7.—Recent Advances in the Knowledge of the Geology of Western Australia.

(Being the PRESIDENTIAL ADDRESS by A. GIBB MAITLAND, F.G.S., Government Geologist of Western Australia, and formerly of the Geological Survey of Queensland, delivered in Adelaide before Section C of the Australasian Association for the Advancement of Science, on the 8th of January, 1907.)

My first duty in assuming the position of the Presidentship of the section of Geology is to express to you my deep sense of gratitude for your confidence in my devotion to the welfare of our science implied in the election of one who, owing to the exigencies of official life, has had few opportunities during the last 19 years of becoming personally acquainted with the majority of the "Brethren of the Hammer" in Australia. The honour, however, is enhanced by the fact that in addressing the members of this section of the Association in Adelaide, I am speaking in the capital of a State which has contributed—in the persons of Messrs. H. Y. L. Brown and H. P. Woodward—so much to the progress of official geological research in Western Australia.

The civilising value of scientific investigation, such as is evidenced by a gathering of this kind, where the "hammerers" from the West meet those from East, upon common ground, for the purpose of discussing, consolidating, and recording the work of the past, must tend to link all parts of this continent together, and time perhaps will show that it may fall to the lot of the Australian men of science to materially assist in the solution of the problem of preserving those harmonious relationships and the strengthening of those ties which are so severely taxing the combined resources of political diplomacy.

It is, I believe, customary for the occupant of the Presidential chair to offer a few observations on some special department of the science which seems in his opinion worthy of attention, and I am therefore unwilling to depart from what must be regarded as traditional usage. On looking over the list of subjects reviewed by my predecessors in this chair, and the contributions of the different members read before this Section, I find few dealing with those portions of Australasia with which I am personally familiar, viz. :—Queensland, British New Guinea, and Western Australia.

After due consideration, therefore, I have chosen to invite your attention for an academic hour to a succinct account of the recent advances in our knowledge of the geology of the Western portion of this Continent, to the investigation of which my attention has been more immediately directed during the last decade.

In a broad and general way the geology of Western Australia offers many interesting points of analogy with that of South Africa and India.

In the present condition of our knowledge of the geology of the State, it is almost impossible to deal systematically with the various formations as a whole, for, owing to a variety of causes, geological inquiry up to the present has consisted merely of a series of unconnected observations, to the co-ordination of which we must look to the future ; nevertheless our observations have been so widely extended as to permit of certain broad generalisations.

Geologically the rocks of the State may, for the purpose of this address, be divided into three distinct groups, viz.:—

(I.) The crystalline, schistose, and metamorphic rocks, a group the members of which have certain features in common, occupy definite areas, and various lines of inquiry point to being of considerable geological antiquity, possibly of Archæan Age, though in the present condition of our knowledge I prefer to adopt the term Pre-Cambrian.

(II.) The sedimentary rocks which extend with many blanks from the Lower Cambrian to the most Recent ; and

(III.) The volcanic rocks which are so largely developed in the northern portion of this State.

I.—The Crystalline Schists and the Metamorphic Rocks.

The Pre-Cambrian crystalline schists, and metamorphic rocks constitute the principal mineral region of Western Australia, and so far as is at present known, the area occupied by these venerable beds is about two-thirds of the total superficial extent of the State, which is 975,920 square miles. As our knowledge advances, however, this estimate of the area occupied by the Pre-Cambrian rocks may be subject to some modification.

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

Considerable interest in connection with these rocks centres, so far as petrographical questions are concerned, in the translation of both the igneous and sedimentary formations into crystalline schists. Observations in the field point to the possibility of the mechanical movements to which the rocks have been subjected having modified or obliterated structural features previously impressed upon them, and that they may contain formations belonging to different geological systems. Sections in the Nullagine District show those beds to be made up of cleaved conglomerates some of whose pebbles consist of a pre-existing conglomerate from an earlier series, of which no trace has yet been found. With a possible exception alluded to later on, it is important to note that this ancient metamorphosed sedimentary series, so abundantly represented in Western Australia, has yielded no fossils as yet.

If perhaps I dwell at a somewhat greater length upon these older rocks, it is that their economic importance has necessitated the attention of the Geological Survey, being up to the present, principally devoted to their investigation rather than to that of the strata lying uncomformably above them.

Time will hardly admit, though there is the inclination, of trespassing upon your time by affecting comparisons with the geology of similar areas of Pre-Cambrian rocks in other countries, nor discussing many of those theoretical questions arising out of the data which have been massed.

These older rocks have been studied in more or less detail in different localities throughout the State, distributed over fourteen degrees of latitude. They consist of rocks of very different types, many of them are in a crystalline condition, and form coarse crystalline schists and gneiss, which differ but little from granite and other rocks of like origin, as well as basic rocks, which have been more or less crushed, foliated, and completely converted into greenstone schists.

A very important feature of these basic schists is the presence among them of unfoliated rocks which sometimes occur in the form of lenticular belts of considerable extent, diabase, dolerite, diorite, epidiorite, pyroxenite, porphyrite, amphibolite, etc.

In some localities these basic rocks can be seen passing by scarcely perceptible gradations into hornblende schists, while in others are bands of magnetite schist, in the centre of some of which are large phacoidal-shaped masses of greenstone occurring in such a way as to indicate that the margins only of the masses have been ground down into schists.

Some of these older rocks are of sedimentary origin, and are practically unaltered ; others are quartz, mica schist, and granulites, whilst these represent the two extremes there are intermediate forms which link them together. The less altered members of these older rocks make their appearance in many portions of the State ; the rocks consist of a great variety of types of indurated slates, quartzites, and conglomerates, together with igneous rocks, some of which there are very good grounds for believing to have been originally lavas and ashes.

Many of these old crystalline rocks have been so altered as to possess characters which cannot be looked upon as original because many of them have lost, not only their individuality, but also their geological identities.

A remarkable and very noticeable feature of these older rocks in most localities in which they have been examined is those bands of laminated quartzites and jaspers (which often contain oxide of iron to such an extent as to warrant their being classed as iron ores). These extend as roughly parallel bands, sometimes several miles in length, in the form of attenuated lenses which, owing to their serrated ridges stand out in bold relief, thus acquiring a conspicuousness perhaps out of all proportion to their real stratigraphical importance. These beds vary from almost pure quartz through varieties of banded hornstone, jaspers of great beauty, to almost pure hematite.

In certain localities these jaspideous beds present a very brilliant appearance, due to the interlamination of red, white, and dark-coloured bands with intermediate varieties, the difference of colour being due to the occurrence of iron in the form of either limonite, haematite, or magnetite.

These bands are often intersected by numerous faults, which, in some districts, are of considerable economic importance, for it is along these fault lines, generally at right angles to the strike of the quartzites, that rich shoots of gold often occur. In some cases these iron-bearing jaspers attain a very great thickness, over 1,000ft., and have been very much plicated and contorted, whilst in places they have been faulted in a direction parallel to the strike. The fault fissures being often filled with a fault breccia of jasper recemented by secondary chalcedonic silica. In all cases these jaspers and quartzites are vertical or inclined at high angles. In many localities these quartzites and jaspers contain magnetite in such quantities to render the use of a compass in the vicinity almost impossible. These beds have been styled quartzites, a term implying that they are sedimentary ; they are, however, not of detrital origin, numerous sections in many of the fields show them passing by almost insensible gradations into the enclosing basic schists, the whole appearance suggesting a gradual replacement of the original rock along lines of maximum compression, a foliation by silicification, in other words they represent a case of metasomatosis on an extensive scale.

It may be of interest to note that these beds invariably occur in the basic schists, in intimate association with auriferous quartz reefs, and are at times themselves auriferous. In order that the present confusion arising through the want of a name to distinguish infiltration or metasomatic quartzites from indurated sandstone may be obviated, I hope some one may be able to suggest a convenient means of escape from possible civil war between the field man and the laboratory man to which the present unsatisfactory system of nomenclature rather tends.

In 1905 the various divisions of these older crystalline rocks as developed on the Norseman Goldfield, were carefully mapped and investigated, the salient features of which may be briefly summarised. The staple formation consists essentially of a series of highly inclined sedimentary rocks estimated to reach a thickness, making due allowance for repetition by folding, of about 800ft.

No argillaceous slates appear to occur in the Norseman district, though associated with the metamorphic sedimentary rocks is a bed of very coarse conglomerate. Some of these ancient sedimentary rocks appear to have been permeated by secondary silica and oxide of iron to such an extent as to form very conspicuous bands of laminated quartzites and jaspers, which make a pronounced feature of the field. Associated with the metamorphic sedimentary beds of Norseman are a series of interbedded igneous rocks, some of which are distinctly amygdaloid, and although most of their original characters have been almost entirely obliterated, there seems every reason to believe them to be ancient lava flows, which were poured out at practically the same geological period as the associated sediments. In addition to these undoubted lava flows, there are a series of diorites and epidiorites, which seem to be interbedded with the former in such a way as to suggest the possibility of their being intrusive sills and dykes. These igneous rocks have been subjected to considerable dynamical alteration, and in places appear as mica and chloride schists.

Another very important feature in the geological structure of Norseman is the occurrence of a large number of quartz porphyry dykes which traverse the eastern portion of the field in a general north-west and south-east direction. These acidic dykes vary much in appearance, colour, and texture, the crystallisation in some cases being such that the rocks look not unlike somewhat fine-grained indurated sandstone. These acidic dykes contain crystals of pyrites, and are occasionally slightly auriferous. These dykes in all probability form the apophyses of that large granite mass which lies to the east of Norseman. There are, in addition, a few isolated veins and dykes of dolerite, one of which is seen intersecting the quartz reef in one of the mines. The newest igneous rock on the field is the intrusive norite, which forms an east and west range, varying from a mile to half a mile wide, and which extends in an uninterrupted line to Mount Norcott, about twelve miles to the east, and for a considerable distance both east and west.

The earliest observer in this district, Mr. S. Goczel, indicates on his geological sketch map of the Auriferous Region of Western Australia the greenstones and allies of Norseman as being of Paleozoic Age, whilst the micaceous and talcose schists of the same district are referred to the Archæan.

The crystalline rocks of the type just described may be traced as far as the Kalgoorlie Goldfield, the wealth of which, coupled with the skill which directs both the mining and the metallurgical operations, have raised Western Australia to the front rank of mining countries in the British Empire.

As is well known, the productive area comprises a relatively small block of ground, which, by reason of the richness of the lodes by which it is riddled, has become known throughout the world as the "Golden Mile."

This area includes the well-known "Great Boulder," "Ivanhoe," "Horseshoe," "Perseverance," "Oroya-Brownhill," "Associated," and "Lake View Consols" mines. The deepest shaft at present is the Great Boulder, which has reached over 2,000ft., while the greatest depth to which the lodes have been followed is over 2,000ft. The country laid open by mining for investigation as judged by the number of drives and crosscuts amounts to several miles, whilst the rocks have been riddled with bore holes in all directions and angles, thus affording opportunities for the scientific study of many of the rocks in critical localities, and in their relation to the ore deposits, such as are hardly found in any other single mining field of the globe.

The geological structure of Kalgoorlie is not of that extreme simplicity which at one time hád been anticipated. The staple formation consists as at Norseman, largely of certain schistose rocks, some of which are distinctly of sedimentary origin. The sedimentary beds are represented by rocks, which range from soft shales to jasperoid slates, grits to flinty quartzite, fine conglomerates or breccias to fairly coarse boulder conglomerate.

In intimate association with the sedimentary beds are a series of hornblendic rocks, but whether these occur in the form of lava flows or are intrusive is as yet by no means clear.

There are, however, in addition to these certain undoubtedly intrusive igneous rocks, sodafelsites and porphyrite.

Most of the rocks of Kalgoorlie appear to have been highly altéred by dynamical causes, with an accompanying recrystallisation of their constituents ; many of them have been carefully analysed and microscopically investigated in the laboratory of the Geological Survey and the results made available. Time will not admit of detailed reference being made to the deductions to be drawn from these investigations, beyond the fact that the "lode formations," for which the field is famed, consist of a series of almost vertical banded schists of lenticular habit, and apparently owe their origin to the dynamo-metamorphisin of a plagioclase-augite rock. Many of these ore lenses are of great length, and in some cases of considerable breadth; at times however, the lateral continuity of the lenses is interrupted by overthrust and normal faults of very variable downthrow.

For a systematic study of the metasomatic history of the auriferous deposits, leading as such must do to the discovery of facts which will materially guide scientific mining, Kalgoorlie offers few, if any, rivals in Australia.

So far as observations have, however, at present been carried there do not appear to be any scientific reasons for believing that the mines of Kalgoorlie have by any means reached the limits of ore deposition, or that the lodes will not prove as a whole productive in depth.

The Pilbara district (lat. 21 degrees) affords better and more continuous sections than are generally to be met with in any of the other districts which have yet been examined; it thus reveals geological structures which are not to be found in the more southerly districts, and on this account serve to throw light upon obscure points in connection with the geology of other districts. These sections furnish very important evidence regarding the terrestrial movements to which these older rocks have been subjected. The Pilbara district contains very large areas of granite, granodiorite and gneiss, which, however, are not the oldest rocks. In every case where their relation to the schists can be observed along the margin, it is seen that these granites are everywhere intrusive, having gradually eaten its way into and partially absorbed them, and several sections may be noticed in which the granite sends out tongues and veins into them. One of the best localities in which the relation of the granite to the metamorphic rocks is at the Wodgina tinfield, which is situated on the headwaters of the Turner River about 24 miles from Port Hedland. The districts consist of a series of metamorphic sedimentary and bedded igneous rocks skirting the margin of an extensive granite mass, several hundred square miles in extent. These sedimentary auriferous rocks are pierced by a multitude of granite veins which in this district are of considerable economic importance by reason of the fact that they form matrices of tin and tantalite, for which Wodgina is noted. Near the tinfield is an instructive section showing a much older instrusive granite rock, which has been invaded by the much newer (though still old) tin-bearing granite. These acidic veins are made up of a coarse-grained rock composed of mica, quartz, felspar, and now and then tourmaline, and may be described as pegmatite, using the term in the sense in which it was applied by Delesse for any coarse-grained granitic rock containing mica, quartz, felspar, and tourmaline. No reference to these old granitic rocks would be complete without some mention being made of the large ice-like quartz reefs, which stand up to considerable altitudes above the surface like a wall, and which can in some cases be traced across country, with more or less interruption, for miles. They may be described as veins or dykes of pure silica, in some of the mine workings in two fields veins of this character are to be seen cutting across the auriferous quartz reefs. The question as to the relationship of these acid intrusive dykes of the type just mentioned and these quartz reefs has recently been attracting considerable attention, and there is a growing tendency to associate some quartz reefs genetically with pegmatite granite veins. In the Coolgardie Goldfield quartz reefs are often intimately associated with acidic dykes, and in some cases the latter gradually pass into pure quartz at their extremities. These acid dykes can be seen to pass by imperceptible gradations into the main mass of the granite at Coolgardie. Similar instances have been noticed in the Wodgina neighbourhood, and doubtless there are numerous other instances, but possibly they may have been overlooked, and their significance unappreciated.

Now a granite mass during the process of cooling gives rise to more acid pegmatite veins, and by further elimination of the bases pure quartz veins may result.

Various intermediate stages between granite and quartz veins have been noticed in Western Australia, and it is more than likely that many quartz veins are very probably intrusive rocks directly secreted from a cooling granite magma. Many pegmatitic granite veins contain tourmaline crystals as one of their essential constituents and many pure quartz veins in Western Australia contain tourmaline also.

Up to the present time, however, no observations have been made in this State with the object of discovering whether there are any of those structural and mineral changes induced in the enclosing rocks by the introduction of the quartz such as may often be observed consequent upon the injection of granitic veins. Observations upon this head, which are much to be desired, would have considerable scientific and even more important economic value.

In the southern portion of the State, the Darling Range, the Northampton District, etc., this fundamental complex is pierced by a much later series of basic dykes, where they sometimes preserve their dyke-like features across country without a break for miles. In the North-West district, however, they occur on a scale of magnificence as yet unknown in any other portion of Western Australia. Owing to the marked features which many of them exhibit these dykes can be readily followed across country, and in certain localities they are of considerable value in working out the details of the geological structures. A feature of significance is the faulting these later dykes have undergone since their injection and consolidation. In the Warrawoona field, an important North-West mining camp, these basic dykes traverse the centre of the auriferous zone almost at right angles to its general strike. The regular continuity of the system of dykes (which extend across country for 30 or 40 miles) has been interrupted in the vicinity of their intersection with the auriferous series, and they have undergone considerable movement since their injection. The peculiar dislocation and apparent displacement in short segments are probably due to a development of step-faulting in a manner not as yet fully understood. The dykes are apparently cut into curved and distorted segments and displaced along more or less vertical planes which have a general tendency to shift the separate portions bit by bit, in one direction, the dykes being dragged to the north-west of their course.

A very important feature in the geology of the Pilbara District is the evidence of great earth movements that affected the district.

In the neighbourhood of the picturesque Doolena Gorge, on the Coongan River, very impressive evidence of a powerful rupturing of the crust is to be seen, represented *inter alia,* by a line of dislocation, which has been proved to extend for nearly 100 miles. The large quartz reefs to which allusion has just been made are seen to be abruptly cut off by this powerful fault, which presents a steep vertical escarpment (unscaleable in places) often over 150ft. in height. At some distance north of this main fault an instance was observed (on the eastern bank of the Strelley River) of one of these large reefs, being not actually truncated, though subjected to deflection by a powerful thrust, exerted in a direction approximately parallel to its strike. In this instance the compression has been so great that this very reef, which is about 30ft. thick, was reduced to six to 10 inches, whilst the horizontal displacement reached about 100ft.

The quartz reefs of the district also afford evidence of overthrusting, contortion, etc., and many of them present features which seem to indicate that they have been wrenched apart by movement along shear planes. A very important instance of this is to be seen at the mining camp of Warrawoona, where a line of reef of a peculiar type traverses the field along a powerful dislocation, which has been followed for two and a half miles.

This dislocation occurs along a persistent reef, portions of which have been torn apart and shifted in segments, producing the peculiar kidney or damper-shaped lenses of quartz, which vary from a few inches to a foot or so in width. The interval between each lens of quartz fluctuates within very wide limits.

The walls of the country enclosing these lenses are scored with striae in the direction of the movement in a vertical direction, and the faces of the striations are often coated with fine films of gold. The abnormal richness, nearly 3ozs. per ton, of this type of auriferous reef has resulted in its being extensively prospected almost along the whole length, hence abundant opportunities are afforded of investigating its peculiarities, both on the surface and below ground.

The ancient sedimentary beds, which consist of highly siliceous rocks, dipping at varying angles to the north and east, consist of fine-grained flaggy quartzites, conglomerates, and quartz schist.

Some of the conglomerates still retain traces of their original character, though in others most of the pebbles have been flattened out and stretched almost beyond recognition.

The oldest series of basic dykes, by which they are traversed, have also been crushed and sheared, and are now represented by bands of schistose greenstones. The rocks are also intersected by certain other acidic dykes now represented by quartz-sericite schist, which may have originally been porphyries. One example from Warrawoona is a quartz sericite schist with "eyes" of a fairly soft mineral, originally a potash felspar, around which the fine foliation of the matrix sweeps in very graceful curves. When submitted to microscopic examination it is found that these porphyritic crystals present that peculiar peripheral granulation so characteristic of crystals and fragments which have been subject to intense crushing.

All the features, both of the rocks and the reefs, coupled with other evidence, clearly indicate the presence of a number of overthrust and normal faults, and point to a series of movements along lines parallel to that of the main trend of the dominant structural features of the district, which is north-west and south-east. The disruption of the newest series of basic dykes to which reference has been previously made, indicates that the enormous terrestrial stresses and strains continued in the same locality over a wide interval of geological time.

Traces of life may perhaps have existed in these old rocks of the north-west. Amongst the quartz schists which form the lofty serrated summit of the main axis of Warrawoona is a bed which here and there contains what at first glance appears to be fossil wood.

A characteristic specimen of this silicified wood (?) has a length of about 4½inches ; cross-sections of it are ellipsoidal in shape, the major axis being about ¾ and the minor axis about ⅝ of an inch in length.

Microscopical sections, both transverse and longitudinal, were prepared and submitted along with the specimens to Mr. Etheridge, of the Australian Museum, who, however, was unable to detect any trace of organic structure in them. It is, however, quite possible that some form of organic life existed at the time these beds were deposited, and that the marked changes which they have undergone obliterated all traces of organic structure.

II.—The Sedimentary Rocks.

The sedimentary rocks, etc., include the whole of the beds which lie between the ancient crystalline rocks and the more recent strata. In spite, however, of the extensive area occupied by the complex of crystalline schists, Cambrian fossils have been as yet noticed from only one locality in the far North of Western Australia.

Mr. E. T. Hardman, of the Geological Survey of Ireland, was the pioneer geological observer in the far North of Western Australia, and his researches carried out in the years 1883 and 1884 laid the foundation of our knowledge of the geology of the Kimberley District. This observer, however, obtained fossils from some limestones which have been referred to the Cambrian.

In 1891 Mr. H. P. Woodward made an extensive examination of the Kimberley District, and added considerably to the observations of Mr. Hardman.

Ten years later, in 1901, in company with Mr. Chas. G. Gibson, Assistant Geologist, I made a series of investigations in the King Leopold Plateau when searching for a reputed goldfield on the Carson River, between the 15th and 16th degrees of latitude.

In the latter part of 1905, and the early months of 1906, Dr. Jack visited Kimberley for the purpose of inquiring into the possibility of artesian water being obtained in the district.

Mr. Woodward revisited Kimberley in the winter of 1906, and examined the country between Mount Broome and the coast on the west, in the vicinity of Collier Bay, and obtained *inter alia* a trilobite from a dun-buff coloured limestone. The trilobite, which has just been submitted to Mr. Etheridge, appears to very closely resemble *Olenellus.*

Mr. Woodward describes these limestone beds as dipping at angles varying from 12 to 23 degrees to the south-west. The basal beds, consisting of limestone and conglomerate, contain fragments and boulders of the schistose and granitic rocks which unconformably underlie them. This observation is of importance in that, with the specific determination of the fossils he collected, light may be expected to be shed upon the age of the crystalline schists.

We thus have a good many details regarding the geology of this far north region, though as our knowledge has advanced it cannot be said that the tangled skein has yet been unravelled.

In the course of his investigations, Mr. Hardman gathered a suite of fossils which were critically examined by Mr. R. Etheridge and Mr. W. H. Foord and Dr. Henry Woodward.

Among the *disjecta membra* were the head and spine of a trilobite belonging to the characteristic Cambrian family, Olenellus Forresti and numerous pteropods, Salterella Hardmani, from a locality which, unfortunately, cannot now be identified. The discovery of the locality from which Olenellus was obtained by Mr. Hardman may be expected to go a long way towards setting at rest much that is at present puzzling regarding the geology of Kimberley.

Dr. Jack, writing in February of 1906, regarding the locality of Olenellus Forresti, says:—

The fossils described by Mr. Foord in his Notes on the Palæontology of Western Australia (Geol. Mag., March and April, 1890), were collected by Hardman in 1883, and presented by him to the British Museum in 1886. Hardman's trip of 1883, described in his first report (1884), extended from Derby to the Leopold Range. Hardman's label on the trilobite in question was:—"River South of Base-line."

There are two base-lines on Hardman's maps: (F9-EB) at Mt. Campbell (Lat. 18.13) (Long. 125.30), and the other (WE-EB) at the Hardman Range (Lat. 17.40) (Long. 128.50). If the *Olenellus* was collected in 1883, the base-line referred to must have been F9-EB since Hardman could not, in 1883, have mentioned a line which was not laid down till 1884. On the other hand, there is *no* river "South of Base-line" F9-EB within the limits of Hardman's work, unless Christmas Creek be meant.

There *is* a "river" (Hardman, in Irish fashion, called all small watercourses "rivers") viz.: the Turner, south of Base-line WE-EB. It washes the south-west side of the Hardman Range, but a good deal farther from the range than Hardman's map gives it. The Base-line WE-EB could only be the one referred to on the supposition that Foord's information as to the date of the discovery was erroneous—that "1883" should read "1884."

But the limestone indicated in *this* case is classed by Hardman as the lower member of his Carboniferous formation, and I saw what is, no doubt, its continuation resting on a considerable thickness of beds of basalt, which lie on the upturned "Devonian" of the Albert Edward Range."

Olenellus is Cambrian.

Altogether, we are confronted by so many contradictory conditions that I am inclined to conclude that the fossil must be ignored as having come from a locality unidentifiable.

Despite the fact of poor localisation of Mr. Hardman's fossils, it may, I think, be taken for granted that Cambrian beds do occur somewhere in Kimberley about south latitude 18 degrees. The recent discovery of *Olenellus* and *Salterella* in the limestones of the Daly River, in the northern territory, by Messrs Brown and Basedow, is of considerable geological importance, indicating a somewhat wide distribution of Cambrian strata, and makes the solution of the Hardman puzzle almost imperative, and more especially so in the light of Mr. Woodward's recent discovery in the Napier Range.

By far the largest area of the Kimberley division is occupied by a formation which extends from Mount Hopeless, near Collier Bay via Mounts Hart, Broome, the Mueller, Saw, and Deception Ranges, Goose Hill, near Wyndham, to the South Australian border. These beds, which rest with a violent unconformity upon the crystalline schists, were provisionally referred by Mr. Hardman to the Devonian. Considerable confusion has arisen, as has recently been pointed out by Dr. Jack in a report on the Kimberley district now going through the press, in consequence of a discrepancy between the first and second reports of Mr. Hardman, in which he describes what recent observations have shown to be the same formation, first as Cambro-Silurian, or Cambrian, and later as Devonian.

These Devonian beds of Kimberley have yielded the following fossils : *Atrypa reticularis, Rhynchonella pugnus,* an *Orthoceras,* and two species of *Goniatites* and *Spirifera.*

A feature of interest and importance in connection with these beds is the evidence they afford of widespread contemporaneous volcanic activity. This was first noticed by Mr. E. T. Hardman in 1883 and 1884, who describes contemporaneous dolerites, volcanic breccias and tuffs. It has been suggested that some of the igneous rocks occur in the form of intrusive laccolites.

In the year 1901, Mr. Gibson and I had abundant opportunities of investigating these beds during six months spent in the exploration of what may be called the King Leopold Plateau. Our observations extended from Wyndham to Mount Hart, near Collier Bay; the Prince Regent and Glenelg Valleys—rendered almost classical by the researches of Sir George (then Lieutenant) Grey, more than 70 years ago—and as far north as Admiralty Gulf. The result of the investigations indicated that the staple formation was made up of a series of quartzites, sandstones, fine conglomerates and shales disposed in a series of broad anticlinal folds. These beds extend as one continuous formation from Mt. Cockburn to Mount Hart, a prominent summit on the King Leopold Range. Associated with the quartzites, etc., are a series of bedded and intrusive igneous rocks, the prevailing types being andesite, dolerite, and diabase. The individual characters of the different beds naturally present a large amount of variation; the rocks are sometimes amygdaloidal, and contain nodules of zeolites and agates. Beds of volcanic ash and breccia are common in certain localities.

In certain isolated portions of the district excellent sections are exposed, showing the intrusive nature of some of the igneous rocks; the sandstones are sometimes altered into hard compact quartzite, portions of which have been caught up in the body of the igneous rock. Other sections indicate quite clearly that the igneous rocks have, in some cases, found an easy passage along the bedding planes of the sedimentary rocks and evidently occur in the form of sills.

The lavas are traversed by almost vertical dykes of epidosite, which are traceable across country for long distances, whilst both the sedimentary and the igneous rocks are intersected by numerous segregation veins of quartz, some of considerable size and horizontal extent.

Mr. Hardman noticed during his explorations in 1883-4 the association of fossils of carboniferous affinities, with those characteristic of the Devonian rocks in the Kimberley beds. Dr. Jack noticed in 1906 a similar association of Devonian and Carboniferous fauna from the beds near Mount Pierre, and makes mention of the carboniferous limestone region, consisting partly of limestones of an older date, and remarks that either there are in the Mount Pierre region separable carboniferous and Devonian strata, or the same strata contain a Devono-carboniferous fauna. It is possible that this apparent admixture of Denovian and carboniferus fossils may have been brought about by post-carboniferous orogenic movements of which there is abundant evidence in different portions of the State.

Three field seasons spent by myself in the Pilbara Goldfield, situated in latitude 21 degrees south, afforded an excellent opportunity for examining a formation consisting of sandstones, grits, conglomerates, and limestones, some of which are magnesian, together with a series of lavas, ashes, and agglomerates of as yet unascertained thickness. In its lithological characters, its behaviour and general physical aspect it bears a very strong resemblance to the quartzites, etc., of the King Leopold Plateau, to which reference has just been made.

This formation, which has been designated the Nullagine series, has a very wide distribution in the North-West, and the associated volcanic beds occupy a large area of country in the southern portion of the district. The series, which presents a plateau-like appearance, certain of the harder beds standing out in bold relief, presenting mural faces at different levels, plays a very important part in the geology of the North-West, in addition to being of some economic value by reason of the fact that the basal conglomerate of the series has been worked for the gold it contains in two widely separated localities, viz :—Nullagine and Just-in-time.

The Nullagine beds have been followed from the Oakover River across the upper reaches of the Nullagine, Coongan, and Shaw Rivers, as far as the western boundary of the Pilbara Goldfields on the Yule River, near Cangan Pool, from which locality they can be followed without a break to the vicinity of Roebourne. The same series constitutes the Hamersley Range, which contains Mount Bruce, the highest summit in the State. The Nullagine beds are probably continuous as far south as the Ashburton River, where both flanks of the valley are formed by extensive beds of magnesian limestone, which may be continuous with those which I observed in 1905 in the recesses of the Hamersley Range.

Regarding the southern extension of the Nullagine series it may be noted that in a deep bore put down by the Government at Onslow, near the mouth of the Ashburton River, volcanic rocks identical with those in the former district were met with. It may thus be that these strata were pierced in the lower portion of the Onslow bore.

Undoubted Permo-carboniferous rocks are known to occupy a large area of country in the watersheds of the Gascoyne, the Minilya, and the Lyndon Rivers, hence the examination at present being undertaken of the country lying between Onslow and Lyndon should afford some valuable information as to the mutual relations of the

Permo-carboniferous and the Nullagine beds. So far as observations have at present been carried there seems to be a gradually ascending geological series as we proceed southwards. What I am inclined to regard as outliers of the Nullagine series occur in the Murchison Goldfield, near south Latitude 27 degrees. In 1904 Mr. Gibson mapped a considerable portion of the auriferous belt of the Murchison, and described a series of fine-grained volcanic ashes, lying almost horizontally on the granite of Mount Yagahong, about two miles south of the townsite of Gabanintha. The beds have evidently a wide extent in the Murchison. At the town of Cue, some distance to the south of Gabanintha, there is a horizontal dolerite sheet capping what is known as Cue Hill, and some little distance to the west on the lower ground are a few outliers of quartzite on a lower horizon. These quartzites evidently form part of a much more extensive formation of which they are but remnants left. There is very little doubt that these beds form part of the same series as the volcanic ashes at Gabanintha.

The igneous rocks associated with the series consist generally of acidic lavas. The great mass of the rocks consist of separate lava flows, each of no great thickness; some of the lavas are distinctly amygdaloidal, the cavities being filled with chalcedony.

Some of the finer-grained ashy beds differ very little in general appearance from many of the banded lavas with which they are associated.

Undoubted volcanic focii, from which these lavas emanated, occur in many parts of the districts, though they have been extinct long enough to allow the process of weathering to reduce them to mere stumps. There are also several acidic dykes which pierce both the sedimentary and the volcanic rocks, and these in all probability represent but another phase of that extraordinary volcanic activity which occurred in the northern portion of Western Australia during the Devonian period.

Considerable interest attaches to the Nullagine series by reason of the nature of the boulder beds at the base of the formation, for two important scientific reasons, viz. :—(*a.*) the occurrence of flattened and striated pebbles to which a glacial origin has been assigned ; and (*b.*) the nature of the gold and iron ore in the conglomerate.

The basal conglomerate of the series is made up of rounded, ellipsoidal, or subangular fragments of the older underlying series. Many of these often include pieces which reach a length of three or four feet. Some portions of the conglomerate contain flattened and striated pebbles of fine-grained sandstone and sandy shales, identical in character with those constituting the underlying strata. To these striated pebbles a glacial origin has been assigned by the late Mr. S. J. Becher, and subsequently by Professor David. The pebbles, however, seem to have had their striation induced prior to their taking part in the formation of the Nullagine series. The beds upon which the series rest, and to the denudation of which the boulders owe their origin, having, as has already been shown, been subject to intense mechanical deformation, it would only be natural to find some slickensided fragments and pebbles in newer rocks. Earth movements have caused the Nullagine beds to be thrown into a series of undulatory folds, but the deformation thus induced has not been of sufficient intensity to cause any striation of the Component pebbles.

Such mining operations as have been carried out in the auriferous conglomerate have been, up to the present, confined to relatively shallow depths along the outcrop ; the conglomerate is in part marked by the presence of large quantities of iron pyrites and its oxidation products. In the inoxidised portion the pyrites occur both as crystals, grains, and rounded or pebble-like forms. A certain interest attaches to the occurrence of these rounded pebbles and pellets of auriferous pyrites and hematite on account of the fact that they have been regarded as owing their shape to attrition, and that the gold and the iron are detrital, having been deposited with the pebbles of the conglomerate, as the result of all disintegration of the underlying auriferous rocks. The evidence respecting the origin of the gold in the Nullagine conglomerates indicates that it is a secondary and not an original constituent, and further, that the primary source of the gold is the quartz reefs which occur in the underlying formation.

From the known occurrence of auriferous quartz reefs, which furnished no small portion of the pebbles of certain portions of the deposit, it is of course quite conceivable that a certain amount of detrital gold forms part of the conglomerate, but there are obviously no means of ascertaining what is the proportion of primary to secondary gold.

There seems, however, good reason for believing that by far the greater bulk of the gold, together with the pyrites, was introduced by solution percolating down to the most porous portions of the conglomerate, the condition being facilitated by the downward inclination of the bed rock, and possibly accentuated in part by the folding which the strata have undergone.

One of the most important advances in Western Australian geology is the recognition of a glacial conglomerate in the marine carboniferous rocks, near the tropic of Capricorn.

The carboniferous rocks of the State cover a wide extent of country, and bid fair to become of considerable economic importance.

The occurrence of Carboniferous rocks would seem to have first been made known through Sir George (then Lieut.) Grey in the year 1841, in his journals of the two expeditions of discovery in

North-Western and Western Australia during the year 1837-9. There are four districts in which fossiliferous Carboniferous rocks are known in the State, viz.:—Kimberley, the Gascoyne, the Irwin River, and the Collie Districts.

The Carboniferous rocks of Kimberley have recently been investigated by Dr. Jack, when in quest for artesian water. This observer's work was carried out in the months of December and January during one of the most severe droughts experienced in the district, and with a temperature often reaching 114 degrees Fahrenheit. Despite the fact that the route followed in investigating these beds, has perforce to be governed by considerations of grass and water, our knowledge of the Carboniferous rocks of Kimberley has been greatly extended. The formation is divisible into a lower or limestone series (in which limestone predominates) and an upper sandstone series (made up largely of sandstones and other sedimentary beds). The two series have been seen to succeed one another conformably in the Haughton Range, south latitude 19 S. and East Long. 127 E. Both series have yielded an assemblage of purely Carboniferous fossils:—*Lepidodendron, sp.; Stigmaria,* sp.; *Stromatopora concentrica* (?) *Stromatopora placenta, sp.; Pachypora tumida; Zaphrentis, sp.; Syringopora* sp.; *Actinocrinus,* sp.; *Platycrinus,* sp.; *Poteriocrinus crassus,* Miller; *Pentremites,* sp.; *Serpula; Spirobis,* sp.; *Fenestella plebeia* (*antiqua,*) McCoy; *Productus, giganteous; Produstus longispinus; Productus semireticulatus; Chonetes,* sp.; *Chonetes Hardrensis; Discina; Orthis resupinata; Strophalosia Clarkei,* Eth. fils; *Rhynchonella pugnus; Rhynchonella pleurodon; Rhynchonella cuboides; Orthotetes crenistria,* Phillips; *Streptorhynchus crenistria; Terebratula hastata* (?); *Terebratula sacculus* (?) *Pleurotomaria,* sp.; *Toxonema,* small sp.; *Natica,* sp.; *Ceriopora,* sp.; *Chaetetes tumidus; Stenopora Tasmaniensis; Cyathophyllum,* sp.; *Cyathophyllum virgatum; Cyathophyllum depressum; Lithodendron affine.*

So far as observations on the Kimberley Carboniferous rocks have been carried, no boulder beds have yet been recognised, though in view of the occurrence of glacial conglomerates in India within 18 degrees of the Equator their presence in Kimberley would cause little surprise. The necessity for a further more or less detailed geological examination of a portion of the Kimberley district is at the present moment under consideration by the Government, and the solution of the many economic questions involved in the stratigraphical research which such an investigation entails is of no less importance to the community than the purely scientific results which of necessity follow.

The Gascoyne beds cover a very large area between the 22nd and the 26th parallels of South Latitude, and excellent sections of them may be seen in the valleys of the Wooramel, Gascoyne, Lyons, Minilya, and Lyndon Rivers. Like their representatives in Kimberley, the strata are divisible into an upper or sandstone and a lower or limestone series. The sandstone series, which is seen resting comformably upon the limestone, is well exposed in the Carandibby, Kennedy, and the Moogooloo Ranges, making a bold outcrop of almost 200 miles in length. The beds forming these ranges were, until quite recently, regarded as of Mesozoic Age. The discovery, however, of *Spirifera, Athyris* (?) *Productus,* and *Strophalosia* in the Kennedy Range, near Trig. Station K 37, on the northern bank of the Gascoyne River, definitely sets at rest the conflicting views until quite recently held regarding their position in the geological time scale.

The country to the east of the Kennedy Range is underlaid by fossiliferous beds of the limestone series, associated with which is the glacial boulder bed.

This bed, which forms a valuable stratigraphical horizon, has been traced across country for a distance of about sixty or seventy miles.

At the most southerly locality at which the boulder bed has been detected in Wooramel Valley, the boulders are of very large size, and is composed of rocks identical in character with those forming the older underlying rocks to the east, *e.g.,* granite and other crystalline and metamorphic rocks.

Some distance northward on the Wyndham River is a boulder bed in the limestone series. The bed, which at this spot attains no greater thickness than three feet, is crowded with boulders and pebbles of granite and crystalline rocks embodied in a calcareous fossiliferous matrix ; a photograph of a specimen of which contains fragments of *Spirifera Productus* and *Poyzoa,* in addition to *Aviculopecten tenuicollis,* will be found in the Annual Report of the Geological Survey for 1900. The pebbles and boulders have a large proportion of smooth and polished faces. The flats in the neighbourhood are covered with boulders and blocks of crystalline rocks evidently derived from the weathering *in situ* of the conglomerate which has a dip of about three degrees to the south-west. In the bed of the Wyndham River beds of flaggy sandy limestone are to be observed passing beneath the boulder beds indicating what is perfectly obvious from numerous sections that the glacial conglomerate does not lie quite at the base of the Carboniferous rocks.

Associated with the boulder beds of the Wyndham River are the following fossils :—*Hexagonella dendroidea,* Hudlestone sp. ; *Pleurophyllum Australe,* Hinde ; fragments of *Crinoid* stems, and *Polyzoa ; Spirifera Musakheylensis,* Davidson ; *Spirifera Hardmani,* Foord ; *Spirifera lata,* McCoy ; *Retcularia lineata,* Martin sp. ; *Athyris Maccleayana,* Eth. fil. ; *Chonetes Pratti,* Davidson ; *Productus* (cf *Pteuni-straitus,* Foord).

Northwards from the Wyndham River the *débris* of the boulder bed makes its appearance in great force. The flaggy sandstones immediately underlying it are covered with large boulders of crystalline rocks. Near Barragooda Pool, on the Arthur River, a thick bed of limestone directly overlies the boulder bed. This limestone has yielded the following fossils :—*Evactinoporo crucialis,* Hudleston ; *Rhombopora tenuis,* Hinde ; *Athyris Macleayand* Eth. fil Var. ; *Productus semireticulatus,* Martin ; *Aulos-teges,* sp. nov. ; *Dillasma,* sp. ind.

A few miles to the north of this, near Trig. Station K. 34, the Carboniferous beds are faulted against the older crystalline rocks which, in this locality, consist of quartz and mica schists, associated with either dykes or sills of porphyry.

In the southern branch of the Minilya River, near Trig. Station K. 49, the boulder bed is seen overlying beds of limestone and shale. The *débris* of the boulder bed consists of a heterogeneous collection of all sorts of crystalline and metamorphic rocks, and contains numerous ice-scratched pebbles ; photographs of several typical examples appear as Plate IV. of the Annual Report of the Geological Survey for 1900.

It may be mentioned in this place that in a deep bore put down by the Government at Pelican Hill, near Carnarvon, that these Carboniferous or Permo-carboniferous beds were met with beneath fossiliferous Mesozoic rocks at 1,406ft., and continued to 3,011ft., the present depth of the bore. The Carboniferous strata are represented by calcareous shales and limestone. The cores from the bore have yielded *Spirifera, Aviculopecten, Anthracoptera,* and *Favosites.* The bore, however, which did not pierce the whole thickness of the Carboniferous rocks gave no signs of the boulder bed. From the few salient features pointed out it appears quite clear that the glacial conglomerate is associated and interbedded with the fossiliferous limestones low down in the Carboniferous series as developed in this part of Australasia.

In the year 1897 I made a traverse up the Murchison valley in an exceptionally dry season, which seriously interfered with geological investigation, and at a point in the bed of the river, about 100 miles south of the boulder bed last mentioned, a conglomerate and breccia composed of angular fragments of a quasi-vitreous quartzite dipping at a low angle to the east was met with ; the base of the conglomerate was not visible anywhere, the most important and significant feature in this section is the fact that many of the pebbles were covered with scratches, not unlike slickensides.

A few yards lower down the river are a few beds of cross-bedded sandstones and fine conglomerates dipping east at an angle of about 20 degrees. One of the beds has been scored to such a degree as to produce surfaces as smooth and polished as plate glass.

The question arises, is this portion of a glaciated pavement, or is it due to faulting ? If the latter, the faulting is nearly horizontal. Some distance further up the river, near the Forty Mile crossing and water reservé 1005, the sedimentary beds are inter stratified with coarse conglomerates or boulder beds; the boulders are principally quartz, though pebbles of sandstone and granite occur. I detected no scratched boulders in this section, though circumstances did not admit of any detailed search being made. The important point in connection with these conglomerates containing the scratched boulders is that they form part of what is at present believed to be the southern extension of the Carboniferous series of the Gascoyne, and form a connecting link between the latter and the Irwin River series, to which reference will be made later.

Beneath the Jurassic rocks of the Champion Bay District and in the valley of the Irwin River and its tributaries is a fairly extensive development of Carboniferous and Permo-carboniferous beds In this district, as in Kimberley, it is possible to divide the strata into two distinct series, viz., the lower, or limestone, and the upper, or sandstone series.

Beneath the Irwin River coal seams are a calcareous shale and limestones, yielding a series of fossils, which have been carefully examined and described by Mr. Etheridge, of the Australian Museum, and will shortly appear as one of the Bulletins of the Geological Survey of Western Australia. The following fossils occur in these beds :—

Nubecularia, Stephensi, How ; *Pleurophyllum Australe,* Hinde; *Fenetella fossula,* Lons. ; *Dielasma,* sp. ; *Seminula subtilita,* Hall ; *Spirifera,* sp. ; *Reticularia lineata,* Martin ; *Productus semireticulatis,* Martin ; *Productus tenuis-triatus,* var Foord Eth. fil. ;*Productus undatus,* Defrance ; *Productus subquadratus,* Morris(?) ; *Chonetes Pratti,* Dav. ; *Aviculopecten Sprenti,* Johnston ; *Conocardium,* sp. Brom. ; *Stutchburia,* sp. Eth. fil. ; *Bellerophon costatus,* J. de C. Spy.

Gastrioceras Jacksoni, sp. nov. (the largest goniatite yet found in Australia, and of an entirely different type to the incomplete forms so far described).

The facies of these fossils is more akin to the Carboniferous than the higher Permo-carboniferous, and only four species are with certainty identical with those found in the Permo-Carboniferous rocks of Eastern Australia, viz. :—*Nubecularia, Productus subquadratus, Fenestella fossula,* and *Aviculopecten Sprenti.*

Associated with the marine series is a boulder bed, the *débris* of which strew the surface for a considerable distance, but there has as yet been no opportunity of investigating these beds in any detail. So far I have seen no striated pebbles among the boulders.

About 25 miles lower down the river, in the vicinity of Mingenew, and close to the railway line, are a series of ferruginous sandstones, on a higher horizon than the limestones, which remind one very forcibly of the sandstone series as developed in the Kennedy Range of the Gascoyne River. These beds have yielded the following fossils :—

Dielasma nobilis, sp. nov. ; *Dielasma hastata,* Dana ; *Spirifera,* sp. ind. ; *Spirifera avicula,* E. B. Spy ; *Cyrtina carbonaria,* var. Australasica, Eth. fil. ; *Cleiothyris Macleayana,* Eth. fil. ; *Productus Subquadratus,* Morris ; *Productus brachythoerus,* E. B. Spy ; *Chonetes,* sp. ind. *Deltopecten subquinquelineatus,* McCoy ; *Modiola* (?), sp. ind. ; *Myalina* (?) *Mingenewensis,* sp. nov. ; *Fenestella* or *Proloretepora.*

On the whole, it seems that the aspect of the fossils is that of the Permo Carboniferous of New South Wales.

It thus seems that there are in the Irwin River valleys beds of Carboniferous and Permo Carboniferous Age, and that the coal seams may possibly be the equivalents of the Greta Coal Measures of New South Wales.

The Collie River beds, which attain a thickness of a little over 2,000ft., are of considerable economic importance by reason of the fact that they contain coal seams to a total thickness of about 137ft., and are of some scientific interest in their relation to the important question of the distribution of the *Glossopteris* flora.

The Collie River coal field lies to the east of Bunbury and south of Perth, north-western edge of the tableland which succeeds the coastal plain. The field itself is traversed by the Collie River at an altitude of about 600ft. above the level of the sea. The area occupied by the Collie River coal measures is approximately 500 square miles. The beds consist of alternations of shales, sandstones, and grits, which rest directly upon granite schist and other crystalline rocks. The boundary of the field is, with one local exception, everywhere defined by faults ; on the south-western side of the field the boundary fault has been estimated to have a down throw to the north-east of at least 2,000ft.

There are several coal seams in the field of variable thickness, they consist in descending order of Cardiff No. 1, seam 9ft. to 12ft. thick.

Cardiff No. 2 or Boulder Seam, 7 feet thick.
Collie Burn No. 1 Seam, 9 feet thick.
Collie Burn No. 2 Seam, 6 feet to 7 feet 10 inches thick.
Coal (no name), 8 feet thick.
Proprietary No. 1 Seam, 4 to 8 feet thick.
Proprietary No. 2 Seam, 5 feet to 7 feet 6 inches thick.
Wallsend Seam, 9 to 17 feet thick.

The coal seams are hydrous, semi-bituminous, non-caking coals, which approach very closely to lignite in some parts; between the various varieties the differences are only of degree for there are no distinctive characters which would find universal application. Owing to the conditions of deposition the coals naturally vary in character, and in places pass insensibly through forms containing a large proportion of earthy matter into carboniferous shales.

The question of the precise geological age of the Collie River beds is one about which there has been, and still is, considerable divergence of opinion.

In the year 1891, Mr. H. P. Woodward, the Government Geologist, assigned an early Mesozoic Age to the beds, basing his determinations principally upon the physical aspect of the field, and the chemical composition of the coals.

A little later some fossils were submitted to the late Mr. R. Etheridge, sen., who detected *Glossopteris* or *Neoggerthia,* and concluded that the beds were Permo Carboniferous.

In 1894, Mr. Woodward, basing his opinion upon the results of Mr. Etheridge's determination, referred the beds to the Upper Carboniferous.

In 1897, Mr. E. F. Pittman, Government Geologist, New South Wales, visited Western Australia, and in a report, referred the strata to the Mesozoic, on the strength of Mr. Etheridge's (jun.) doubtful recognition of *Sagenopteris.*

Upon a geological map accompanying a report by myself, published in 1898, the age of the beds was defined as uncertain.

In 1898, Sir Frederick McCoy reported the discovery of *Glossopteris Browniana* in some fossils sent to him by the Premier of the State, and stated that the beds were of "the exact geological age of the great coal fields of Newcastle, New South Wales." I may add, however, that these fossils were not collected by, nor were they ever seen by, any member of the geological staff.

Mr. R. Etheridge, jun., in his "Notes to accompany a miscellaneous collection of Western Australian fossils," submitted to him by myself in 1903, recognised undoubted *Glossopteris* in a good state of preservation, from the Moira Colliery, and constrained him to support the age assigned to the Collie River beds by his father, viz., Permo-Carboniferous. Mr. Etheridge carefully examined the *Sagenopteris* (?) obtained by Mr. Pittman, and in the same report abandons his previous determination, and now looks upon it as *Glossopteris.*

In 1904 Dr. Jack received a Commission from His Excellency the Governor to fully investigate all aspects of the Collie coal industry, including *inter alia* geological conditions. Accompanying the Commissioner's Report is an excellent geological map and longitudinal section ; upon the former the age of the Collie River beds is set down as undetermined. Dr. Jack in his report says:—

The evidence bearing on the age of the Coalfield is at best inconclusive. High authorities have indeed expressed the opinion that it was of Palæozoic Age—Carboniferous, or Permo-Carboniferous—but all these opinions are founded exclusively upon the presence of the form *Glossopteris,* which is now known to range from Carboniferous to late Cretaceous. The shales are coarse-grained and incoherent, and badly adapted for the preservation of plant remains.

Dr. Jack draws attention to the fact that the various beds in the series are less coherent than is customary among the Carboniferous or Permo-Carboniferous formations of Europe, Africa, and Australia, and concludes :—

In a somewhat wide experience I have seen nothing which the Collie Coal Measures, coal seams included, so much resemble as the Oligocene Coal Measures of Croatia. While eagerly looking forward to the production of further evidence and open to conviction, I am at present inclined to believe that the Collie Coalfield will turn out to be possibly of Cretaceous Age, newer than the Coalfields of Ipswich and Burrum of Queensland.

The next and perhaps most important evidence bearing upon the controverted question is contained in some "Notes on fossils from the Collie Coalfield, Western Australia," in the "Collection of the National Museum, Melbourne," by Mr. F. Chapman, the Palæontologist to the Natural History Museum, Melbourne, just about to be printed as one of the Bulletins of the Geological Survey of Western Australia.

This writer recognised the plants :—*Glossopteris browniana ; Glossopteris browniana var indica; Glossopteris browniana var communis ; Glossopteris browniana var angustifolia ; Glossopteris browniana gangamopteroides.*

And in the associated sandstones the following Foraminifera:—*Endothyra ; Valvulina plicata* (U. Carb. List, England) ; *Bulimina* (Permo-Carboniferous, N.S.W.) ; *Truncatulina haidingeri* (Permo-Carb., N.S.W.) ; *Pulvinulina exigua.*

The *Valvulina* of Collie, though very much dwarfed, is essentially a Carboniferous form whilst the other species Mr. Chapman detected and described point in a general way to the Palæozoic Age of the series.

Mr. Howchin pointed out in 1893, in his "Census of the Fossil Foraminifera of Australia," that the Australian Palæozoic foraminifera show a closer affinity with the Permian fauna of the Northern hemisphere than the Palæozoic.

In view of all the evidence at present to be deduced from the plant remains and the marine organisms in the beds associated with the Collie coal seams, despite the nature of the coal and the physical characteristics of the basin, I am constrained to admit that a Permo-Carboniferous Age of the series presents the strongest claims to acceptance. I make no excuse for the fact that my present views on this much debated question are not those I previously held, but our most cherished opinions, like everything else, must yield to that stern logician—fact.

Jurassic rocks have been found up to the present in only one district—that of Champion Bay, near Geraldton; but the beds have not been investigated in any detail by the Survey, hence our information about them is at the best somewhat meagre.

Mr. Crick, of the British Museum, in a paper on "A Collection of Jurassic Cephalopoda, from Western Australia," records *Ammonites* (*Perisphincts*) *Championensis* from Cape Riche, to the East of Albany, and naturally claims a Jurassic Age for the beds.

In 1898 I visited Cape Riche. The beds consist of sandy limestones, which extend between Cape Riche and Warriup, and are fossiliferous. The Cape Riche beds have yielded :—Impressions of a Cycadaceous leaf (?) *Hemiaster,* sp. ; *Pectunculus, near P. flabellatus ;* Ten. Woods, internal casts of *Cytherea, Arca, Lima, Mactra, Amusium* and *Voluta,* in addition to *Venus,* near *V. Voseotineta,* Baird.

The Warriup beds have yielded:—*Cardium,* sp. ; *Cardium hemicardium,* Linn ; *Trochus personatus* (?) Phil. and *Arca reticulata,* G.M. These strata would therefore seem to be either recent or very young Tertiary. Even assuming that the Cape Riche series turn out on further investigation to be Secondary, I do not think the Jurassic can put in any claim for recognition. I am, therefore, inclined to think that Mr. Crick's Ammonite recorded from Cape Riche has been wrongly localised, and really came from Champion Bay.

The Champion Bay Jurassic beds cover a fairly large area of country to the south in the neighbourhood of the coast line; they are seen to rest with a violent unconformity on the Carboniferous rocks of the Irwin River valley. They also probably extend northwards, for in the deep bore near Carnarvon strata high up in the Mesozoic series have been recognised, between 1,200 and 1,500 feet.

The Champion Bay beds consist of oolitic limestones, clays, sandstones, grits, and conglomerates. Fossils are abundant, and they include a considerable number of Cephalopoda:—*Belemnites,* sp. ; *Nautilus perornatus,* sp. nov. ; *Ammonites* (*Dorsetensia*) *Clarkei,* sp. nov. ; *Ammonites* (*Stephanoceras*) *Australe,* sp. nov. ; *Ammonites* (*Sphaeroceras*) *Woodwardi,* sp. nov. : *Ammonites* (*Sphaeroceras*) *semiornatus,* sp. nov. ; *Ammonites* (*Perisphinctes*) *Championensis,* sp. nov. ; *Ammonites* (*Perisphinctes*) *robinginosus,* sp. nov. There have also been obtained:—*Trigonia Moorei, Lycett, Myacitus Sandfordii,* Moore ; *Lima,* sp. ; *Lima* allied to *L. pectiniformiss,* Gold ; *Cucullaea semi-striata,* Moore ; *Pleuromya, Astarte Cliftoni,* Moore ; *Cresslya,* sp. ; *Gryphaea,* sp. ; *Mytilus* allied to *M. Cygerensis,* D'Orb ; *Pecten frontalis,* Dumortier.

No estimate can as yet be made of the thickness of these Jurassic beds; they have, however, been pierced by four bore holes in the Champion Bay district, the deepest being at Dongara. This bore was sunk for the purpose of the delimitation of the seaward extension of the Irwin River coal measures, which there are good grounds for believing to lie beneath the Mesozoic beds. The bore attained a depth of 2,111 feet when operations were stopped owing to the capabilities of the boring plant being exhausted without the base of the Jurassic rocks having been reached. There are thus over 2,000 feet of these beds in this locality.

The recognition by Mr. W. D. Campbell of the remnants of an extensive dolomitic limestone formation at an altitude of about 900 feet above the level of the sea at Norseman, and distant about 100 miles due North from the coast at Esperance Bay (Long. 122 degrees East) containing fossils of either late Tertiary or Recent Age is, perhaps, next to the Carboniferous Glacial beds, one of the most important of the recent advances in our knowledge of the younger geological formations.

Two small outliers of this formation occur on the western bank of Lake Cowan and four near Lake Dundas. The beds, which in the vicinity of Norseman occupy but a very small area, consist principally of a dolomitic limestone, with several siliceous bands. These beds contain species of *Turitella,* allied to *T. terebra ; Pecten, Cardium* (or *Cardita*) *Magellania,* and fragments of *Polyzoa.* These discoveries are of considerable importance, and must be thoroughly examined some day, as they involve a whole series of important conclusions which depend upon the age of the fossils the beds contain.

At Balladonia, many miles to the east and in what is known as the Eucla limestone plateau, the flesh coloured limestones have yielded:—A Pecten, allied to *Chlamys asperimus,* Lamck ; near Madoura Station a shell aglomerate yielded *Venus peronii* var *conularis,* Lamck ; and *Tapes,* probably *T. Avaneosus,* Phillipsi, a living species. These fossils seem to indicate a deposit of comparatively recent age.

Entering the State at its eastern frontier in the Nullabor Plains, and extending without any interruption as far as Israelite Bay, is very large development of strata of Recent and Tertiary Age. These strata consist of flesh-coloured limestones associated with sandy porous beds, into which the rainfall is rapidly absorbed and discharged seawards in the form of fresh water springs, and are the western extension of the beds pierced in the five bores in South Australia.

These beds form what is known as the Premier Downs. An immense limestone plateau extending from Goddard's Creek (E. Long. 124 degrees) to the South Australian frontier, terminating abruptly along its southern border by a conspicuous escarpment

400 feet high in some places. The limestone plateau extends for miles into the interior, and the average altitude (so far as can be ascertained) of the inland margin is about 1,000 feet above sea level.

The bore nearest the Western Australian frontier is at Albalakaroo, on or near the telegraph line at about 45 miles east of Eucla. This bore attained a total depth of 1,084 feet, and bottomed on granite at 1,073 feet, after passing through (in descending order) 565 feet of (Eucla) limestone, 426 feet of clay (?shale), and 82 feet of a "hard rock," which those in charge of the operations could not determine.

Two bores have been sunk by the Western Australian Government near Madura. No. 1 bore was put down at a point 110 feet above sea level, and distant 30 chains south of the Eucla limestone escarpment, which is 350 feet high. The bore was carried down to a total depth of 2,041 feet, and passed (in descending order) through about 766 feet of limestone, underlaid by alterations of clay shale, sometimes Glauconitic dolomitic limestone. The bore ended in a soft mudstone. The second or No. 2 bore was situated 30 miles to the north of No. 1, on the limestone plateau, and about 300 feet above the level of No. 1. It was carried down to a depth of 412 feet, and passed through nothing else but limestone—the Eucla limestone. The sequence of strata in the Western Australian bores coincides in its essential particulars with that indicated by the South Australian bores, and there can be very little doubt as to identity of the two series of beds whatever may be their age.

Laterite.—No mention of the recent advances in Western Australian geology would be complete without some reference to that extensive development of residual deposits which have been found over the whole length and breadth of the State.

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

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

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

The lateritic deposits naturally vary in their lithological characters. They are often very porous and weather into caverns and cavities of all sizes. The surface of the rock is often covered with a glaze of hydrated oxide of iron. When freshly broken the rock presents a mottled appearance owing to the different shades of brown, yellow, and red. The rock passes gradually into the underlying rocks without any sharp line of demarcation. That ferruginous and siliceous laterites are more commonly met with is due to the fact that deposits of this type are better able to resist disintegrating influences than the softer varieties; they thus not only remain themselves, but act as a protecting cover for the rocks beneath.

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

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

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

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

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

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

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

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

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

These analyses show variations in alumina from 7.52 to 44.66 per cent. ; ferric oxide, 10.02 to 88.23 per cent.; silica, 1.53 to 23.26 per cent. ; combined water, 8.10 to 26.44 per cent. ; and oxide of titanium, .59 to 3.10 per cent.

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

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

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

In the southern portion of the State where the rainfall is greatest, the lateritic deposits support an abundant vegetation. The well-known karri and jarrah growing in all their splendour thereon. In fact the mapping of the lateritic deposits of this portion of the State would define the areas over which both karri and jarrah occur.

Elsewhere in the State the laterites support but a scanty vegetation.

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

We have, however, as yet, little authentic evidence on this point, though it may be mentioned that a bore put down at Coolgardie, on Reserve No. 23, certain plant remains were found in a deposit containing what is evidently the detritus of the lateritic beds. These plant remains have, on examination, been held to belong to the *Eucalypti.* McCoy has described definite eucalyptus foliage from the older gold drifts in Victoria, whilst Ettinghausen describes several species from the Upper Tertiaries of New South Wales and deep lead in the New England Tinfield.

On this evidence, therefore, the laterites seem to be of earlier age than the Tertiary, though there is but little doubt that lateritic deposits are forming at the present time.

III.—Volcanic Rocks.

Volcanic rocks have played an important part in the geological history of Western Australia, and the evidences of this igneous activity are to be found in the form of lava flows, ash beds, breccias, dykes, stills, etc., which make a prominent feature in certain portions of the State.

Many writers and observers, it must be noted with regret, treat volcanic rocks in such a fashion as to suggest that they constitute a more or less meaningless interpolation in geological history, and I have no desire to be included in the same category.

There are, so far as is at present known, three distinct periods in which Western Australia has been the scene of igneous activity of more or less intensity. These periods are :—

(*a.*) In Pre-Cambrian time, prior to the deposition of the beds containing the Olenellus fauna. These old igneous rocks are of importance in the part they appear to have played in connection with the formation of the ore deposits of the State. These have been more or less fully described in the opening portions of this address.

(*b.*) A period commencing early in the Nullagine (Devonian) time, but ceasing before the Carboniferous. The interstratification of lavas and ashes with the sandstones and conglomerates point to subaqueous eruptions, though from the amygdaloidal nature of many of the lavas, the bulk of these volcanic rocks must, I think, be sub-aerial. Several of the focii from which the lavas, etc., emanated, have been noticed. The magnificent series of basic dykes of the North-West and elsewhere, to which reference has already been made, suggest to one who has examined the Devonian Volcanic Series, that fissure eruptions, of which these dykes may form part, have been in some way responsible for the wide extent of the lava flows, which cover some hundreds of square miles.

(*c.*) After the deposition of the Jurassic Beds, and believed to be of Tertiary Age, they consist of basic lavas and ashes, which occur in great force in the Kimberley District.

In the Ord and Bow River valleys these lavas appear to have levelled up the depressions formed therein (except certain knife edge ridges of the older rocks, which still protrude above the level) and in places rest upon the Devonian Volcanic plateau. On the Behn River, just above what is known as the "Gorge," Dr. Jack noted a dome or "pug" of basalt, which apparently formed the focus from which some of these lavas issued.

At Bunbury, and one or two points on the coast round the south-west corner of the State, bedded columnar basalts occur. Over large areas, and far into the interior, numerous volcanic ejectmenta, in the form of obsidian bombs occur, and were probably derived from volcanoes of which no trace has yet been found, it is quite possible they may owe their origin to that volcanic region which skirts the northern coast of Australia.

The geological age of these basaltic lavas in the present state of our knowledge is a matter for inference only, but if we assume that they all belong to one period, they must be set down as Tertiary.

Some of the basic intrusive dykes, which are also widely distributed in the North-West, and form such pronounced features in the scenery, belong to a later period, that of the volcanic eruptions of Nullagine (Devonian) times ; for many cases have been noticed in which they traverse the Nullagine Beds for many miles. Since the Nullagine volcanic fires became extinct Western Australia appears to have known no outbreak of igneous activity until pretty well Tertiary times.

The history of volcanic action in Western Australia is thus the history of Pre-Cambrian, Devonian, and the Tertiary periods.

It is hardly possible within the scope of a single address to consider the whole question of the Geology of Western Australia. My object has been to point out what light has been thrown thereon through recent investigations, by merely touching the fringe of the subject, and my task has now been completed.

In the fulfilment of the task I have endeavoured to inflict to the full that punishment which, by the irony of fate, seems to be the recognised method by which a President conveys his appreciation of being made the recipient of one of the highest honours which his scientific brethren have within their power to bestow.

Whether or not I anticipate your endorsement of or disagreement with the verdict that the "Punishment fits the Crime," I *know* that I am voicing your feelings when I say that during our efforts to wrest from Mother Earth those secrets which are graven in mystic characters on her face, we geologists by merely wandering over the surface, exchanging the genial sunlight for the feeble flicker of the miner's candle, peering down the tube of the petrological microscope, calling to our aid the delicate chemical balance, or poring over the "Medals of Creation" in the seclusion of the Museum Cabinet, re-echo the sentiments of one of Germany's greatest poets and thinkers.

"Ach, wunderschön ist Gottes Erde!"
"Und schön auf ihr ein Mensch zu sein."

A. GIBB MAITLAND,

Government Geologist.