpipe and in the wet way, proved the presence of lead and tellurium and the absence of sulphur."

The associated minerals are calaverite, coloradoite, and petzite. Altaite is seen on several specimens from two sets in the Geological Survey Collection; these exhibit masses of solid tellurides and sulphides from the Hidden Secret Gold Mine. [10908, 10938]. The chief constituent of [10908] is hessite, the next most important being chalcopyrite. A single mass of altaite is present; it is about  $\frac{1}{2}$ -inch (12 mm.) in size in each direction. No crystal faces are seen on this mineral, but it possesses a perfect octahedral cleavage, the roughly measured angles being  $70^\circ$  and  $110^\circ$  which are those between adjacent and alternate faces of the

\*L. J. Spencer: Mineralogical Notes on Western Australian Tellurides: The non-existence of "Kalgoorlite" and "Coolgardite" as mineral species. Mineralogical Magazine, Vol. XIII., p. 268. † *Ibid.* p. 278.

octahedron. It is brittle, with uneven fracture. Colour, tin white ; lustre, metallic splendid. Composition:—

*Altaite, Kalgoorlie.*

	per cent.	molecules.
Lead .. .. .	61·33	·296
Silver .. .. .	·43	·004
Gold .. .. .	·02	..
Copper .. .. .	·01	..
Iron .. .. .	·13	·002
Zinc .. .. .	Trace	..
Tellurium .. .. .	38·43	·301
Selenium .. .. .	·08	·001
	<hr/> 100·43	
Sp. gr. at 4° .. .. .	8·223	

In a polished longitudinal section of a hessite vein from the Hidden Secret Mine, altaite is seen in five small rounded masses embedded in solid hessite. This appears to be the typical mode of occurrence throughout this mine.

The Kalgoorlie altaite fuses at a low temperature and is completely and readily soluble in 10E nitric acid.

57A.—RICKARDITE.

Telluride of copper,  $\text{Cu}_4\text{Te}_3$ . A copper telluride has recently been reported from the Kalgurli Gold Mine. From the meagre descriptions to hand it would appear to differ from typical Rickardite. Copper appears to have a greater affinity for sulphur than for tellurium, and in the presence of abundant pyrites would hardly be expected to have combined with tellurium. In the form of copper pyrites this metal is abundant in the Hidden Secret Mine embedded in large masses of various tellurides.

58.—BLENDE (SPHALERITE).

Sulphide of zinc,  $\text{ZnS}$ . This mineral in small amounts is seen in several of the mines, being found most usually in small granular aggregates in secondary quartz veins, or less commonly covering fracture faces. It is found in granules as small as 0·01 mm., and in granular aggregates up to 10 mm. in diameter. The smaller grains are only to be detected in microscopic sections, so that this mineral might easily be more plentiful than at present proved. In addition to quartz its immediate associates are free gold, pyrites, and dolomite, or ankerite. The following mines have yielded specimens showing this mineral:—Oroya, Boulder Queen Consols (G.M.L. 1194), Hawk's View (G.M.L. 1040), South Kalgurli.

Typical specimens in the collection are :—

[1949], Hawk's View Gold Mine. Masses  $\frac{1}{2}$ -inch (12 mm.) in diameter in a quartz vein.

[8990], 820ft., Oroya Gold Mine. Grey schistose ore assaying 1oz. 13dwts. gold per ton. The composition of the whole ore is given on page . It contains 0.20 per cent. of zinc, equal to 0.30 per cent. of blende. This mineral is seen in small brown crystalline grains scattered over the face of a cross fracture. A thin slice of the ore also shows this mineral in an almost continuous band of granules forming with quartz, pyrites, free gold, and ankerite a narrow veinlet in the ore, *see* Figs. 22 and 23.

[10844], 1,200ft., South Kalgurli Gold Mine. Dark-grey lodestuff, showing a little free gold, and of an unusual type, owing its dark colour to the presence of a large proportion of microscopic crystals of tourmaline. A thin slice shows isolated granules, and strings of granules, of light-brown blende in narrow veinlets of quartz and dolomite. Pyrites and tourmaline are abundant in the adjacent lodestuff.

#### 62.—COLORADOITE.

Telluride of mercury,  $\text{HgTe}$ .\* With the exception of calaverite this mineral is the commonest telluride on the Kalgoorlie field. It is also the widest in distribution, being found throughout the whole length of the telluride zone. It is associated with monotellurides (hessite, petzite, altaite), a sesquitetelluride (tetradyomite), and bitellurides (sylvanite, calaverite). It has been recorded from the Ivanhoe, Golden Horseshoe, Great Boulder Proprietary, Great Boulder Main Reef, Great Boulder Perseverance, Associated, Hannan's Star, Kalgurli, South Kalgurli (Fig. 30), Oroya, and Hidden Secret Mines.

This mineral has been found in very few localities throughout the world and these, with the exception of Kalgoorlie, yield only small much contaminated masses. At Kalgoorlie on the contrary magnificent specimens have been obtained, particularly in the Associated Gold Mine, masses of several pounds in weight having been recovered. The finest specimen in the Geological Survey Collection is from the Oroya Gold Mine, and consists of a lens of coloradoite about  $125 \times 50 \times 25$  mm. ( $5 \times 2 \times 1$  inch) embedded in a greenish sericite schist. In other specimens this mineral appears as irregular masses, films, or lenses varying in size from a small speck upwards. In most cases no crystal faces are seen, but a cleavage is apparent in many masses, being especially well marked

\* A doubt was previously expressed (G.S.W.A., Bull. VI., p. 27) as to whether the formula of the Kalgoorlie mineral was  $\text{HgTe}$  or  $\text{Hg}_2\text{Te}_3$ . Recent work, however, has settled beyond all doubt that the formula is  $\text{HgTe}$ .

in [6363] from the Hidden Secret Gold Mine and [8956] from the Oroya Gold Mine. In both cases the cleavage is seen usually in a series of minute steps as shown in Fig. 24. A single cleavage



FIG. 24.

can be traced over areas up to 15 x 15 mm. In the large Oroya specimen almost every fragment broken out shows at least one direction of cleavage, several two, others more. Associated with these are occasionally well-defined portions of crystal faces, with light striations. In one case these striations were in two sets, making an angle of 60 degrees with one another. Some of these faces are moderately dull, but most are extremely brilliant, so much so that the dark colour is largely masked and the mineral on these surfaces appears almost white when giving a direct reflection of daylight. The angle measured between a face and a cleavage was 70 degrees, which is that of an octahedron, confirmation of which is to be found in the angle of 60 degrees between surface striations. It is not easy to obtain measurements as the full number

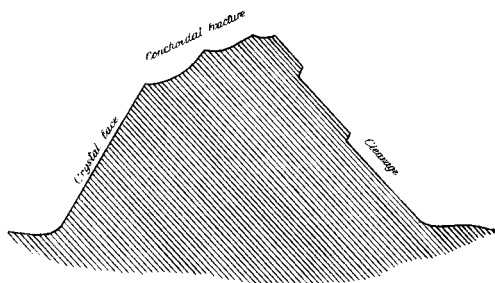


FIG. 25.

of cleavages or faces are never present, and those which are represented do not meet one another, but are interrupted by smaller or greater conchoidal surfaces of fracture, see Fig. 25. At times traces of the one cleavage are observable over a large area. In the smaller masses in which this mineral most usually occurs cleavages and crystal faces are rarely if ever observed. The mineral is then either compact massive with conchoidal to subconchoidal fracture, or granular.

In colour the Kalgoorlie coloradoite is greyish-black. At times it is somewhat tarnished with a dull-black or brownish black surface. It is brittle with a hardness of  $2\frac{1}{2}$  to 3. The specific gravity is

8.0 to 8.1. In appearance the mineral is identical with petzite and not unlike hessite and tennantite, all of which are at times found intergrown with it. Its behaviour in the closed tube, however, is specific, it melts with more or less decrepitation, is entirely volatile and yields globules of mercury in addition to oxide of tellurium, and free tellurium. Other minerals found intergrown with it are calaverite, sylvanite and free gold.

The composition of the Kalgoorlie mineral is given by the following analyses :—

*Coloradoite, Kalgoorlie.*

Mine	..	..	..	Main Reef	Oroya
Analyst	..	..	..	L. J. Spencer	E. S. Simpson
Mercury	..	..	..	60.95	61.62
Tellurium	..	..	..	39.38	38.43
				<hr/>	<hr/>
				100.33	100.05
				<hr/>	<hr/>
Sp. gr. at 4°	..	..	..	8.071	8.025

The material analysed by the writer consisted of a single fragment from the large mass of coloradoite described below under [8956]. It showed well marked octahedral cleavage and included only one crystal individual. The minute flakes of metallic gold were liberated from the mineral on treatment with nitric acid. Their total weight was less than one-fifth of a milligram. No trace of selenium could be detected on saturating with sulphur dioxide a strong hydrochloric acid solution of the weighed tellurium precipitate.

Typical specimens in the collection are :—

[8956], Oroya Gold Mine. Foliated greenstone with much sericite on cleavages. Large lens of coloradoite, about 125 x 50 x 25 mm. enclosing small masses of calaverite. Some free gold round the edges of the tellurides. On a slickenside some paint calaverite (or sylvanite). Tourmaline in small needles projecting into the coloradoite. The latter shows strong evidences of crystallisation in the development of fragments of crystal faces, and in well marked cleavages, see above. This is the best specimen of this mineral in the collection.

[6363], 200ft., Hidden Secret Gold Mine. Greenstone with much pyrites and chrome-vanadium mica enclosing large mass and small veins of hessite. Enclosed in the hessite is an irregular mass of coloradoite, showing a distinct cleavage over an area of 15 x 15 mm.

[6732], 865ft., Ivanhoe Gold Mine. Grey chalcadonic quartz with much pyrites. Several small irregular masses of coloradoite, compact massive and granular, no certain cleavage visible. A little free gold associated with it.

[6781], 1,900ft., Great Boulder Proprietary. Grey quartz with pyrites and free gold. A fair amount of sylvanite with a little intergrown coloradoite on one face, on the opposite face a thin film of brownish-black coloradoite with one cleavage extending over an area of  $60 \times 15$  mm. ( $2\frac{1}{2} \times \frac{1}{2}$ -inch).

[438], Kalgurli Gold Mine. Block of slightly foliated ore oxidised externally and along cracks, but quite unoxidised in the centre. Three moderately large lenticular masses of coloradoite. Portions only of one mass show a cleavage, the rest is massive with an even to subconchoidal fracture. A considerable amount of dull mustard gold towards one side.

#### 66.—CINNABAR.

Sulphide of mercury,  $\text{HgS}$ . This mineral has been reported to occur at Kalgoorlie, and a specimen of supposed cinnabar has been presented to the Department. This consisted of a few small and very thin splashes of crystalline mineral on a fracture face of silicious ore from the Golden Horseshoe Gold Mine. This mineral is orange in colour and much more closely resembles realgar than cinnabar.

#### 68.—GREENOCKITE.

Sulphide of cadmium,  $\text{CdS}$ . A note in one of the Monthly Reports of the Chamber of Mines of W.A. (Vol. I., p. 132), says that this mineral occurs in the sulphide ore of the Great Boulder Proprietary Gold Mine. This record lacks confirmation.

#### 74.—PYRRHOTITE.

Sulphide of iron,  $\text{Fe}_7\text{S}_8$ . In the early days of the field it was usual to hear of the sulphide ore carrying "auriferous pyrites and pyrrhotite." A careful examination of the numerous specimens in the National Collections failed to disclose any of this mineral in the ore, but grains of 1 to 2 mm. diameter are to be seen in a few of the rocks, as for instance in [11026] from the Pirie G.M.L. 1112E.

#### 77.—MELONITE.

Telluride of nickel,  $\text{NiTe}_2$ . Small quantities of this mineral have recently\* been reported on good authority to occur in the Hidden Secret Gold Mine.

#### 83.—CHALCOPYRITE.

Sulphide of copper and iron,  $\text{CuFeS}_2$ . Small quantities of this mineral have been found in the sulphide ore of many of the mines.

---

\*Feb., 1911.



It would appear to be most abundant in the Hidden Secret Gold Mine, where it is found in masses up to  $1\frac{1}{2}$  inches (40 mm.) in diameter intimately associated with hessite, petzite, tetradymite, and coloradoite, see [10908], [10938]. It is also represented in the Geological Survey Collection in ore from the Lake View Consols [5266], and North Kalgurli Gold Mine [8342]. It has been seen in ore from the Associated Northern Gold Mine, and is doubtless well distributed in small amounts of the same order of greatness as the tellurides.

The composition of the chalcopyrite associated with hessite in the Hidden Secret ore [10908] was ascertained to be:—

	per cent.
Copper .. .. .	34·84
Iron .. .. .	30·04
Silver .. .. .	Trace
Sulphur .. .. .	35·75
Tellurium .. .. .	<i>Nil</i>
Vanadium .. .. .	<i>Nil</i>
	100·63

Vanadium was looked for because of the large proportion present in the gangue of this ore and because it is known to form a double sulphide with copper, viz.—Sulvanite,  $3\text{Cu}_2\text{S.V}_2\text{S}_5$ .

#### 85.—PYRITES.

Sulphide of iron,  $\text{FeS}_2$ . This is an important constituent of both rich and poor sections of the Kalgoorlie lodes, and has been encountered in greater or less amount in all the productive mines on the field. The extent to which it occurs is seen in the accompanying table:—

TABLE XII.—*Proportion of Pyrites in Kalgoorlie Ore.*

G.S.M. No.	Mine.	Depth.	Pyrites.	Gold in ore.	Silver in ore.
		ft.	%	oz. dwt.	oz. dwt.
8990 <sub>B</sub>	Oroya .. .. .	820	10·3	0 4	0 1
8990 <sub>F</sub>	Oroya .. .. .	820	11·8	1 8	0 3
10959	Associated Northern ..	550	7·0	3 15	0 12
10962	Great Boulder Proprietary (Schist)	2,200	10·3	1 2	0 16
10961	Great Boulder Proprietary (Quartz)	2,200	2·1	2 5	2 12
10847 <sub>A</sub>	Fair Play .. .. .	200	6·5	0 12	0 4
10938 <sub>B</sub>	Hidden Secret .. .. .	(?)	43·1	19 13	165 9
..	Great Boulder Main Reef	(?)	6·8	6 10	2 10
206	Lake View Consols ..	300	8·2	9 12	6 7
1732	Hannan's Paringa ..	(?)	5·3	1 13	0 16

The proportion of pyrites in Kalgoorlie ore seldom exceeds 12 per cent., the average from above figures being 11.1 per cent., or excluding the rich Hidden Secret ore, 7.6 per cent. The rich patches of telluride ore in the Hidden Secret Mine (Figs. 18, 37) are quite exceptional in their contents in pyrites, the only other vein-stuff approaching them being some pyritic graphite schists and banded quartz veins opened up near Mt. Hunt, four miles south of Boulder. These latter yielded, however, only traces of gold, and were abandoned as soon as their barren nature was demonstrated. Beyond the lode channels in both massive and sheared rocks the proportion of pyrites is very small, probably never more than 1 per cent. of the whole rock. It is evidently a secondary mineral, whose appearance is closely related to the appearance of the precious metal in the shear zones. The proportion of iron in the pyritic sheared lodestuff and in the non-pyritic massive "country" adjoining it is identical. On a smaller scale quite moderately-sized specimens are found to be partly green chloritic rock devoid of pyrites, partly light-grey pyritic rock devoid of chlorite, the iron percentage in both parts being identical. It is plain that the pyrites has not been introduced *in toto* during ore deposition but simply that sulphur vapours or alkaline sulphides have been introduced which have attacked the iron silicates already present, converting them wholly or in part into pyrites. The mineral thus formed has shown vigorous crystalline growth, perfect cubes,\* modified cubes (*see* Fig. 21), and pyritohedra being abundant, and the mineral always exhibiting convex surfaces towards the surrounding minerals. The mineral is found either in masses composed of numerous crystal individuals (Figs. 20, 22), or in single grains of all sizes, from the minute specks seen in Figs. 31, 43, 44, some of which are less than one-two-hundredth of a millimeter in diameter, up to the larger crystals seen in Fig. 21, some of which are one millimeter in diameter. Several pyritohedra in [2983] from the Associated Northern Gold Mine reach 6 mm. ( $\frac{1}{4}$ -inch) in diameter. The composite masses are sometimes many times this size.

It has been said that the finer-grained pyrites at Kalgoorlie is gold-bearing, and the coarser-grained barren. It does not appear, however, that any experiments have been made to support this statement. No gold has ever been detected actually in the pyrites, nor could any concentration test, in the presence of tellurides of gold, give any information on this point. The statement may be loosely worded and intended to convey the idea that fine-grained pyrites is associated with rich ore, and coarse-grained with poor ore. Whilst this may be true of some individual mine it certainly is not of general application. Some of the richest ore from the

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\*See [10963]. Sec. 1352, G.B. Main Reef G.M.

Hidden Secret Gold Mine carries very coarse pyrites, some of the poorest from the Associated and Oroya Gold Mines carries considerable proportions of very fine-grained pyrites.

With regard to its associates in these mines, pyrites is found embedded in vitreous quartz (Fig. 22), chalcedony (Fig. 31), sericite, tourmaline (Fig 18), vanadiferous and chromiferous micas (Fig. 20), phlogopite ? (Fig. 45), and dolomite (ankerite). In ore from the Associated Northern Gold Mine many of the pyrites grains are completely surrounded by a deep green chlorite. No marcasite has been detected in association with the pyrites except in the above-mentioned barren lodes on the slopes of Mt. Hunt.

In most of the bands of graphitic greenstone schist nodules of pyrites occur of spheroidal or ellipsoidal shape, about the size of a marble, and with crystalline radiating internal structure. These carry neither silver nor gold. Similar nodules occur in abundance under similar circumstances at Bulong and Norseman. It is evident that the conditions attending their formation were very different from those under which granular pyrites was formed in the lodes. It is probable that their appearance was contemporaneous with the introduction of graphite into these crush zones, which latter mineral appears to owe its origin to the action of ferric compounds on intruding hydrocarbons.

#### 96.—MARCASITE.

Sulphide of iron,  $\text{FeS}_2$ . This mineral has not been encountered in any of the auriferous lodes. It occurs in several barren lodes on the slopes of Mt. Hunt. A specimen [3339] of lode material from the Lady Dora G.M.L. 3766E, which consisted of quartz, pyrites, marcasite, and graphite, was found to yield on assay gold, trace ; silver, 3dwts. 19 grains per ton. A similar specimen [3335], from the Boulder View G.M.L. 3603, yielded gold, trace ; silver, 3dwts. 6grs. per ton.

#### 97.—LOLLINGITE.

Arsenide of iron,  $\text{FeAs}_2$ . Some long-bladed crystals from the Kalgurli Gold Mine were said to be this mineral, but a detailed examination revealed the presence of much sulphur as well as arsenic, so that they must be arsenopyrite, *q.v.*

#### 98.—ARSENOPYRITE (MISPICKEL).

Sulpharsenide of iron,  $\text{FeAsS}$ . Small patches of this mineral are encountered from time to time in the ore channels or adjacent to them. It is invariably in long thin crystals, often in twins, more rarely in trillings. These would appear to be more often

associated with secondary non-auriferous fissures than with the main gold veins. In the Kalgurli Gold Mine crystals are scattered through a dark-green massive propylite [2171], the principal associated minerals being chlorite, dolomite, sericite, albite, and quartz (Fig. 27).

In [5059] from the middle lode at the 200ft. level of the same mine a crystal 40 mm. long by 3 mm. wide is embedded in similar material. In [5058] from the same a trilling is seen in grey carbonated propylite.

At the 1,750ft. level of the Perseverance Gold Mine crystals were collected from an altered propylite carrying much magnetite (Fig. 26). The mineral has also been reported from the Golden Horseshoe Gold Mine.

#### 104.—SYLVANITE.

Telluride of gold and silver  $(\text{Au}, \text{Ag})_2\text{Te}_4$ . Ratio of gold to silver usually 1 to 1, but may vary. To this species is generally referred the silver-white telluride with perfect cleavage, found in some few of the Boulder Mines. It is certainly one or other of the two species, sylvanite or krennerite, these minerals resembling one another and differing from all other tellurides in both being bitellurides of gold and silver of light colour and with one perfect cleavage. In the absence of well-developed crystal outlines it is impossible to decide absolutely to which species the Boulder mineral belongs. The principal distinctions and resemblances are:—

—	Sylvanite.	Krennerite.	Boulder Mineral.
Formula .. ..	$(\text{Au}, \text{Ag})_2\text{Te}_4$	$(\text{Au}, \text{Ag})_2\text{Te}_4$	$(\text{Au}, \text{Ag})_2\text{Te}_4$
Ratio Au : Ag ..	1 : 1, but also 2 : 1, 3 : 1, etc.	Variable	Variable
Crystal form ..	Monoclinic	Orthorhombic	(?)
Perfect cleavage ..	Vertical	Basal	In one case vertical
Striations .. ..	None recorded	Vertical	Vertical
Behaviour on heating	Fuses quietly	Decrepitates violently	Fuses quietly

This mineral is confined to four or five adjacent mines. It is most plentiful in the Lake View Consols Gold Mine, where according to E. H. Liveing,\* it formed “the greater part of the rich ore of the bonanzas found at the 300ft. level in 1899, when 52,000 ozs. of gold were taken out in a single month.” It has also been recorded from the Associated Main Reef, Great Boulder Proprietary,

\*Eng. and Mining Jour., 30-5-1903.

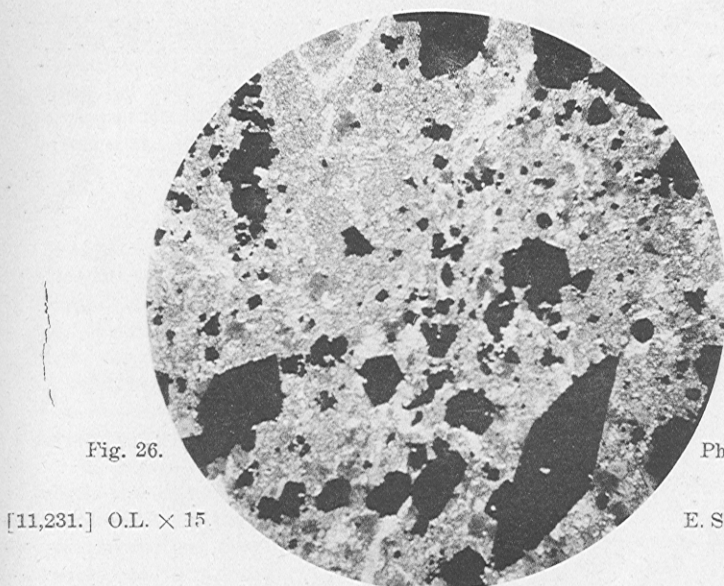


Fig. 26.

Photo. by

[11,231.] O.L.  $\times 15$ .

E. S. Simpson.

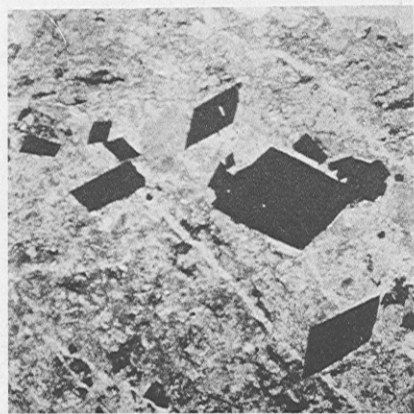


Fig. 27.

Photo. by

[2,171.] O.L.  $\times 15$ .

E. S. Simpson.

Fig. 26.—Propylite (Ore ?) with Arsenopyrite, 1,750ft., Great Boulder Perseverance G.M. Coarsely crystallised Arsenopyrite and Magnetite in a ground mass of Sericite, Albite, Chlorite, and Carbonates.

Fig. 27.—Propylite (Ore ?) with Arsenopyrite, 100ft., Kalgurli G.M. Coarse crystals of Arsenopyrite in ground mass of Sericite, Albite, Chlorite, and Carbonates.

Golden Horseshoe, Perseverance, and Kalgurli \* Gold Mines. It occurs mostly in irregular masses up to several inches in length, which are seen from the cleavages to be made up of one or many crystal individuals. In almost every case these have very irregular boundaries, both externally and relatively to one another. To what extent the outlines of the masses are governed by surrounding crystals of quartz, dolomite, etc., is well shown in Fig. 28. In such cases it is impossible to orient the cleavage. In one specimen [8961] from the "Lake View" lode of the Lake View Consols Gold Mine several among many intergrown individuals show one well-defined face with apparently a deep vertical striation to which the cleavage is parallel. L. J. Spencer says † "sometimes on their rough striated exterior there are unmistakable indications of twinning about a plane perpendicular to the direction of cleavage." The mineral is soft and very brittle, and possesses a very brilliant metallic lustre.

It does not appear to be often associated with free gold, except where the latter forms a thin film in the surface as the result of the oxidation of the tellurium. When the cleavage is well-developed and parallel or nearly so to the surface of the specimen, it can readily be recognised even in very thin films and small specks. When, however, the cleavage is less distinct or is almost at right angles to the surface of the specimen it is often difficult to decide whether a small speck or thin film is sylvanite or calaverite.

The composition of the Kalgoorlie mineral is shown in the following analyses :—

TABLE XIII.—*Analyses of Sylvanite, Kalgoorlie.*

—	(1.)	(2.)	(3.)	(4.)
Gold .. ..	36.60	28.55	29.85	36.95
Silver .. ..	3.82	9.76	9.18	8.30
Copper .. ..	..	.32	.15	..
Iron .. ..	..	.06	..	..
Nickel .. ..	..	.10	.10	..
Tellurium .. ..	58.63	60.83	60.45	54.50
Selenium .. ..	..	.20	..	..
Sulphur .. ..	..	.09	..	..
	99.05	99.91	99.73	99.81
Sp. gr. .. ..	8.14	..	..	..
Authority .. ..	Frenzel	Krusch	Carnot	Higgin
Au : Ag : Te ..	11 : 2 : 26	5 : 3 : 8	5 : 3 : 8	17 : 7 : 39

\*Teste, A. G. Holroyd.

† Loc. cit., p. 271.

Analysis (4) seems to be either that of a mixture of the bi-telluride sylvanite with the monotelluride petzite, or else the estimation of gold and tellurium is at fault.

The proportions of gold and silver in Kalgoorlie sylvanite have frequently been determined. The figures available are :—

TABLE XIV.—*Gold and Silver in Kalgoorlie Sylvanite.*

—	(5.)	(6.)	(7.)	(8.)	(9.)	(10.)	(11.)	(12.)	(13.)	(14.)
Gold, per cent. ..	36.6	36.1	25.5	26.1	33.4	29.2	29.2	29.4	32.58	33.07
Silver, per cent. ..	3.5	4.45	11.2	11.4	6.0	10.6	9.4	9.3	6.64	6.46
Gold, molecules ..	9	9	9	9	9	9	9	9	9	9
Silver, molecules ..	1½	2	7	7	3	6	5	5	3	3
Authority ..	Live- ing	Live- ing	Live- ing	Live- ing	Live- ing	Live- ing	Simp- son	Simp- son	Simp- son	Simp- son

(5) and (6).—The so-called “Speculite” of Liveing, who calls it the chief telluride in the Lake View Consols Gold Mine, Sp. gr. 8.64.

(7) and (8).—Typical sylvanite, Spr. gr. 8.04. Mine not stated.

(9) and (10).—Thought by Liveing to be mixtures because the ratio of gold and silver is intermediate between the “Speculite” and typical sylvanite. They are, however, probably not mixtures but true sylvanite.

(11) and (12).—From specimen (1501), Lake View Consols Gold Mine.

(13) and (14).—From specimen (8958), Associated Gold Mine.

The following are descriptions of typical specimens in the Survey Collection :—

[87], Lake View Consols Gold Mine. A small specimen of typical schist on one end of which is a triangular mass of sylvanite about  $\frac{3}{4} \times \frac{3}{4} \times \frac{1}{8}$  inch. Well-developed cleavage differing in direction in two halves of the mass, which comprises two crystal individuals. Ragged boundaries. Contains 37.10 per cent. of gold. This is the mineral referred to as *Krennerite* in Bulletin No. 6.

[8963], Perseverance lode, Lake View Consols Gold Mine. Green lodestuff, not highly foliated, with several masses of sylvanite mostly developed along joints in thin slabs. One such is over 2 inches long, width varying up to  $\frac{1}{2}$ -inch, thickness about one-sixteenth, cleavage plane continuous all over. A second mass with a single continuous cleavage fills not only a main crack about  $1\frac{1}{2}$  inches long, but also several branch cracks more or less at right angles to the main one. A few very small needles of black tourmaline occur on one cleavage face of this lodestuff. They are embedded in sericite, etc. (Fig. 28).

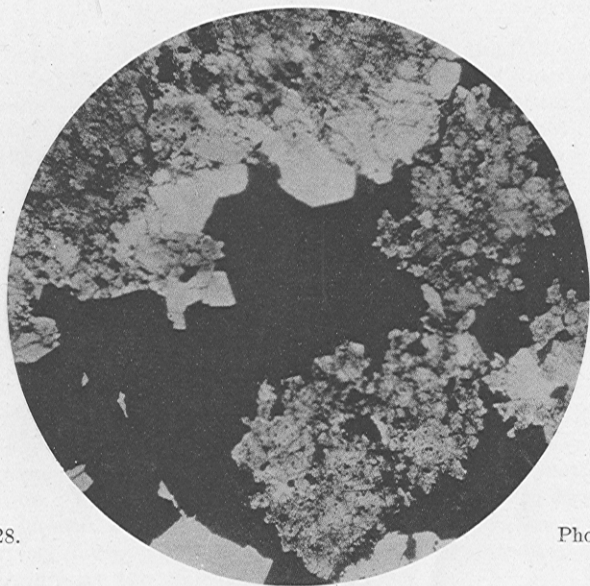


Fig. 28.

Photo. by

[8,963.] O.L.  $\times 15$ .

E. S. Simpson.

Sylvanite in Ore (Carbonated Schist), Lake View Consols G.M. The Sylvanite appears as large and small black masses bounded by grey and white Ankerite and white Quartz. Finely granular ground mass of Ankerite, Sericite, and Albite.



[1501], Lake View Consols Gold Mine. Dark green chloritic and sericitic schist with a large mass of telluride developed on a cross joint. One part of this mass about  $2\frac{1}{2}$  inches long and  $\frac{1}{2}$  to 1 in. wide, but not very thick, is sylvanite, in two individuals with well-developed cleavage. Continuous with this is a mass of pale telluride apparently devoid of cleavage and probably calaverite, beyond again a little more sylvanite. The large mass of sylvanite shows a series of partings at right angles to the cleavage, and a minor cleavage, the trace of which on the plane of the main cleavage makes an angle of approximately 70 degrees with the trace of the parting. Further small masses of sylvanite occur in the same specimen.

[8961], Lake View Lode, Lake View Consols Gold Mine. A large mass of sylvanite in partly silicified schist. Many individuals present, some showing a fairly well-defined striated crystal face up to  $\frac{1}{4}$ -inch in height. Some further details given above. A little calaverite appears enclosed in the sylvanite.

[166], Lake View Consols Gold Mine. Sylvanite with thin coating of mustard gold, the result of surface oxidation of the mass.

[145], Golden Horseshoe Gold Mine. A small mass of sylvanite with well-defined cleavage in dark green lodestuff. Fair amount of tourmaline present in fine needles.

[5271], 1,200ft., Great Boulder Main Reef Gold Mine. Speck of sylvanite in schist with quartz veins.

[8958], Associated Gold Mine. Large mass of dark-grey and reddish greenstone schist with much fine pyrites and scattered gold telluride. Cross vein of quartz with thin almost continuous mass of sylvanite, about 4 inches by 2. Cleavage distinct, composition given above, Nos. 13 and 14. Some coloradoite present and a little altaite (?).

[7944], 2,200ft., Great Boulder Gold Mine. Two somewhat small pieces of dark greenish-grey schist with numerous small masses of a brilliant white telluride which in places shows a cleavage. One mass is intergrown with numerous small needles of tourmaline, a second has a little primary gold.

[6781], 1,900ft., Great Boulder Gold Mine. Two medium-sized specimens of siliceous ore with much sylvanite in rather small thin films on one main joint plane and filling numerous minor cracks. The cleavage is not readily discerned, the masses being composed of numerous small individuals with unconformable cleavages. A fair amount of coarse and fine free gold and tourmaline associated with the sylvanite.

## 104A.—GOLDSCHMIDTITE.

On page 16 of Bulletin 6 reference is made to the occurrence of this mineral at Kalgoorlie. As first described it was a bitelluride of gold and silver  $(\text{Au}, \text{Ag})\text{Te}_2$ , in which the ratio of Au : Ag was 5 : 3. The original goldschmidtite has since been shown to be merely an indeterminate variety of sylvanite, so that the Kalgoorlie mineral previously called by the former name must be referred to sylvanite, *q.v.*

## 105.—KRENNERITE.

Telluride of gold and silver  $(\text{Au}, \text{Ag})_2\text{Te}_4$ . It is possible that the cleavable telluride occurring at Kalgoorlie may be krennerite, which is orthorhombic in form, and not sylvanite, which is monoclinic. For a discussion of this question see under Sylvanite, p. 102.

## 105A.—CALAVERITE.

Telluride of gold,  $\text{Au}_2\text{Te}_4$ .\* This mineral, which contains more gold and less silver than any other precious metal telluride, is the most plentiful of all tellurides at Kalgoorlie. It is devoid of crystalline form, occurring in irregular grains, often with many ramifications (*see* Fig. 29) and varying in size from microscopic granules up to masses many ounces in weight. It is either silver-white or yellowish in colour, sometimes distinctly brass yellow, the latter tint possibly due to tarnish along the minute fissures, which usually penetrate it in great numbers. It has a bright metallic lustre inferior in brilliance to that of either the sylvanite of the Boulder mines or the altaite of the Hidden Secret Gold Mine. Its specific gravity is 9.3, hardness 2.5. In the upper oxidised portions of the lodes it has been attacked by oxidising agencies, the tellurium being completely removed and the residual spongy gold left *in situ* filling incompletely the space originally occupied by the telluride.

Calaverite was the first telluride to be recognised at Kalgoorlie, having been detected in a vein of calcite and dolomite (Fig. 29) at the Block 45 G.M.† (now part of the Kalgoorlie Amalgamated). In the National Collection specimens are present from the following mines :—Ivanhoe, Golden Horseshoe, Great Boulder Main Reef, Associated, Lake View, South Kalgurli, Kalgurli, Associated Northern, and Oroya. In addition it has been reported from the following mines :—Perseverance,‡ Brown Hill, and Brown Hill Extended.‡

The composition of calaverite calculated from the formula  $\text{Au}_2\text{Te}_4$  would be gold, 43.6 per cent. ; tellurium, 56.4 per cent. The actual composition of various samples of Kalgoorlie calaverite is given in Table XV.

\*See below, page 164.

† A. G. Holroyd : The Discovery and Occurrence of Telluride of Gold upon the Kalgoorlie Goldfields. Trans. Aus. Inst. Min. Eng., Vol. IV., p. 186.

‡ L. J. Spencer, loc. cit.

TABLE XV.—*Analyses of Calaverite, Kalgoorlie.*

—	(1.)	(2.)	(3.)	(4.)	(5.)	(6.)	(7.)	(8.)
Gold .. ..	41.37	41.76	38.70	42.6	37.54	33.90	42.15	42.41
Silver .. ..	58	80	1.65	7	2.06	4.82	60	61
Copper .. ..	..	..	21	..	29	63	..	16
Iron .. ..	..	..	18	..	09	trace	..	none
Nickel .. ..	..	..	..	..	07	..	..	none
Lead .. ..	..	..	trace	..	..	..	..	none
Bismuth .. ..	..	..	trace	..	..	..	..	none
Zinc .. ..	..	..	trace	..	..	..	..	05
Tellurium ..	57.27	56.64	59.69	54.1	58.63	60.30	57.00	56.52
Selenium ..	..	..	..	..	1.13	..	..	none
Sulphur ..	..	..	09	..	10	..	..	none
	99.22	99.20	100.53	97.4*	99.91	99.65	99.84	99.75
Sp. gr. ..	9.311	9.377	..	..	..	..	9.314	9.238
Analyst ..	Simpson	Mingaye	Rogers	Mc-George	Kluss	Carnot	McIvor	Bowley
Mine .. ..	Associated	Associated	Lake View	Block 45	(?)	(?)	(?)	Oroya

The following are details of some typical specimens in the Survey Collection :—

[8952], Golden Horseshoe Gold Mine. A large block of dark and light-grey mottled quartz, partly chalcedonic, spotted with a few specks of pyrites and carrying a little sericite. The whole of one side covered for about 6ins. x 5ins. x  $\frac{1}{8}$ in. to  $\frac{1}{4}$ in. (150 x 130 x 3 to 6 mm.), with finely and coarsely granular calaverite, a little coloradoite at one corner and a little paint gold near by. This is the finest specimen of this mineral in the collection.

[8955], Oroya Gold Mine. Greenstone schist with a little scattered pyrites and free gold. Calaverite scattered in small specks and streaks. One large lenticular mass about 5ins. x  $2\frac{1}{2}$ ins. (130 x 65 mm.) of massive calaverite, devoid of cleavage, but showing traces of a parting due to pressure perhaps. It has a yellowish tarnish. Some coloradoite and tourmaline associated with it.

[8752], South Kalgurli Gold Mine. Four blocks of ore consisting of silvery-white schist carrying an unusually large proportion of sericite and traversed by small quartz leaders. Irregular branching intergrowths of calaverite and coloradoite (see Fig. 30), occur associated with a little free gold in both quartz veins and to a less extent in the schist. A little tourmaline is present in the latter.

[9198], Kalgurli Gold Mine. Dark greenish-grey schist with grains and irregular masses of white calaverite, which in sections are seen to be closely associated with pyrites, leucoxene pseudomorphs after ilmenite, sericite and dolomite

\*Also 2.4 per cent. of admixed arsenopyrite.

[143], Block 45 Gold Mine.—Veinstuff mainly calcite with some ankerite and quartz. Numerous small grains of white calaverite. These have very ragged boundaries (see Fig. 29).

#### 106.—NAGYAGITE.

Sulphide and telluride of gold, lead and antimony. Formula unknown,\* perhaps  $\text{Au}_2\text{Te}_4\text{Sb}_2\text{S}_3\cdot 10\text{Pb}(\text{S},\text{Te})$  (?). In the Monthly Journal of the Chamber of Mines of W.A. Vol. IV., p. 690, is published a letter from Mr. F. B. Merritt, then Assayer to the South Kalgurli Gold Mine, which reads as follows:—

Mr. H. A. Shipman, Superintendent of Oroya-Brownhill Co., Ltd., gave me certain specimens from the Oroya chute for analysis, and to the peculiar character of one of them Mr. E. S. King, Metallurgist of the same Company, first drew my attention. On being analysed at the School of Mines, it was found to resemble closely a form of Nagyagite, and gave the following results:—

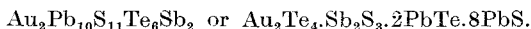
#### NAGYAGITE.

Cleavage, one perfect. Form, massive foliated. Laminae, flexible, sectile, and rather malleable. Colour, lead-grey. Lustre, metallic splendent.

Analysis—

<i>Nagyagite.</i>				
			per cent.	molecules.
Gold	..	..	10.16	.052
Lead	..	..	52.55	.254
Silver	..	..	1.12	.010
Sulphur	..	..	8.62	.270
Tellurium	..	..	18.80	.148
Antimony, about	..	..	7.00	.051
				<hr/>
				98.25

The column of molecules has been added by the present writer, from it the formula deduced would be—



No other writer has mentioned the occurrence of this mineral at Kalgoorlie, nor does it seem to be represented in the National Collections.

#### 145.—PROUSTITE.

Sulphar enite of silver  $3\text{Ag}_2\text{S}\cdot\text{As}_2\text{S}_3$ . Some years ago some ore from water level in the Associated Gold Mine was found to assay unusually high in silver. Before crushing, red streaks, similar to those of ruby silver in the Rivertree (N.S.W.) ores, had been noticed in the ore. These may have been proustite. No subsequent opportunity of confirming or disproving this supposition

\* Sipocz (Zeits. fur Kryst., XI., 211) gives  $\text{Au}_2\text{Pb}_{14}\text{Sb}_3\text{Te}_5\text{S}_{17}$ ; Priwosnic (Zeits. fur Kryst., XXXII., 186) writes it  $\text{AuPb}_6\text{Te}_3\text{S}_8$  and denies the presence of antimony in uncontaminated Nagyagite, ascribing the antimony shown in some analyses to admixed stibnite or jamesonite.

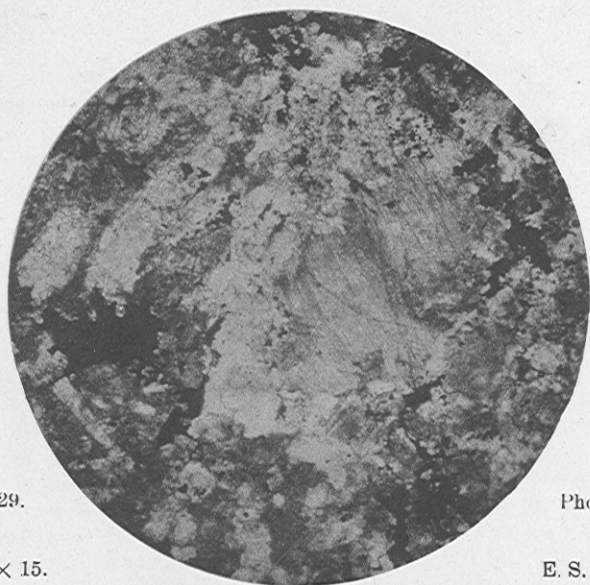


Fig. 29.

Photo. by

[143.] O.L.  $\times 15$ .

E. S. Simpson.

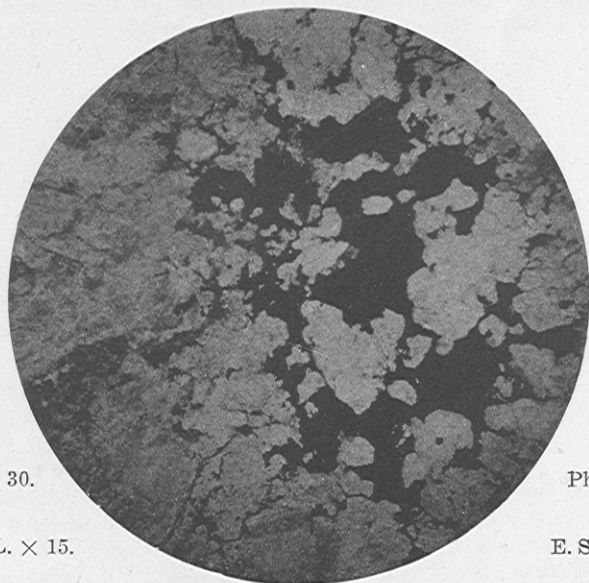


Fig. 30.

Photo. by

[8,752.] O.L.  $\times 15$ .

E. S. Simpson.

Fig. 29.—Telluride Ore with Calaverite, Block 45 G.M. The Calaverite appears as large and small ragged black masses embedded in fine grained Dolomite and Quartz and coarsely crystallised Calcite. One of the first telluride specimens found at Kalgoorlie.

Fig. 30.—Tellurides and free Gold, South Kalgurli G.M. In a ground mass of coarse grained Quartz, with Ankerite, Sericite, and Albite, are a series of branching irregular masses (black) composed of Calaverite and Coloradoite with a little free Gold.

has arisen. It would not be an unexpected mineral, since tennantite (sulpharsenite of copper) exists below water level and would give rise to proustite by interaction with the solutions of silver chloride in brine formed during the weathering of the upper portions of the lodes.

#### 149.—TENNANTITE (ARSENICAL FAHL ORE).

Essentially slupharsenite of copper  $4 \text{ Cu}_2\text{S} \cdot \text{As}_2\text{S}_3$ . The arsenic is partly replaced by antimony, the copper by iron, zinc, etc. A black mineral said by Spencer to be tennantite is not uncommon in the ores in the Boulder group of mines. It occurs in lenticular or irregular masses up to an inch in length in secondary quartz or dolomite veins and in typical schistose ore. It is also found in thin films on cleavage planes. Its gross amount is comparable with that of the tellurides which frequently occur adjacent to it or close by. It is iron-black in colour, opaque, usually granular massive, but sometimes compact massive, with either uneven or subconchoidal fracture. In the last case it is indistinguishable to the eye from coloradoite or petzite. Treated in the closed tube, however, it differs considerably in yielding a complex sublimate which includes yellow arsenious sulphide, red antimony oxysulphide, and black or grey arsenic.

An analysis of this mineral from a specimen exhibited at the Paris exhibition of 1900, was made for P. Krusch\* with the following results :—

<i>Tennantite, Kalgoorlie.</i>			
		per cent.	molecules.
Gangue	.. .. .	·26	..
Gold	.. .. .	·12	} ·650
Silver	.. .. .	·22	
Copper	.. .. .	41·69	
Iron	.. .. .	4·76	} ·129
Nickel	.. .. .	·15	
Zinc	.. .. .	2·68	
Lead	.. .. .	·10	} ·261
Arsenic	.. .. .	16·87	
Antimony	.. .. .	4·30	
Tellurium	.. .. .	·05	} ·886
Sulphur	.. .. .	28·43	
		99·63	

This analysis does not agree too well with the typical tennantite, the sulphur being undoubtedly high and the iron suspiciously so. For these reasons Krusch looked upon this material as probably enargite ( $3\text{Cu}_2\text{S} \cdot \text{As}_2\text{S}_3$ ), which, however, should contain more

\* Zeitschrift für praktische Geologie, June, 1901. Vide Appendix A. to this Bulletin.

sulphur than appears in the above analysis. In order to make this analysis chippings may have been taken from several specimens, the results in such a case being not clean tennantite, but a mixture of tennantite and associated minerals.\* The analysis may represent a mixture of about 93 per cent. tennantite, 7 per cent. pyrites, and a trace of petzite or calaverite.

Some years ago a minute fragment of a black mineral, said to come from Kalgoorlie ore, was submitted to the writer for identification. It gave reactions for copper, lead, antimony, arsenic, and sulphur, and was provisionally classed as Bournonite,  $3(\text{Cu}_2, \text{Pb})\text{S} \cdot (\text{Sb}, \text{As})_2\text{S}_3$ . The occurrence of bournonite has not since been confirmed, and it is possible that this mineral was fahl ore, either tennantite or tetrahedrite perhaps intergrown with a little galena. With this exception wherever the Kalgoorlie fahl ore has been tested it has yielded stronger reactions for arsenic than for antimony, and is therefore to be ascribed to Tennantite rather than Tetrahedrite (antimonial fahl ore).

In view of the fact that the only analysis made of the Kalgoorlie mineral differed considerably from that of typical tennantite, endeavours were made to secure sufficient of it to enable an analysis to be made. Efforts in this direction failed however. The following results were made on a very small fragment from the Great Boulder Proprietary Gold Mine :—

	per cent.	molecules.
Copper .. ..	38·96	·613
Lead .. ..	·43	} ·152
Iron .. ..	3·94	
Zinc .. ..	5·12	
Arsenic .. ..	10·01	
Antimony .. ..	9·57	·213
Sulphur .. ..	30·17	·941
	<hr/> 98·20	

These results, such as they are, were made on a single mass of material from a solid quartz vein in which no other mineral could be seen. It is highly improbable that the substance examined is a mixture, yet the results obtained rather tend to support Krusch's contention that the mineral is not tennantite but enargite. In further support it may be mentioned that the Kalgoorlie mineral decrepitates strongly when heated in the closed tube, which is not the case with typical tennantite, but is recorded as a characteristic of enargite.

This mineral is recorded from the following mines :—Ivanhoe, Great Boulder Main Reef, Great Boulder Proprietary, Associated,

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\* Cf. Carnot's experience in the case of "Coolgardite."

South Kalgurli, Golden Horseshoe, Associated Northern, and Hidden Secret. Details of its occurrence follow :—

[6734], 865ft., Ivanhoe Gold Mine. Mainly massive dolomite, with quartz veins and masses, coarse free gold, pyrites, and numerous grains and larger masses of tennantite. Latter in contact with gold in one instance, also occurring with pyrites and chlorite in thin film on a cleavage plane.

[8953], Golden Horseshoe Gold Mine. Dark-grey quartz with a little fine pyrites, enclosing a few specks of calaverite, some coarse gold and fine grained fahl ore.

[1783], 500ft. Great Boulder Proprietary Gold Mine. Dark-grey quartz with sericite and some fahl ore, partly granular, partly compact, massive, with subconchoidal fracture.

#### 158.—ENARGITE.

Sulpharsenite of copper,  $3\text{Cu}_2\text{S}.\text{As}_2\text{S}_3$ . See under tennantite, p. 109.

#### 166.—HALITE (SALT).

Chloride of sodium,  $\text{NaCl}$ . A thin crust of common salt is to be found in parts of the dry surface of Hannan's Lake, whilst water extracts of the soils throughout the Kalgoorlie district show that this salt is a common constituent in them. The underground waters in the district contain it in solution in abundance, see p. 155.

#### 169.—CERARGYRITE.

Chloride of silver,  $\text{AgCl}$ . Only one reference to the occurrence of this mineral can be found in the literature of the subject. E. F. Pittman, writing in 1898, \* says :

“Chloride of silver is stated to have been found in considerable quantity in one of the mines near the surface.”

It is impossible to say to which mine this statement refers. Within recent years fine specimens of this mineral have been obtained from the oxidised ores of the Hidden Secret Gold Mine, a mine which below water level yields large bunches of hessite and petzite. In the two specimens [6726], [6727], from this mine in the National Collection, cerargyrite appears as the sole filling of irregular veins up to  $\frac{3}{8}$ in. (9 mm.) in width in weathered greenstone (lodestuff). It is somewhat cellular in structure, crystalline, pale yellowish-green, or greenish-yellow in colour, sectile, and translucent. A little free gold occurs with it in one specimen. It is soluble in ammonia water. Heated in a closed tube with potassium pyrosulphate and a little manganese dioxide, it fuses readily to a light red globule, and does not give off any vapour of

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\* Rec. Geol. Surv. N.S.W., Vol. VI., p. 11.



bromine or iodine. Some excellent specimens from this mine were exhibited at the Franco-British Exhibition, and an endeavour was made to induce the owners to sell these to the Government, but without success.

Considering the amount of silver occurring in depth in many of the Kalgoorlie mines, it is at first sight a matter of surprise that this mineral was not of more frequent occurrence in the oxidised ores. As a matter of fact, there appears to have been much less silver in the oxidised than in the unoxidised ores. This is probably accounted for by the fact that all the ground water met with in the mines is strongly saline, containing usually over one per cent. of both sodium and magnesium chlorides. Solutions of these salts, especially of the latter, are good solvents of silver chloride, so that most of the cerargyrite produced in the decomposition of silver-bearing tellurides would dissolve in the ground water, and circulate with it until precipitated by sulphides at a greater depth. Had the ground water contained an appreciable amount of bromine or iodine, the far less soluble embolite (bromochloride of silver), bromyrite (bromide) and iodyrite (iodide) would have been found unattacked in the upper levels of the mines.

#### 175.—FLUORITE (FLUOR SPAR).

Fluoride of calcium,  $\text{CaF}_2$ . In the year 1900 the writer was shown at the Associated Northern Gold Mine some rich ore from the 500ft. level of that mine. Several of the specimens showed occasional small specks of a bluish mineral, which the manager stated were fluorite. No sign of this mineral is to be seen in any specimens in the Survey Collection, nor have I heard of any being found elsewhere at Kalgoorlie, though fluorine was a not unimportant constituent of the mineralising waters as shown by the development of secondary muscovite and tourmaline, both of which minerals contain distinct traces of that element.

#### 210.—QUARTZ.

Oxide of silicon,  $\text{SiO}_2$ . Vitreous quartz is a subordinate element in the ores of the Kalgoorlie district, where large well-defined reefs of it, such as are seen in very many other goldfields of the State, are unknown. Siliceous lodes do occur, but these are invariably chalcedonic replacements of sheared rock, see below. In the ore deposits vitreous quartz is found as residual grains of primary quartz, such as are seen in the enclosing rocks, and which have evidently survived the crushing and impregnation of the rock with gold (Fig. 32). These are usually recognisable by being small isolated masses surrounded entirely by sericite, dolomite, etc., by their shape which discloses their original interstitial character,

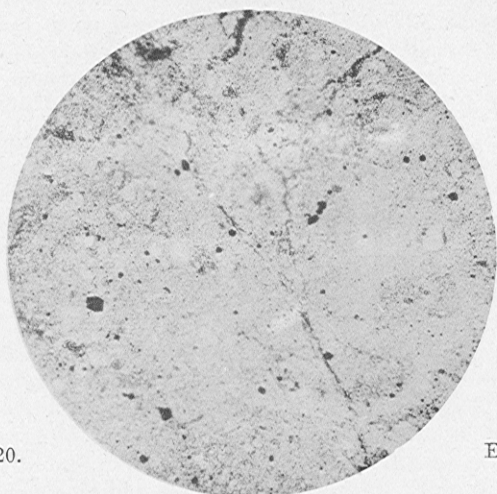


Fig. 31.

[10,961.] O.L.  $\times 20$ .

Photo. by

E. S. Simpson.



Fig. 32.

[10,478.] O.L.  $\times 60$ .

Photo. by

E. S. Simpson.

Fig. 31.—Rich Chalcedonic Ore, 2,200ft., Great Boulder Proprietary G.M. Mainly Chalcedony, with a little fine grained Ankerite and Pyrites.

Fig. 32.—Primary Quartz in rich Telluride Ore, Kalgurli G.M. A grain of primary Quartz with colourless needles of Apatite (?). The quartz has been invaded in places by secondary Carbonates, Chlorite, and Sericite.

by their enclosures of fine needles of apatite, and by their freedom from pyrites and other secondary minerals. In the surrounding propylites and quartz amphibolites or epidiorites a micropegmatitic intergrowth of quartz and felspar occurs. This structure rarely persists in the ore bodies.

Vitreous quartz of secondary origin occurs as the filling of numerous lenticular and root-like veins, the latter usually arising at a joint in the ore body and penetrating the lode across its schistosity to irregular distances on either side. The secondary quartz veins are never very wide nor of great length. They apparently fill irregular contraction fissures formed during the considerable metasomatism which accompanied the impregnation of the shear zones with gold. These veins may be either quite barren, moderately auriferous, or extremely rich in gold and tellurides, *see* Figs. 22, 23. Secondary vitreous quartz forms also quite irregular replacements of lode matter accompanying the tellurides, etc., *see* Figs. 28, 30.

*i* / Chalcedony occurs as an important constituent of lodcs in the "western" mines, viz., Ivanhoe, Golden Horseshoe, Great Boulder, and other adjacent mines. It is evidently here the result of metasomatic replacement of the original propylite rock. Its origin is revealed in surviving traces of rock structure, in the numerous sporadic inclusions of fine-grained dolomite and sericite, and in the irregular boundary between it and the less altered rock constituting the surrounding lodestuff, *see* Fig. 31.

"Jasper bars" are known at the southern end of the field, which are composed of chalcedony with more or less iron oxide and which are evidently replacements of shear zones in the basic rocks. From a graphitic schist near Hannan's Lake some beautiful specimens of mammillated and finely banded chalcedony of a snow-white or slightly yellowish colour were obtained, *see* specimens [250] to [253]. These evidently represented the early stages of the conversion of a shear zone into a jasper bar.

## 212.—OPAL.

Hydrated oxide of silicon,  $n\text{SiO}_2 \cdot \text{H}_2\text{O}$ . On the north-western edge of Hannan's Lake (G.M.L. 1860E, Oxley), there are the surface evidences of a thermal spring. For some distance round a small cave-like hole in the ground there is a mass of travertine, hydrated iron oxide, and common opal, more or less intermingled. The opal appears as large kernels in this spring deposit and also as an amorphous iron-stained cementing material. The latter is invariably opaque, but the fresh included lumps of opal are translucent to subtransparent, when freshly exposed, gradually becoming milk-white and opaque by loss of water on weathering.\* *See* specimens [374], [667], [668].

\* *See* G.S. W.A., Bulletin 6, p. 78.

## 223.—WATER.

See chapter on Surface and Underground Waters, p. 152.

## 229.—MASSICOT.

Oxide of lead,  $PbO$ . L. J. Spencer says \* : "On one specimen from the Golden Horseshoe Estates, the sponge gold is accompanied by a few small colourless rhombohedra of dolomite and a yellowish-green ochreous substance which is perhaps massicot ( $PbO$ ). A chemical examination showed the presence of much lead, with a little copper and water, and possibly some antimony."

This substance would appear to be an oxidation product of fahl ore.

## 232.—HAEMATITE.

Oxide of iron,  $Fe_2O_3$ . The only reference in the literature to the occurrence of this mineral is by E. F. Pittman, who says †—"The dykes are also characterised by numerous ironstone veins, consisting of specular iron and limonite, which branch off from the productive portions or 'lodes' into the walls." The Geological Survey Collection contains several good specimens of haematite, though this mineral is not of common occurrence at Kalgoorlie. These specimens show that this mineral is found at varying depths, from within a few feet of the surface down to 1,200ft. The mineral is always lamellar or micaceous, mostly in large rather than small scales. It is not clear whether it is confined to non-auriferous material or is also to be found within the ore-shoots. Specimen [142] from the North Boulder Gold Mine is a firm red weathered greenstone-schist with a large mass of lamellar haematite covering a cleavage-face. The enclosing rock assays gold, trace; silver, trace. Specimen [10909] from the Associated Gold Mine shows a vein in silicified pyritous rock filled with micaceous haematite in fan-shaped bunches. On the walls of the vein are a little quartz and brown carbonate (siderite?). [2250] is a specimen of green weathered propylite from a depth of 275ft. in the Hannan's Star Gold Mine, on a joint plane of which are several broad plates of this mineral. The rock assays gold, trace; silver, trace. [5625] from a depth of 1,200ft. in the Lake View Consols Gold Mine is part of a vitreous quartz reef several inches wide. It encloses a large irregular mass of micaceous haematite including both small and large scales. A small amount of a pale yellow ferriferous carbonate is also present.

Haematite is also known from the Brown Hill Gold Mine, [35]; and Kalgurli Gold Mine [1574]. In small quantities in a finely divided state it enters into the composition of the jasper bars in the vicinity of Mt. Hunt.

\* Loc. cit., p. 282.

† Rec. Geol. Surv. N.S.W., Vol. VI., p. 11.

## 233.—ILMENITE AND LEUCOXENE.

Ilmenite in composition is an oxide of titanium and iron,  $\text{FeTiO}_3$ . Leucoxene, a white or yellow alteration product accompanying or entirely replacing ilmenite, varies in composition. It may be either a silico-titanate of calcium (titanite or sphene), an oxide of titanium (rutile or anatase), or in certain cases, a hydrate of titanium.

Ilmenite is one of the more important constituents of the amphibolites and propylites within the auriferous area at Kalgoorlie. In the uncrushed, or but slightly crushed, ore and rocks it is found as coarse grains, as large crystalline masses with very irregular indented and branching outlines, (Fig. 33), or as skeleton crystals built up of a number of plates parallel to a series of rhombohedral faces, and separated in part by other rock constituents. In all cases it may be partly or wholly altered to white or yellow leucoxene (Fig. 34). In the more schistose rocks or lodestuffs it is represented by fractured fragments of leucoxene or by fine grains or minute crystals of rutile.

In the lodes which are not highly silicified, ilmenite and its alteration products are of importance in determining the relationship between the auriferous shear zone and the uncrushed barren rocks enclosing it. Ilmenite and leucoxene, or mixtures of the two pseudomorphous after ilmenite, either whole or fractured, are seen in thin slices of all ores of the propylite type. They are absent in those which represent shear zones in altered peridotite or porphyry. At times ilmenite appears to have been altered into pyrites.

Some typical examples of its occurrence are :—

[10478]. Rich telluride ore, Kalgurli Gold Mine. A grey slightly foliated lodestuff with veinlets of quartz in which tellurides are visible. A section of the lodestuff shows it to consist of a ground-mass of fine-grained dolomite and sericite with some primary quartz enclosing apatite (?) needles. A considerable proportion of pyrites is present, and numerous skeleton crystals of ilmenite, almost wholly altered to whitish leucoxene, are scattered over the field. One of these is completely enclosed by pyrites, and in many cases the two minerals are in juxtaposition.

[10963]. Grey schistose ore, 1,800ft., Great Boulder Main Reef Gold Mine. Large irregular crystalline grains of milky-white leucoxene, pseudomorphous after ilmenite, are plentiful. Most of them have been fractured and slightly displaced. A little residual black mineral (ilmenite or magnetite), helping to emphasise the original rhombohedral structure, seen in one or two instances. The ore contains much dolomite (ankerite), in veinlets and disseminated, also a little tourmaline and some sericite, pyrites, and quartz.

Fig. 33.

[11,184.] O.L.  $\times 15$ .

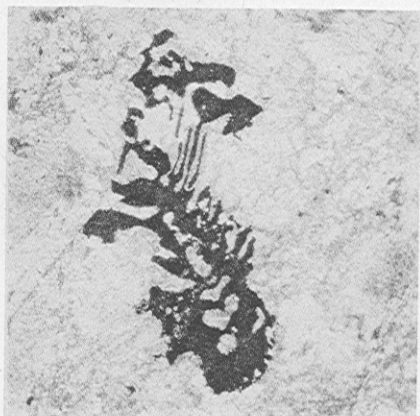


Photo. by

H. Bowley.

Fig. 34.

[11,041.] R.L.  $\times 30$ .

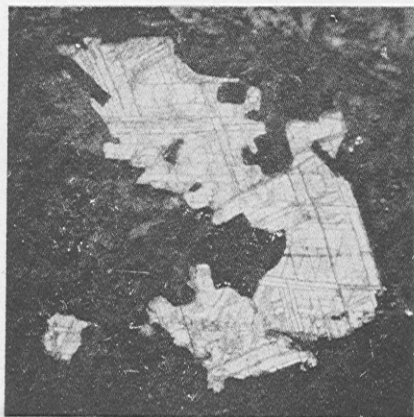


Photo. by

H. Bowley.

Fig. 33.—Ilmenite in Propylite, 400ft., Lake View Consols G.M. The Ilmenite is partly altered to Leucoxene; it exhibits a locally characteristic skeletal structure.

Fig. 34.—Leucoxene in Carbonated Rock, Oroya G.M. (North Block). When thus taken by reflected light, the planes of parting and twinning of the original Ilmenite are rendered conspicuous.

[10964]. Grey schistose ore, 1,900ft., Lake View Consols Gold Mine. Grains of white leucoxene very plentiful. These are from 0.05 up to 0.5 millimetre in length and are evidently dislocated fragments of larger individuals. Section shows much sericite, dolomite, and albite with primary quartz and secondary pyrites and magnetite.

[541]. Schistose ore, 60ft., Australia East Lode, Associated Gold Mine. Granular (fractured) yellowish leucoxene abundant. Often encloses grains of pyrites.

[10844]. Schistose ore, 1,200ft., S. Kalgurli Gold Mine. In this ilmenite is replaced partly by leucoxene, partly by pyrites.

Typical examples of the occurrence of ilmenite and leucoxene in the rocks of the district are:—

[1841]. Propylite from Bore, Chaffer's Gold Mine. Much unaltered ilmenite in large typical irregular masses, partly skeletal, and several millimetres in diameter.

[1716]. Propylite, Central Boulder Gold Mine. Much ilmenite in grains up to one millimetre and in very varying stages of alteration into white leucoxene.

[1748]. Propylite, Hannan's Gold Estates, G.M.L. 1879. Many large and partly skeletal grains of ilmenite completely altered to yellowish leucoxene.

[1730]. Chlorite schist, Imperial Boulder G.M.L. 1222. Large individuals of ilmenite altered partly into white leucoxene, partly into finely granular pyrites.

[11003]. Amphibolite, Outridge Gold Mine. Some brilliant orange yellow subtranslucent pseudomorphs after ilmenite. These may be either sphene or rutile.

### 237.—MAGNETITE.

Magnetic oxide of iron,  $\text{Fe}_3\text{O}_4$ . Messrs. Pittman and Card \* were the first to note the presence of this mineral both in the lodes and rocks at Kalgoorlie. From the specimens in the Geological Survey Collection it would appear to be one of the less commonly occurring minerals. When seen at all, however, it is usually abundant whether in rocks, auriferous lodes, or barren mineralised veins. In most cases it is plainly visible to the unaided eye in small grains, with more or less regular outlines embedded in rock or ore which is then often unusually pale in colour from the absence of much chlorite or pyrites. From the assay results given below it would appear that those portions of the lodes which are characterised by magnetite are usually very poor in precious metals. It is evidently one of the latest minerals to appear in the ore or rock, having been formed at the expense of previously existing iron carbonate or,

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\* Rec. Geol. Surv. N.S.W., Vol. VI.

in some instances, ilmenite or chlorite. The chief, if not sole, black iron ore in the least altered rocks of the district is ilmenite, magnetite being conspicuous by its absence in these.

Some typical examples are :—

[10964]. Lodestuff, 1,900ft., Lake View Consols Gold Mine. Grey schistose ore with very little pyrites but very numerous evenly distributed grains of magnetite from 0.5 to 1.5 mm. in diameter. Under the microscope the structure and composition are those of typical propylite ore. A granular ground-mass of sericite, dolomite, albite, and probably orthoclase, in which are embedded grains of primary quartz, leucoxene, and pyrites. Numerous grains and granular aggregates of magnetite are seen, the former sometimes in well-defined octahedra. Assay values of four separate lumps of this ore were :—

		Gold.			Silver.		
		oz.	dwt.	gr.	oz.	dwt.	gr.
(A)	.. ..	0	0	17	0	0	9 per ton
(B)	.. ..	0	1	2	0	0	9 per ton
(C)	.. ..	Trace			Trace		
(H)	.. ..	0	2	4	0	1	15 per ton

[10844]. Lodestuff, 1,200ft., South Kalgurli Gold Mine. Grey pyritous schist containing a considerable number of minute black crystalline grains of magnetite. Though this specimen came from the lode, chippings from it assayed only : gold, trace ; silver, trace.

[11231]. Barren lode (?), 1,750ft., Perseverance Gold Mine. A pale very granular base of dolomite and sericite in which are embedded grains of primary quartz, much chlorite or chloritoid (?), numerous bladed crystals of arsenopyrite and very many large and small grains of magnetite, many of which show well-defined crystal outlines (Fig. 26).

[10958]. Lodestuff, 1,350ft., Kalgurli Gold Mine. Grey schist with a little granular magnetite scattered throughout, also a thin almost continuous granular layer on a joint face. Assay value, gold, 13 grains per ton ; silver, trace.

[1828]. Highly altered amphibolite, 400ft., Chaffer's Gold Mine. A pale-grey rock mottled with innumerable small irregular black grains of magnetite. The ground-mass consists of sericite, albite, dolomite, leucoxene, and primary quartz.

[10913], (108a). Dark green propylite, Paringa Gold Mine. Sections of this show much chlorite and sericite, with embedded leucoxene and numerous small well-formed crystals of magnetite.

[3294]. Serpentine rock, Hannan's Lake. Finely granular magnetite forms linear aggregates enclosed in serpentine pseudo morphs after olivine.



## 241.—CHROMITE.

Oxide of iron and chromium,  $\text{FeO} \cdot \text{Cr}_2\text{O}_3$ . Small black grains of this mineral occur in the serpentine at Hannan's Lake. Under certain conditions of extreme metamorphism it gives rise to fuchsite, *q.v.*

## 250.—RUTILE.

Oxide of titanium,  $\text{TiO}_2$ . This mineral is somewhat widely distributed as very minute grains and crystals, but is more common in the altered diabase rocks than in the lodes. In most cases it appears to be the ultimate product of alteration of ilmenite, the first stage in which is the production of white or greyish-white leucoxene by the leaching out of the iron oxides. Massive rutile is found as a bright yellow or orange, translucent or opaque mass, partly with white leucoxene or wholly by itself as a pseudomorph after ilmenite. In the more crushed rocks rutile is found in strings of grains, or irregularly scattered grains, representing broken and dislocated leucoxene. In some of the most altered rocks, such as the fuchsite-mesitite rock of the north end or the ottrelite-sericite-ankerite schist of the Lake View Townsite, the mineral is well crystallised and fairly evenly distributed throughout the rock (Fig. 35). In several instances granular rutile appears as an alteration product of a mica, possibly biotite (Fig. 36). It is accompanied by a bleaching of the mica or by complete alteration into a mixture of carbonates, etc. The evenly distributed granular or crystalline rutile may also in part represent an alteration product of amphibole, since in one instance the rutile was largely confined to areas of chlorite.

Some of the crushed rocks in which rutile occurs freely may be looked upon as "barren lodes," since they carry tourmaline or fuchsite or other secondary minerals in the production of which fumarole action has been involved. Examples of this are [10439] and [11095] of which notes are given below.

In the auriferous lodes typical rutile is not very common, the titaniferous element being either ilmenite or more commonly snow-white or grey-white leucoxene. It is, however, met with both massive, finely granular and crystallised, and examples are noted below.

The crystals of rutile are all on a microscopic scale, never exceeding 0.1 mm. in length. They may be single rods or more commonly twins on the plane (301) occurring as doublets or quartets. Complicated groups of many needles are common, which may be in some cases five or ten individuals twinned on (301) or (101). An occasional doublet is seen twinned on (101). The terminations of the prisms are difficult to make out, in many cases they are very acute simple or compound pyramids (Fig. 35).

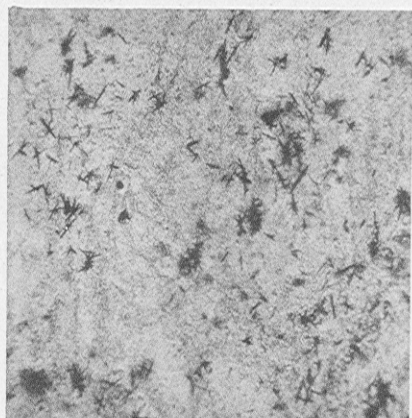


Fig. 35.

[11,086.] O.L.  $\times 40$ .

Photo. by

E. S. Simpson.

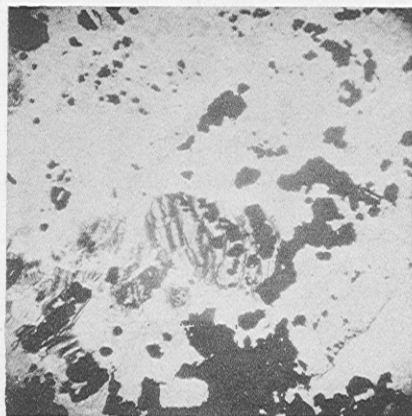


Fig. 36.

[10,847.] O.L.  $\times 20$ .

Photo. by

E. S. Simpson.

Fig. 35.—Rutile Crystals in Ore, Golden Slipper G.M. The ground mass is an extremely fine grained mixture of Sericite, Ankerite, Chlorite, and Albite.

Fig. 36.—Rutile Webs in Pyritic Ore, 200ft., Fair Play G.M. Shows large masses of a magnesian Mica completely altered to a Carbonate with "webs" of Rutile.

Typical examples of its occurrence are :—

[10938a]. Very rich lodestuff with free gold and tellurides, Hidden Secret Gold Mine. A thin slice shows the ore to be composed of about equal parts of pyrites, green mica, and colourless white material which is largely albite. Several groups of minute brownish crystals of rutile, partly single crystals, partly multiple.

[8990c]. Lodestuff with free gold, 820ft., Oroya Gold Mine. Very finely granular rutile is evenly distributed throughout this. On analysis this ore yielded 1.10 per cent,  $\text{TiO}_2$ .

[10847]. Lodestuff, 200ft., Fair Play Gold Mine. Composed fuchsite, carbonate, pyrites, etc. Several moderately coarse brownish grains of rutile, pseudomorphs after ilmenite. Several pseudomorphs after a mica containing parallel wavy strings of finely granular rutile. On analysis this ore yielded 0.54 per cent.,  $\text{TiO}_2$ .

[11086]. Lodestuff, Golden Slipper Gold Mine, near Boulder Railway Station. In a fine-grained base of sericite, carbonates, and chlorite, etc., are innumerable crystals, single and multiple, of brown rutile (Fig. 35).

[11095]. Tourmaline rock, 10 chains south of Slug Hill. Composed largely of small prisms of green tourmaline in a colourless finely granular base. This base includes very many minute crystals of rutile, largely in doublets on plane (301).

[2117]. Amphibolite, G.M.L. 1219, part of Golden Horseshoe Estates. Large and small pseudomorphs after ilmenite, some of snow-white leucoxene, some of orange yellow adamantine rutile, some partly of both.

[10439]. Fuchsite-mesitite rock, Bonnie Lass Gold Mine. Section shows a vein of tourmaline and a carbonate. In rock several moderately coarse orange grains of rutile, also webs in mica pseudomorphs, also very minute crystals, single prisms, doublets after both laws and multiple groups.

[11018]. Amphibolite with tourmaline, Mt. Hunt. Many moderately coarse pseudomorphs after ilmenite consisting of a mixture of a colourless transparent substance with bright yellow or orange, opaque or translucent, rutile. Several pieces of bleached biotite with granular inclusions of rutile either scattered or aggregated round the periphery.

[10913], (32a). Propylite, Jacky Hawk's Nest Gold Mine. Minute crystals and crystal groups scattered throughout the section, chiefly embedded in chlorite.

[11107]. Ottrelite-sericite-ankerite schist, Lake View Townsite. Crystals, single, twins, and multiple, scattered thickly through all constituents of rock. On analysis this rock yielded 1.09 per cent. of titanium oxide.

## 255.—TURGITIE.

Hydrate of iron,  $2\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . This is the most important constituent of the laterite hill-cappings, of which it constitutes from 50 to 90 per cent., the remainder being limonite, bauxite, titanium hydrate, and silica. It is found in cellular or concretionary masses, varying in colour from dark brown to black, and in lustre from dull to bright. It is readily distinguished from all other iron ores by its violent decrepitation when heated.

Its composition may be gauged from the following analyses :—

TABLE XVI.—*Analyses of Turgite and Turgitic Laterite from Kalgoorlie.*

G.S.M. No. . . . .	3282	3282	2907	2991
Sample . . . . .	Turgite Nodule from Laterite	Turgitic Laterite	Turgitic Laterite	Turgitic Laterite
Locality . . . . .	King Orry G.M.L.	King Orry G.M.L.	Mt. Ferrum G.M.L.	Thunderbolt G.M.L. 1121
$\text{Fe}_2\text{O}_3$ . . . . .	84.44	78.38	75.41	79.41
$\text{Al}_2\text{O}_3$ . . . . .	6.48	9.92	12.29	5.97
$\text{Cr}_2\text{O}_3$ . . . . .	min. trace	.01	.05	.60
$\text{V}_2\text{O}_5$ . . . . .	.49	.40	.45	.65
$\text{MnO}_2$ . . . . .	.10	.07	.41	.07
$\text{MgO}$ . . . . .	Trace	.35	None	1.56
$\text{TiO}_2$ . . . . .	1.82	2.01	2.55	3.10
$\text{SiO}_2$ . . . . .	2.33	2.67	1.77	2.52
$\text{H}_2\text{O}$ . . . . .	4.83	6.00	7.05	6.89
	100.49	99.81	99.98	100.77

It is interesting to note the constant presence of vanadium oxide in relatively large quantities in these deposits, this, like the iron, alumina, and other constituents, being derived from the weathering of the subjacent greenstones. Meteoric waters charged with carbonic acid saturate the latter from time to time and dissolve out iron and other oxides. The solution in dry weather is drawn up to the surface by capillary action, and its metallic contents deposited there on evaporation of the water.\* The iron would be at

\*Confirmation of this theory is found in the fact that drives beneath the laterite on G.M.L. 1007E, show that immediately below the greenstone has lost practically all its iron oxide, and been converted into a white or yellowish clay, which in its upper portions is traversed by numerous veinlets of hydrated iron ore.

first in the condition of limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$  with 14·5 per cent. water), but under the influence of the great heat and dry atmosphere of Kalgoorlie this would wholly or in part be converted into the less hydrous turgite (5·3 per cent. water). Where the laterite overlies rocks of the peridotite type, chromic oxide appears as an important constituent, *vide* [2991] above.

#### 258.—MANGANITE.

Hydrate of manganese,  $\text{Mn}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . Two small specimens of oxidised ore, from the main workings at the 200ft. level of the A.W.A. United Gold Mine, are composed almost wholly of this mineral in aggregates of minute black crystals.

#### 259.—LIMONITE.

Hydrate of iron,  $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ . This is a common mineral above the water level of the district, resulting from the weathering of pyrites and ferruginous carbonates or silicates. The oxidised ores contain a considerable proportion in the form of a yellow or brown powder. It is abundant in many of the laterite hill cappings, where it is associated with turgite (*q.v.*), and a little bauxite and titanium hydrate. The following figures show the composition of a limonitic laterite [2119] from the Eureka Extended G.M.L. 1275E.

##### *Limonitic Laterite, Kalgoorlie.*

$\text{Fe}_2\text{O}_3$	..	..	..	..	62·67
$\text{Al}_2\text{O}_3$	..	..	..	..	12·76
$\text{Cr}_2\text{O}_3$	..	..	..	..	·08
$\text{V}_2\text{O}_5$	..	..	..	..	·15
$\text{MnO}_2$	..	..	..	..	·35
$\text{MgO}$	..	..	..	..	·99
$\text{TiO}_2$	..	..	..	..	6·00
$\text{SiO}_2$	..	..	..	..	2·73
$\text{H}_2\text{O}+$	..	..	..	..	14·46
					<hr/> 100·19 <hr/>

#### 261.—BAUXITE.

Hydrate of aluminium,  $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ . This occurs in small amounts in the laterite cappings either in intimate admixture with the limonite and turgite or filling the spaces between concretions of those minerals. The percentage of alumina in the laterites, multiplied by 1·3, gives approximately the proportion of bauxite present. It would appear to range between 8 and 16 per cent.

## 269A.—ASBOLITE.

This is the cobaltiferous variety of psilomelane, and is composed of hydrated oxides of manganese and cobalt. Asbolite is confined to the oxidised ores of the district, where it is occasionally found in films coating the sides of fractures. Rarely these films increase to the thickness of small veins, but are very limited in extent. Samples of the latter nature in the Collection include [1801] from the 100ft. level, Golden Horseshoe Gold Mine, and [2955], [2956] from the 200ft. level, Ben Lomond Gold Mine. The composition of these specimens is indicated by the following figures:—

	Golden Horseshoe.		Ben Lomond.
	A.	B.	
Cobalt, per cent. . . .	2·06	3·29	1·01
Nickel, per cent. . . .	·04	trace	·18
Copper, per cent. . . .	·24	·18	·06
Insoluble in HCl . . .	50·68	(?)	8·32

## 270.—CALCITE.

Carbonate of calcium,  $\text{CaCO}_3$ . This mineral is very rare in the Kalgoorlie lodes, in fact it has only with certainty been detected in ore from two mines, the Perseverance and the Block 45 (Kalgoorlie Amalgamated). The ore body originally worked in the latter mine was a vein about 2 to 3ft. wide composed mainly of carbonates but carrying also some quartz (Fig. 29). This vein was in places very rich in fine-grained calaverite. It is represented in the Geological Survey Collection by several specimens. [143] consists of irregular masses of coarse-grained calcite embedded in a finer grained mixture of calcite, ferruginous dolomite, and quartz. Much calaverite is present, *see* Fig. 29. Much of the calcite has strongly curved faces. This is well shown in [238], a cleavage rhomb with faces about 25 mm. long with a concavity of 2 to 3 mm. It is milk-white or pale grey in colour. Specimen [821] from the Perseverance Gold Mine is representative of a small vein of quartz and carbonates in which fairly coarse crystalline calcite is conspicuous. Both calcite and ankerite are practically absent from the oxidised ores, where all carbonates seem to have been converted into sulphates by decomposing pyrites and then for the most part removed by the ground waters.

On W.R. 1 at Hannan's Lake, milk-white calcite in large rhombohedra forms the filling of a narrow vein in serpentine, *see* [249]. The composition of a single crystal was :—

<i>Calcite, Hannan's Lake.</i>					
CO <sub>2</sub>	..	..	..	..	43·86
CaO	..	..	..	..	55·54
MgO	..	..	..	..	·47
MnO	..	..	..	..	·06
FeO	..	..	..	..	·27
					100·20
Sp. Gr.	..	..	..	..	2·71

The calcite in all these veins doubtless owes its origin to the carbonation of soda-lime feldspars and actinolite or other similar calcareous mineral. Its presence in the Block 45 mine and in other isolated places, and general absence elsewhere, is to be explained by a difference in the available amount of carbonic acid during the carbonation of the rocks. Wherever carbonic acid was abundant, lime, magnesia, and iron were all attacked and the result is dolomite, ankerite, etc. Where, however, it was limited in quantity the lime was attacked in preference to the iron and magnesia, the result being calcite alone or a mixture of calcite with dolomite or ankerite.

Calcite is a normal constituent of some of the metamorphosed rocks within the auriferous area. The following approximate figures have been obtained by calculation from analyses of these rocks.

G.S.M	.. 1729	.. 1800	.. 1728	.. 1750
Rock	.. Propylite	.. Propylite	.. Propylite	Chlorite-schist
Mine	.. Perseverance	Horseshoe	Central Boulder	Oroya
	%	%	%	%
Calcite	.. 12·4	3·0	2·9	2·6
Ankerite	.. 6·9	8·4	24·0	26·4

Travertine is abundant as a crust varying from a few inches to a few feet in thickness and underlying the surface soil. Small irregular beds occur quite on the surface at Hannan's Lake. It is somewhat porous, of a yellowish colour, and composed largely of very fine-grained calcite with some admixed sand, clay, iron oxide, etc.

A thin incrustation of travertine on the surface of propylite at the Boulder Perseverance Gold Mine had the following composition :—

*Travertine, Boulder.*

Nitrogenous organic matter.				Strong trace.
Soluble in HCl	H <sub>2</sub> O	—	.. ..	1.80
	H <sub>2</sub> O	+	.. ..	3.99
	CaO		.. ..	29.98
	MgO		.. ..	2.87
	FeO		.. ..	1.11
	Fe <sub>2</sub> O <sub>3</sub>		.. ..	4.87
	Al <sub>2</sub> O <sub>3</sub>		.. ..	.14
	CO <sub>2</sub>		.. ..	25.66
	SO <sub>3</sub>		.. ..	.28
	P <sub>2</sub> O <sub>5</sub>		.. ..	Trace
Insoluble	CaO		.. ..	.20
	MgO		.. ..	.24
	FeO		.. ..	Trace
	Al <sub>2</sub> O <sub>3</sub>		.. ..	1.69
	K <sub>2</sub> O		.. ..	Trace
	Na <sub>2</sub> O		.. ..	1.35
	SiO <sub>2</sub>		.. ..	25.59
				99.77
Sp. gr. .. ..				2.29

271.—DOLOMITE, AND 271A.—ANKERITE.

Dolomite (bitter spar) is essentially a carbonate of calcium and magnesium, CaCO<sub>3</sub>.MgCO<sub>3</sub>. More or less of the magnesia is commonly replaced by ferrous oxide, and when the latter is so abundant as to be approximately equal in amount to the magnesia present, the mineral is known as Ankerite. / / / / / / / /

/ / Ferruginous dolomite and ankerite are amongst the commonest constituents of the lodes below ground-water level, constituting usually from 20 to 30 per cent. of the whole ore. In addition dolomite is an equally important constituent of the propylite country rock and also of the carbonated peridotite near Hannan's Lake. Its origin is therefore of considerable interest. G. W. Card, who appears to be the only writer to study this aspect of the question, says \* :—

“The tellurides of gold together with the associated carbonates of lime and magnesia and the secondary quartz have been introduced into the ore by solutions which found ready access along planes of parting produced by the incipient foliation.”

\* Rec. G.S. N.S.W., Vol. VI., p. 39.



He assumes, therefore, a vast mass of dolomite and ankerite, averaging 20 to 30 per cent. by weight of the whole ore, to have been introduced from external sources into the present ore bodies. This is hardly conceivable, and a much simpler explanation of its presence can be advanced, which besides is more in accordance with the facts. There can be no doubt that the original rock, of which the lodes represent crushed and chemically altered zones, was one containing considerable amounts of calcium, magnesium, and iron silicates, such as labradorite (soda-lime-felspar) and pyroxene or its alteration product, actinolite (silicate of lime, iron, and magnesia). The expiring efforts of a volcanic intrusion are invariably accompanied by the expulsion of immense quantities of carbon dioxide and steam under a high pressure. It is easy to imagine that this carbon-dioxide and steam under such conditions of pressure should penetrate the surrounding rocks, especially such as are by reason of a foliation more readily penetrable, and should there more or less completely alter into a mixture of carbonates and free silica, etc., such minerals as labradorite, pyroxene, etc. See *ante*, page 63.

Under such circumstances the resulting carbonates might be any one of several minerals according to the relative abundance in the particular portion of rock or lode of lime, magnesia, and iron. The proportion of iron converted into carbonates would also be influenced by the presence of sulphur compounds, which would tend to produce pyrites by union with iron compounds. The more or less ferruginous dolomite when formed might remain *in situ* or, being soluble to a very appreciable extent in waters carrying carbonic acid, might in part be removed to some little distance from the point of formation.

One can now appreciate the facts concerning the occurrence of dolomite at Kalgoorlie, viz. :—

(1.) It varies in composition from typical dolomite with very little iron, to typical ankerite with much iron.

(2.) It occurs under three conditions, viz. :—(a) *in situ* scattered in small crystalline grains throughout the foliated lodestuff and propylite ; (b) forming irregular, sometimes veinlike masses, which are metasomatic replacements of chlorite schists ; (c) in comparatively coarse crystals filling, either by itself or with quartz and other carbonates, secondary cracks, both small and large, in the lodestuff. Under all three conditions it may envelope free gold, calaverite, or other tellurides.

The composition of typical examples is shown by two analyses, the first of some large pale-grey rhombohedral crystals of ankerite lining a small vugh in the Lake View Consols Gold Mine, the second

of some granular white dolomite [3239] filling in a large vein in serpentine at Hannan's Lake.

			Ankerite. Lake View G.M.		Dolomite. Hannan's Lake.	
			per cent.	molecules.	per cent.	molecules.
CO <sub>2</sub>	..	..	42.48	965	46.40	1,054
CaO	..	..	27.14	484	29.70	529
MgO	..	..	6.84	170	19.46	482
FeO	..	..	22.93	319	3.87	54
MnO	..	..	1.01	14	.67	9
			100.40		100.10	
Sp. Gr.	..	..	3.103		2.94	

A small auriferous cross vein at the 500ft. level of the Associated Northern Gold Mine was composed of large crystals of siderite and ankerite, the latter with 31.2 per cent. ferrous carbonate.

The approximate composition of the fine-grained carbonate seen in all thin sections of the lodestuff can be calculated from the ultimate analyses given on page 61. Examples are:—

TABLE XVII.—*Calculated composition of Carbonates in Kalgoorlie Ores.*

G.S.M. No.	8990c	10962	10961	10959	10847
Mine	Oroya	Gt. Boulder	Gt. Boulder	Assoc. North	Fair Play.
Depth	820ft.	2,200ft.	2,200ft.	550ft.	200ft.
Ore	Schist	Schist	Silicious	Schist	Schist
	Per Mole- cent. cules.	Per Mole- cent. cules.	Per Mole- cent. cules.	Per Mole- cent. cules.	Per Mole- cent. cules.
CaCO <sub>3</sub>	11.3 113	11.5 115	3.4 34	10.9 109	25.5 255
MgCO <sub>3</sub>	5.3 63	5.6 67	1.6 19	6.7 80	23.0 273
FeCO <sub>3</sub>	3.6 31	3.9 34	1.3 11	12.4 107	.5 4
Probable minerals	Fers. dolomite	Fers. dolomite	Fers. dolomite	Siderite and Ankerite	Dolomite

The ratio of MgCO<sub>3</sub> to FeCO<sub>3</sub> in this table is not necessarily exact. There is not sufficient carbonic acid present in the ore to satisfy all the magnesia and iron oxide, and in the calculations on which the above table is based it is assumed that the proportion of the respective oxides converted into carbonates is in the same ratio as the total oxides present. If the iron is more readily attacked than the magnesia, ankerite instead of ferruginous dolomite would be present in each case except in the ore from the Fair Play Gold Mine.

Typical occurrences in addition to those already mentioned are :—

[10960]. Silicious ore, 1,650ft., No. 3 Lode, Golden Horse-shoe Gold Mine. Outwardly almost solid quartz with somewhat brecciated appearance due to the irregular distribution of greenish-grey material. The microscope reveals embedded in the quartz a considerable amount of dolomite, colourless, and in crystalline grains of varying sizes, usually in colonies. Typical cleavage and outline freely developed.

[6734]. Ore, 865ft. Ivanhoe Gold Mine. Massive grey dolomite including irregular patches of quartz, chalcedony, fahl ore and free gold, with a little chloritic or micaceous material. This is evidently a metasomatic replacement of greenstone schist.

[10907]. 1,400ft., Lake View Consols Gold Mine. Grey pyritous lodestuff forming wall of a vugh. On the inner face is a layer of coarse quartz crystals, on top of which is a cluster of rhombohedral crystals of ankerite. These crystals have faces up to  $\frac{3}{4}$ -inch (20 mm.) in length. On a fresh fracture they are greyish-white in colour and were originally so on the surface, but exposure to the air soon developed a brownish-yellow film of iron oxide. For the composition of these crystals, *see* above.

[10847]. Lodestuff, 200ft., Fair Play Gold Mine. Somewhat bright green, slightly foliated, lodestuff with a moderate amount of pyrites. Carries about 49 per cent. of non-ferruginous dolomite associated with a bright green chrome-vanadium mica, some free quartz, etc. In a thin slice granular dolomite is seen to be widely distributed. Crystallised dolomite also forms minute veins, some of the crystals being multiply twinned.

#### 272.—MAGNESITE, AND 272A.—MESITITE.

Magnesite is essentially carbonate of magnesium,  $\text{MgCO}_3$ . At times it contains some iron carbonate, and when this latter constituent reaches important proportions the mineral is known as Mesitite.

Neither magnesite nor mesitite appear to be constituents of the auriferous lodes.

Magnesite is found in large nodules of great purity on the surface of the ground in the north-eastern portion of the Kalgoorlie townsite. It doubtless bears the same relation to underlying magnesian rocks that ordinary travertine bears to calcareous rocks. These nodules are somewhat soft and mammilated on the surface, in the interior they are very hard and compact with the appearance of unglazed porcelain. The following analysis of the internal portion of a nodule from the corner of Cotter and Hare Streets, Kalgoorlie, illustrates the remarkable purity of this mineral.

*Magnesite, Kalgoorlie.*

CO <sub>2</sub>	..	..	..	..	51.80
MgO	..	..	..	..	47.63
CaO	..	..	..	..	.12
FeO	..	..	..	..	.01
MnO	..	..	..	..	Minute trace
SiO <sub>2</sub>	..	..	..	..	.01
SO <sub>3</sub>	..	..	..	..	Trace
H <sub>2</sub> O.	..	..	..	..	.15
					<hr/> 99.72
Sp. gr.	..	..	..	..	<hr/> 3.00

Magnesite of this quality is of commercial value if only occurring in sufficient quantity. It is used in the production of aerated waters, epsom salts, firebrick, cupels, calcined magnesia, etc.

Snow-white magnesite somewhat stalactitic in form is found partly or completely filling veins from  $\frac{1}{8}$  to  $\frac{3}{4}$  in. (3 to 20mm.) wide in a graphitic schist near the Leviathan Battery, Hannan's Lake, see [1100].

A somewhat ferruginous magnesite (Breunerite) is an important constituent of the carbonated peridotite occurring on the west side of Hannan's Lake. In a specimen of the rock analysed some years ago it occurred to the extent of about 37 per cent. in the form of crystalline grains, averaging 1 to 2 millimetres in diameter.

A white ferruginous magnesite closely approximating to typical mesitite is one of the chief constituents of the bright green fuchsite rock, [10913], (19a), occurring to the east of the Hannan's North Gold Mine. This rock was found to contain in addition to silica, etc.—

			per cent.	molecules.
CO <sub>2</sub>	..	..	25.98	590
CaO	..	..	1.34	24
MgO	..	..	19.95	495
MnO	..	..	.19	2
FeO	..	..	8.70	121

In [3324] a propylite rock from the 250ft. level, Bonnie Lass Gold Mine, there is a small vein of pale grey mesitite in coarse rhombohedra, small crystals of the same mineral being also scattered through the chloritic base of the rock. The mesitite in this and the previously described rock is characterised by being dissolved by hydrochloric acid only at a temperature close to boiling point and even then but slowly.

## 273.—SIDERITE.

Carbonate of iron, FeCO<sub>3</sub>, sometimes carrying a fair percentage of carbonate of magnesium. The only specimen from Kalgoorlie

in which this mineral is visible to the unaided eye [2984] is one taken from a small cross vein in the lode at the 500ft. level, Associated Northern Gold Mine. This vein was composed of coarsely crystallised carbonates of two species: one light grey, containing 31 per cent. ferrous carbonate, was ankerite; the other, brown in colour, contained 83 per cent. ferrous carbonate, and was evidently a magnesian variety of siderite. This vein carried tellurides.

Finely granular siderite appears to be a constituent of the schistose ore in the Associated Northern Gold Mine and other mines. See table on page 126.

#### 288.—MALACHITE.

Hydrated carbonate of copper,  $\text{CuCO}_3 \cdot \text{Cu}(\text{HO})_2$ . This mineral is seen in a single specimen of oxidised ore [1952] from the Kapunda Boulder Gold Mine. It occurs in thin fibrous crusts on fracture faces, the total copper in the ore amounting to 2.3 per cent.

#### 313.—ORTHOCLASE.

Silicate of aluminium and potassium,  $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ . This mineral occurs as phenocrysts and also in the groundmass of intrusive dykes of felspar porphyry, and analyses point to its presence in the finely granular groundmass of some of the ore, *e.g.*, [10962*g*], Great Boulder Proprietary Gold Mine, and [10964*l*], Lake View Consols Gold Mine. See Table IV., p. 169.

#### 316.—ALBITE.

Silicate of aluminium and sodium,  $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$ . This mineral is an important constituent of both the lodes and the propylites which enclose them. In these cases it is clearly a secondary mineral resulting largely, if not solely, from the alteration of the labradorite of the original rock. Its presence in the lodestuff was first suspected from the appearance of a fair amount of soda in the analyses, and this suspicion was confirmed by microscopic investigation. The average soda content of six schistose ores was 1.16 per cent. Assuming that of this a small amount is present in the sericite of the ore, and that the balance occurs as albite, the average proportion of the latter mineral would be 8.5 per cent., the maximum being 15 per cent., the minimum 4 per cent.

Albite cannot be recognised in any hand specimens of ore and only rarely does it have its typical appearance in thin slices. Usually it is distributed through the ore in small clear colourless grains which under crossed nicols appear untwinned or singly twinned, with a somewhat uneven junction between the two halves of the twin.

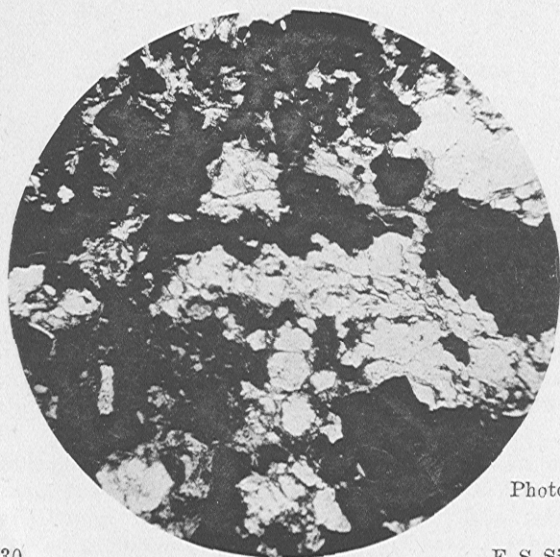


Fig. 37.

Photo. by

[10,938.] O.L.  $\times 30$ .

E. S. Simpson.

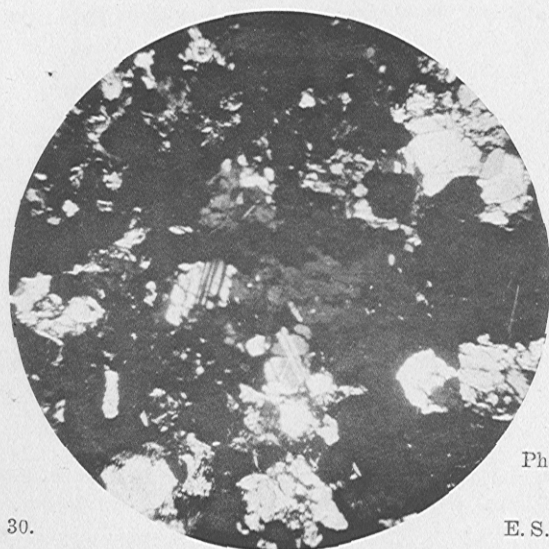


Fig. 38.

Photo. by

[10,938.] C.N.  $\times 30$ .

E. S. Simpson.

Figs. 37 and 38.—Telluride Ore with Albite, Hidden Secret G.M. In addition to much Pyrites, the ore carries Quartz and multiply twinned Albite, and Phlogopite (grey in Fig. 37).

In rich ore from the Hidden Secret Gold Mine and in somewhat poor ore from the Lake View Consols the grains are larger and exhibit the characteristic multiple twinning.

[10938*h*]. Rich lodestuff, Hidden Secret Gold Mine (Figs. 37 and 38) show several small and large grains of albite associated with much pyrites, quartz, and the brown micaceous mineral referred to on page 140. The specimen from which this section was cut was extremely rich in tellurides.

[10938*a*]. Rich lodestuff, Hidden Secret Gold Mine (Fig. 46), shows a large crystal of albite interrupted by areas of green mica and pyrites. This is almost the only instance in which this structure was apparent.

[10964*h*]. Poor ore, 1,900ft., Lake View Consols Gold Mine. Grey schistose ore assaying gold, 2dwts. 4 grs. ; silver, 1dwt. 15grs. Under the microscope it is seen to consist of a granular base of dolomite, sericite, and albite, with embedded pyrites, magnetite, leucoxene and magnetite. Albite is very plentiful and shows multiple twinning. It is mostly somewhat large grained and often interrupted by intrusions of sericite.

[10962]. Lodestuff, 2,200ft., Great Boulder Gold Mine. A thin slice shows the ore to have a very finely granular base of dolomite sericite, and albite, the last mineral mainly collected into groups of grains. Embedded in this base are coarser grains of quartz, pyrites, leucoxene, and dolomite.

### 319.—LABRADORITE.

Silicate of aluminium, calcium, and sodium. Triclinic feldspars more basic than albite occur as important primary constituents of the intrusive porphyrite on the west side of the Kalgoorlie belt and of the gabbro west of the Boulder abattoirs reserve. These have not been studied in detail in the Laboratory, as they nowhere occur as constituents of lode material.

### 325.—PYROXENE.

Diallage (silicate of calcium, magnesium, iron, and aluminium) forms about one-half of the unaltered gabbro lying on the west side of the field. It occurs in distinct prismatic grains averaging about 1 to 2 m.m. (one-sixteenth inch) in length, and of a grey-green colour. Occasional crystals with ophitic habit reach 8 to 10 m.m. (three-fifths inch) in length, and exhibit a distinct schiller.

No variety of pyroxene has been found in any of the ore bodies. Even in the rocks it is rare, being mostly converted by metamorphism into uralite (actinolite).

## 338.—AMPHIBOLE.

This is one of the commonest rock-forming minerals in the Kalgoorlie District. It is entirely absent from the lodes where it has succumbed to the thermal activity concentrated in the ore channels, and been converted wholly into carbonates, etc. In the immediate vicinity of the lodes too it has for the most part been attacked and converted into chlorite, dolomite, etc., though even there several considerable areas of amphibole-rock are to be found, as for example near the Golden Horseshoe Gold Mine, and again near the Hannans' Reward Gold Mine.

Most of the Kalgoorlie amphibole is secondary *Actinolite* (Uralite) replacing an original pyroxene. C. G. Gibson and J. Allen Thomson have also noted a little *Tremolite*. Primary *Hornblende* is plentiful in the intrusive porphyrite and fairly common in some areas of amphibolite. This group of rock-forming minerals has been studied in detail by Mr. C. G. Gibson. The following brief notes deal simply with one or two typical occurrences of mineralogical interest.

[11035]. Porphyrite,  $1\frac{1}{2}$  miles west of, Mt. Hunt. A thin slice shows a fine-grained felspathic groundmass in which are embedded many crystals of amphibole (hornblende), many with perfect outline. Colours (a) pale yellow, (b) dull green, (c) somewhat brighter green. Extinction, maximum noted 17 per cent. Zonal structure not uncommon, five zones seen in one basal section. Twinning parallel to "a" common, mostly single, occasionally multiple. Maximum length of crystal, 3 m.m. ( $\frac{1}{8}$ -inch) average about 1 m.m.

[2117]. Coarse amphibolite, G.M.L. 1219, Golden Horseshoe Estates. In hand specimens this appears to consist largely of short broad crystals of pale grey-green amphibole. In thin slices this mineral is seen to be very plentiful, to be almost colourless, and to have a fibrous structure with beardlike extensions into the surrounding mineral aggregate. It is evidently a secondary actinolite (uralite) pseudomorphous after diallage, the schiller of which is still preserved. A precisely similar mineral in [11003] from the Outridge Gold Mine exhibits excellent pleochroic halos surrounding apatite and allanite, *see* Figs. 39, 40, 49.

[2117] shows also a considerable proportion of a primary hornblende with corroded edges. This hornblende is bicoloured, some crystals being brown, other blue-green, others again partly one partly the other, with no sharp line between the colours. The pleochroic colours are either (a) very pale yellow, (b) rich brown, (c) dark brown; or (a) very pale yellow, (b) dull green, (c) moderately deep blue. The halo round the crystal of allanite in Fig. 41 is partly in uralite, partly in this primary hornblende.



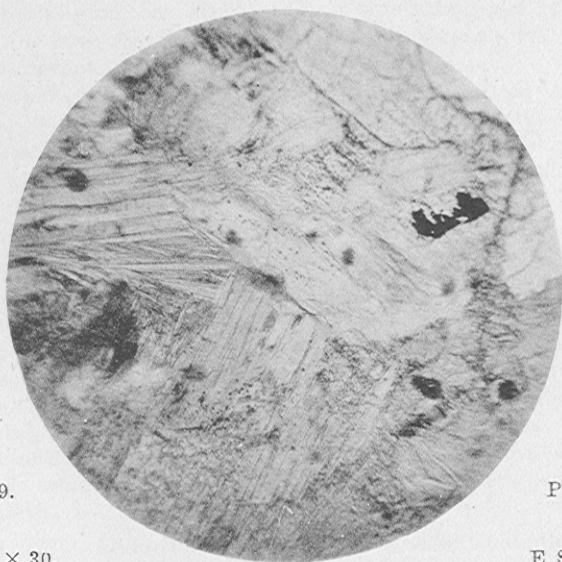


Fig. 39.

[11,003.] P.L.  $\times 30$ .

Photo. by

E. S. Simpson.



Fig. 40.

[11,003.] P.L.  $\times 30$ .

Photo. by

E. S. Simpson.

Figs. 39 and 40.—Amphibolite with Pleochroic Halos, Outridge G.M.  
The "halos" are discoloured spheroidal portions of the secondary Actinolite (Uralite) caused by the radioactivity of small inclusions.

[10436]. Basic pegmatite, Maritana Gold Mine. This consists very largely of a greenish black amphibole in large crystals up to lin. in length, and  $\frac{1}{2}$  in. in width. The mineral is probably "common hornblende." The composition of the pegmatite is:—

*Basic Pegmatite, Kalgoorlie.*

SiO <sub>2</sub>	..	..	..	..	44·17
TiO <sub>2</sub>	..	..	..	..	4·99
ZrO <sub>2</sub>	..	..	..	..	None
CO <sub>2</sub>	..	..	..	..	·35
P <sub>2</sub> O <sub>5</sub>	..	..	..	..	·40
H <sub>2</sub> O +	..	..	..	..	2·28
K <sub>2</sub> O	..	..	..	..	·16
Na <sub>2</sub> O	..	..	..	..	1·94
CaO	..	..	..	..	9·12
BaO	..	..	..	..	·01
MgO	..	..	..	..	4·56
MnO	..	..	..	..	·51
FeO	..	..	..	..	10·92
Fe <sub>2</sub> O <sub>3</sub>	..	..	..	..	9·20
Al <sub>2</sub> O <sub>3</sub>	..	..	..	..	10·57
V <sub>2</sub> O <sub>5</sub>	..	..	..	..	·19
Cr <sub>2</sub> O <sub>3</sub>	..	..	..	..	None
FeS <sub>2</sub>	..	..	..	..	·26
H <sub>2</sub> O —	..	..	..	..	·16
					<hr/> 99·79
Sp. gr.	..	..	..	..	<hr/> 3·27

[268]. Vein in amphibolite, Chandos G.M.L. The vein is composed of large crystals of pale grey-green actinolite. Individual crystals are from 1 to 1½ inches long and broad in proportion.

[3381]. Asbestos, Water Lease 9E, Hannans' Lake. A very pale green asbestos, in fine soft flexible fibres of low tensile strength and of an average length of 4 inches (10 c.m.). It is associated with a bright green vermiculite and with veins of calcite. Composition:—

*Actinolite-Asbestos, Hannans' Lake.*

SiO <sub>2</sub>	..	..	..	..	54·62
MgO	..	..	..	..	21·20
CaO	..	..	..	..	12·50
MnO	..	..	..	..	·48
FeO	..	..	..	..	6·03
Fe <sub>2</sub> O <sub>3</sub>	..	..	..	..	2·64
Al <sub>2</sub> O <sub>3</sub>	..	..	..	..	·92
H <sub>2</sub> O +	..	..	..	..	1·86
H <sub>2</sub> O —	..	..	..	..	·32
					<hr/> 100·57
Sp. gr.	..	..	..	..	<hr/> 3·01

## 376.—CHRYSLITE (OLIVINE).

Silicate of iron and magnesium,  $2(\text{Mg.Fe})\text{O.SiO}_2$ . Unaltered olivine has not been detected in the Kalgoorlie District but typical serpentine pseudomorphs after olivine form the great bulk of the serpentine rock which occupies a large area near Hannans' Lake. See especially [3218] from M.L. 14, immediately to the west of the Leviathan Battery, Fig. 48.

## 394.—ZIRCON.

Silicate of zirconium,  $\text{ZrO}_2.\text{SiO}_2$ . Traces of zirconia have been detected in several rocks and in lode material. This points to the existence of small quantities of zircon in these instances, the maximum amount being 0.04 per cent. in a porphyrite.

## 406.—ZOISITE, AND 466A.—CLINOZOISITE.

These are identical in composition and origin, being hydrous silicates of calcium and aluminium, resulting from the alteration of lime feldspars. Neither has been detected in any lode material where the carbonation has been so complete that no lime is left in combination with silica. Zoisite is, however, frequently seen in thin slices of the rocks of the district and clinozoisite is also reported by Mr. J. Allen Thomson to occur.

## 407.—EPIDOTE.

Hydrous silicate of calcium, aluminium, and iron. This alteration product of rock forming minerals, like zoisite, is not found in any of the lodestuff, but is of somewhat frequent occurrence in the metamorphic rocks. In these it occurs in microscopic grains and clusters of grains, colourless or pale yellow in thin sections. Its high index of refraction and high order interference colours are characteristic. It mostly occurs in association with chlorite in propylite rocks, but is also known in altered porphyrite and in amphibolite. Hand specimens are rare but not unknown.

[2329]. Propylite, Lucky Hit G.M.L. This specimen carries a considerable mass of crystalline epidote of typical greenish yellow colour.

[10913], (173). Propylite, Hannan's North Gold Mine. Thin slice shows many granules with chlorite, etc.

[10913]. Propylite, Eagle Hawk United G.M.L. Epidote is seen in a thin slice as scattered granules and as a filling or lining of small fissures.

[2117]. Coarse amphibolite, G.M.L. 1219, Golden Horseshoe Estates. Occasional granular aggregates of epidote associated with urallite, etc.

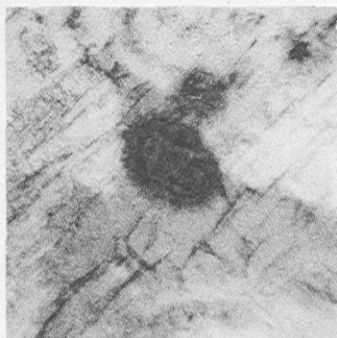


Fig. 41.  
[11,003.] P.L.  $\times 110$

Photo. by  
E. S. Simpson.

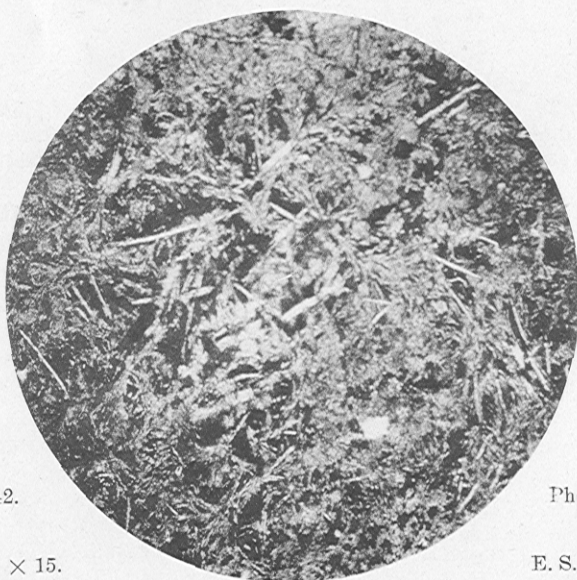


Fig. 42.  
[10,913.] O.L.  $\times 15$ .

Photo. by  
E. S. Simpson.

Fig. 41.—Allanite crystal in Amphibolite, Outridge G.M. The crystal occurs at the junction of a primary Amphibole (Hornblende) and a secondary Amphibole (Uralite), in both of which it has produced a pleochroic halo.

Fig. 42.—Amphibolite with dendritic Zeolite (?), 300ft., Brown Hill North G.M.

[ \* ]. Altered porphyrite (Ceratophyre), Kalgoorlie Power Station. Granules of epidote seen in thin slices of this rock.

#### 409.—ALLANITE.

Hydrous silicate of calcium, aluminium, iron, cerium, lanthanum, etc. This mineral has not been detected in any lode matter. In a section of the amphibolite from the Outridge Gold Mine [11003], two small well defined crystals are seen which are referable to this species. These crystals are about 0.1 m.m. long and 0.05 m.m. wide; they are brown in colour and somewhat strongly pleochroic. The index of refraction and double refraction are both high. The crystals are embedded in amphibole, one wholly in secondary actinolite, the other on the point of intergrowth of this mineral with primary green hornblende. The allanite is strongly radioactive as evidenced by the well marked brown pleochroic halos surrounding the crystals, *see* Fig. 41.

#### 410.—AXINITE.

Borosilicate of aluminium and calcium with some iron and manganese. Mr. J. Allan Thomson collected a few small pieces of this mineral near the Warden's residence. The formation of this mineral is no doubt contemporaneous with that of tourmaline. Both minerals are formed by the action of boron-bearing waters on rocks, axinite when abundance of lime and but little magnesia or alkalis are present, tourmaline when but little lime is available, but iron or magnesia is abundant.

#### 426.—TOURMALINE.

Iron tourmaline. Complex silicate of aluminium, boron, iron, and soda. This mineral in small quantities is somewhat widely distributed at Kalgoorlie. Most frequently it occurs as black needles, or radiating or parallel bundles of needles, each about 0.5 x 0.05 m.m., on the cleavage planes of schistose ore, the long axis of the crystals lying in the cleavage planes, embedded in sericite, etc. Similar needles of equal or larger size up to 2 ins. in length occur in veins of vitreous quartz. In both these cases they seem to be indicative of rich ore, and indeed at times are intergrown with calaverite or petzite. More usually they are intergrown with sericite or pyrites, the latter sometimes completely enveloping, or enveloped by, the tourmaline. In one specimen [10836], from the Great Boulder Main Reef G.M., this mineral forms a vein from 1 to 12 mm. wide on the side of a large dolomite vein. A somewhat similar vein, associated with narrow veinlets of dolomite in schistose lodestuff is seen in a specimen from the A.W.A. United Gold Mine. Other specimens from the same mine

---

\* Unregistered specimen.

show very many small crystals scattered through the ore in somewhat narrow zones parallel to the schistosity, *see* Fig. 18.

It is not found in any of the oxidised ores except occasionally in single crystals in solid quartz where it has been protected from the action of weathering pyrites, which completely destroys it, leaving only a residue of fine quartz, clay and limonite.

No analysis has been made of this mineral, but its identity has been established by blowpipe tests and by examination of detached needles and thin slices of lode under the microscope.

It is undoubtedly of secondary origin and contemporaneous in formation with much of the pyrites and tellurides. The silica and bases were derived from pre-existing chlorites or actinolite, the boron and fluorine from magmatic vapours or solutions carrying possibly borates or boric acid and alkaline bifluorides.

In the collections at my disposal are specimens of lodestuff showing tourmaline from the Boulder Main Reef, Lake View Consols, Associated, Golden Pike, Great Boulder Proprietary, Ivanhoe, Brown Hill, Associated Northern, Brown Bill Extended, A.W.A. United, Cassidy Hill, South Kalgurli, and Brown Hill Junction.

Typical examples are:—

[7944]. 2,200ft., Great Boulder Proprietary Gold Mine. Dark green schist with small masses of sylvanite, some of which are penetrated by small isolated needles, and bunches of needles, of black tourmaline.

[4435]. Great Boulder Proprietary Gold Mine. Vitreous quartz with much tourmaline in the shape of bundles of fine straight and slightly curved parallel fibres up to 40 m.m. (1½ in.) in length. The bundles are interrupted by narrow horizontal cross fractures filled with quartz. Tellurides of gold occur in thin films between the fibres.

[8962]. Perseverance lode, Lake View Consols Gold Mine. Dark green schist, with quartz, pyrites, and a little calaverite. Fine and somewhat coarse tourmaline needles embedded in pyrites, sericite and chlorite on cleavage faces.

[10836]. 1,550ft., Great Boulder Main Reef Gold Mine. Granular dolomite vein 50 m.m. (2 in.) wide, with walls of mica-chlorite schist. On the face of the schist are some very fine needles of tourmaline. Between the dolomite and the schist on one side is a continuous vein of tourmaline varying in thickness from 1 to 12 m.m. (0.04 to ½ inch.) A section was made of this at its widest part. In the slice it is seen to be composed very largely of coarse prismatic crystals or rounded basal sections. It is mostly very ragged in outline, and fibrous in structure, dark grey blue to colourless in colour, and very full of inclusions. The latter comprise dusty brown or black material of indeterminate character giving the fibrous appearance to the crystals, also pyrites and quartz.

In several places coarse pyrites completely enclose tourmaline crystals, which in their turn again enclose small pyrites grains. Between the tourmaline prisms, which are mostly parallel to the schistosity, are the normal constituents of the auriferous schists, quartz, dolomite, etc.

[10843]. 300ft., Thornett's A.W.A. United (late Mt. Ferrum) Gold Mine (Fig. 18). The specimens embraced under this number show much more tourmaline than any other lodestuff in the collection. Except for the tourmaline the ore has to the eye the appearance of the typical greenish grey schistose lodestuff devoid of visible quartz. Tourmaline constitutes quite 2 or 3 per cent of the whole ore and is in crystals from microscopic size up to 3 m.m. x 1 m.m. (0.12 x 0.04 inch). For the most part they are scattered throughout the ore in a roughly banded way. In one specimen this mineral forms a double (at times multiple) veinlet associated with veinlets of dolomite. Much finely granular pyrites is associated with the tourmaline. A thin slice of one specimen (*see* Fig. 18) shows this mineral to be much better crystallised, more transparent and freer from inclusions than that in the previously described specimen. It still, however, includes many small grains of quartz and pyrites, and occasionally dolomite, whilst some pyrites encloses small granules of tourmaline. For the most part the tourmaline is coarse-grained (0.2 to 0.8 m.m. in diameter and 0.7 to 2.0 m.m. in length). It is strongly pleochroic, very pale brown to dark grey green. Cross sections are often fairly well formed triangles with curved faces, and show zonal structure in different shades of grey-green. These appear in prismatic sections as longitudinal stripes of varying intensity of colour. Associated with the tourmaline is granular dolomite, quartz, pyrites, etc.

[1756]. 300ft., East Lode, Ivanhoe Gold Mine. Pyritous and dolomitic quartz vein, with schist walls in which are embedded many fine spicules of black tourmaline.

[1440]. 240ft., Croesus North No. 1 Gold Mine. Auriferous greenstone schist with irregular quartz veinlets. On one cleavage a thin continuous mass of granular pyrites in which are embedded many well crystallised tourmaline needles, occurring singly or in radiating bunches. The crystals are from 0.1 to 4.0 m.m. in length. Many much smaller needles occur in chlorite, etc., on a second face of the specimen.

[10844a]. 1,200ft., South Kalgurli Gold Mine (Figs. 19, 43, 44). Block of very dark grey ore comprising two walls of schist, each about 1 inch (25 m.m.) thick between which is 3in. (75 m.m.) of more massive ore with small cross veinlets of dolomite. A thin slice was cut across the foliation of one of the walls. About one-half of this section consists of small tourmaline crystals from 0.05 m.m. to 0.1 m.m. in diameter and 0.1 to 0.6 m.m. in length. As-

Fig. 43.

[10,844.] O.L.  $\times 60$ .

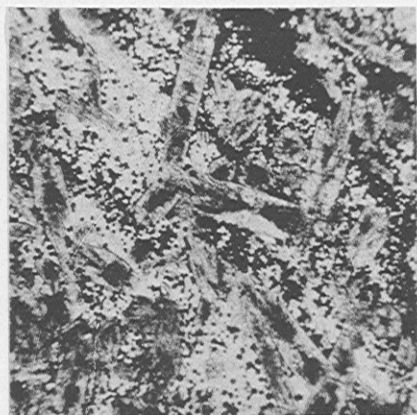


Photo. by

E. S. Simpson.

Fig. 44.

[10,844.] O.L.  $\times 60$ .



Photo. by

E. S. Simpson.

Figs. 43 and 44.—Tourmaline crystals in Telluride Ore, 1,200ft., South Kalgurli G.M. The figures show the peculiar arrangement of inclusions in the Tourmaline, which in cross section (Fig. 44) are like six spokes to a wheel, in longitudinal section (Fig. 43) taper to a point at the centre of the crystal.



sociated with these are innumerable minute crystals of pyrites (average 0.01 m.m. in diameter). Quartz, sericite, and dolomite are freely developed. A veinlet of the latter mineral carries some blende. Much of the tourmaline contains black inclusions arranged in a somewhat peculiar manner. In cross section the inclusions appear as six narrow rays radiating from the centre towards each of the six angles of the crystals (Fig. 44). In longitudinal section (Fig. 43) these rays are seen to be wedge-shaped, coming to a point midway in the length of the crystal.

Tourmaline is occasionally seen in amphibolite, *e.g.*, [11018], Mt. Hunt, more frequently in barren shear zones, *e.g.*, [11095], south of Slug Hill, and [10439], Bonnie Lass Gold Mine. See under Rutile, page 119.

#### ZEOLITE.

A zeolite whose species has not been determined is a prominent constituent of [10913], (88a), a propylite from the Brown Hill North Gold Mine. The zeolite is in thin branching fibres, which are colourless, and give low interference colours. See Fig. 42.

#### 458.—MUSCOVITE AND FUCHSITE.

Hydrous silicate of potassium and aluminium,  $2\text{H}_2\text{O.K}_2\text{O.3Al}_2\text{O}_3.6\text{SiO}_2$ . In fuchsite a little chromic oxide replaces part of the alumina. Typical coarse-grained muscovite is unknown in the Kalgoorlie district, but the minutely scaly variety, known as sericite, is one of the most important constituents of the ores at all depths. It is also developed as a secondary mineral in much of the barren rock, especially where the latter is at all foliated.

G. W. Card \* seems to have been the first to record the presence of this mineral in abundance. He says:—

“Sericitic-mica, always present. The vividly polarising little rods of the substance have a crisscross arrangement when the rock is not schistose; in the latter cases they are foliated, thereby causing the schistosity.”

L. J. Spencer † later wrote:—

“The matrix of the telluride specimens is usually a pale greenish sericite-schist with a silvery reflection. . . . A thin section (of Associated lode-stuff), perpendicular to the schistosity, showed under the microscope much sericite.”

Sericite is not an original mineral in the lodes but a product of metamorphism accompanied by an intrusion into the ore-body of potassium-bearing solutions during the period of ore deposition. The latter phenomenon has been shown to be accompanied by a marked increase in the percentage of potash in the rock. The interaction of this added potash with the aluminium silicates of

\* Rec., G.S., N.S.W., Vol. 6, p. 21, *et seq.* † Mineral. Mag., Vol. 13, p. 281.

pre-existing feldspars, chlorite, etc., would result in the formation of sericite. In the schistose lodestuff which has been analysed the sericite has been calculated to vary between 12 per cent. and 28 per cent. with an average of 18 per cent.

The sericite of both the lodes and rocks of Kalgoorlie is in minute silvery white scales, which are usually arranged in very thin lenticular groups of parallel scales. These groups form lines of weakness in the ore, along which it splits readily, and are hence responsible for the somewhat foliated structure of most of the ore. The mineral is most plainly seen on the surface of such cleavages. It usually appears to the eye as a less important constituent than analysis shows it in fact to be.

In a fine telluride specimen [8752] from the South Kalgurli Gold Mine sericite is so abundant that the ore appears to be a typical silvery white sericite schist. Even in the very silicious ores the same thin lenses of sericite occur though in far less amount than in the typical schistose ore. It is least plentiful in ores of the basic type (*e.g.*, Hidden Secret Ore), where the potash appears to exist mainly in the form of phlogopite. In other cases fuchsite or roscoelite or other vanadiferous mica takes its place.

The only rocks in which sericite occurs in appreciable quantities are those highly altered greenstone schists which are grey in colour through conversion of all iron silicates into carbonates.

Examples are—

No. .. .. .	1796	2817	11107
Rock .. .. .	Foliated Siderite Rock.	Dolomite Schist.	Ottrelite Schist.
Mine .. .. .	Golden Horseshoe	Mt. Charlotte	Trafalgar Townsite
Potash, per cent. .. ..	1.5	1.5	.7
Equal to sericite, per cent.	12.7	12.7	5.9

Fuchsite, the chromiferous variety of sericite, is characterised by its brilliant green colour, due to the presence of a small percentage of chromium. This variety is seen in several places at the northern end of the Kalgoorlie field. It is, like normal sericite, a secondary mineral formed in the lodes and barren shear zones by the action of potassium-bearing waters upon chromite and aluminous silicates. The most typical instance of its occurrence is [10913], (19a), a shear-zone rock occurring at the south end of the Kalgoorlie Rifle Range. This is an altered basic igneous rock composed

largely of finely granular white mesitite and minute scales of emerald green fuchsite, and having the following composition :—

*Fuchsite-mesitite Rock, Kalgoorlie.*

SiO <sub>2</sub>	..	..	..	..	33·80
TiO <sub>2</sub>	..	..	..	..	·33
ZrO <sub>2</sub>	..	..	..	..	·02
CO <sub>2</sub>	..	..	..	..	25·98
P <sub>2</sub> O <sub>5</sub>	..	..	..	..	·11
H <sub>2</sub> O +	..	..	..	..	·59
K <sub>2</sub> O	..	..	..	..	2·11
Na <sub>2</sub> O	..	..	..	..	·30
CaO	..	..	..	..	1·34
BaO	..	..	..	..	None
MgO	..	..	..	..	19·95
MnO	..	..	..	..	·19
FeO	..	..	..	..	8·70
Fe <sub>2</sub> O <sub>3</sub>	..	..	..	..	·40
Al <sub>2</sub> O <sub>3</sub>	..	..	..	..	5·72
V <sub>2</sub> O <sub>3</sub>	..	..	..	..	trace (·005)
Cr <sub>2</sub> O <sub>3</sub>	..	..	..	..	·50
FeS <sub>2</sub>	..	..	..	..	·24
H <sub>2</sub> O —	..	..	..	..	·09
					100·37
Sp. gr.	..	..	..	..	2·97

A similar rock [10439] with evenly distributed fuchsite occurs on the Bonnie Lass Gold Mine.

Inclusions consisting largely of fuchsite occur frequently in the intrusive porphyry dykes, *e.g.* [11296], No. 18 level, Associated Gold Mine, and [1739], 400ft., Hawk's View Gold Mine.

Micas containing both chromium and vanadium occur at Kalgoorlie, *vide* "Roscoelite."

462.—BIOTITE.

Hydrous silicate of potassium, aluminium, magnesium, and iron. This is only rarely met with at Kalgoorlie, and even then in minute scales only recognisable under the microscope. In lodestuff [10847] from the 200ft. level, Fair Play Gold Mine, there are present pseudomorphs after biotite carrying strings of granular rutile, *see* Fig. 36. This is the only case in which traces of biotite were observed in lode material. In the rocks it is somewhat more common, typical examples being :—

[11023]. Biotite schist, Boulder Telluride Blue Gold Mine. Small scales of olive coloured biotite are plentiful in this, forming with green hornblende phenocrysts in a felsite groundmass.

[11018]. Amphibolite with tourmaline, Mt. Hunt. This carries several pieces of bleached biotite with granular inclusions of rutile either uniformly scattered through the mica or else aggregated round the periphery.

## 462A.—PHLOGOPITE.

Magnesia-mica, silicate of potassium, aluminium, and magnesium. A mineral which may be phlogopite occurs in some specimens of Hidden Secret Gold Mine ore. It is pale brown in colour, occurs in thin elastic scales and gives strong reactions for potassium and magnesium by microchemical tests. Its typical mode of occurrence is seen in Figs. 45 and 37.

## 463.—ROSCEOELITE.

Vanadium mica, silicate of potassium, aluminium, and vanadium. This mineral was first suspected to occur by T. A. Rickards, who says \* :—"In 1897 several specimens of the ore from the Great Boulder Main Reef mine at Kalgoorlie were sent to me, and I thought that roscoelite was discernible. Mr. Pearse subsequently made an investigation which confirmed this opinion." Mr. Pearse presented the results of his examination to the Colorado Scientific Society.† The results of a partial analysis made for him by F. C. Knight are given in column 1 below, whilst column 2 gives the composition of a typical Californian example :—

*Roscoelite.*

				Kalgoorlie.	Placerville, California.
				per cent.	per cent.
SiO <sub>2</sub>	..	..	..	43·65	45·17
TiO <sub>2</sub>	..	..	..	Not det.	·78
V <sub>2</sub> O <sub>3</sub>	..	..	..	27·11	24·01
Al <sub>2</sub> O <sub>3</sub>	..	..	..	9·95	11·54
FeO	..	..	..	Not det.	1·60
CaO	..	..	..	1·43	None
MgO	..	..	..	1·51	1·64
K <sub>2</sub> O	..	..	..	Not det.	10·37
Na <sub>2</sub> O	..	..	..	Not det.	·06
Li <sub>2</sub> O	..	..	..	Not det.	Trace
H <sub>2</sub> O	..	..	..	Not det.	4·69
				83·65	99·86

Beyond numerous repetitions of the above statements no further reference to this mineral occurs in the literature.

A careful search both macroscopic and microscopic revealed the presence of a dull greenish mica in several specimens of lode-stuff in the National Collections, whilst chemical analysis indicated the presence of quite appreciable amounts of vanadium in all the

\* Telluride Ores of Cripple Creek and Kalgoorlie, Trans. Amer. Inst. Min. Eng., Vol. 30, p. 718.

† Notes of a peculiar occurrence of Tellurium in a Gold Ore from the Gt. Boulder Main Reef, W.A., Bull. Col. Sci. Soc. No. 8, 1897.

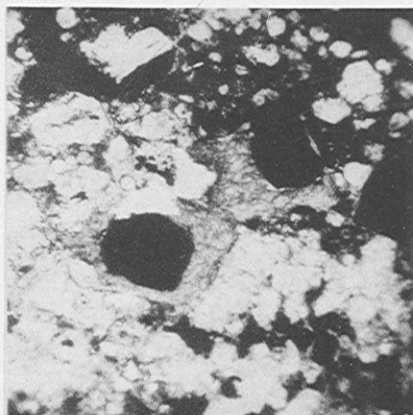


Fig. 45.

[10,938.] O.L.  $\times 40$ .

Photo. by

E. S. Simpson.

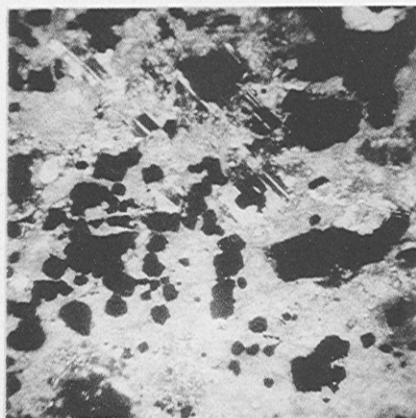


Fig. 46.

[10,938.] C.N.  $\times 30$ .

Photo. by

E. S. Simpson.

Fig. 45.—Rich Telluride Ore with Phlogopite, Hidden Secret G.M. The ore contains much Pyrites with Albite, etc. The Phlogopite is in the centre of the figure partly surrounding two large grains of pyrites.

Fig. 46.—Rich Telluride Ore with Chrome-Vanadium Mica, Hidden Secret G.M. Pyrites and multiply twinned Albite in a ground mass of fine scales of an emerald-green Mica, which carries both Chromium and Vanadium.

unoxidised ores. The results obtained for  $V_2O_3$  and for  $Cr_2O_3$ , which also yields a green mica, were :—

Unoxidised ore, 820ft. Oroya G.M.	$V_2O_3$	0.06 %	$Cr_2O_3$	0.03%
Do. (schist) 2,200ft. Gt. Boulder G.M.		0.12		0.02
Do. (quartz) 2,200ft. do.		0.11		Nil
Do. 200ft. Fair Play G.M.		0.32		0.22
Do. ? Hidden Secret G.M.		1.21		0.50

In the quartz from the Great Boulder Gold Mine small masses of scales of a dull green colour were observed in several places. Some of this scaly matter was scraped off and tested for vanadium and chromium with the following results :—

	per cent.
$V_2O_3$ .. .. .	1.12
$Cr_2O_3$ .. .. .	0.04

These green scaly masses evidently accounted for the  $V_2O_3$  appearing in the bulk analysis of the quartz. The scrapings analysed are too poor in  $V_2O_3$  to be pure roscoelite, and may be either a muscovite with a small percentage of vanadium, or an intergrowth of roscoelite with muscovite, accompanied by more or less quartz.

In the sections of [8953a], a specimen from the Golden Horse-shoe Gold Mine extremely rich in flake gold, there is a large amount of a light green mica which Mr. J. Allen Thomson, B.A., B.Sc., considers typical roscoelite. In one section it appears as pale green masses of considerable area, composed of aggregates of minute scales surrounding free gold, pyrites, and quartz.

In a section of [9206] from the Great Boulder Main Reef Gold Mine a similar green mica appears, both as finely granular aggregates and also as well defined flakes associated with pyrites, free gold, and coloradoite. These flakes are somewhat strongly pleochroic, the colours being clear green and greenish yellow, and exhibit strong double refraction.

In the ores from the Fair Play Gold Mine and Hidden Secret Gold Mine, which are of the basic type, there occurs a strong green mica which would appear to contain both vanadium and chromium, and which in this respect differs from typical roscoelite. Material from the Hidden Secret Gold Mine, showing in thin section only pyrites, hessite, albite, quartz, and apparently a single species of green mica in scaly aggregates (*see* Figs. 20 and 46), yielded in bulk 1.21 per cent.,  $V_2O_3$  and 0.50 per cent.,  $Cr_2O_3$ , both of which could only have been derived from the green mica. This mica is especially abundant in this mine, where it characterises the richest ore and is often found enveloping hessite and petzite.

These micas are in all cases evidently of secondary origin, formed under the influence of the introduction of potassium-bearing fluids. The chromium and vanadium pre-existed in the rocks in the immediate vicinity of the lode in some form, the former doubtless as chromite in the basic rocks of the North-end series. The chromium in two rocks, originally olivine- and chromite-bearing was—

	per cent.
Serpentine, Mt. Hunt .. .. .	$Cr_2O_3$ .. 0.24
Fuchsité-mésité rock, Kalgoorlie (North end) ..	$Cr_2O_3$ .. 0.50

The origin of the vanadium is somewhat obscure. Vanadium is found in unusually large amount in almost all the pieces of "greenstone" from the district which have been analysed. Thus—

G.S.M.			per cent.
10418	Gabbro, W. of Abattoirs, Boulder,	$V_2O_5$	0.06
10436	Gabbro pegmatite, Kalgoorlie		0.19
3306	Quartz-epidiorite, Kalgoorlie		0.25
11003	Amphibolite, Kalgoorlie		0.10
3231	Epidiorite, South of Boulder		0.08
2502	Ankerite-rock, Trafalgar		0.33
11184	Propylite, Boulder		0.04
11105	Propylite, Kalgoorlie		0.30

Vanadium has been shown to occur in primary pyroxene and ilmenite, both of which occur in the gabbros analysed, whilst ilmenite and the alteration products of pyroxene occur in the other rocks cited.

It is interesting to note that roscoelite is a constituent of many gold lodes in California, where at several points it has been found to be accompanied by gold tellurides.

#### 467.—OTTRELITE.

Hydrated silicate of iron and aluminium with manganese or magnesium. At the north-east corner of the Lake View (Trafalgar) Townsite a foliated rock occurs which carries numerous crystals of Ottrelite (*see* specimens Nos. [1811, 1812, 11107]).

The composition of this rock is:—

$SiO_2$	..	..	..	..	50.94
$TiO_2$	..	..	..	..	1.09
$ZrO_2$	..	..	..	..	Trace
$CO_2$	..	..	..	..	8.24
$P_2O_5$	..	..	..	..	.45
$H_2O +$	..	..	..	..	2.81
$K_2O$	..	..	..	..	.66
$Na_2O$	..	..	..	..	1.28
$CaO$	..	..	..	..	5.47
$BaO$	..	..	..	..	.02
$MgO$	..	..	..	..	3.04
$MnO$	..	..	..	..	1.06
$FeO$	..	..	..	..	9.44
$Fe_2O_3$	..	..	..	..	2.74
$Al_2O_3$	..	..	..	..	12.04
$V_2O_5$	..	..	..	..	.09
$Cr_2O_3$	..	..	..	..	None
$FeS_2$	..	..	..	..	.77
$H_2O—$	..	..	..	..	.16
					<hr/> 100.30 <hr/>
Sp. gr.	..	..	..	..	<hr/> 2.88 <hr/>

The ottrelite crystals are disc-like, averaging about 0.8 m.m. in diameter and 0.3 m.m. in thickness. They appear black to the unaided eye, and are commonest in the more sericitic portions of the rock, where the discs cut across the foliation planes of the rock far more often than not. In thin sections of the rock they are abundant. Where cut approximately parallel to the vertical axis they exhibit well-defined parallel basal planes with clean cut or ragged sides (*see* Fig. 47).

Such sections show imperfect cleavages both parallel to, and perpendicular to the base. At times a faint hour-glass structure, as described in Rosenbusch \* is seen; polysynthetic twins are common. The mineral is strongly pleochroic, the colours being (a) olive-green, (b) indigo, (c) pale yellow. The Kalgoorlie mineral would appear to agree in all respects with the type ottrelite of Ottrez in Belgium.† Inclusions are very numerous in the crystals.

#### 468A.—PENNINITE, AND 469—PROCHLORITE.

Hydrated silicates of iron magnesium and aluminium belonging to the Chlorite group. Dark green chlorite containing much ferrous oxide is characteristic of the propylites (altered quartz diabases or gabbros) which form the wall rocks of the lodes. During the further crushing and carbonation of the shear zones, which accompanied or immediately preceded the introduction of gold into them, almost the whole of this chlorite was converted into ankerite, magnetite, pyrites, etc. The chlorite in the rocks is either a finely granular, strongly or moderately pleochroic green mineral (prochlorite ?) as seen in [11814], or a very strongly pleochroic (strong green to colourless or pale yellow) mineral in well-defined flakes as seen in [1828], Chaffer's Gold Mine; [1827], Mt. Charlotte; [1983], Brown Hill Extended; [10913], (16a), Don. The latter variety often shows well defined basal planes and occasionally basal twinning in vertical sections. It exhibits a tendency to grow round crystals of secondary pyrites and magnetite, with its basal plane against the faces of the iron mineral. In [10913], (16a), from Don G.M.L., and [10913] from Jacky Hawk's Nest G.M.L., it exhibits strong pleochroic halos round an undetermined colourless mineral, probably apatite.

A mineral similar in most if not all respects to the last described variety of chlorite is seen in sections of lodestuff from several mines. This mineral possesses similar pleochroism and structures, and shows the same tendency to envelop secondary pyrites. Typical examples are:—

[1771]. Westernmost lode, 400ft., Great Boulder Proprietary Gold Mine. A few scattered flakes with sericite, dolomite, pyrites, leucoxene, and primary quartz.

\* Rosenbusch, Idding's translation. Microscopic physiography of rock-forming minerals. Plate XXI., Fig. 3.

† *Ibid.* p. 289, *et seq.*



[10959]. Lode, 550ft., Associated Northern Gold Mine. Moderately plentiful in large irregular flakes. Twinning apparent. Many strongly pleochroic halos round small colourless inclusions of very irregular outline which are probably apatite. The chlorite shows a strong tendency to form round pyrites crystals. A bulk analysis of this ore appears on page 68.

[10845]. Lode, 700ft., South Kalgurli Gold Mine. A fair number of scales of this mineral are seen associated with pyrites.

In much of the ore chlorite occurs only as a very finely disseminated pigment not recognisable except by the green tinge given to the lodestuff in mass.

#### 481.—SERPENTINE.

Hydrated silicate of magnesium with more or less iron,  $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ . Massive dark green serpentine forms the chief constituent of a considerable area of rock on the west shores of Hannan's Lake. The appearance under the microscope shows this mineral to be an altered olivine, *see* Fig. 48. Under the influence of large emanations of carbonic acid certain areas of this rock at Hannan's Lake and close to Kalgoorlie are completely carbonated, the serpentine being converted into a mixture of carbonates and free silica, the latter at the north end of the field entering partly into the composition of fuchsite (chrome mica).

A typical serpentine rock [3294] from Mt. Hunt was found to have the following composition:—

##### *Serpentine-rock, Mt. Hunt.*

$\text{SiO}_2$	..	..	..	..	39.06
$\text{TiO}_2$	..	..	..	..	.51
$\text{ZrO}_2$	..	..	..	..	None
$\text{CO}_2$	..	..	..	..	2.88
$\text{P}_2\text{O}_5$	..	..	..	..	.26
$\text{SO}_3$	..	..	..	..	.37
$\text{H}_2\text{O} +$	..	..	..	..	8.38
$\text{K}_2\text{O}$	..	..	..	..	.08
$\text{Na}_2\text{O}$	..	..	..	..	.12
$\text{CaO}$	..	..	..	..	2.43
$\text{BaO}$	..	..	..	..	None
$\text{MgO}$	..	..	..	..	32.94
$\text{MnO}$	..	..	..	..	.77
$\text{FeO}$	..	..	..	..	5.93
$\text{Fe}_2\text{O}_3$	..	..	..	..	2.77
$\text{Al}_2\text{O}_3$	..	..	..	..	3.36
$\text{V}_2\text{O}_3$	..	..	..	..	.01
$\text{Cr}_2\text{O}_3$	..	..	..	..	.24
$\text{H}_2\text{O} -$	..	..	..	..	.54
					<hr/>
					100.65
					<hr/>
Sp. grav.	..	..	..	..	2.72
					<hr/>

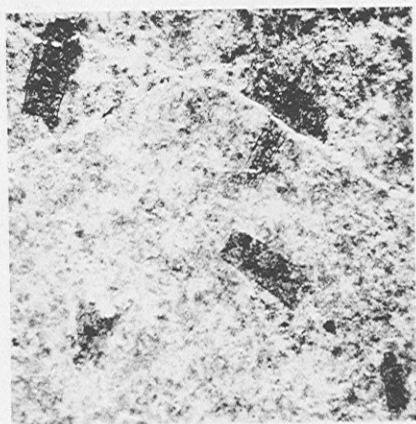


Fig. 47.

[11,107.] O.L.  $\times 15$ .

Photo. by

H. Bowley.

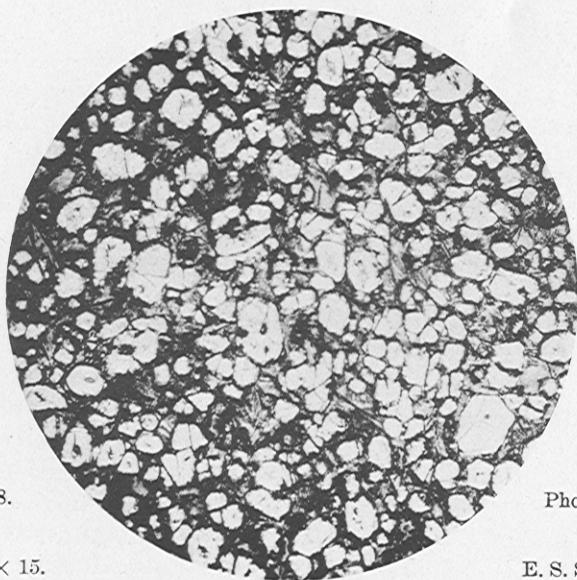


Fig. 48.

[3,218.] O.L.  $\times 15$ .

Photo. by

E. S. Simpson.

Fig. 47.—Ottrelite Schist, Lake View Townsite. Large crystals of Ottrelite in a ground mass of Sericite, Albite, and Ankerite.

Fig. 48.—Serpentine Rock, West side of Hannan's Lake. The Serpentine (white) is plainly pseudomorphous after granular crystalline Olivine. Its fibrous structure is only apparent under crossed nicols.

## 484.—TALC.

Hydrated silicate of magnesium,  $3\text{MgO} \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$ . Early descriptions of the Kalgoorlie field speak of the ore then showing (presumably the oxidised ore of the Great Boulder and adjacent mines) as being a "talcose schist." \* The material thus referred to was a soft white or yellow greasy mixture of kaolin and sericite, the result of the weathering of an albite-sericite-dolomite ore, the dolomite having been completely removed by solution. No true talc has been discovered in any Kalgoorlie ore, either oxidised or unoxidised.

It is rarely found in the district as the product of alteration of rocks rich in magnesium silicate. The following instances have come under the writer's notice :—

[274]. Foliated greenstone, Broad Arrow Road, east of Golden Zone Gold Mine. This is from an area mapped by Mr. Gibson as occupied by an ultrabasic intrusion. It contains a considerable proportion of pale green talc, slightly foliated.

[11100]. Altered amphibolite. This is a massive dark green rock with a greasy feeling, it is soft enough to be scratched by the finger-nail and the rock powder is very unctuous. The rock probably contains a fair proportion of talc.

## 492.—KAOLIN.

Hydrated silicate of aluminium,  $2\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ . This is an important constituent of all the oxidised ores, where it occurs as the result of weathering of albite and, possibly also to some extent, sericite and orthoclase, under the influence of meteoric carbonic acid and of sulphuric acid formed during the oxidation of pyrites.

In an oxidised ore [547] from the 200ft. level of the Lake View Consols Gold Mine, which was analysed, there would appear to be about 17 per cent. of kaolin associated with sericite, limonite, and quartz. Some other oxidised ores in the National Collection showing large proportions of kaolin are :—

[132] and [133], 100ft., Great Boulder Proprietary Gold Mine.

[6], Perseverance Gold Mine.

[6735], 100ft., Ivanhoe Gold Mine.

[138], Opencut, Associated Gold Mine.

[2499], 130ft., Ceresus North Gold Mine.

[10466], 88ft., Hannan's Reward Gold Mine.

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\* Cf. Pittman, Rec. G.S. N.S.W., Vol. VI., p. 10.

White or yellow kaolin forms, with quartz sand, the "wash" or "cement" of the Boulder auriferous deep lead. Examples of such auriferous "wash" are:—

[642] and [645], Ivanhoe Venture Gold Mine.

[656], Golden King Gold Mine.

[2682], Escort Gold Mine.

The surface soil of the Kalgoorlie district consists largely of brown iron-stained kaolin. From this material much detrital gold was obtained in places. Thin beds of white or grey clay are common in the most low-lying parts of the district such as Hannan's Lake.

#### 493.—HALLOYSITE.

Hydrated silicate of aluminium,  $3\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 + n\text{H}_2\text{O}$ . A mineral identical with halloysite or closely related to it was collected from the Lake View and Boulder Junction Gold Mine (*see* [47]). After air-drying for about thirteen years it appears as a soft white wax-like solid, breaking with a sub-conchoidal fracture. It still contained 8.74 per cent. of water, removable at a temperature of 100 degrees C., and a further 17.88 per cent. removable on ignition. The complete analysis was:—

##### *Halloysite, Boulder.*

			per cent.	molecules.
$\text{Al}_2\text{O}_3$	..	..	34.48	337
$\text{SiO}_2$	..	..	36.92	612
$\text{H}_2\text{O} +$	..	..	17.88	993
$\text{H}_2\text{O} -$	..	..	8.74	487
CaO	..	..	.58	
Undet.	..	..	1.40	
			<hr/> 100.00 <hr/>	

#### 505.—CHLOROPAL.

Hydrated silicate of iron,  $\text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot 5\text{H}_2\text{O}$ . A single specimen [272] of this mineral has been collected at Kalgoorlie from near the Rose and Shamrock Gold Mine. It occurs as small yellowish-green waxy masses filling small spaces in a quartz vein.

#### 549.—APATITE.

Fluophosphate of calcium,  $\text{CaF}_2 \cdot 3\text{Ca}_3\text{P}_2\text{O}_8$ . Chemical analysis and microscopic examination shows this mineral to be present in

all the Kalgoorlie ores and rocks. It occurs as clear, colourless crystals or corroded grains of primary origin (Fig. 49), and when embedded in any coloured iron-bearing silicate, such as chlorite or amphibole, frequently gives rise to pleochroic halos in the latter. In such cases it is probably radium-bearing.

The largest amounts of apatite detected in any rocks were :—

[11184]. Propylite, Lake View Gold Mine—Apatite, 2·1 per cent.

[3208]. Porphyrite, Boulder Abattoirs—Apatite, 1·6 per cent.

The smallest amounts were :—

[10913]. Fuchsite-mesitite rock, East of Golden Zone Gold Mine—Apatite, 0·25 per cent.

[3231]. Epidiorite, South-east of Boulder Abattoirs—Apatite, 0·25 per cent.

The quantities in several ores, as indicated by analysis, were :—

[8990]. Sulphide, 820ft., Oroya Gold Mine—Apatite, 0·38 per cent.

[10962]. Sulphide, 2,200ft., Great Boulder Gold Mine—Apatite, 0·48 per cent.

[10938]. Sulphide, Depth (?), Hidden Secret Gold Mine—Apatite, 0·78 per cent.

[10959]. Sulphide, 550ft., Associated Northern Golden Mine—Apatite, 0·88 per cent.

[10964]. Sulphide, 1,900ft., Lake View Consols Gold Mine—Apatite, 1·71 per cent.

#### 552.—VANADINITE.

Chlorovanadate of lead,  $\text{PbCl}_2 \cdot 3\text{Pb}_3\text{V}_2\text{O}_8$ . Mr. A. G. Charleton\* says : “ Vanadate of lead occurs, it is said, in the Associated Mine.” This statement may be correct, but it needs confirmation. Vanadium compounds are fairly abundant in the Kalgoorlie ores, but lead compounds are extremely rare.

#### 683.—NATRONITRITE (SODA NITRE).

Nitrate of sodium,  $\text{NaNO}_3$ .

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\* Gold Mining and Milling in W.A., Footnote on p. 102.



Fig. 49.

Photo. by

[11,003.] P.L.  $\times 110$ .

E. S. Simpson.

Apatite in Amphibolite, Outridge G.M. A corroded grain of Apatite embedded in Uralite and surrounded by a pleochroic halo.

## 716.—THENARDITE.

Sulphate of sodium,  $\text{Na}_2\text{SO}_4$ .

## 718.—GLAUBERITE.

Sulphate of sodium and calcium,  $\text{Na}_2\text{Ca}(\text{SO}_4)_2$ .

These three minerals occur in small quantities in the soil of the Kalgoorlie district. The mild steel pipes conveying water to the field having been found to corrode rapidly in contact with the soil, several samples of the latter were analysed. The following are typical results:—

*Saliferous Soil, Kalgoorlie District.*

Locality, in miles, west of Kalgoorlie				2½	7
Railway Station .. .. .				per cent.	per cent.
Insoluble in water .. .. .	..	..	..	98·774	98·631
Calcium carbonate .. .. .	..	..	..	·026	·017
Calcium sulphate .. .. .	..	..	..	·205	·189
Magnesium sulphate .. .. .	..	..	..	·185	·171
Potassium sulphate .. .. .	..	..	..	·006	..
Sodium sulphate .. .. .	..	..	..	·129	·482
Sodium nitrate .. .. .	..	..	..	·161	·004
Sodium chloride .. .. .	..	..	..	·514	·506
				100·000	100·000

## 719.—BARITE (BARYTES).

Sulphate of barium,  $\text{BaSO}_4$ . In the Monthly Records of the Chambers of Mines of W.A., Vol. I., page 317, Walter H. Ince, Ph.D., F.I.C., says:—"Several sulpho-telluride ores on the Kalgoorlie field contain appreciable quantities of barium sulphate (heavy spar) probably reported as silica, *i.e.*, insoluble portion." The only Kalgoorlie ore in which the writer has seen this mineral is [10964] from the 1,900ft. level, Lake View Consols Gold Mine. This ore is a typical grey schist, with which are associated small veins of chalcedony. Both schist and chalcedony are traversed by minute veinlets of later date and these are filled mainly with dolomite and quartz, but small crystalline blades or grains of white

or pink barite are common in them. These masses of barite are seldom more than one m.m. thick (the width of the veinlet) and two or three m.m. in length. The mineral is sometimes bladed in structure, with the blades lying parallel to the walls of the veinlet.

Several other ores were examined for barium, but only quantities varying from a trace to 0.04 per cent. were detected in ores of the usual type. In two ores of a more basic type more barium was found, viz., 0.13 in ore from the Hidden Secret Gold Mine, and 0.43 in ore from the Fair Play Gold Mine. In the latter case, however, the barium was found to be mainly if not wholly present as carbonate in the dolomite which formed a large proportion of the whole ore.

#### 722.—ANHYDRITE.

Sulphate of calcium,  $\text{CaSO}_4$ . On page 319 of Vol. I. of the Monthly Records of the Chamber of Mines, Dr. Ince says: "In many of the ores on the Golden Mile, Kalgoorlie, large masses of anhydrite are found and it is disseminated through the samples." This statement lacks confirmation. Gypsum, the hydrated sulphate of calcium, is not uncommon, and it is undoubtedly this mineral to which Dr. Ince refers.

#### 746.—GYPSUM.

Hydrated sulphate of calcium,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ . This mineral is fairly plentiful in the ore bodies at about water level, or slightly below, but is not represented in specimens from any considerable distance above or below that level. It doubtless results from the action of sulphuric acid (produced by oxidising pyrites) on dolomite and other calcareous carbonates. It occurs in the transparent colourless crystalline masses known as selenite. In the case of [2360] from the North Kalgurli Gold Mine it forms a single crystalline mass 4ins. long by 2ins. thick. In [3090] from the Lake View East Gold Mine the individuals are smaller and discontinuous, being interrupted by masses of granular quartz and silicates. Mr. L. J. Spencer notes \* that veins of fibrous gypsum penetrate one specimen of lodestuff in the British Museum collection.

Gypsum occurs finely disseminated through the soil of the district and in the dry bed of Hannan's Lake.

The underground water of the district contains much sulphate of lime, which separates out in the form of gypsum crystals when the water is evaporated naturally or artificially.

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\* Loc. cit.



## 748.—EPSOMITE.

Hydrated sulphate of magnesium,  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ . This salt occurs in a minute state of subdivision in the soils of the district, *see* analyses on page 148. Sulphate of magnesium is also an important constituent of the underground waters, which on evaporation yield crystals of epsomite, amongst other salts.

## 809.—EMMONSITE ; 810.—DURDENITE.

Hydrated tellurites of iron. These being the most stable oxidised compounds of tellurium one would expect that they would have been recognised at Kalgoorlie. That they have not been so more generally is doubtless due to the ease with which such scaly or ochreous minerals would be overlooked in an ore consisting largely of iron oxides, clay and sericite. The writer has been unable to detect any such mineral, but the very poor collection of oxidised ores in the Department's museum partly accounts for this. T. A. Rickard \* definitely asserts the presence of one of them in the following words :—

“The tellurite of iron, which Knight was the first to determine, has a light brown colour and a bright yellow streak. It occurs also in a specimen which I obtained at Kalgoorlie through the courtesy of Mr. J. W. Sutherland of the Lake View Consols Mine.”

## 814.—SCHEELITE.

/// Tungstate of calcium,  $\text{CaWO}_4$ . This mineral is one of rare occurrence at Kalgoorlie, being recorded only from two mines, viz., G.M.L. 265 of the Hannan's Reward and Mt. Charlotte Co. and the Brown Hill Extended Gold Mine. In both mines it occurs in fairly large masses associated with rich ore.

/// [5245]. Hannan's Reward Gold Mine. Part of a vein with one wall of well oxidised brown schist, against which is a band of white quartz of varying thickness. On the inside of the quartz is a mass of scheelite which in one part of the specimen reaches 40 m.m. ( $1\frac{1}{2}$  inches) in thickness. It is pale yellow to light brown in colour, very coarsely granular in structure, with numerous cracks running through it. The faces of these are for the most part covered with a very thin film of asbolite. A plate of gold fills one small crack. Except for these two minerals the scheelite is free from any admixture.

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\* Trans. Amer. Inst. Min. Engrs., Vol. 30, p. 712.

[3958] and [5261]. Brownhill Extended Gold Mine. Large masses of coarsely granular scheelite, pale gray in colour and in places translucent. In [3958] a veinlet of quartz is present, in [5261] a fair amount of white granular calcite. Small specks of sulphides are not infrequent. These include pyrites and a black mineral which may be tennantite. It is said that scheelite is associated with rich ore in this mine.

# IV.—SURFACE AND UNDERGROUND WATERS OF KALGOORLIE.

By E. S. Simpson.

Kalgoorlie lies within a section of the State where the rate of evaporation largely exceeds the rate of precipitation of rain, and where the permeability of the soil and surface rocks increases the rapidity with which all surface water disappears. It is only for a few hours following an ordinary rain storm or for a few days after an unusually heavy fall that water is to be found at the surface. At rare intervals only is any quantity of water to be found even in the "lakes" and "clay pans" which occur in the lower lying portions of the district.

The rainfall and evaporation at Kalgoorlie \* during the years of which records are available have been as follow :—

TABLE XVIII.—*Kalgoorlie Rainfall and Evaporation.*

Year.				Inches of rainfall.	Inches of water evaporated.
1896	..	..	..	9.54	No record
1897	..	..	..	4.75	No record
1898	..	..	..	7.18	No record
1899	..	..	..	9.97	66.62
1900	..	..	..	11.71	82.61
1901	..	..	..	8.03	80.48
1902	..	..	..	12.01	89.16
1903	..	..	..	13.20	80.21
1904	..	..	..	10.72	82.93
1905	..	..	..	8.03	84.97
1906	..	..	..	9.05	92.49
1907	..	..	..	8.81	91.62
1908	..	..	..	9.98	87.36
1909	..	..	..	12.86	81.93
1910	..	..	..	9.33	88.59
Average .. ..				9.68	86.61

Owing to the comparatively large proportion of soluble salts present in the soil † and underlying rocks, all surface accumulations of water rapidly become brackish, and, as evaporation proceeds,

\*These figures were kindly supplied by the Commonwealth Meteorological Bureau. The figures quoted for evaporation are really those for Coolgardie, none for Kalgoorlie being available. The conditions at Kalgoorlie, are, however, identical in this respect with those at Coolgardie, which is only 24 miles distant across flat country.

† See page 148.

more and more saline. Despite such unfavourable conditions organic life is not unknown in these pools. In 1909, when a large portion of Hannans' Lake was covered for a short time with water, Mr. L. Glauret found in it countless numbers of a phyllopod resembling *Apus* and of a second crustacean. The water at the time was brackish. Drs. Michaelsen and Hartmeyer found in 1905,\* in a slightly brackish puddle, artificially deepened, on the edge of Hannans' Lake, two species of Phyllopods of the genera *Apus* and *Branchipus*, and many larvæ of a species of fly. They recorded also :—

“Real amphibious animals, tadpoles, larvæ of flies, and Trichoptera, Phyllopods, Planarians, etc. . . . in the smallest puddles of fresh water . . . even in the gold districts of Day Dawn and Kalgoorlie.”

In the early days of the Kalgoorlie field shallow wells were sunk in the bed of Hannan's Lake to supply water to the mines. The composition of this water is indicative of the degree of salinity attained by the surface water of the district when subjected to considerable evaporation.

*Water, Hannans Lake.*

Date	..	..	..	..	..	1895	1899
Analyst	..	..	..	..	..	Earp	Simpson
						per cent.	per cent.
Potassium chloride	..	..	..	..	..	·133	str. trace
Sodium chloride	..	..	..	..	..	5·090	12·837
Magnesium chloride	..	..	..	..	..	·771	1·926
Magnesium sulphate	..	..	..	..	..	·285	·492
Calcium sulphate	..	..	..	..	..	..	·398
Calcium carbonate	..	..	..	..	..	·105	·005
Iron and aluminium oxides	..	..	..	..	..	·105	·004
Silica	..	..	..	..	..	·038	·005
Organic and loss	..	..	..	..	..	·048	..
Total per cent.						6·575	15·667
Specific gravity at 4°						..	1·120

The ground water of the district has been profoundly affected by the advent of civilised man and the strenuous development of the mining industry. The most seriously disturbing elements have been :—

(a.) Opening up of the ground at innumerable points to varying depths up to 2,500ft. ;

(b.) Constant pumping of water from the mines to surface where much of it evaporates or is used up in various ways ;

(c.) Pumping of highly saline water from beneath the dry lake bed up to the higher lying ground round the mines ;

(d.) Introducing into water at the surface various sulphates from roasted ore as well as cyanides and other artificial salts ;

\* Jour. W.A. Nat. Hist. Soc., Vol. II., Part 5, p. 12.

(e.) Introducing daily into the district several millions of gallons of fresh surface water from the Mundaring Reservoir in the Darling Ranges.

With regard to the last factor, which is probably the most important, this water, which is pumped a distance of 400 miles to Kalgoorlie, has the following composition \* :—

TABLE XIX.—*Analyses of Mundaring Water.*

Point where sampled.	Parts per 100,000.		
	Mundaring.	Merredin.	Kalgoorlie.
Sodium chloride .. ..	25·71	25·39	25·49
Magnesium chloride .. ..	5·15	5·54	5·46
Calcium sulphate .. ..	2·31	2·31	2·17
Calcium carbonate .. ..	·57	·66	·78
Magnesium carbonate .. ..	1·37	1·03	·99
Silica .. ..	·28	·34	·38
Iron oxide .. ..	·02	·04	·02
Total mineral solids .. ..	35·41	35·31	35·29
Free carbonic acid, CO <sub>2</sub> .. ..	·88	·75	·68

In consequence of these various disturbing factors only those analyses of ground water made during the first few years of the field's history are of any interest or value from a geological standpoint. Table XX. gives the results of all available analyses.

\*Goldfield Water Supply Administration : Corrosion of Steel Main, Joint Report of Sir Alex Binnie, Son and Deacon ; Sir William Ramsay and Mr. Otto Hehner, p. 4. London, 1909.

*Kalgoorlie Ground-water.*

Ill	Brown Hill Watershaft.	Brown Hill Extd. Mine.	Govt. Bore, Kalgoorlie.	Ivanhoe Mine.	Kalgoorlie Mint Mine.	Ceresus Sth. United Mine.
	trace	..	..	..	..	..
37	3·477	4·487	7·904	3·453	3·056	3·819
	·255	..	·790	..	·648	..
	..	..	..	..	·271	..
·8	·290	·460	·496	·580	..	·463
	..	·130	..	·213	·329	·116
·2	..	..	·993	..	..	..
0	·058	·124	·533	..	..	·232
1	·019	·022	·092	..	..	·020
1	·058	·036	..	·048	·029	·025
9	4·157	5·259	10·808	4·294	4·333	4·675
	Earp 1896	Earp 1897	Earp 1895	Earp 1896	Earp 1896	Earp 1897

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It is regrettable that these early analyses of the ground water were not made in greater numbers and in greater detail, since they are of the highest importance in studying the causes and effects of surface and other local enrichments of the ore-bodies.

Prior to the arrival of the Mundaring water on to the field in 1903, the quantity and quality of local water supplies was a question of the highest technical and social importance. It would, however, under present circumstances be altogether out of place to deal with the subject in the detail demanded by the standpoint of those days. Suffice it to say that with a single exception, viz., that from the well on Mt. Hunt quoted above, all the underground water was far too saline to be drinkable, or to be used without disastrous results in boilers. For both these purposes it was condensed. For wet crushing the water was not unsuitable, but the large proportion of magnesia in it rendered preliminary treatment with lime or other chemical necessary before using it to make up cyanide solutions. Without exception the waters were alkaline in reaction with methyl orange, as was to be expected in the presence of notable proportions of carbonates of calcium and magnesium. No free mineral acid could exist underground in a district where both lodes and adjacent rocks contained abundant carbonates of lime, magnesia and iron, with only minor amounts of pyrites, the oxidation of which latter would give rise to free sulphuric acid but for the presence of excess of neutralising carbonates.

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## V.—NATURAL GAS IN THE BOULDER MINES.

By E. S. Simpson.

Marsh gas (fire-damp) of natural origin has been encountered in at least two of the Kalgoorlie mines, viz., the Associated Northern and Great Boulder Proprietary. The former occurrence is described in detail by the State Mining Engineer in the following words \*:—

"On the 14th May, 1905, an unusual occurrence was met with in the Northern Associated Mine at Kalgoorlie, while boring with a diamond drill, at the 1,048 feet level, there having been a fairly strong outburst of inflammable gas. The 'country' in which the Kalgoorlie lodes exist being igneous rocks of great geological age (probably pre-cambrian), it is difficult to suggest a satisfactory explanation of the phenomenon. It is possibly connected with the common occurrence of graphite in the so-called 'graphite slates' of the district, which appear to be the filling of fault fissures, and are most probably formed by the attrition of the walls of the faults one against the other. These 'slates' are often highly impregnated with very finely divided pulverulent graphite. The existence of carbonaceous matter in the country may have some connection with the genesis of gold in the lodes of Kalgoorlie, and the following notes on the outbreak of gas are put on record as being possibly of use in future investigations on the problem. The outburst of gas is described by Mr. J. O. Hudson, Inspector of Mines, thus—

'The gas was located in a bore-hole at the 1,048 feet level, in a cross-cut 310 feet west. The hole had an inclination of 60 degrees to the east. About three o'clock, 14th ult., the drill had reached a depth of 687 feet, when a rush of gas occurred, and, coming in contact with one of the candles, became ignited. It burned for a considerable time. The men escaped, one being very slightly burnt on the arm. The foreman of the drill states that the pressure rose from 80lbs. to 200lbs. per square inch. The following morning the pressure was 20lbs. the gas coming away in rushes. Safety lamps were obtained from the School of Mines and the rods drawn, while doing so the gas forced the water from the bore about 10 feet in height. The odour of the gas was identical with naphtha, and it gave a blue flame. The drill core, where the gas was tapped, is mineralised greenstone with small quartz seams. After the drill was withdrawn, an endeavour was made to fill the hole with water, but this was found impracticable. The hole having previously been overflowing this points to the existence of a cavity, but the drill did not locate one. This morning the hole was again overflowing, and a sample of gas was obtained. The position of the drill should be in close proximity to a band of graphite schist, according to the position of this in the upper levels.'

Two days later there was still a little gas issuing from the bore, but it soon ceased. The samples of gas collected were analysed by Mr. E. A. Mann, Government Analyst, with the following result:—

. . . . . It was odourless. . . . . No absorption by fuming sulphuric acid; absence of heavy hydrocarbons. No absorption by cuprous chloride; absence of carbon monoxide. . . . . No combustion with palladium; absence of hydrogen.

The quantitative analysis of the samples differed somewhat, that contained in a bag (gas) was probably altered by diffusion, and that in the bottle may also have been affected through being collected over water. These differences due to methods of sampling are not, however, of great importance.

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\* An. Rept. Dept. Mines for 1905, page 98.

## COMPOSITION OF GAS.

	In bag.	In bottle.
Carbon dioxide .. .. .	·28	·33
Oxygen .. .. .	5·36	7·70
Methane .. .. .	56·50	42·50
Nitrogen (by difference) .. .. .	37·86	49·47
	<hr/> 100·00	<hr/> 100·00

The core from the bore was examined by Mr. L. K. Ward, Lecturer in Mineralogy at the School of Mines, Kalgoorlie, who says :—

“ . . . . The core from the gas-bearing zone . . . . consists of sericite schist which has been greatly crushed. . . . In spite of a careful examination of all the constituents of this brecciated zone under the highest powers of the microscope, I fail to recognise any remarkable percentage of gaseous inclusions. Neither do I find any trace of graphitic matter in those portions of the core which I have sliced. Therefore I am forced to the conclusion (which of course, may quite possibly be reversed by subsequent examination) that the gases have their origin outside this brecciated zone of schist, into which they have penetrated on account of the readier access that would be afforded by the crushed zone rather than by the uncrushed rock.”

In the *Australian Mining Standard* of 28th June, 1905, the Western Australian correspondent describes the occurrence of natural gas at this mine and the paragraph concludes with the statement—

“ Similar occurrences to this have previously been reported in the adjoining Oroya East Block, and also in the Golden Link lease at the south end of the field.”

There is no official record of the last mentioned occurrences, but quite recently a similar gas was encountered in the workings of the Great Boulder Proprietary Gold Mine, and the manager, Mr. Richard Hamilton, kindly supplied the following particulars to the Inspector of Mines at Kalgoorlie :—

“ In response to your request for a report on the occurrence of gas in the Great Boulder main shaft, I have much pleasure in sending you the following particulars :—

Yesterday morning I interviewed Messrs. C. Wreford, H. Riggs, R. Poole, H. Carter, and G. Stevenson, who had been engaged in sinking the shaft. With the exception of Riggs all the others had seen the gas burning. When I spoke to you on this matter before, I was under the impression it was the gas struck in drilling that ignited. This is not so. Gas was most abundant when pulling down the laminations of graphitic slate, and all the men with the exception of Riggs had seen the gas take fire. The noise of ignition was very slight, being little more than a puff, and then afterwards the sheet of flame would dwindle down to small jets of flame of bluish colour here and there along the face of the slate. All the men agree in saying that when the bottom of the shaft was covered with water the gas freely bubbled through it. Most gas escaped when there was most graphite to be seen. I have also learned that at the 2,500 feet level, north end, gas has been found, the eastern wall of the level being graphite slate in places. The men did not feel any ill effects while working in the gas. They stated that when shovelling if they stood up quickly, they felt a bit giddy.”

In all these cases there would appear to be a direct connection between the gas and the graphite schists, the gas being encountered either actually in such rocks or in fractured rocks close to, and in direct communication with them. This lends support to the theory long held by the writer, and apparently shared by the State Mining Engineer, that the "graphite slates" found in lenticular masses in the heart of large areas of amphibolite and greenstone schist, at Kalgoorlie, Cue, Coolgardie, and elsewhere, are in reality shear zones in the greenstone into which hydrocarbons of volcanic origin have penetrated, depositing finely divided carbon in them during slow combustion. This oxidation may have been at the expense of oxygen in the pores of the rock, or at the expense of ferric compounds capable of reduction to a lower state of oxidation.

In a letter to the *Engineering and Mining Journal*, dated 23rd January, 1902, Mr. W. A. Pritchard says :—

"Carbonic acid gas is met with in some boreholes. One in the Lake View Consols has given off this gas for the past two years."

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## VI.—THE CONSTITUTION OF THE NATIVE TELLURIDES.

By E. S. Simpson.

An article \* published by Dr. Victor Lenher in 1909 entitled "Some observations on the Tellurides" raises some most interesting questions as to the constitution of the native tellurides and the means whereby they have been introduced into auriferous deposits. The concluding paragraphs are these :—

"From the experimental evidence at hand, it would seem that the tellurium gold minerals partake more of the nature of alloys than of chemical compounds.

"The manner in which the gold and tellurium are united is an unusually difficult problem to approach, and thus far little of definite character, so far as the constitution of these minerals are concerned, has been established. The experimental data which is available all seems to point to the non-existence of a definite artificial telluride, the artificial products being largely of the nature of alloys and in general character resembling the telluride minerals."

There are five forms in which solid mineral substances occur, viz. :—

- (1.) A pure element.
- (2.) A true chemical compound.
- (3.) A mechanical mixture of elements or chemical compounds.
- (4.) A crystalline solid solution.
- (5.) An amorphous solid solution.

Native tellurium and a few other native elements may come under Group (1), but the tellurides all contain more than one element, and cannot therefore belong to this group. Being crystalline they cannot be classed, with such substances as obsidian, in Group (5), but must belong to one of the three remaining groups. / / /

The fundamental characteristics of a chemical compound are that wherever or however obtained it is always perfectly homogeneous and contains the same elements in the same definite proportion, and that it cannot be separated into two or more simpler bodies by purely mechanical means, such as by hand picking, by flotation in heavy solutions, etc. A chemical compound has usually a definite orientation of its molecules which finds expression in a characteristic crystalline form. The etching of a polished surface of a single crystal of a chemical compound will not reveal any differences of texture between different portions of the same surface, but the etching of a polished surface of an agglomeration of crystals may reveal slight differences due to varying orientation of individual crystals. Only a minority of minerals are simple chemical compounds, common instances of such are to be found in quartz and pure calcite. It should be remembered that minerals are

\* Victor Lenher: "Some Observations on the Tellurides," *Economic Geology*, Vol. IV., p. 544.

formed under conditions extremely favourable to contamination, and the presence of a relatively small amount of mechanically entangled impurity would not justify one in saying that a certain mineral was not a true chemical compound any more than the presence of a small amount of suspended clay in water would be justification for declaring that water was not a true chemical compound.

A mechanical mixture is a more or less intimate intermingling of two or more different elements or compounds, each retaining their individuality and distinguished readily by etching of a polished surface of the mixture, and separable more or less perfectly by specific gravity methods or other like mechanical means. The size of the individual particles may vary within wide limits, the smallest sizes being only distinguishable as a mixture under the highest powers of the microscope. It is obvious that there is no limit to the variations in chemical constitution of a mixture. Also a mixture has not a specific individual crystalline outline. All rocks and other mineral aggregates are of this nature.

A solid solution (as found in minerals) is a very special case of mixture, only arising under such restricted conditions that the result is an approximation to a chemical compound. It resembles a mechanical mixture in that it consists of an intermingling of variable amounts of two or more substances without rearrangement or interaction of the atoms constituting the molecules of each. It resembles a true chemical compound in that the constituent molecules are for the most part chemically equivalent and very similar to one another in constitution, though not chemically identical, and their molecular volumes and crystalline forms are identical or almost so. Further the intermingling is perfect and on a molecular scale, so that there is perfect homogeneity within the limits of a single crystal and no heterogeneity can be detected by etching of a polished surface or by mechanical methods of separation. The individual members of a solid solution are not devoid of orientation as are the members of a mechanical mixture, on the contrary all the molecules are definitely orientated, the result being that a solid solution has a characteristic crystalline form which is the mean of the closely related forms of its components. The majority of minerals are such solid solutions.

Alloys are most frequently mechanical mixtures, rarely, however, they are true chemical compounds or solid solutions, so that Lenher's conclusions do not in themselves convey any definite idea as to what he considers the constitution of the native tellurides to be. Taken in conjunction with the rest of his paper it is evident, however, that he considers that they are not true chemical compounds nor, like so many other minerals, solid solutions of two or more definite isomor-

phous compounds. He would seem to infer that in the case of native tellurides we are dealing with an intimate mixture of tellurium with gold and with silver, or possibly with silver telluride. His chief arguments are: that hitherto it has been found impossible to form a telluride of gold by precipitation of a gold solution with hydrogen telluride or an alkali telluride, or by coprecipitation of gold and tellurium by reducing agents; that the tellurium in these minerals behaves chemically as it would in a mixture, thus it will precipitate gold quantitatively from solutions of gold chloride, and will interact with oxidising agents with liberation of free unaffected gold; that at a moderately low temperature in a neutral atmosphere the tellurium can be wholly volatilised leaving pure gold or a mixture of gold and silver behind\*; finally, that it appears impossible to construct a structural formula for the gold tellurides.

Whilst no fault can be found with the experimental work carried out by Lenher, the results obtained will bear a totally different interpretation as will be shown. Some of Lenher's mineralogical premises are incorrect, thus he has assumed that "kalgoorlite" and "coolgardite" were true mineral species. but Spencer has shown that these names were applied to chance mixtures of petzite, coloradoite, etc. Again he speaks of montanite as a tellurate of mercury derived from coloradoite (telluride of mercury), whereas montanite is a tellurate of bismuth derived from tetradyte (telluride of bismuth). And again "Genth regarded coloradoite as a telluride of mercury, but by reason of its content of gold and silver it may be regarded as related to kalgoorlite." We now know that coloradoite is a perfectly pure telluride of mercury containing neither gold nor silver, though often associated closely with gold bearing tellurides such as petzite.

Analysis leads one to the conclusion that native tellurides of gold and silver contain molecules whose empirical formulæ are:—

$\text{Au}_2\text{Te}$ , in petzite.

$\text{Ag}_2\text{Te}$ , in petzite, hessite.

$\text{AuTe}_2$ , in calaverite, krennerite, sylvanite, nagyagite (?).

$\text{AgTe}_2$ , in calaverite, krennerite, sylvanite.

and that they do not contain any excess of gold, silver, or tellurium over and above the amounts required to form these molecules.

$\text{Au}_2\text{Te}$  and  $\text{Ag}_2\text{Te}$  are normal compounds of univalent gold and silver with the structural formulæ:—

$\text{Au-Te-Au}$

$\text{Ag-Te-Ag}$ .

$\text{AuTe}_2$  and  $\text{AgTe}_2$  would, however, appear to be impossible compounds of univalent silver and gold or trivalent gold, since, as Lenher shows, no structural formulæ can be assigned to them. But the

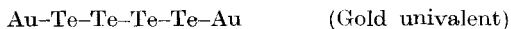
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\*T. K. Rose says not, *vide infra*, p. 165

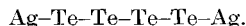
same analytical figures which yield the empirical formulæ,  $\text{AuTe}_2$  and  $\text{AgTe}_2$  are completely satisfied also by the formulæ,  $\text{Au}_2\text{Te}_4$  and  $\text{Ag}_2\text{Te}_4$ , which are quite possible compounds with the structural formulæ :—



or—



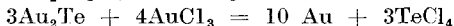
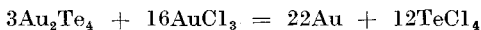
and—



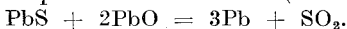
In view of the extent to which these compounds replace one another isomorphously in calaverite, krennerite, and sylvanite, the second of the two structural formulæ for the gold compound is probably the correct one. In any case the empirical formulæ,  $\text{AuTe}_2$  and  $\text{AgTe}_2$ , cannot be upheld, it is better to replace them by  $\text{Au}_2\text{Te}_4$  and  $\text{Ag}_2\text{Te}_4$ .

Calaverite, sylvanite, and krennerite are undoubtedly solid solutions of the two definite isomorphous compounds,  $\text{Au}_2\text{Te}_4$ , and  $\text{Ag}_2\text{Te}_4$ . Lenher's first objection to this, viz., the supposed impossibility of such compounds existing has been dealt with above and shown to have no weight. The second objection was the failure on his part to form  $\text{Au}_2\text{Te}$ ,  $\text{Au}_2\text{Te}_4$ , or  $\text{Ag}_2\text{Te}_4$  in the wet way, though  $\text{Ag}_2\text{Te}$  was easily formed.\* On the other hand Rose, by fusion of tellurium and gold, obtained clear evidence of the formation of  $\text{Au}_2\text{Te}_4$ . Failure to produce the other compounds indicated, under laboratory conditions, does not lead one to the conclusion that it is impossible for them to form under any conditions whatever. Many well established mineral compounds have not yet been prepared artificially, for the reasons that it is difficult to ascertain the exact conditions under which they have been formed in nature, and having ascertained them to repeat those conditions in the laboratory.

The fact that native tellurides of gold will precipitate metallic gold from solutions of gold chloride in accordance with the equations :—



is no argument in support of the contention that the tellurium is not in chemical combination with the gold, even if these reactions should prove to be of a unique type. What would appear to be a parallel instance is the precipitation of lead by the interaction of lead sulphide and lead oxide (both undoubted compounds), thus—



\* Recently, G. Pellini and E. Quercigh have, by the freezing-point method obtained evidence of the existence of the two compounds  $\text{Ag}_2\text{Te}$  and  $\text{AgTe}$ . See Atti R. Accad. Lince, XIX., ii., 415.

The only apparent difference is that in the former case water is the ionising solvent, in the latter case, a lead slag.\*

The final argument of Lenher against the presence of tellurium in combination in the auriferous tellurides is the ease with which the tellurium can be oxidised whilst the gold is left unaffected. This again can be interpreted differently. It is simply a statement that tellurium readily combines with certain non-metallic elements such as oxygen to form stable compounds whilst gold does not. Thus on roasting  $\text{Au}_2\text{Te}_4$  or  $\text{Au}_2\text{Te}$ , volatile  $\text{TeO}_2$  is formed and metallic gold remains. Similarly in roasting mercury sulphide (an undoubted chemical compound),  $\text{SO}_2$  is formed and metallic mercury results. Again in the wet way potassium permanganate oxidises the tellurium to  $\text{TeO}_2$ , but leaves the gold unaffected. This would, however, be the result whether the gold and tellurium were either mixed or combined since neither oxides of gold nor aurates of the alkalis appear to be formed under these circumstances with alkaline permanganate. On the other hand when one of these minerals is attacked by a substance capable of forming a stable compound of both gold and tellurium, both are equally readily attacked as is the case when a telluride is treated with *aqua regia*.

The breaking up by heat in a neutral atmosphere of a gold telluride into pure gold and pure tellurium is a simple case of dissociation which can be paralleled in the case of innumerable undoubted compounds.†

Some other aspects of the problem have not been touched upon by Lenher. One of the most important is the question of crystalline form. When two crystalline substances grow together in evident admixture, this mixed mass has either no crystalline form whatever or else the component in larger amount (in rare instances the component in minor amount) forms large crystals which envelope the particles of the other component, and the mixture thus appears to have *in toto* the crystalline form of the major constituent. No mechanical mixture can have a crystalline form of its own, independent of those of its components. Gold crystallises in the isometric system, tellurium in the rhombohedral. A mixture of the two without chemical combination would therefore either have no crystalline form or would show the isometric form if gold predominated or the rhombohedral if tellurium. The native tellurides, sylvanite and calaverite, are, however, monoclinic in form, krennerite and nagyagite are orthorhombic; only petzite is doubtfully isometric.

\* Since the above was written an article entitled "Notes on Tellurium-bearing gold ores," by W. G. Sharwood, has appeared in *Economic Geology*, Vol. VI., p. 22. Mr. Sharwood, who attacks this argument of Prof. Lenher, quotes the interaction of lead oxide and lead sulphide. A further instance he adduces is  $2\text{H}_2\text{S} + \text{SO}_2 = 3\text{S} + 2\text{H}_2\text{O}$ .

† T. K. Rose found in the case of alloys of gold and tellurium, that the dissociation was never complete, some gold volatilising with the tellurium, and some tellurium being held tenaciously by the gold. See T. K. Rose, *Metallurgy of Gold*, p. 7.



Amongst the surest tests of a substance, mineral or otherwise, being a single chemical compound are a uniformity in percentage composition, and the correspondence of such composition to a simple molecular ratio. In the case of minerals which are solid solutions in variable proportions of two or more definite chemical compounds, the various analyses should be capable of division into two or more corresponding parts, each of which will satisfy the conditions of a chemical compound isomorphous with the others. These principles must be applied to the native tellurides of gold. Of all these sylvanite appears at first sight to be the most erratic in composition and therefore most likely to prove an intimate admixture in quite indefinite amounts (an "alloy" in the sense used by Lenher) of gold, silver, and tellurium. The following figures are, however, the results of a critical analysis of the chemical composition shown for several specimens of Kalgoorlie sylvanite:—

TABLE XXI.—*Kalgoorlie Sylvanite.*

## PERCENTAGE COMPOSITION—

Gold .. .. .	36.60	29.85	33.07	26.1
Silver .. .. .	3.82	9.18	6.46	11.4
Tellurium .. .. .	58.63	60.45	(60.47)*	(62.5)*

## ATOMIC RATIOS—

Gold .. .. .	22	10	28	22
Silver .. .. .	4	6	10	18
Tellurium .. .. .	52	16	76	80

## EQUIVALENT TO MOLECULES—

$\text{Au}_2\text{Te}_4$ .. .. .	11	5	14	11
$\text{Ag}_2\text{Te}_4$ .. .. .	2	3	5	9

None beyond the bounds of analytical error.

Excess of Au, Ag, or Te.

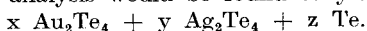
By the application to sylvanite of the rules ordinarily applied to calculations of mineral formulæ it is found that the apparently irreconcilable analyses of various specimens of sylvanite indicate solid solutions in every case of the two isomorphous compounds  $\text{Au}_2\text{Te}_4$  and  $\text{Ag}_2\text{Te}_4$ .† Were sylvanite an "alloy" (in Lenher's sense) or a mixture ungoverned by the rules of chemical combination, we should have in some cases at least an excess of either gold, silver, or tellurium over that required by the formula—



or as usually written by mineralogists—



and the analysis would be found to yield some such formula as



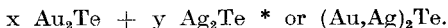
The same reasoning applied to the case of calaverite indicates that that mineral is also a solid solution of  $\text{Ag}_2\text{Te}_4$  in  $\text{Au}_2\text{Te}_4$ , the

\* Includes a little copper, iron, nickel, etc.

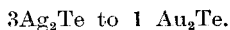
† A series of specific gravity determinations of the highest accuracy would be helpful in regard to this question.

proportion of  $\text{Ag}_2\text{Te}_4$  in this case being very small and the form and composition approaching that of pure  $\text{Au}_2\text{Te}_4$ .

In the case of petzite one is dealing with a solid solution (perhaps a double salt) of different compounds, viz.,  $\text{Ag}_2\text{Te}$  and  $\text{Au}_2\text{Te}$ . The formula for this mineral is:—



The relative proportions of  $\text{Au}_2\text{Te}$  and  $\text{Ag}_2\text{Te}$  in this case being fairly constant, never far from—



This would lead one to suspect either a double salt or else a solid solution of two compounds which do not mix in all proportions but become at certain strengths mutually saturated. In this connection it is interesting to note, in the Hidden Secret Mine, hessite (pure  $\text{Ag}_2\text{Te}$ ) in contact with petzite. Evidently one molecule of  $\text{Au}_2\text{Te}$  is saturated by three molecules of  $\text{Ag}_2\text{Te}$ .

The case of krennerite requires further investigation. If it were a solid solution of  $\text{Au}_2\text{Te}_4$  in  $\text{Ag}_2\text{Te}_4$  we should expect its form to be monoclinic and not orthorhombic. The study of analyses of this mineral leave no doubt, however, of its being a solid solution of two definite compounds  $(\text{AuTe}_2)_n$  and  $(\text{AgTe}_2)_m$ , where the value of "n" remains still to be discovered. The apparently anomalous crystalline form is probably due to polymerism and isodimorphism in the case of the compounds having the composition—

Gold, 43.6 per cent. ; Tellurium, 56.4 per cent. ; and

Silver, 29.7 per cent ; Tellurium, 70.3 per cent.

In the case of nagyagite we have not sufficient first-class analyses to enable a formula to be even guessed at, some authorities alleging the presence of 7 per cent. of antimony in this mineral, others denying the presence of any except as a contamination with stibnite or jamesonite.† Its crystalline form being invariable it is almost certainly a simple chemical compound or a solid solution of two or more isomorphous compounds.

The conclusions arrived at are—

(1.) Several native tellurides are simple chemical compounds, *e.g.* coloradoite ( $\text{HgTe}$ ), hessite ( $\text{Ag}_2\text{Te}$ ).

(2.) Most native tellurides, including all the auriferous tellurides, are crystalline solid solutions of two simple chemical compounds. *e.g.*, sylvanite and calaverite ( $x\text{Au}_2\text{Te}_4 + y \text{Ag}_2\text{Te}_4$ ). In this respect they are identical with the majority of well known minerals such as the triclinic feldspars, the various garnets, fahl ore, tantalite, etc., etc.

(3.) No native tellurides can be considered "alloys" in the sense of Lenher, *i.e.*, more or less intimate mixtures of tellurium with the metals, ungoverned by any of the laws of chemical combination.

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\* Never  $x\text{Au}_2\text{Te} + y\text{Ag}_2\text{Te} + z\text{Au}$  nor  $x\text{Au}_2\text{Te} + y\text{Ag}_2\text{Te} + z\text{Ag}$ .

† See footnote to page 108.

## VII.—THE ANALYSIS OF TELLURIDE MINERALS.

By E. S. Simpson.

Native tellurides of the metals are sufficiently rare to have escaped detailed attention in most works on analytical chemistry. As the estimation of their constituents presents some difficulties not otherwise encountered, it will not be out of place here to give some details of methods which have been used with success by the writer and others.

For analytical purposes a distinction must be drawn between those minerals which contain only very small amount of gold and those which contain an appreciable percentage. Table XXII. gives the theoretical composition of the best known tellurides.

---

*tical Composition of Native Tellurides.*

cury.	Copper.	Nickel.	Lead.	Bismuth.	Antimony.	Tellurium.	Selenium.	Sulphur.
..	..	..	..	..	..	100	..	..
..	..	..	..	52	..	48	..	×
..	..	..	..	..	..	37	..	..
..	..	..	..	..	..	33	×	..
..	40	..	..	..	..	60	..	..
..	..	..	62	..	..	38	..	..
1	..	..	..	..	..	39	..	..
..	..	10	..	..	..	81	..	..
..	..	..	..	..	..	63	..	..
..	..	..	..	..	..	45	..	..
..	..	..	..	..	..	57	×	..
..	..	..	55	..	7	20	×	8

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In this table the symbol "X" indicates that that particular constituent, though not an essential one, has been found on occasion in quantities exceeding one per cent. Quantities of copper and selenium up to one-half per cent. are common in all tellurides, and other metals such as iron and nickel are frequently found in minute amounts.

As the presence of gold and silver has a modifying influence on the methods of estimating the other constituents, these elements should be looked for at the outset. Very accurate results for these constituents have been obtained in a short time by careful cupellation. The process followed is :—About one-fifth of a gramme of coarsely powdered mineral is weighed out on an assay balance and transferred to a small lead foil dish weighing 20 grammes. This is folded up and placed in a preheated mabor cupel, and cupelled at a moderate heat. The resulting button is weighed and parted and the parted gold weighed. The gold and silver absorbed by the cupel are recovered by grinding up the cupel and fusing with the following charge (for a 50 gramme cupel) :—

	grammes.
Sodium bicarbonate .. ..	40
Borax (calcined) .. ..	15
Glass powder .. ..	20
Fluor spar .. ..	30
Argol .. ..	3

The resulting lead button is cupelled as before in a mabor cupel, and the second small doré button thus obtained weighed, and parted.

A correction is made for any gold or silver in the lead foil used. The following figures show the comparison between results obtained by this and by wet methods.

*Calaverite Kalgoorlie.*

	By cupellation.	By wet process.
Gold .. ..	42.41 per cent.	42.41 per cent.
Silver .. ..	0.62 per cent.	0.61 per cent.

Having determined the proportion of gold present, the analysis by wet methods is proceeded with. It will differ according as the gold is less than one-half per cent. in amount or greater

"A"—*Gold less than 0.5 per cent.*—This method is applicable to tetradymite, rickardite, altaite, coloradoite, and melonite. About 0.5 gramme of finely powdered mineral is placed in a small beaker and covered with 20 to 30 cc. of dilute (5E) nitric acid, and warmed till solution is complete, the liquid being finally boiled. If there is a slight residue of gold, the solution is diluted slightly, cooled, and filtered. In these cases, where the gold is less than 0.5 per cent., the small amount of tellurium retained by it may be neglected,

it would certainly be well under 0.1 per cent. One or two drops of hydrochloric acid \* are stirred into the solution which is then allowed to stand to separate any  $\text{AgCl}$  which is filtered off. The filtrate is evaporated to complete dryness on a water bath, and the residue taken up by warming with 5E hydrochloric acid and the solution diluted. Sulphuretted hydrogen is passed to saturation and the precipitated sulphides are filtered off on a tared filter and washed well with  $\text{H}_2\text{S}$ -water. In the filtrate traces of iron are precipitated with ammonium chloride and ammonia after boiling off all  $\text{H}_2\text{S}$ . The ammoniacal filtrate is tested with  $\text{H}_2\text{S}$  for nickel and zinc.

The freshly washed sulphides of tellurium, copper, mercury, etc., are treated with hot yellow ammonium sulphide (if much mercury is present) or potassium sulphide (if much copper is present), and washed well with water containing a trace of the reagent, and finally with  $\text{H}_2\text{S}$  water. This extracts all sulphur and sulphides of tellurium, selenium, and antimony. The residue in the case of coloradoite is pure  $\text{HgS}$ , which is dried at 100 degrees, and weighed on the tared filter. † After drying and weighing it is ignited gently and any residue weighed and tested for copper, etc.

In the case of tellurides other than coloradoite, the sulphides insoluble in alkaline sulphide are treated in the usual way for the estimation of lead, copper, and bismuth.

The alkaline solution of tellurium, and possibly selenium and antimony, is evaporated down to about 20 cc. Excess of concentrated nitric acid is then added and the covered beaker heated until all action has ceased. The acid solution is evaporated to dryness and the residue taken up with a little hydrochloric acid and water. The solution is diluted and sufficient sodium sulphite added to neutralise the greater part of the hydrochloric acid. The solution is then saturated with gaseous sulphur dioxide and set aside in a warm place for 24 hours. The tellurium and selenium are filtered off on a Gooch filter and washed well with dilute sulphurous acid. Finally they are washed twice with 6 to 1 alcohol, twice with absolute alcohol, and twice with ether, and then dried at 100 degrees and weighed. The alcoholic and etherial washings are rejected. The main filtrate is treated with a little more sodium sulphite and again saturated with  $\text{SO}_2$  to recover any further tellurium. After removing all the latter the final filtrate is boiled to remove sulphur dioxide and any antimony precipitated with  $\text{H}_2\text{S}$ . Any precipitate found is dissolved in hydrochloric acid and titrated with permanganate.

After weighing the tellurium, it is dissolved in dilute (5E) nitric acid, evaporated to dryness and taken up in 10E hydrochloric

\* A minimum should be used. One drop of 10E  $\text{HCl}$  precipitates about 0.05 gm. of silver.

† *Vide* Spencer, loc. cit.

acid. The strongly acid solution is put in a glass stoppered bottle and saturated with sulphur dioxide and allowed to stand for 24 hours. Selenium is thus precipitated as a brick red granular powder. If contaminated with tellurium it will be darker, even black in colour. In this case the main part of the supernatant liquid (containing the greater part of the tellurium in solution) is decanted off, the remainder with any precipitate transferred to a beaker, evaporated to dryness, dissolved in nitric acid, again evaporated to dryness and the residue taken up in concentrated hydrochloric acid and treated as before. Any selenium is weighed on a Gooch crucible as such.

"B."—*Gold exceeds 0.5 per cent.*—From 0.5 to 1.0 grmme of finely powdered mineral is heated with 20 cc. 5E nitric acid until all action ceases. The solution (Sol.A) is decanted through a small filter and the residue well washed with water. The residue is treated with a little *aqua regia* till completely dissolved and then poured through the same filter to dissolve any small particles of gold, etc., adhering to it, the filter being well washed with water. The filtrate is evaporated almost to dryness, diluted with water and allowed to stand till all silver chloride has separated out, when it is again passed through the same filter (Sol.B). Any silver chloride adhering to the filter is dissolved in a minimum of ammonia water and added to solution A.

Solution "A."—This contains all silver and base metals, together with most of the tellurium and selenium. A few drops of hydrochloric acid are added to it and the solution allowed to stand for 24 hours when AgCl is filtered off on a tared filter, washed with water, dried at 100, and weighed. The filtrate is added to Solution "B."

Solution "B."—This contains all constituents but silver. It is evaporated to fumes with 10 cc. 10E sulphuric acid. Whilst still fuming any telluride oxide is reduced to tellurous by addition of a little solid potassium bromide. The whole is then taken up with a minimum of hydrochloric acid and water, the solution diluted, and H<sub>2</sub>S passed to saturation. The precipitate is filtered and washed with H<sub>2</sub>S-water. The filtrate is examined in the usual way for iron, nickel, and zinc.

The residue of sulphides is treated on the filter with warm colourless potassium sulphide which dissolves all tellurium, selenium, and antimony, and some of the gold (Sol. C). The residue is dissolved in *aqua regia* (Sol. D).

Solution "C."—This is evaporated nearly to dryness, oxidised with nitric acid and treated as described under method "A" to recover all tellurium and selenium together with any gold.

Solution "D."—This contains most of the gold and all copper, bismuth, etc. It is evaporated to dryness to remove all nitric



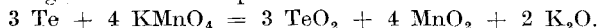
acid and taken up with hydrochloric acid. The operation is repeated and the residue finally taken up with water and HCl. It is then nearly neutralised with sodium sulphate and saturated with sulphur dioxide. The precipitated gold is caught on the same filter as that containing the tellurium and balance of the gold, and the whole washed as previously described, dried at 100 degrees and weighed as gold plus tellurium plus selenium.

The selenium is determined as previously described.

The gold may be estimated by the cupellation method and checked in the wet way on a fresh portion of the mineral or on the combined precipitate as follows. The precipitate or one gramme of mineral ground fine is warmed with 5E nitric acid until all action ceases, diluted somewhat and filtered. The filtrate is rejected. The residue contains the whole of the gold together with part of the tellurium and silver. It is dissolved in *aqua regia*, evaporated twice to dryness over the steam bath with HCl, and taken up with a little of the same acid and water, making solution up to about 150 cc. Ten grammes of pure oxalic acid are added, and the solution boiled until all the gold is precipitated, when it is filtered off on to a weighed paper of Gooch filter and weighed.

When the amount of material available is very small the filtrates from the gold estimation are used for the estimation of the other constituents. The oxalic acid is removed by evaporation with 17E nitric acid and the acid expelled by evaporation with sulphuric acid. The tellurium is then reduced to the lower oxide by potassium bromide as described above.

Lenher \* describes a good volumetric method for the estimation of tellurium in tellurides of gold and silver. The finely powdered mineral is boiled for several hours † with a measured amount of an alkaline solution of permanganate of known strength. The following reaction takes place:—



The gold and silver are unaffected. When the mineral is completely decomposed the permanganate used up is estimated by adding excess of a standard solution of ferrous ammonium sulphate and titrating with standard permanganate.

\* Economic Geology, Vol. IV., p. 554.

† Fifteen in one experiment quoted.

## APPENDIX I.\*

*Die Tellurerze Westaustraliens (The Telluride Ores of Western Australia), by P. Krusch. Translated from "Zeitschrift für praktische Geologie" for June, 1901, by E. S. Simpson.*

The year 1886 was the first in which West Australia appeared as a gold producing country, with an output of 302ozs.; ten years later the output reached 281,265 ozs. In 1896 the highly important discovery of telluride gold ores was made at the Great Boulder Main Reef Mine, Hannans' District. These tellurides had not been previously recognised there, only quartz reefs with free gold and auriferous pyrites having been worked. Immediately attention was directed to these peculiar ores, at first sight unimportant, but yet wonderfully rich in the precious metals, they were soon found in many places, and there appeared a previously unexpected increase in the gold production. Already in 1897 it had more than doubled (674,994 ozs.), in 1898 it reached over a million ozs., in 1899 over  $1\frac{1}{2}$  million (1,606,460ozs.), and in 1900 over  $1\frac{1}{3}$  million ozs.

In 1899 Western Australia stood third on the list of gold producing countries—Transvaal, 3,529,826ozs.; U.S.A., 3,391,196ozs.; Western Australia, 1,606,463ozs. For 1900 no comparison can be made owing to the abnormal state of the gold market consequent on the Transvaal war.

## GEOLOGY.

The extraordinarily rich gold-telluride deposits lie in a district whose geological structure is comparatively simple. On the Archean formation, consisting of gneiss, granitic rocks and schists, which constitute the greater part of the Western Australian tableland, rest small areas of strata of Cambrian, Silurian, Devonian, Carboniferous, Mesozoic, and Cainozoic ages.

The chief matrices of the gold deposits are the older metamorphic rocks, which are very generally ascribed to the Archæan era, though up to the present no positive proof of this has been adduced. According to H. P. Woodward, a former Government Geologist of W.A., who has given the results of his researches in 21 reports and 6 geological maps, the schists form a number of parallel north and south belts and are intruded by numerous eruptive dyke rocks (diorite and granite).

The most westerly of these belts stretches from the Murchison River to the South Coast. It consists of slates and quartzites

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\*This and the following Appendix II. are published as being important contributions to the study of Kalgoorlie minerals, not accessible to the ordinary reader. The present writer does not necessarily endorse all the statements made therein.—E.S.S.

traversed by dykes of diorite and granite and lodes of lead, copper, and zinc. The second which forms the Darling Ranges consists of gneiss and schists with dykes of diorite, granite, and felsite, and quartz reefs. It yields tin in places. The third consists of granite and gneiss with dykes of diorite and acidic rocks. It is barren of valuable minerals. The fourth (or first gold-bearing) zone lies to the east of this, stretching from the Phillips River to the Ashburton River passing through Southern Cross, Cue, and Peak Hill. It is composed mainly of greenstone-schists with granites and diorite dykes and deposits of gold, copper, and iron ores. The fifth zone consists of barren granite. The sixth zone is highly auriferous and its eastern boundary is not yet defined. It begins on the south in the Dundas Hills and passing through Coolgardie, Kalgoorlie, etc., finally ends in the far North-West in the Pilbara Fields. This second gold-bearing zone consists of similar rocks to the first.\*

On these goldfields the most diverse gold occurrences are found in genetic relationship; one observes secondary deposits alongside primary, and among the latter both veins and beds are distinguishable. Schmeisser in his "Goldfields of Australasia" (and after him all writers on "West Australian Ore Deposits") draws a distinction between simple quartz veins and composite veins. Single fissures are present in simple veins which are usually filled with quartz. The composite veins have usually a selvage on the foot wall, and consist besides of a zone of highly altered country rock, which is traversed by numerous quartz veins and strings of ore.

Since the telluride gold ores are almost exclusively confined to the composite veins, the latter alone interest us here. The country rock consists mainly of hornblende-schists, but chlorite, mica, and talc-schists also occur as well as isolated quartzite and sandstone. It was some time before we became even to a small degree clear as to the nature of the amphibolites or hornblende schists which have so close a connection with the telluride ores, the first exact definition being published by Vogelsang. The rocks which in a fresh condition are quite dark green and often plainly schistose, and which are briefly described by the West Australian miner as "diorite" on account of their usually macroscopic resemblance to that rock, consist of an intimate mixture of hornblende fragments up to two m.m. in length with which are associated epidote, chlorite, quartz, carbonates, and subordinate biotite, apatite, titanite, zircon, magnetite, ilmenite, and leucoxene; in addition a dirty green chloritic material is widely distributed. The interstices between the minerals enumerated are occupied by an aggregate of quartz and felspar.

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\*This paragraph is considerably condensed from the original.—E.S.S.

On account of their strong foliation, the amphibolite masses have been included with the crystalline schists of similar form ; but at the 196ft. level of the " Lady Mary " Mine, Cue, they met with an amphibolite dyke about 3ft. thick, and cutting through the quartz diorite, which probably represents a crushed diabase. One must therefore note the possibility that the stratified amphibolites represent altered and foliated diabase rocks.

The composite telluride ore veins occur mainly at Coolgardie, Kalgoorlie (chief mines, Great Boulder, Lake View, Ivanhoe, and Hannan's Brown Hill), and at the Broad Arrow, Bardoc, and Bulong groups. The most notable development is to be found at Kalgoorlie where from 1895 to 1899,  $1\frac{1}{2}$  million ozs. gold have been won principally from them. The lodes run mainly south with a slight deviation to the east or west (those running easterly are usually poorer) and dip mostly to the west, whilst the ore is often inclined to occur in shoots. The veins vary in width from 3-60 feet, but in spite of this are difficult to recognise at the surface ; in contradistinction to the simple quartz veins which project in high dykes, the adjacent rock being weathered away.

The gold telluride is not confined solely to the veins running through the country rock, but occurs also in the rock itself in pockets and more or less lens-shaped masses.

In the upper levels (the water-level is 60-150 feet deep) the ore veins and country rock are greatly decomposed. The latter forms a soft brick-red or yellow, ironstained clayey and talcose rock, in which the ore veins occur as more or less porous masses carrying free gold. The telluride of gold has been broken up with a loss of the tellurium ; though originally the gold also went into solution, it was soon reprecipitated as a fine dust-like coating in points and stars on the cleavage planes, etc.

Not infrequently it occupies, in moss or sponge-like forms of extraordinary porosity and dull yellow colour, the whole space of the original telluride vein. It occurs also, however, in rough pieces, thin flakes, and fragments of the most diverse forms and sizes, which must be looked upon as originating from secondary concentration.

Usually the gold occurs in shoots, running in a horizontal direction through the matrix, but even in these zones of enrichment the contents in precious metals varies considerably. The zone of oxidation is, of course, as everywhere, especially rich in gold. One may assume that the lodestuff in the composite veins contains 10ozs. and more, whilst the country rock lying between the veins varies from a trace up to 1oz. per ton.

## THE TELLURIDE ORES.

In the deep ground there are a series of minerals which consist of compounds of tellurium with gold, silver, and mercury. Especially noticeable are sylvanite, calaverite, krennerite, petzite, hessite, coloradoite, and kalgoorlite. Unfortunately the desired light has not been cast upon the composition of these minerals, but I shall endeavour in the following lines to give a survey of the present position of our knowledge of the West Australian telluride ores.

TABLE I.

—				Calaverite.			Coloradoite.	Kalgoorlite.
Te	..	..	..	59·69	56·64	57·27	49·48	37·26
Au	..	..	..	38·70	41·76	41·37	Trace	20·72
Ag	..	..	..	1·66	·80	·58	·12	30·98
Hg	..	..	..	..	..	..	50·40	10·86
S	..	..	..	·09	..	..	..	·13
Cu	..	..	..	·21	..	..	..	·05
Fe	..	..	..	·18	..	..	..	..
Pb	..	..	..	Trace	..	..	..	..
Bi	..	..	..	Trace	..	..	..	..
Zn	..	..	..	Trace	..	..	..	..
				100·53	99·20	99·22	100·00	100·00
Sp. Gr.	..	..	..	..	9·377	..	9·21	8·791

The above collection of analyses is given by Gibb Maitland in his "Mineral Wealth of Western Australia."

TABLE II.—*Analyses of W.A. Minerals collected by Rickard.\**

—				Calaverite.†	Coloradoite.‡	Petzite.		
Au	..	..	..	41·56	..	25·5	24·64	24·62
Te	..	..	..	57·79	38·5	32·5	34·60	34·83
Ag	..	..	..	·65	..	42·0	40·47	40·55
Hg	..	..	..	..	61·5	..	·29	..
				100·00	100·00	100·00§	100·00	100·00

\* The Telluride Ores of Cripple Creek and Kalgoorlie: Trans. Amer. Inst. of Min. Engrs., 1900, p. 708.

† This analysis is a misquotation by Rickard of an analysis by myself.—E.S.S.

‡ This is a misquotation of Rickard, who says that the theoretical composition of coloradoite, if its formula be  $\text{HgTe}$ , is tellurium 38·5, mercury 61·5—E.S.S.

§ This analysis is a similar misquotation of Rickard. It is the theoretical composition of petzite, not the actual analysis of a Kalgoorlie specimen.—E.S.S.

The mercury in the second last analysis must be derived from a slight admixture of coloradoite.

At the Paris Universal Exposition there was naturally an extraordinarily rich collection of local telluride ores in the Western Australian pavilion. One must compliment those responsible for this exhibit on their great knowledge of Mineralogy and Ore Deposition which enabled them to collect within a comparatively small space everything that was needful to present a clear and complete picture of the gold deposits of W.A. to the eye of the inquirer.

Mr. Holroyd, the member of the W.A. Exhibition Commission, who merits the most praise in this section, placed at my disposal a valuable collection of telluride ore to pick out material for analysis. I was able to separate sharply five different minerals, which I then handed over for examination to the Royal Geological Institute and Mining School. Four of the ores proved to be compounds of tellurium, as follows :—

TABLE III.

—	Sylvan ite.	Calaverite.	Petzite.	$(\text{Ag.Au})_5\text{Te}_3$ 6 : 1
Au .. ..	28.55	37.54	24.33	15.06
Ag .. ..	9.76	2.06	40.70	45.95
Cu .. ..	.32	.29	.10	1.16
Fe .. ..	.06	.09	.07	.08
Ni .. ..	.10	.07	.08	.06
Te .. ..	60.83	58.63	32.60	36.90
Se .. ..	.20	1.13	1.45	..
S .. ..	.09	.10	.26	.45
Gangue .. ..	.05	.23	.12	.22
Sb .. ..	..	..	..	.12
Zn .. ..	..	..	..	.04
	99.96	100.14	99.71	100.04

*Calaverite*.—This mineral was discovered and named by Genth in the Stanislaus Mine, Calaveras Co., Colorado. It is bronze-yellow, has a yellowish-grey streak and conchoidal fracture. Its composition corresponds to the formula  $(\text{Au.Ag})\text{Te}_2$ , and it should theoretically contain 57.4 per cent. Te, 39.5 per cent. Au, and 3.1 per cent. Ag. The Calaverite from Colorado consists of 55.9–57.6 Te, 38.8–40.9 Au, and 2.2–3.5 Ag., and therefore agrees very closely, as does the analysis in the second column, with the theoretical formula.

The analyses of calaverite in the first table, and those published by Rickard (Table II.) are, in comparison with the others, not only unusually rich in gold, but also markedly poor in silver, containing less than 1 per cent. Since in this respect they differ from the Colorado calaverite, and since besides the analysis in Table II. shows that there is also in W.A. calaverite of the normal composition, the conclusion is, perhaps, not altogether unjustified that the difference in the analyses of calaverite of Table I. is due to the method of analysis employed.

*Coloradoite* is almost pure telluride of mercury with only very little gold. Genth was the first to find coloradoite, viz., in the Mountain Lion Mine at Magnolia, Colorado. It is comparatively rare in Western Australia. Rickard obtained this iron-black mineral with conchoidal fracture and strong metallic lustre from the Kalgurli Mine at Kalgoorlie. It was there called "black tellurium," and looked upon as native tellurium. On heating in a glass tube it is completely volatilised, and deposits the mercury in little globules on the colder part.

*Kalgoorlite* is almost iron-black, has a conchoidal fracture and corresponds to the formula,  $\text{HgAu}_2\text{Ag}_6\text{Te}_8$ . Since in outward appearance kalgoorlite differs but little from coloradoite, Rickard is (in view of the chemical composition) of the opinion that kalgoorlite is only an impure variety of coloradoite, in fact a mixture of petzite and coloradoite. Pittman, the Government Geologist of New South Wales, who visited Western Australia in the Autumn of 1897, considers it possible that the samples of amalgam which were found in the Boulder Perseverance Mine were derived from the decomposition of Kalgoorlite.

*Sylvanite*.—This telluride, which is very seldom found in Western Australia, is silvery white, and shows a perfect cleavage and corresponds to the formula  $(\text{Au.Ag})\text{Te}_2$ . According to the analyses of sylvanite from Offenbanya and Colorado, the proportion of tellurium varies between 59 and 62, gold 26 and 29, and silver 11.3 and 13.8. Within the same limits lie also the analyses of sylvanite from the Red Cloud Mine, Boulder, Colorado, which Rickard publishes.

A. Frenzel describes\* from Western Australia an almost silver-white telluride of gold with brilliant metallic lustre and strikingly perfect cleavage in one direction, with a hardness of  $2\frac{1}{2}$  and sp. gr. 8.14, which consists of—

Te .. .. .	58.63
Au .. .. .	36.60
Ag .. .. .	3.82
	<hr/>
	99.05

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\* Tscherm. Min. Mitth., 1897, XVII., 288, 289.

The description agrees exactly with sylvanite, but the analytical results differ from analyses of typical sylvanite by the remarkably small percentage of silver. Perhaps we are dealing here with Krennerite.

*Krennerite* is quite like sylvanite in appearance, but the colour inclines towards yellow. This mineral is the most beautiful of all telluride ores. It has the composition  $(\text{Au}.\text{Ag})\text{Te}_2$  and the specific gravity of 8.5.

*Hessite* is a pure telluride of silver of lead grey colour and formula,  $\text{Ag}_2\text{Te}$ . Its hardness is  $2\frac{1}{2}$ , specific gravity, 8.13 to 8.45.; it contains at times a little gold and lead.

*Petzite*.—This steel-grey to iron-black, and usually rare mineral, has a conchoidal fracture and is plentiful in Western Australian gold telluride veins. Its composition corresponds to the formula,  $(\text{Ag}.\text{Au})_2\text{Te}$ . The three analyses of petzite quoted by Rickard have 32.5–34.8 Te, 40.5–42.0 Ag, and 24.6–25.5 Au. The analyses of similar minerals from California and Colorado give 32.2–34.9 Te, 40.7–46.8 Ag, and 18.3–25.6 Au.

In the last column of Table III. is given the composition of a telluride mineral which corresponds to the formula  $(\text{Ag}.\text{Au})_5\text{Te}_3$ , and which in its appearance differs somewhat from petzite. It is almost lead-grey, and shows signs of a cleavage. So far as I am aware, no other similar mineral is up to the present known. In the ratio of precious metals to tellurium it stands between the monotellurides (petzite, hessite), and the bitellurides (sylvanite, calaverite) but approaches very close to the former, and especially to petzite.

Tellurite of iron, which Knight discovered in the Cripple Creek District, consists of 32.72 per cent.  $\text{Fe}_2\text{O}_3$ , 65.45 per cent.  $\text{TeO}_2$ , and 1.83 per cent.  $\text{H}_2\text{O}$ . It is light-brown and has a shining yellow streak. The fracture is uneven; hardness, 3–4. This mineral is only of scientific interest. It is also found in Kalgoorlie.

In general, so far as the telluride ores of Western Australia are concerned, it would appear that there is a connection between the colour and composition, that is to say, the light telluride ores are always bitellurides with high content in tellurium and gold, and diminished silver (as sylvanite, calaverite), the dark ones, are tellurides with high silver content, and low tellurium and gold (as petzite, hessite).

#### OTHER VEIN-MINERALS.

Besides the telluride ores a series of other minerals occur in the Western Australian lodes. In the deep ground there exist both auriferous pyrites and free gold. Galena is fairly plentiful,\*

\* There is some confusion here between the ores of Kalgoorlie and those of other fields in Western Australia. Galena is extremely rare at Kalgoorlie, but elsewhere in the State is frequently found in fair quantities associated with native gold.—E.S.S.



and is considered a sign of the impoverishment of the vein in gold. Galena is even more frequently seen with free gold.

Vanadinite occurs with gold at Coolgardie, and gold has also been observed in the arsenical pyrites there. A remarkable discovery was made at Bayley's United Gold Mine at Coolgardie of arsenical pyrites veins traversed by a network of very fine veins of gold. Zinc blende is only present to a slight extent, but is looked upon at Coolgardie as a good indication. Native bismuth and bismutite are rare.\*

Sulphides of copper occur at Kalgoorlie, and native copper is recorded from Coolgardie.

With the telluride ores there occurs an iron-black mineral which has been looked upon up till now, on account of its appearance, as a particular kind of gold telluride. An analysis showed, however, that it was an ore of copper of the following composition:—

Gangue	..	..	..	..	..	26
Cu	..	..	..	..	..	41.69
Ag	..	..	..	..	..	22
Au	..	..	..	..	..	12
Fe	..	..	..	..	..	4.76
Zn	..	..	..	..	..	2.68
Ni	..	..	..	..	..	15
Pb	..	..	..	..	..	10
S	..	..	..	..	..	28.43
As	..	..	..	..	..	16.87
Sb	..	..	..	..	..	4.30
Te	..	..	..	..	..	05
						<hr/> 99.63 <hr/>

It would appear to be a copper ore closely related to Enargite ( $\text{Cu}_3 \text{AsS}_4$ ) but containing less sulphur.

Finally, amongst metallic ores Scheelite remains to be mentioned. Of gangue minerals quartz is by far the most important.† Cases have also been noted at Kalgoorlie of gold occurring in more or less magnesian calcite.

#### GENESIS OF THE GOLD TELLURIDE.

Much controversy exists as to the genesis of the Western Australian telluride ores.

Sloet van Oldruitenborgh‡ looks upon the amphibolites as eruptives, and the telluride ores as secretions from the magma. The fissures which are now filled by the ores were derived from the contraction of the rock.

Pittman§ looks upon the amphibolites as altered quartz felspar porphyries, into which the ores were conveyed by metallic

\* Here, again, confusion is made between Kalgoorlie ores and those of other W.A. fields. Neither metallic bismuth nor bismutite are found at Kalgoorlie.—E.S.S.

† Not at Kalgoorlie.—E.S.S. ‡ Technical Observations on the Coolgardie Gold-fields.—Liege, 1897. § Aust. Min. Standard 1898, 481 and 483.

solutions. The gold quartz veins, which, before the discovery of the telluride ores, constituted the basis of the mining industry, are filled up contraction fissures.

William Frecheville\* is also of the opinion that the amphibolites are eruptive rocks, but thinks that the ores were first introduced as an additional constituent by means of solutions.

Schmeisser † assumes that the quartz reefs, as well as the telluride ore veins, owe their origin to one and the same action. One is dealing with fissures (simple veins) which have been filled by mineral waters, and which were partly combined with crushed zones on the hanging wall.

Gibb Maitland ‡ considers the simple veins as genuine fissure fillings, and looks upon the composite veins, therefore also the telluride deposits, as zones of impregnation in the rock, which have been crushed by tectonic action, and later cemented again by mineral solutions. According to him, the amphibolites are very closely related to diorites.

From this résumé it appears first of all that all those who have carefully studied the Western Australian telluride ore deposits look upon the amphibolites as altered eruptive rocks in which the gold telluride is chiefly but not exclusively deposited in defined channels (lit. locally).

S. van Oldruidenborgh is the only one who believes in a genetic relationship between the country rock and the ore bodies (magmatic secretion). However, this last theory is of little probability. The extraordinarily rich specimens from Western Australia which are included in the Berlin "Bergakademie" collection of ores, and which perhaps represent the most complete collection of the kind existing anywhere in Europe, does not contain any piece which exhibits the least indication of magmatic secretion. There always appears a vein filling of telluride ore and quartz; one never observes inclusions of the amphibolite country rock in the gold telluride, nor does there ever appear a gradual transition of ore into country rock, as we have so frequently in cases of magmatic secretion. Finally, against this hypothesis stands the circumstance that up till now telluride of gold has nowhere been observed as the result of such action, and that in Western Australia, besides occurring in amphibolite schists, it occurs occasionally in veins in other rocks. §

The telluride ores must therefore represent precipitates from mineral solutions which, after the solidification of the country rock, filled in gaps or fissures in the country rock which perhaps owed their origin to the same tectonic actions as produced the schistose structure of the rock.

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\* Min. Journal 12th March, 1898, p. 310. † Goldfields of Australasia. ‡ Mineral Wealth of W.A. § This is doubtful.—E.S.S.

The age of the Western Australian telluride veins is also not known with certainty. It has been observed that a number of the simple gold-quartz veins are of the same age as the composite telluride veins, sometimes perhaps even still younger. In general the fissures, from the filling of which both forms of veins originate, appear therefore to be of the same age, and so, since they do not pass up into the mesozoic strata, of an age older than mesozoic. The problem of the age of the vein fillings is not, however, solved thereby.

When the Western Australian telluride veins were discovered they were represented in the classification of ore deposits as of the same age as the gold-quartz veins which previously formed the sole foundation of the gold mining industry and classed with the so-called "old gold-silver group," that is, with the precious metal bearing veins which owed their existence to the thermal after-effects of older eruptive rocks.

This opinion, however, seems to be open to dispute. For everywhere where telluride gold ores occur, in Transylvania, at Savodinsky in the Altai, at Minas Geraes in Brazil, in Bolivia, Mexico, California, and on the Coromandel Peninsula, the telluride ores are contained in the newer eruptive rocks, and in Western Australia newer eruptives occur also.

A second point is the association of tellurium with mercury in Western Australia. In our mercury deposits we do not always know the eruptive to whose after effects the mercury deposit is due ; in the cases, however, where the rock concerned is known, it belongs to the group of newer eruptives so that the conclusion is not unjustified that all mercury deposits are geologically of quite late age.

On these grounds the opinion is justified that the Western Australian gold telluride veins are of late age, representing thermal after effects of tertiary eruptives, and on this account must be included with the so-called "newer gold-group."

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## APPENDIX II.

*Sur les Tellurures d'Or et d'Argent de la Région de Kalgoorlie, Australie Occidentale (The Tellurides of Gold and Silver of the Kalgoorlie District, West Australia), by Ad. Carnot. Bulletin de la Société Française de Minéralogie, XXIV., 7, Juin, 1901. Translated by E. S. Simpson.*

At the Universal Exposition of 1900 general attention was directed to the rich gold ores and particularly the magnificent specimens of tellurides exhibited by the West Australian Commission in the Trocadero pavilion. These telluride ores have been furnished principally by the East Coolgardie or Kalgoorlie Gold-field, situated in the Eastern Division of Western Australia. Mr. Holroyd, the representative of the Commission, was kind enough to offer me, for the Museum of the Ecole Supérieure des Mines, some fragments of these tellurides, and asked me to give him a detailed analysis of them. This I proceeded to do with pleasure, the more so because I have never had previous opportunities of analysing such minerals.

The gold district of Kalgoorlie was discovered in 1893; but the surface alluvial deposits were the only ones at first recognised. Later, tellurides were discovered, and in 1899 a considerable development in the mining took place. The mines have been described in two memoirs published in the *Annales des Mines* in 1899 \* and 1901 †.

The telluride ores appear to form almost vertical veins with quartzose filling, running north-west, in a belt of country 300 to 400 yards wide. These veins are interstratified with the amphibolite schists, to which the name of diorite is usually applied locally. The ores are very much altered in the upper zones, and the precious metal is found there generally in the form of free gold, whilst when one descends to the water level, the walls are better defined and the metals are in the state of undecomposed tellurides.

It is these tellurides which form the collection presented by Mr. Holroyd. They were handed over to me in six small glass tubes, numbered from 1 to 6. The fragments contained in No. 1 came from the Lake View Consols Mine; the others are all marked as coming from the Great Boulder Proprietary Mine. Both these mines are situated in the vicinity of the town of Kalgoorlie.

I do not know whether the fragments collected under one and the same number are derived from one and the same spot or from different pockets, but I notice that in some of the tubes

\* Gascull, Notes sur les champs d'or de Coolgardie.  
miniére de l' Australie occidentale.

† Kuss, L'Industrie

all the fragments had not the same appearance and colour. I have, therefore, thought it necessary to take the precaution of analysing separately the fragments of different appearance, when ever the quantity of material permitted it. I have thus been led to make nine distinct analyses, of which the following are the results :—

—	1.	2A.	2B.	3A.	3B.	4.	5.	6A.	6B.
Te .. ..	69.45	56.55	53.70	32.33	33.00	60.30	51.13	31.58	41.11
Au .. ..	29.85	23.15	27.75	24.16	23.42	33.90	37.06	23.58	26.10
Ag .. ..	9.18	16.65	13.60	41.22	41.37	4.82	4.71	43.31	30.43
Hg .. ..	..	3.10	3.70	2.00	2.26	..	3.70	.88	.70
Cu .. ..	.15	.10	.25	.10	.16	.63	.88	.20	.60
Ni .. ..	.10	..	..	..	..	..	..	..	..
Fe .. ..	..	tr.	tr.	..	..	tr.	.90	tr.	.40
Sb .. ..	..	.20	.15	..	..	..	1.20	.30	.80
	99.73	99.75	99.15	99.81	100.21	99.65	99.58	99.85	100.14

No. 1. The first lot of tellurides was very small ; I had to proceed with great care in order to secure about 1 gramme, destined to serve as a type. This telluride is distinguished from all others by a distinct and brilliant cleavage and an uneven fracture in an adjacent direction (direction voisine) ; the structure is somewhat fibrous and conchoidal in the other directions. The cleavage planes have a metallic lustre with a silver-white colour, in other directions the mineral is inclined to steel grey.

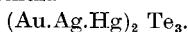
According to the analysis the molecular ratio of tellurium to metals is 4.72 to 2.38. The molecular composition is therefore exactly expressed by the formula—



This formula is that adopted for the Sylvanite of Offenbanya. The relative proportions of gold and silver are sensibly the same as in the telluride from Transylvania, that is to say about, 3 : 1.

No. 2. The fragments of the second lot only showed exceptional traces of cleavage planes, the fracture is always conchoidal. The colour is in some samples, iron-grey, in others, yellow-grey inclined to bronze. This difference made me decide to make separate analyses of two fragments, but there was very little difference in the results, as shown in the table above.

There was only a difference in the relative proportions of gold and silver caused by substitution, from which it would appear that the observed differences in colour resulted. As to the ratio of tellurium to total metals, this remains almost constant (4.19 and 4.41 to 2.85 and 2.87). The molecular compositions correspond therefore to the formula—

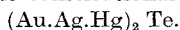


This composition does not seem to have been previously observed in other tellurides. The fragments from the Great Boulder con-

stitute therefore a new species, characterised by the formula of a sesqui-telluride as well as by the presence of the three metals, gold, silver, and mercury. I propose to give to this species, by reason of its origin, the name of Coolgardite.

No. 3. The fragments comprised under No. 3 were all of like appearance. They are not crystallised and have no cleavage planes, but a broadly conchoidal fracture. The colour is dark steel-grey, passing after a certain time into iron-black. The mineral can be broken and powdered very easily.

The analyses of two fragments have given almost identical results. The molecular ratios were found to be 2.53 and 2.58 of tellurium to 5.15 and 5.13 of the three metals combined (gold, silver, and mercury). The constitutional formula is therefore—



Petzite, a mineral long known, corresponds to the same formula except that neither the analyses of Petz and Genth on specimens from Transylvania and Colorado, nor those of Rickard on those from Australia, have mentioned the presence of mercury.

Pittman, on the contrary, has noted (from an analysis by Mingaye) 10.86 per cent. of mercury in a fragment coming from Kalgoorlie, and has given to this mineral the name of Kalgoorlite, attributing to it the constitutional formula,  $\text{Au}_2 \text{Ag}_6 \text{Hg Te}_6$ . My analyses have clearly established the presence of mercury but in a much less proportion. However, not to uselessly multiply mineral varieties, I prefer to give the name of Kalgoorlite to the mineral I have analysed.

No. 4. This mineral is grey, with a yellowish tinge, some fragments are darker, being blackish grey. The fracture is conchoidal and at the same time a little unequal but without any cleavage proper. According to the analysis the molecular composition is represented by the formula  $(\text{Au.Ag})\text{Te}_2$ , which is that of sylvanite, but the proportion of silver is much less in these fragments than in those from Offenbanya and from the Lake View Consols, whilst they contain more gold and a little copper. This mineral might be classed with the yellowish grey or bronze-coloured variety, without crystalline structure, found in Calaveras county, analysed by Genth and named calaverite, a variety having the formula  $(\text{Au.Ag})\text{Te}_2$ .

No. 5. The fragments comprised under this number are of a yellowish-grey colour with conchoidal fracture, appearing like curved scales. The chemical composition is that of a complex telluride, in which were noticed the presence of both mercury and antimony in appreciable quantities. The molecular composition corresponds to  $(\text{Au.Ag.Hg.Cu.Fe.Sb})_2 \text{Te}_3$  or, more simply  $(\text{Au.Ag.Hg})_2 \text{Te}_3$ . It approaches, therefore, that of the sesqui-telluride which we have already met under No. 2 and which we have called Coolgardite, but the silver in it is in much smaller proportion, whilst there is more gold and other metals.

No. 6. The fragments composing No. 6 are of a greyish black tint. They are much larger in general than the preceding ones, but resemble an aggregate of small elements without faces or conchoidal fractures of any extent. Their metallic lustre and uneven and conchoidal fracture recalls somewhat the appearance of some anthracites.

The two fragments examined, whose analyses figure in the table above, furnished sensibly different results, one of which (*a*) corresponds to the formula  $(\text{Au.Ag})_2\text{Te}$ , the other (*b*) to  $(\text{Au.Ag})_4\text{Te}_3$ . The first appears to be referable to Kalgoorlite. The second looks as if it should be considered as a mixture of different species, which would not be surprising in a mineral of confused appearance and devoid of crystalline character. The analysis leads one to consider it a mixture of the two varieties of tellurides, which I have designated above by the names of Kalgoorlite (No. 3), and Coolgardite (Nos. 2 and 5).

To summarise—the fragments of tellurides from Western Australia, whose analyses I have given above, are referable to the following species :—

Sylvanite, bitelluride of gold and silver  $(\text{Au.Ag})\text{Te}_2$  of crystalline structure (No. 1).

Calaverite, a bitelluride analogous to the preceding one but much less crystalline and containing a smaller proportion of silver (No. 4).

Coolgardite, or sesqui-telluride of gold, silver, and mercury,  $(\text{Au.Ag.Hg})_2\text{Te}_3$ , with variable proportions of gold and silver, which replace one another to a large extent (Nos. 2A, 2B, and 5).

Kalgoorlite  $(\text{Au.Ag.Hg})_2\text{Te}$ , in which the relative proportions of the metals are variable (Nos. 3A, 3B, and 6A). Fragment 6b appears to be a mixture of the two last species, Coolgardite and Kalgoorlite.

#### METHOD OF ANALYSIS.

It remains for me to describe the method of analysis adopted with these West Australian tellurides.

As far as possible I have operated on one or two grams of mineral free from gangue. After powdering and weighing, the material is attacked with pure nitric acid in a porcelain capsule. It is heated up to the point when all reddish fumes disappear and taken up in faintly acid water. It is then decanted into a very small filter in order to retain the extremely fine particles which might be carried over. This is repeated three or four times, and finally a washing with hot water is given.

The following are left to deal with, an insoluble residue A, and a nitric solution B.

A. The insoluble residue, which is more or less black or bronze-coloured, is treated in the capsule and on the filter with hydrochloric acid and a few drops of nitric. It is warmed, diluted with cold water, and passed through the little filter, which retains a little chloride of silver together with a very small or imperceptible quantity of gangue. After washing, the silver chloride is dissolved in a little ammoniacal water and precipitated afresh by acidifying with nitric acid, in order to add it to the principal portion of the silver coming from solution B.

The yellow hydrochloric solution contains the whole of the gold, a small portion of the tellurium and sometimes a little antimony. The nitric acid is entirely removed by slow evaporation with an excess of hydrochloric acid and a little ammonium chloride. To the solution, somewhat diluted but still very acid and warmed to about 60 degrees C, is added oxalic acid, which reduces the gold only. A precipitate forms and the liquid becomes decolourised. It is finished at a boiling temperature, then the precipitate is caught on a filter, washed with boiling water and calcined and the metallic gold weighed.

Through the filtrate, strongly acid and warm, is passed a current of sulphurous anhydride. This is allowed to act for some time, when the solution is finally raised to the boiling point. The precipitate of tellurium is caught on a tared filter and washed well with hot water. To it is subsequently added the principal part of the tellurium, which has passed into the solution B.

The filtrate is heated till all sulphurous odour has disappeared, diluted with water and sulphuretted hydrogen passed through it. If an orange precipitate of sulphide of antimony forms, it is caught on a small tared filter and weighed after desiccation.

B. The nitric solution contains the greater part of the silver and tellurium as well as the whole of the mercury, copper, nickel, and iron.

The silver in it is precipitated with dilute hydrochloric acid, added little by little until it no longer gives an opalescence. It is well shaken and when the liquid has cleared, the silver chloride precipitated in this operation is caught on a tared filter, together with that isolated in treating the insoluble residue A, and the total silver determined by weighing.

The filtrate is evaporated with a little sulphuric acid to the point of appearance of sulphuric vapours in a sufficiently large porcelain capsule. In this way the whole of the nitric acid is removed without spirting and without peroxidising the tellurous acid, the subsequent reduction of which is very simple.

The residue is taken up with sufficient hydrochloric acid. The solution is coloured deep yellow but becomes almost colourless on the addition of water. It is heated to 100 degrees in a glass



beaker, removed from the fire and a current of sulphurous anhydride, supplied from a syphon of liquid  $\text{SO}_2$ , passed through it. The greyish black precipitate of tellurium soon forms in abundance and is generally complete in about 10 or 15 minutes. It is heated to 100 degrees to facilitate the deposit, then a portion of the clear liquid is decanted off and submitted afresh to the action of the  $\text{SO}_2$ . If it does not give a fresh precipitate the original precipitate is caught on the tared filter which already contains the tellurium found in the residue A. It is washed with boiling water, dried at 100 degrees and weighed as tellurium.

The hydrochloric solution may still contain mercury, copper, nickel, and iron.

After driving off all  $\text{SO}_2$  a current of sulphuretted hydrogen is passed through it, and after standing in a covered beaker, the black precipitate of mercury and copper sulphides is separated. The copper alone is dissolved by nitric acid, and according to the quantity is either converted into  $\text{Cu}_2\text{S}$  and weighed, or the solution rendered ammoniacal and titrated with cyanide.

The sulphide of mercury alone remains unaffected by the nitric acid and is digested with ammonium sulphide, washed, dried, and weighed. To make certain that it is sulphide of mercury, it is dissolved in a little *aqua regia*, and portion saturated with potash, and potassium iodide added in very small quantities at a time. The reaction gives a precipitate, first yellow and then red, which is very characteristic and redissolves if excess is added of the reagent.

Iron and nickel are only present in traces. They can be recognised and separated after expulsion of  $\text{H}_2\text{S}$  and peroxidation, by precipitating ferric hydrate and observing the blue colour of the solution caused by the nickel.

A test for sulphur of some fragments of telluride with *aqua regia* and barium chloride gave negative results.

Such are the methods which furnished the results given above for the composition of tellurides of gold, silver, and mercury from West Australia.

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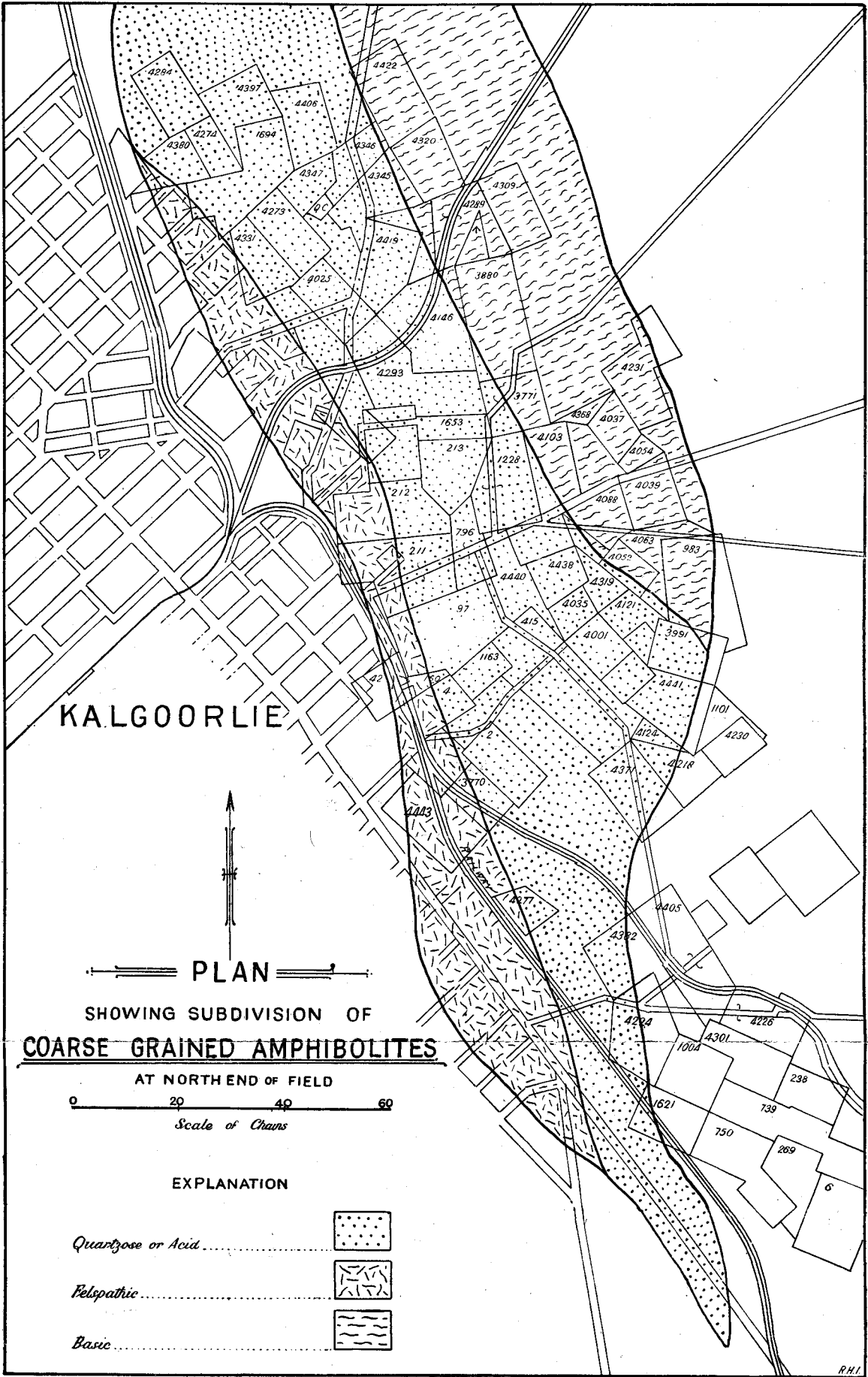
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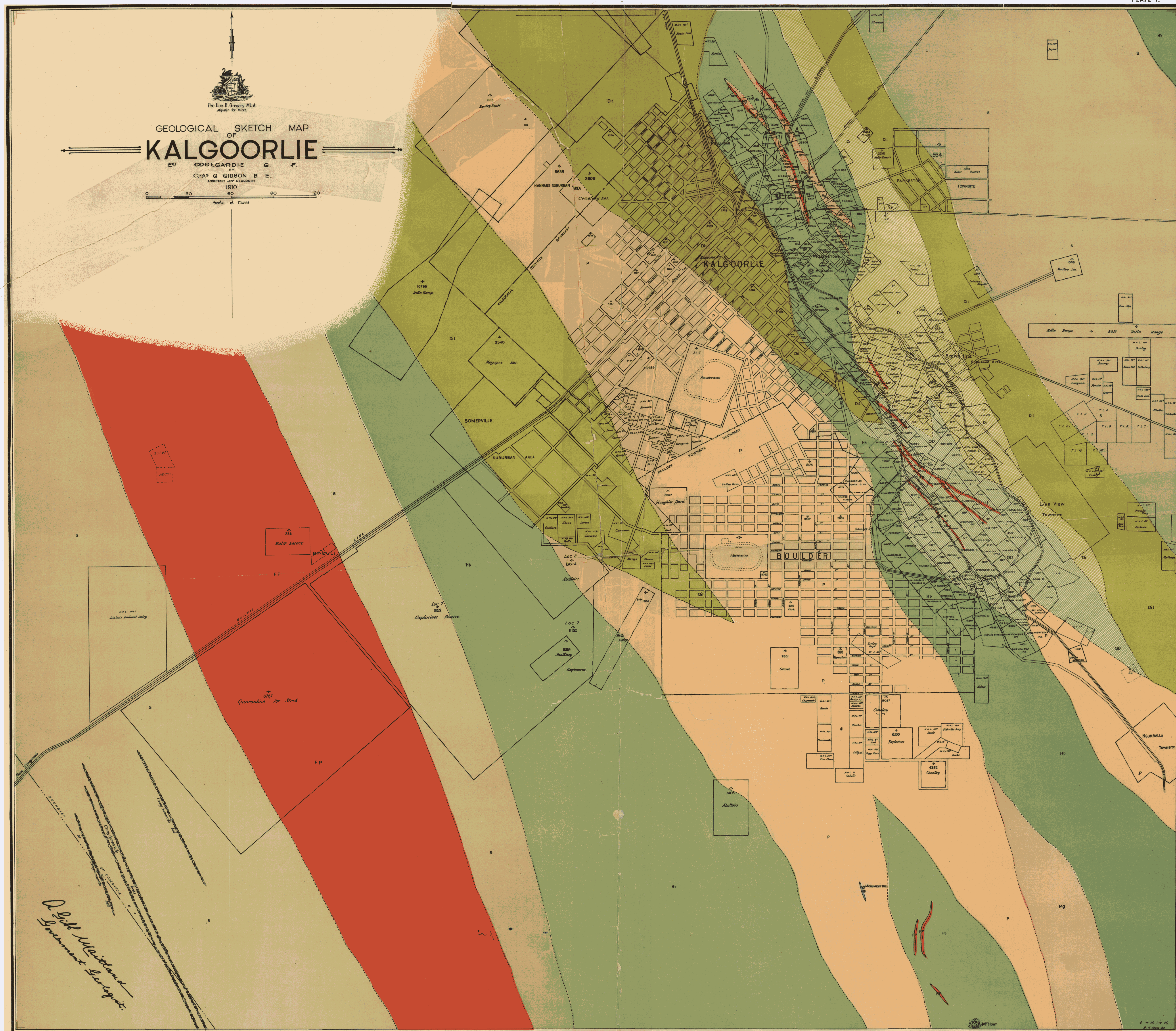
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**EXPLANATION**

<p>ANCIENT SEDIMENTARY ROCKS (<i>Shales, Sandstones, Grits</i> etc.).....</p> <p>CALC SCHISTS (<i>Older Greenstones</i>).....</p> <p>FINE GRAINED AMPHIBOLITES (<i>Older Greenstones</i>).....</p> <p>QUARTZ DIABASE (<i>Later Greenstones, intrusive</i>).....</p>	<p><b>S</b></p> <p><b>Di</b></p> <p><b>Di</b></p> <p><b>QD</b></p>	<p>COARSE GRAINED AMPHIBOLITES (<i>Later Greenstones, intrusive</i>).....</p> <p>(INCLUDING AMPHIBOLITES, EPIDORITES &amp; PORPHYRENTS)</p> <p>PORPHYRYTE.....</p> <p>QUARTZ &amp; FELSPAR PORPHYRIES.....</p> <p>PERDOTITE AND ITS DERIVATIVES (<i>Intrusive</i>).....</p>	<p><b>Hb</b></p> <p><b>P</b></p> <p><b>FP</b></p> <p><b>Mg</b></p>
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GOLD MINING LEASE <sup>100' or more</sup> <sub>100' or more</sub> GREAT BOULDER MINER HOMESTEAD LEASE <sup>1/4</sup> <sub>1/4</sub> M. H. L. 70' DIKES GEOLOGICAL BOUNDARIES INTER RIVER <sup>100'</sup> <sub>100'</sub> W. R. WATER LEASE <sup>100'</sup> <sub>100'</sub> W. L. TAILING LEASE <sup>100'</sup> <sub>100'</sub> T.

NOTE: THIS MAP SHOWS STRUCTURAL FEATURES ONLY. RECENT DEPOSITS (SANDS, LOAMS, LATENTES &c.) OMITTED.