H. L. Whitelaw Esq.
with E. W. Skeats' kind regards

A. F. Chambers
Mines Dept
Bendigo

GEOLOGY OF THE COMMONWEALTH

BY

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CORRIGENDA.

Page 256, line 52, for "*Aechna*" read "*Aeschna*"
,, 257, ,, 21, for "*Tremanotus*" read "*Trematonotus*"
,, 257, ,, 41, for "*Fenestallidæ*" read "*Fenestellidæ*"
,, 258, ,, 10, for "*Rhachopteris*" read "*Rhacopteris*"
,, 262, ,, 29, for "trilolites" read "trilobites"
,, 266, ,, 32, for "*Rhachopteris*" read "*Rhacopteris*"
,, 266, ,, 43, for "*Streptorhyncuhs*" read "*Streptorhynchus*"
,, 270, ,, 45, for "*Glossoptris*" read "*Glossopteris*"
,, 275, ,, 41, for "*Macrotænipteris*" read "*Macrotæniopteris*"
,, 275, ,, 43, for "*Cladophebis*" read "*Cladophlebis*"
,, 276, ,, 26, for "*Tremanotus*" read "*Trematonotus*"
,, 277, ,, 9, for "*Beyrichia endothyra*" read "*Beyrichia. Endothyra*"
,, 277, ,, 32, for "*Tremanotus*" read "*Trematonotus*"
,, 277, ,, 42, for "*Cladophebis*" read "*Cladophlebis*"
,, 282, ,, 10, for "*gregarious*" read "*gregarius*"
,, 282, ,, 11, for "*Archæomene*" read "*Archæomæne*"
,, 282, ,, 27, for "Killak" read "Kirrak"
,, 282, ,, 37, for "*Macrotæinopteris*" read "*Macrotæniopteris*"
,, 286, ,, 47, for "*Pentrune*" read "*Penteune*"
,, 287, ,, 41, for "*Meiolonia*" read "*Meiolania*"
,, 291, ,, 31 and 35, for "*Olenollus*" read "*Olenellus*"
,, 291, ,, 34, for "*Huenolla*" read "*Huenella*"
,, 294, ,, 34, for "*Spiriferina dielasma*" read "*Spiriferina, Dielasma*"
,, 294, ,, 36, for "senilia" read "senilis"
,, 294, ,, 40, for "*Cyrtina syringothyris*" read "*Cyrtina, Syringothyris*"
,, 295, ,, 12, for "*Ptycomphalina*" read "*Ptychomphalina*"
,, 295, ,, 39, for "spirifeidæ" read "spiriferidæ"
,, 296, ,, 9, for "*Plagiophyllum*" read "*Pagiophyllum*"
,, 296, ,, 39, for "*Cladophebis*" read "*Cladophlebis*"
,, 297, ,, 3, for "*Cladophebis*" read "*Cladophlebis*"
,, 297, ,, 21, for "*Alithopteris*" read "*Alethopteris*"
,, 298, ,, 4, for the table as given, read :—

McCoy and Chapman.	Hall and Pritchard.	Tate and Dennant.
5. Pleistocene		
4. Upper Pliocene (Chapman)	4. Werrikooien (Pleiocene)	Pleistocene (Tate) Pliocene (Dennant)
3. Lower Pleistocene ..	3. Kalimnan (Miocene)	Miocene
	1. Janjukian (Eocene)..	? Oligocene (Tate) Eocene (Tate and Dennant)
2. Miocene	Aldingan (Eocene in part)	Eocene in part
1. Oligocene.. ..	2. Balcombian (Eocene)	Eocene

Page 298, line 30, for "*Carcharodon, Megalodon*" read "*Carcharodon megalodon*"
,, 301, ,, 24, for "*antiaustralia*" read "*antiaustralis*"
,, 306, last sentence should come after first sentence on page 305
,, 307, line 26, for "osmiridian" read "osmiridium"
,, 309, ,, 43, for "melanite-hauy-syenite" read "melanite-hauyn-syenite."

C.12154.

CHAPTER VII.

THE GEOLOGY OF THE COMMONWEALTH.

By T. W. Edgeworth David, C.M.G., D.Sc., F.R.S., Professor of Geology in the University of Sydney.

SYNOPSIS.

1. Introduction.

An observer taking a bird's-eye view of Australia and Tasmania would see the great island continent carpeted nearest the coast with strips of dark-green gum forest on the east, south-east, and north, and again in the south-west of Western Australia, with an outlying strip upon the Flinders Range, of South Australia. The remainder would present a curious patchwork, partly of the dull green sage bush, salt bush, and other salsolacious herbs of the steppes, the grasses of the savannahs, and the dark-green mulga scrubs, partly of patches of red and brown sands of desert areas dotted with oases which fringe the worn-down stumps of ancient inland mountains.

White specks in numbers would be conspicuous in this patchwork of green and red and brown wherever the saline surfaces of dead lakes, or "playas," reflect the sunlight, or where the highlands of New South Wales and Victoria are white with snow, except in late summer. To the south-east the emerald isle of Tasmania, the south coast of South Australia, the south-east coast of Victoria, and in places, the inland uplands of tropical Queensland would appear jewelled with live lakes. To the north the great island of New Guinea would loom large with its alpine ranges whitened with snow; its mountain uplands, where visible through breaks in the mist, showing verdant grassy slopes encircled by sombre pines and cypress. Lower still would be seen the dense dark-green jungle of the coastal plains.

Australia is well known as the home of the eucalypt, and this most characteristic tree is in itself an epitome of the climatic conditions of Australia in late geological time.

The most primitive types of our eucalypts develop their leaves with the broad surfaces horizontal, pointing to a time when there was no need to take special precautions to conserve moisture. On the other hand, in the vast majority of eucalypts, the leaves hang with their broad surface vertical, so as to offer as little evaporating surface as possible to the sun's rays. These eucalypts in their early stages of growth show the atavistic tendency to develop their leaves with the broad surfaces horizontal.

This adaptation of plant to climate in such a way as to enable the plant to resist drought connotes a former better rainfall, and this in turn suggests a former higher relief for the Australian land surface inducing a more abundant convectional rain, and thus the eucalypts record the most recent climatic changes of Australia, and prepare us for those evidences of peneplained and downward warped mountain chains with recently uplifted coast lines, which harmonize with its large disintegrated drainage system. This disintegration of the drainage is again in harmony with the shallow wide-bottomed valleys choked with the rock *débris*, with the vast red soil plains, and with the kunkars, laterites, "pindan, ironstones," and porcellanites, so characteristic of the interior of Australia, as of all countries where the rainfall is scant and the evaporation great. But that these inland areas of low rainfall are not without those blessings of aridity, the rich plant foods which have accumulated during the sabbatical periods of drought, is proved by the extension inland through methods of dry farming, of the wheat belt, and the consequent contraction of the central waste areas.

Australia, including Tasmania, has an area of 2,974,600 square miles; it is just a trifle larger than the United States of America, and twenty-five times as large as the United Kingdom. As it extends over 33° of latitude, its climate varies from tropical to cool temperate.

2. Coastal Physiography.

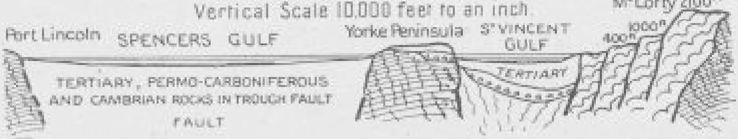
A glance at the map (Pl. III.) explains some of the chief reasons for the shape of the Australian coast.

The chief coastal indent—the Gulf of Carpentaria—is to be correlated with strong tectonic lines, approximating to a meridional direction which determined the position of the northern end of the Cretaceous Basin. The dominant folds in Arnhem Land, on the west side of the Gulf, are parallel to its shore line, the folds in the Palæozoic rocks of the Cape York Peninsula are approximately meridional, with a very heavy downthrow at the trough of the Little River coal-field. The southern shore of the Gulf seems related to the W.N.W., E.S.E. fold axes which run through the Etheridge and Gilbert gold-fields.

The Great Australian Bight again appears to be of tectonic origin, lying between the old fold mountains (recently block-faulted) of the Mount Lofty and Flinders Ranges, near Adelaide, and the vast peneplain of Western Australia, with its worn-down folds, shaped in plan like an inverted S. (See Pl. III.).

The two deep indents—Spencer Gulf and St. Vincent Gulf—are clearly "Senkungsfelder," the southern end of the Great Rift Valley which extends by way of Lake Torrens (92 feet above sea level) to Lake Eyre (about 60 feet below sea level). (See Fig. 1.)

FIG 1. SKETCH SECTION. (Suggested by works of Walter Howchin)
ACROSS THE RIFT VALLEY OF SOUTH AUSTRALIA



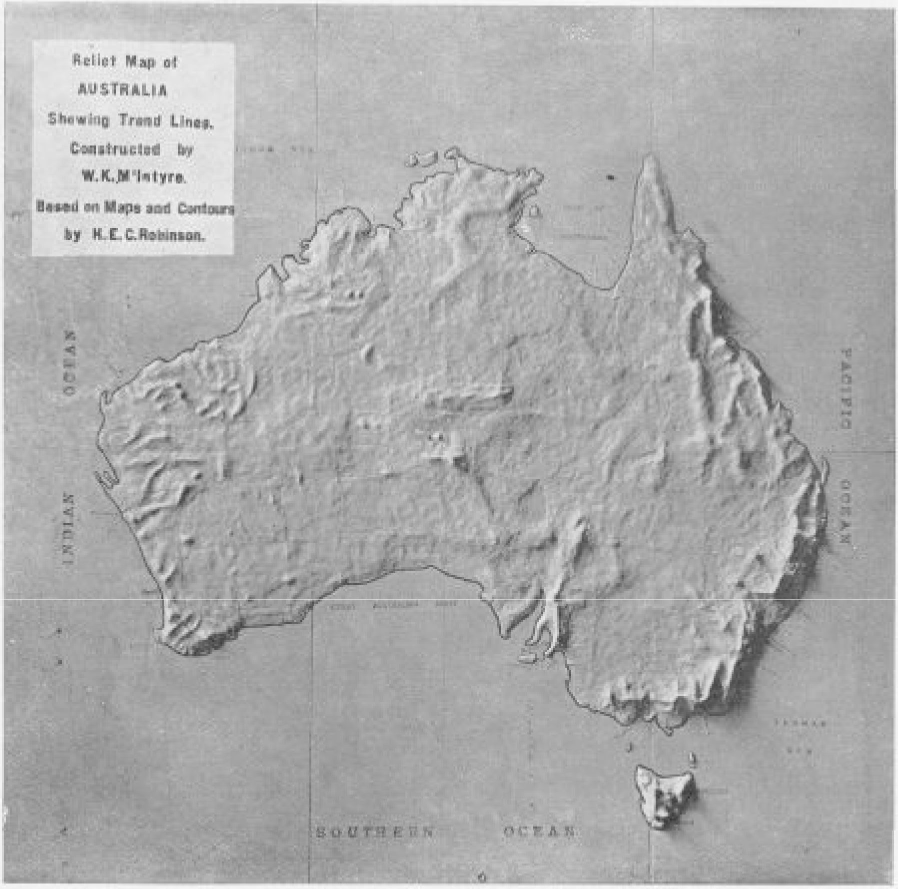

Relief Map of
AUSTRALIA
Shewing Trend Lines.
Constructed by
W.K.M'Intyre.
Based on Maps and Contours
by H.E.C.Robinson.
INDIAN OCEAN
PACIFIC OCEAN
SOUTHERN OCEAN

Plate I.

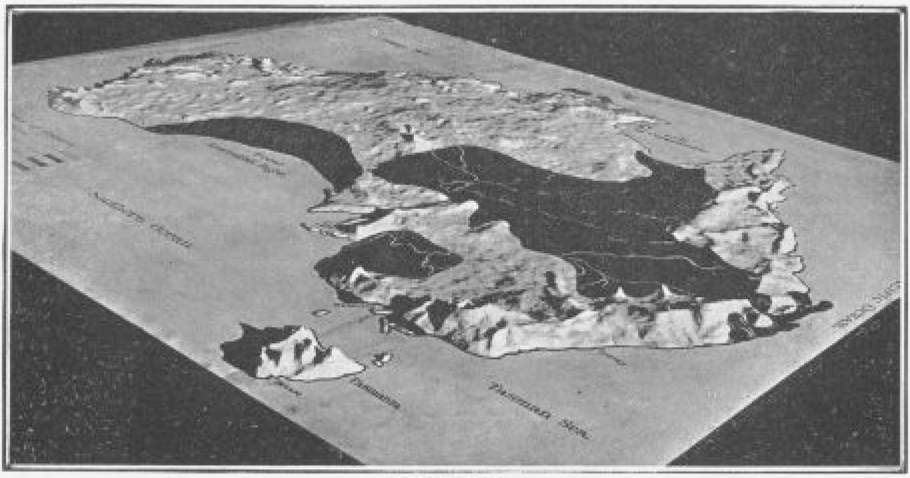


PLATE II.

RELIEF MODEL OF AUSTRALIA AND TASMANIA, by W K McIntyre,

showing the horst of Tasmania, with its high peaks of diabase sills, to left of the fault trough of Bass Strait, Mt. Kosciusko, 7,300 feet, is just to the right of the right hand of the two small black shadows on the north side of Bass Strait, at the knotting point between the east and west trend lines of the southern coast of Victoria, and the more of less meridional trend lines of the east coast of Australia. To right of Kosciusko the Hunter Geocol is seen in front of and midway between the sharp peaks of the Warrumbungle Mountains on the left, and the Nandewar Ranges on the right. Further to the right the dark patch crossing the range represents a narrow tongue of Jurassic sediments joining the large dark area of the main artesian basin to the plain of Jurassic and Cretaceous rock, also showing dark, lying along the middle area of the east Australian coast line. Further to the north-east is the steep-to rückland coast of north-eastern Queensland, rising in the Bellenden-ker Range to 5,428 feet. To the left of the main dark patch, showing the Central Artesian Basin, and between it and Tasmania the smaller dark patch indicates the Cainozoic plains of the Darling-Murray Rivers. Beyond the mouth of the Murray River is the long horst of the Mt. Lofty and Flinders Ranges, with Kangaroo Island at the extreme left, and the rift valley of Spencer's Gulf just above it. Above Spencer's Gulf is shown a narrow ridge, assumed to be formed of Palæozoic, or older rock, separating the Central Artesian Basin from the crescent-shaped dark area to the left, the Bight coastal plain, occupied by Older Tertiary marine limestones overlying Cretaceous glauconite sandstones. It is possible that there is a narrow gap in this ridge making the main Cretaceous basin continuous with this coastal sub-artesian basin. To the right of and above the ridge is the sharp peak of Pre-Cambrian rock of Mt. Woodroffe, in the Musgrave Ranges.

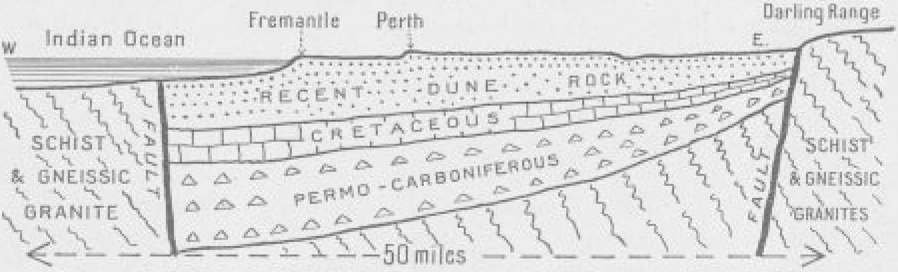
The rest of the continent, chiefly Pre-Cambrian, is a vast peneplain, from 1,000 to 3,000 feet above sea-level. In the extreme south-west are block-faulted mountains, the Stirling Range, &c. Along the extreme western coast is a narrow coastal plain, scarcely visible on the model, from its present point of view, with the two dark promontories of Sharks Bay, near its northern end. Further to the right is the deeply dissected region of Pilbara, much block-faulted. Still further to the right, and immediately above the eastern half of the Tertiary basin of the Great Bight, near the north-west coast, is the depressed area of the Great Desert Artesian Basin, of Permo-Carboniferous age.

Bass Strait, as shown by the geological evidence, is another rift valley crossing the older "grain" of the country, and so is Torres Strait.

A positive movement of the strand line by about 200 feet would re-unite Tasmania and Australia, and a positive movement of only about 100 feet would re-unite Australia and Papua. The latter might easily result from a negative movement of the ocean of about the above amount, such as probably occurred towards the culmination of the latest Ice Age, when the sea level in temperate and sub-tropical latitudes was probably 100 feet lower than at present, owing to the locking up of water to form the great ice sheets.

The features of Cape Leeuwin and Cape Naturaliste are certainly due to a heavy coastal trough fault just to their east, which in that south-west part of Western Australia has determined for a great distance the trend of the western coast line. (See Fig. 2.)

FIG. 2.—Section across the Great Trough Fault of Western Australia (vertical scale 8,000 feet to an inch) from data suggested by A. Gibb-Maitland, F.G.S.



Hobson's Bay, or Port Phillip, south of Melbourne, is probably on a meridional rift valley.

The Hunter Valley and port of Newcastle are situated on a N.W. to S.E. rift valley.

The whole of the Queensland coast coincident with the Great Barrier Reef for 1,200 miles N.N.W. from Rockhampton, owes its trend to powerful downthrows to the east, perhaps compensating for the epeirogenic movement of land to the west.

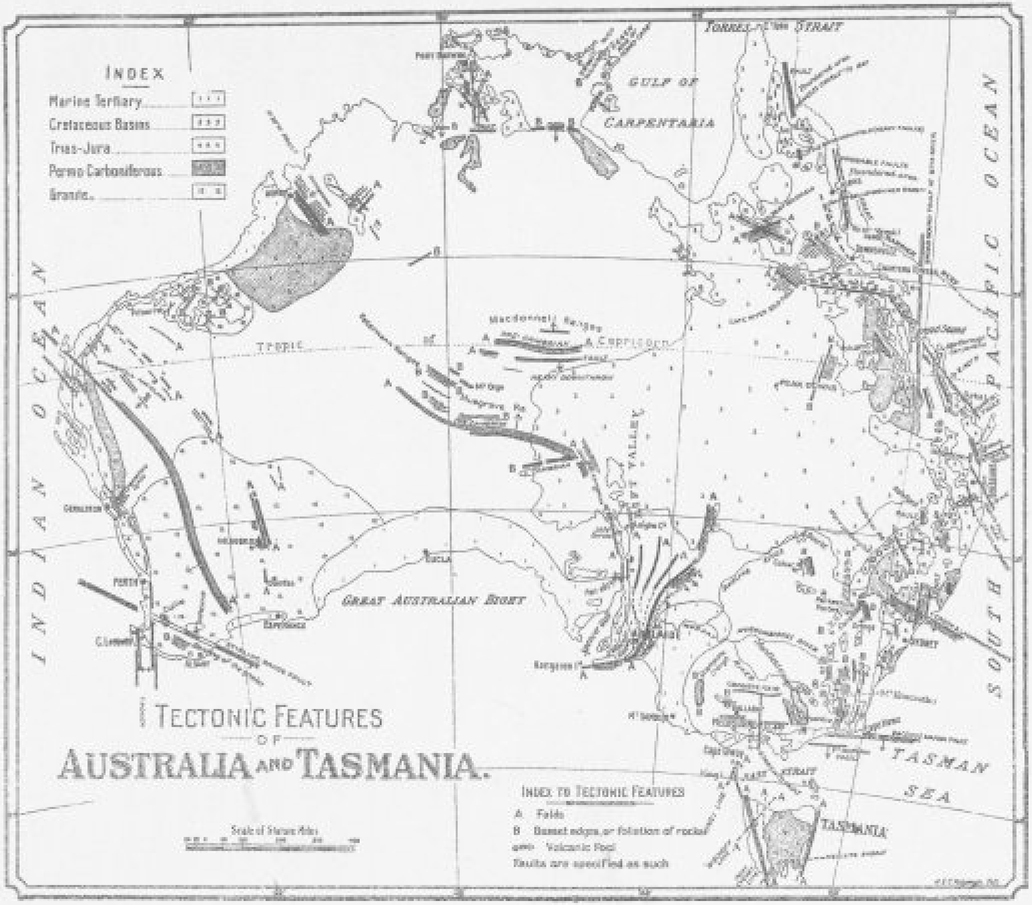
The trend of the east and west shores of Tasmania is parallel to axes of folding.

It is obvious that the south coast of Australia, as well as the whole of its north and north-west coast, is of an Atlantic type. On the contrary, the south-west coast of Western Australia, the east and west coast of Tasmania, and the north-east coast of Queensland are as regards their trends of a Pacific type. The south-east coast of Australia does not appear to be either wholly Atlantic or wholly Pacific. The term sub-Pacific has been suggested for it. As regards its geological structure, the Australian coast at Fremantle, near Perth, consists of a recent dune rock cemented by lime derived chiefly from remains of mollusca and *Lithothamnion*. Numbers of artesian wells sunk in this rock near Perth yield copious supplies of artesian water. Cretaceous rocks have been penetrated there at about 1,000 feet below sea-level. Similar calcareous dune rock forms the coast at Cape Northumberland, in South Australia, at Warrnambool, in Western Victoria, and at Sorrento, on the east side of the entrance to Port Phillip, but so far has not been proved to carry artesian water.

From Cape Naturaliste to Cape Leeuwin the coast is formed of recent dunes resting on granite, while towards Albany a deeply indented coast of granite makes its appearance with dunes lodging in the hollows. Further eastwards, near Cape Riche, is a small basin of marine Jurassic rocks, while near Cape Arid, the coast is marked by the Recherche Archipelago, mostly formed of ancient crystalline rocks. East of Cape Arid to Fowler's Bay, in the direction of Eyre's Peninsula, the coast line is formed of nearly perpendicular cliffs, up to 250 feet in height, with a further gentle rise inland towards the Nullarbor Plains, of about 290 feet. At the base they are formed of white chalky rock with *Gryphæa* and layers of flints. the whole capped by polyzoal and molluscan limestones. At present the whole of this series is attributed to some time between Eocene and Lower Miocene. At about 900 feet below sea level, at the Madura bore, to the west of Eucla, the Tertiary limestone rests on a thick series of Cretaceous greensands with a well preserved marine fauna. No rivers exist anywhere along this 500 miles of unbroken coast line, nor indeed along the further eastward extension of the coast for another 500 miles from Fowler's Bay to the head of Spencer's Gulf. As the rocks inland are mostly almost horizontal porous Tertiary limestones, there is no surface run-off of the rain water, but it sinks in swallow-holes to tortuous subterranean tunnels, by which it is discharged at the foot of the sea cliffs, or between tide marks or out at sea, as in the case of the catavothra of Greece. From Fowler's Bay around the headlands of Eyre's Peninsula and lower end of Spencer's Gulf, the coast line is formed partly of Tertiary sediments, partly of pre-Cambrian schists, gneiss and granite. The last-mentioned is well seen in the north and south Neptunes at the entrance to St. Vincent's Gulf. A plain of erosion along the coast, part of a block faulted peneplain, crosses Yorke's Peninsula to the east side of St. Vincent's Gulf, and extends to the western side of the Mount Lofty Ranges. This coast is formed partly of Post Pliocene flood loams, containing remains of *Pallimnarchus pollens*, partly of richly fossiliferous Tertiary marine limestones, partly of Permo-Carboniferous glacial beds, and partly of the highly folded Cambrian series with their glacial beds. For general interest and variety this part of the coast line is probably unequalled elsewhere in Australia. The strand line has here recently undergone an emergence of 12 feet, and Port Adelaide and Port Wakefield are built on the land thus naturally reclaimed. This evidence of recent 12 feet emergence can be traced around the greater part of Australia, and is probably due to a eustatic negative movement of the ocean. Kangaroo Island is formed of Cambrian rocks, capped by Tertiaries and basalt at its east end. The Cambrian rocks continue along the coast east of Backstairs Passage to the mouth of the Murray River at Port Elliott. In the reclaiming, as the result of positive movement of the strand line, of the Tertiary basin which extends far inland from this part of the coast, the rivers Murray and Darling have become engrafted.

From the mouth of the Murray to Cape Northumberland, the coast line is mostly formed of loose dune sand or consolidated dune sand like that of Cape Northumberland. The dune rock rests either on marine Tertiaries, or on recent alluvials of the Murray basin, or on small inliers of granite.

Inland from Cape Northumberland are the recently extinct volcanoes of Mount Schanck, Mount Gambier, etc. From Cape Northumberland to east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Permo Carboniferous
Granite
TORRES STRAIT
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INDIAN OCEAN
SOUTH PACIFIC OCEAN
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GERALDTON
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B Basset edges, or foliation of rocks
Volcanic Foci
Faults are specified as such

of Warrnambool the coast is similar with occasional outcrops of Tertiary sediments capped by basaltic lava, until the Otway coast is reached. This is formed of freshwater Jurassic strata, in places containing small seams of coal.

East of the dune rock of Sorrento, the Victorian coast is formed of Tertiary rocks and older basalt; then of the Gippsland coal measures in which the claw of a dinosaur and teeth and scales of ceratodus have lately been discovered; then at Cape Liptrap the cliffs are partly Silurian and partly Ordovician slaty rocks, while at Wilson's Promontory they are of granite. Beyond Corner Inlet there follows to the north-east the long stretch of sands deposited in the slack water between the southerly flowing East Australian current, and the current flowing easterly out of Bass Strait. This sand has engrafted many of the rivers, and formed the Gippsland Lakes. Probably the reclamation has been helped by a positive movement of the strand line. At Gabo Island and Cape Howe granites form a rück-land coast, which continues with the addition of Ordovician, Silurian, and Devonian sediments to Moruya and Milton.

To the north of Milton, the coast partakes more of the nature of a forland coast and a distinct coastal plain is developed, formed of the sediments of the Permo-Carboniferous and Triassic basins. This continues north for over 200 miles to Port Stephens. In its deeply indented estuaries, harbors, and drowned valleys, such as those of Jervis Bay, Port Hacking, Botany Bay, Port Jackson, Broken Bay, Port Stephens, etc., and in the entire absence of marine Tertiary deposits, this part of the strand line shows evidence of recent negative movement. From Jervis Bay to Wollongong, the strata in the sea-cliffs are rich in Permo-Carboniferous marine fossils, while those of Bulli and the cliffs 100 miles north, extending to Newcastle, show frequent coal seams, and abound especially near Newcastle in Permo-Carboniferous fossil plants.

From Port Stephens to near Grafton, the coast is mostly of an indented type, with drowned valleys between hills coming close to the coast, with numerous bar harbors, and with a narrow coastal plain fringing Carboniferous, Devonian, and probably Ordovician strata. An outlying part of an immense belt of serpentine, intrusive into Middle Devonian radiolarian rocks, touches the coast at Port Macquarie. From the Clarence River to the Richmond there is a forland coast of Jurassic coal measures, the Clarence basin. A low indented rückland coast, again of Ordovician strata, cherts, tuffs, and quartzites, and capped by alkaline basalts and acid pitchstones stretches from Ballina to near the mouth of the Brisbane River. A forland coast in part Jurassic, stretches from the Brisbane River to Gladstone. The interesting volcanic rocks, comendites, riebeckite trachytes together with alkaline andesites and basalts form conspicuous domes and sugarloaves a short distance inland from the coast, which is there fringed with dunes, the largest in Australia, up to 800 feet high. At Maryborough and Great Sandy Island marine Cretaceous rocks outcrop with a basin of productive coal (the Burrum Basin, the only basin of Cretaceous coal worked within the Commonwealth) immediately overlying them. From Gladstone to Cape York there is a remarkable coast, chiefly of the rück-land type, with mountain ranges from 2,000 feet up to over 5,000 feet high (Bellendenker, 5,428 feet) coming mostly close to the coast line, and having high islands like Hinchinbrook, which rises to an altitude of 3,560 feet, close inshore. This part of the coast and coastal shelf is so heavily faulted and studded with small islands, which have survived the block faulting, as to deserve Suess' title of "panzer-horst." In places there is a coastal plain, as at the Jurassic (or Cretaceous (?) coal-basin of Broadsound, at Port Mackay, and to north-west and south-east of Townsville North), in others the old rocks, chiefly Carboniferous strata, with *Lepidodendron* and *Phillipsia*, or Devonian rocks with massive coral and stromatoporoid limestones, both systems intruded by granites, form bold cliffs and headlands. This remarkable part of the coast line is opposite to the Grand Canal of Australia which runs between the Great Barrier Reef and the main land. These high coastal hills are obviously part of the Old Main Divide, its eastern slope with nearly all the easterly flowing rivers being faulted eastwards under the Barrier. This coast terminates in granite capped with the horizontal Upper Cretaceous desert sandstone, which forms Cape York. Throughout this great stretch of coast from Cape Howe to Cape York, a distance of 2,150 miles, marine Tertiary deposits are wholly unknown. From Cape York around the rocks of the Gulf of Carpentaria, the coast is of a low forland type, formed of Desert Sandstone at first then of late Tertiary and Post Tertiary freshwater deposits, with an inner zone of marine Cretaceous rocks.

It is thought by some that the main submarine outlet of the Great Artesian Basin lies somewhere towards the southern shore of the Gulf of Carpentaria.

On the west side of the Gulf are numerous islands, formed of Permo-Carboniferous rock. A short distance inland from the mouth of the Roper River, the late Cainozoic sediments give place to Cambrian sandstones and limestones, the latter on the Daly River being largely formed of *Salterella hardmani*. These limestones are many thousands of feet thick, and rest on an older volcanic series. From here around to Darwin, the coast is formed chiefly of Cretaceo-Tertiary and Permo-Carboniferous rocks, with an occasional low-lying outcrop of older Palæozoic or Pre-Cambrian rocks. Proofs of recent positive movement of the strand line are everywhere evident except between Arnhem Bay, the English Company's Islands, and Cape Arnhem, where there appears to have been recent negative movement. Elsewhere upraised Post Tertiary muds with echinoderms and crayfish and banks of dead coral are clear proofs of recent positive movement of the strand. One of the most beautiful parts of the whole Australian coast is that at the north-east extremity of Arnhem Land. Tectonic disturbances are present as major faults running N.E. and S.W. These are crossed by minor faults throwing to north-east. At Point Charles lighthouse, near Darwin, rolled specimens of *Ammonites* and *Scaphites* occur in great numbers.

At Port Darwin the coast is composed of whitish shales and sandstones containing numerous casts of *Belemnites*, and in places consisting almost entirely of radiolaria. These were originally deposited at a considerable depth, which suggests a positive movement of this part of the coast of that amount since Upper Cretaceous time, the epoch to which these rocks belong.

The remainder of the coast line is described in less detail in Chapter III., by T. Griffith Taylor. Readers are referred to that chapter for an account of the other physiographic features of the Common wealth.

3. Palaeogeography and Present Relief.

Reference to the photograph of the relief model of Australia and Tasmania (Pls. I. and II.) shows the broad physical features of the Commonwealth, while the orographic map (Pl. IV.) gives the actual contour lines, and the tectonic map (Pl. III.) the chief trend lines. These maps, together with the sections (Plates VI. and VII.), show that Australia is essentially a vast peneplain. This has been in part abandoned by the ocean, in part warped upward or downward in arches and compensating troughs, and this warping has been accompanied by heavy fractures. The latest of the true fold mountains of Australia dates back to Carboniferous time, for although in the Gympie region of Queensland the Permo-Carboniferous rocks are steeply tilted, they are never closely folded as the Carboniferous rocks often are. Great peneplanation took place in Permo-Carboniferous (Permian) time, followed by a considerable transgression of the sea in a wide belt sweeping inland on either side of Sydney, then swinging northwards through Queensland at least as far as Townsville. In Triassic and Jurassic time Tasmania with Bass Strait and Southern Victoria were covered by great lakes and swamps, in which the coal measures of that age were formed. Contemporaneously a vast lake stretched from at least as far east as Brisbane more or less continuously to Lake Eyre, a distance of nearly 1,000 miles. It is not known yet how far this great lake stretched in a meridional direction, but it must have been of the order of at least 500 miles. Gondwana Land was probably still in existence as far as can be judged from the Australian, Indian, New Zealand, South American, and Antarctic evidence. Now in late Jurassic or Post Jurassic time supervened those gigantic intrusions of diabase (dolerite) on a scale perhaps unprecedented in geological history. These intrusions took the form of sills which dominate the whole physical features of Tasmania, the Karroo, Antarctica, and British Guiana. That these intrusions were connected with the sinking in of the Gondwana Land and consequent compensating warping up of the sea floor, and probably a further shallowing of the sea floor through submarine extrusions of the dolerite seems highly probable, and it may account for those world-wide transgressions of the oceans in Cretaceous time which Suess considers one of the most conclusive pieces of evidence in favour of the ocean surface at times undergoing an eustatic positive movement.

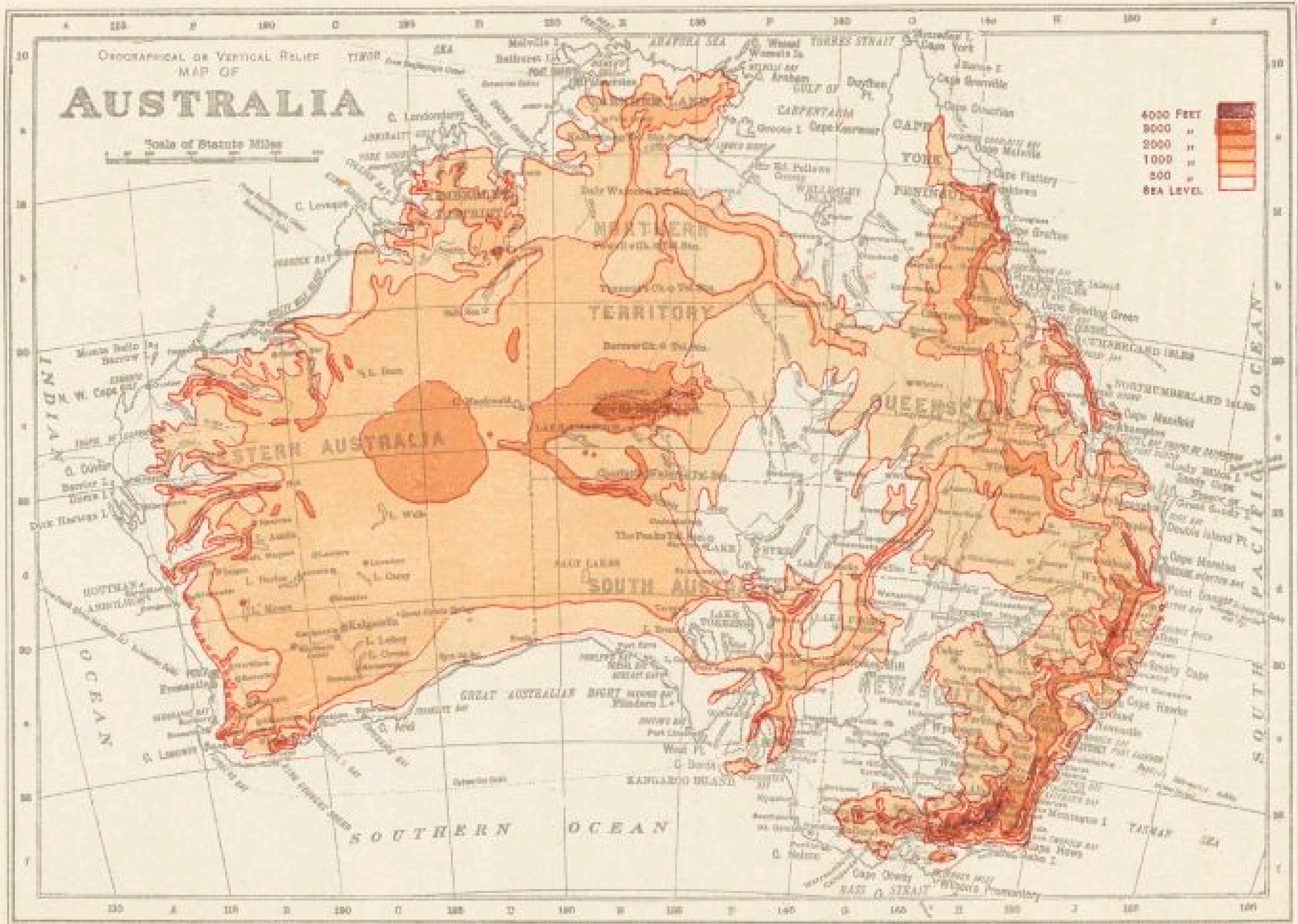
Australia was no exception to the general rule of transgressing epicontinental seas of vast size in Cretaceous time. During the older Cretaceous ("Rolling Downs") series, Australia was perhaps severed, so far as the portion of the continent which is still preserved is concerned, by a sea stretching from the Gulf of Carpentaria to the Great Australian Bight. The marine fauna of this sea is essentially that of a local Mediterranean. On the other hand, the Cretaceous rocks of the west coast of Western Australia have a cosmopolitan Cretaceous marine fauna closely resembling that of India.

Thus the old land barrier which united East Australia and India in Permo-Carboniferous (Permian) time does not seem to have been wholly broken down in early Cretaceous time.

In Upper Cretaceous time, marine conditions were largely replaced by lacustrine, the lake surfaces with small marine basins here and there covering about one-half of the whole area of Australia. During this period was deposited the so-called Desert Sandstone which at one time probably covered about three-quarters of the whole area of Queensland, one-third that of South Australia, and at least one-fifth of the total area of New South Wales.

In early Miocene time a considerable portion of southern and north-western Victoria, part of north-western Tasmania, the extreme south-west corner of New South Wales, a large area around St. Vincent and Spencer's Gulfs, and a still larger area at the head of the Great Australian Bight were submerged. It is important to note that the submergence crept inland as far as the surface of the peneplain at Lake Cowan, near Norseman, in Western Australia. Deposits of marine sponge spicules occur there superimposed on the peneplain. Some marine molluscan remains have also been found resting on the old peneplain on the shores of Lake Cowan, but unfortunately the geological age of these shells has not yet been determined. The date of the vast peneplain of Western Australia, Northern Territory, and probably that of East Australia as well, depends largely on the determination of the age of these fossils.

It has been argued that the Australian and Tasmanian peneplain survived without serious warping into Pliocene time. This provisional conclusion is based on the uniform character of the Pliocene flora as far as the few fragments of it preserved allow us to judge. This is thought to be due to the Australian land at this time over large areas being nearly reduced to sea level. That some warping of the peneplain had commenced probably as far back as the Oligocene, is proved by the fact that in Victoria the so-called "older basalts," of perhaps Eocene or Oligocene Age, are capped by the Lower Miocene marine beds, and there is evidence to show that Tasmania after being joined to Australia in early Tertiary times, was divided from the mainland by a strait in Middle Tertiary or early Pliocene time, then reunited or nearly reunited in late Pliocene or Pleistocene time, allowing the Tasmanian aborigines, ignorant of the building of sea-going canoes to migrate into Tasmania from the mainland. That the warping of the Australian and Tasmania peneplain was chiefly Post Miocene is proved by the locally folded and uplifted Lower Miocene beds in the Mount Lofty Ranges, near Adelaide. Also the latest great outburst of volcanic energy in all the States of the Commonwealth (except Northern Territory) took place in Post Miocene time. Moreover the glaciation of the Tasmanian highlands and those of south-east Australia, took place in late Pliocene or Pleistocene time, and these glaciations were almost certainly contemporaneous with accentuated crust warping, though it is not intended to suggest that there was necessarily a causal connexion between the two phenomena, though there possibly may have been. Next the existence of abundant remains of large herds of Pliocene or Pleistocene marsupials, some of elephantine proportions, in what are now low-lying arid regions, with the discovery of remains of the late Pliocene or Pleistocene crocodile *Pallimnarchus pollens*,



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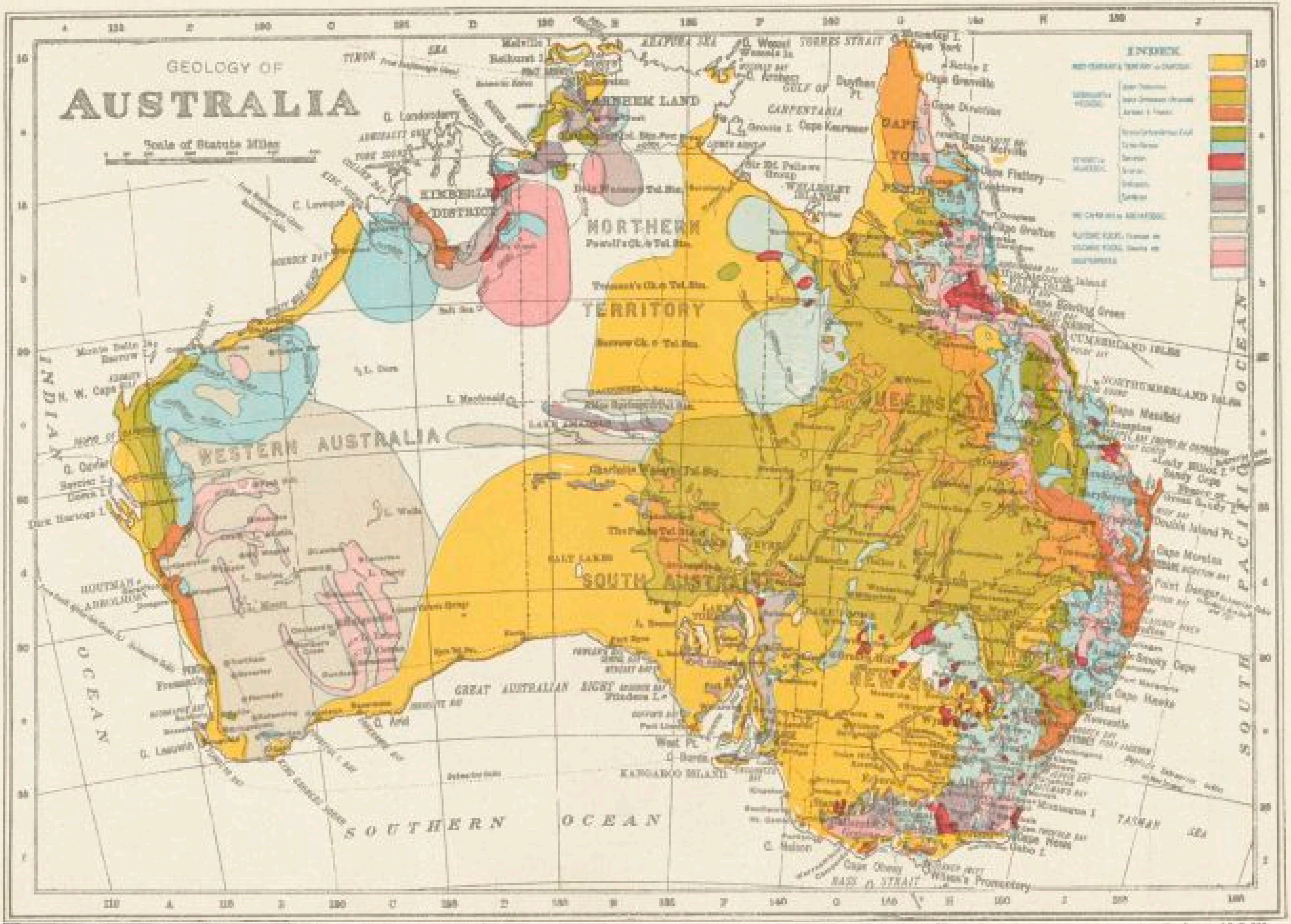

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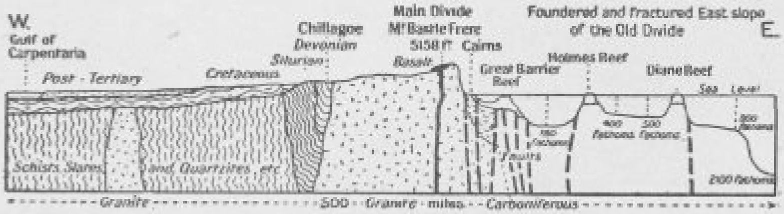
as far south as the valley of the Torrens, near Adelaide, demands a higher rainfall, warmer climate, and probably higher relief for the interior of Australia than it at present possesses. Then too, the canyons of the Upper Flinders, of the eastward-flowing New England rivers, like the Macleay, the Hastings, etc., and the canyons of the Blue Mountain rivers, the Shoalhaven River, etc., imply that no very great time has elapsed since the warping, otherwise the valley walls would be flared down and reduced to gentle slopes.

All over the highlands of Tasmania, as well as over the Kosciusko plateau, there is evidence of a succession of Glacial Epochs. These were probably synchronous with the recent maximum glaciation in Antarctica and in South America, possibly with the phases of the Great Ice Age in the Northern Hemisphere.

Amongst the newest of the tectonic movements has been the development of the great tensional faults, which have so strongly block faulted the Flinders Range (see fig. 1) and the main Eastern Divide, especially along the Barrier Reef area, where as in the neighbourhood of Cairns, the upper end of the Barron River is left hanging on the upthrow side of the fault block (fig. 3). The fault which bounds the Darling Ranges of Western Australia (fig. 2) on the west, probably is a development of very late Pleistocene or early Recent time.

Fig. 3.—Sections across Queensland.



4. Stratigraphical Features.

(a) The Geological Succession in the Commonwealth of Australia.

Group.	System.	Thickness in Feet.	Representative Formations.
Post-Tertiary	*Recent* ..	..	1. River alluvium and sand dunes, with hard calcareous dune rock. Aboriginal kitchen middens. Laterites ("pindan" gravels and nodular ironstone). Nodular tufaceous limestone ("kunkar"). Salt deposits and muds of the "playas." Active crater of Mount Victory in Papua; recent craters of Mount Gambier (South Australia), Tower Hill, near Warrnambool (Victoria). The Great Barrier Reef of Queensland.
		1,000	= maximum thickness of dune rock.
			2. Raised beaches, mostly 15 feet above sea around Australian coast. In Papua recent coral rock extends up to 2,000 feet above sea-level. Submerged peat beds about 100 to 200 feet below sea to north of Sydney.
			3. *Helicidæ* sandstone of Bass Strait Islands, and *Helicidæ* limestone to west of Cloncurry, Queensland.

STRATIGRAPHICAL FEATURES—GEOLOGICAL SUCCESSION—*continued*.

Group.	System.	Thickness in Feet.	Representative Formations.
POST-TERTIARY—*continued*.	*Pleistocene*	..	4. Mammaliferous drift and old lake muds, with remains of *Diprotodon*, *Nototherium thylacoleo*, *Thylacinus*, *Sarcophilus*, *Sus papuensis* (in Queensland), together with *Pallimnarchus pollens*, *Megalania prisca*, *Genyornis*, *Canis dingo*, etc. In places these deposits may date back to late Pliocene.
			5. Glacial deposits of western Tasmania and of the Kosciusko plateau.
TERTIARY	*Pliocene* ..	300	6. Basalt sheets of the fissure eruptions in east and south-east Australia and Tasmania, Kangaroo Island (South Australia), and Bunbury (Western Australia). These range from Pliocene through Pleistocene to Recent. Newer "deep leads" of alluvial gold and tin in eastern Australia and Tasmania.
	Lower Pliocene or *Upper Miocene*	1,000 (?) 1,000	7. Older Marine Pliocene beds of Adelaide. Possibly Launceston Lake beds belong here. Port Moresby radiolarian cherts, etc.
		2,000	8. Belt of alkaline lavas and tuffs from Coleraine to Springsure, about 1,500 miles. Melilite and nepheline basalts of Tasmania.
		100 (?)	9. *Ostrea sturti* beds of the Lower Murray River. Lithothamnion limestone of Hallett's Cove, Adelaide.
	Miocene ..	80 to 1,000	10. *Cellepora gambierensis* limestones passing into chalk with flints, around the Bight. At Table Cape, Tasmania, the oldest Australian marsupial, *Wynyardia bassiana*, occurs in this formation. *Lepidocyclina* occurs in places.
		Several thousands of feet	Purari lignitic and oil-bearing series, Papua, with abundant *Lepidocyclina*.
		200 to 1,500(?)	11. Older basalts and tuffs, and the older, "deep leads" of Gippsland (Victoria), New South Wales, and southern Queensland. Much laterite and bauxite is associated with this series.
			12. Important brown coal series of Victoria, with fossil plants and lignites. At Morwell, in Gippsland, these lignites are 888 feet thick.
MESOZOIC ..	*Cretaceous*—Upper ..	100 to 300	13. Desert sandstone, mostly of freshwater origin, with thin seams of coal in places, passes downwards into radiolarian shales with belemnites. *Ichthyosaurus* occurs in the remarkable opal beds in this series. The sandstone is occasionally marine, with *Rhynchonella croydonensis*.
	Lower ..	2,000	14. Rolling downs formation, chiefly glauconitic sands and clays, with abundant foraminifera, *Maccoyella*, *Cytherea*, *Crioceras*, *Lamna*, *Belonostomus*, *Notochelone*, *Ichthyosaurus*, *Plesiosaurus*, *Æchna flindersensis*, Ammonite beds (Scaphites) of Darwin. The *Alveolina* limestones of New Guinea perhaps may be referred to this horizon. At Maryborough, Queensland, the Burrum coal seams are interstratified in the marine series.

STRATIGRAPHICAL FEATURES—GEOLOGICAL SUCCESSION—*continued.*

Group.	System.	Thickness in Feet.	Representative Formations.
MESOZOIC—*continued.*	*Jurassic*—Upper ..	500 to 1,000	15. Diabase sills of Tasmania.
		1,000 to 3,000	16. Sandstones of the great artesian basin, with lignitic coal in places. At Leigh's Creek, south of Lake Eyre, a 47-ft. seam of brown coal in this series. Coal measures of Wonthaggi and Cape Otway Clarence Series, Clifton, Ipswich, Callide, and Broadsound. Quartz-trachyte tuffs of Brisbane. *Tæniopteris daintreei* is specially characteristic, and cycadaceous forms like *Otozamites, Pterophyllum, and Alethopteris* also abundant. *Unio eyrensis* numerous. Claw of dinosaur in Victoria, also fossil ceratodus. In Western Australia and Papua marine Jurassic rocks occur with abundant ammonites.
	Triassic ..	3,000	17. Productive coal measures of Tasmania. *Phyllotheca* present, with *Thinnfeldia, Alethopteris,* etc. Hawkesbury series of New South Wales, with abundant fossil fish, and large undescribed labyrinthodonts. Contains *Beyrichia,* abundant *Estheria, Tremanotus* (*? in situ*). Much red and green tuff at base of series.
PALÆOZOIC ..	*Permo-Carboniferous (Permian)*	..	18. Acid granites of New England. Alkaline series of Port Cygnet, Tasmania, and of Kiama, New South Wales.
		1,500	19. Upper or Newcastle coal measures, with 35 to 40 feet workable coal. *Glossopteris* predominates over *Gangamopteris. Dadoxylon* abundant. The Upper Bowen coal measures of Queensland, and Collie coalfield, Western Australia, probably are on this horizon.
		2,200	Dempsey Series. Barren freshwater strata.
		500 to 1,800	Middle coal measures (Tomago or East Maitland), about 1,800 feet workable coal.
		6,400	Upper Marine Series, mudstones and sandstones, with abundant *Productus brachythærus, Crinoids,* "glendonite" pseudomorphs, occasional glacial erratics in shales, with abundant *Fenestallidæ.*
		100 to 300	Lower or Greta coal measures, with about 20 feet of workable coal. *Gangamopteris* predominates over *Glossopteris.* The Dawson coal measures probably belong here, in Queensland, and the Mersey coal measures of Tasmania.
		4,800	Lower Marine Series, with *Eurydesma cordatum* specially characteristic. Sodic basalts and andesite tuffs are interstratified. The series ends in glacial beds 300 feet thick. In Victoria there are the Bacchus Marsh beds, over 2,000 feet thick, with at least four beds of true tillite. At Wynyard, in Tasmania, and Hallett's Cove, near Adelaide, these tillites are very well developed. In Victoria and South Australia the tillites rest on beautifully striated pavements.

STRATIGRAPHICAL FEATURES—GEOLOGICAL SUCCESSION—*continued.*

Group.	System.	Thickness in Feet.	Representative Formations
PALÆOZOIC—*continued.*	* * *		The Gympie beds of Queensland are Lower Marine.
	(Unconformity.) *Carboniferous.*	..	20. Sphene-granites of New England. 21. Blue-granites of New England.
		20,000	22. Star Series of Queensland, with *Lepidodendron australe*, *Aneimites*, and *Phillipsia*. The marine and freshwater beds in New South Wales, with *Phillipsia*, *Productus semireticulatus*, *Lepidodendron australe*, *L. volkmannianum*, *L. veltheimianum*, *Rhachopteris*, etc. A thick series of acid, to intermediate lavas and tuffs, occur in this system. In Victoria the Mansfield beds and the Grampians sandstones may be included here, together with the felsites and basalts of Mount Wellington, Victoria. 23. Serpentine belt of New England, New South Wales.
	Devonian—Upper ..	10,000	24. *Spirifera disjuncta* quartzites of Mount Lambie, New South Wales, with *Lepidodendron australe*. The *Archæopteris* sandstones of Victoria may belong here.
	Middle ..	9,000	Radiolarian cherts, reef limestones, and spilites of Tamworth, New South Wales. Burdekin series of Queensland, with reef limestone up to 7,000 feet thick, an ancestor of the Barrier Reef. Buchan and Bindi limestones of Victoria, with andesites. Devonian rocks of Kimberley, Western Australia.
	Lower ..	14,000	Murrumbidgee series, New South Wales, with *Receptaculites* and bony-plated fish like *Asterolepis*, also a thick series of acid to intermediate lavas. In Victoria are the series of acid lavas and tuffs, the Snowy River porphyries. Dacites, quartz-porphyries, and granodiorites of this age occur in Victoria. Most of the granites of Tasmania are thought to be Devonian. Devonian rocks occur in Papua.
	Silurian ..	3,000 to 5,000	25. Shales, sandstones, limestones, contemporaneous tuffs. The type area is Yass, New South Wales. Hausmannia and Encrinurus, with the corals *Rhizophyllum* and *Mucophyllum* and *Pentamerus knightii* are characteristic. At the base of series is *Halysites* in great abundance. At Lilydale in Victoria, Chudleigh in Tasmania, Chillagoe in Queensland, limestones of this age are well developed. They are frequently associated with radiolarian cherts.
	* * * (Unconformity.) *Ordovician*	9,000(?)	26. These rocks are either littoral, like the Tempe Downs beds, south of the Macdonnell Range, with *Asaphus* and *Endoceras* abundant, or are of the Victorian type, black shales, sandstones, graptolitic shales, with some sponge spicules, phosphatic slates, and cherts. They are also developed in New South Wales at Tallong, Mandurama, etc. The rich graptolite fauna is described later in this article.

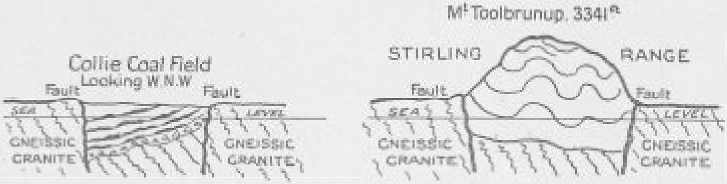
STRATIGRAPHICAL FEATURES—GEOLOGICAL SUCCESSION—*continued.*

Group.	System.	Thickness in Feet.	Representative Formations.
PALÆOZOIC—*continued.*	*Cambro-Ordovician (?)*	..	27. These rocks consist of the diabases and tuffs, probably spilitic, of Heathcote and other areas in Victoria. Probably the porphyroid series with breccias, tuffs, etc., of western Tasmania also belong here.
	Cambrian	10,000(?)	28. This system is chiefly developed in South Australia and Northern Territory. In Northern Territory thick sandstones overlie massive *Archæocyathinæ* limestones, perhaps 7,000 feet in thickness, another forerunner of the Barrier Reef. Beneath the richly fossiliferous limestones (*Salterella* limestones of Northern Territory) is a vast thickness of basalts and basic tuffs. About half-way up in the series in South Australia are tillites up to about 1,000 feet in thickness.
	* * * (Great Unconformity.)		
PRE-CAMBRIAN	*Algonkian*	..	29. The Mosquito Series of the Pilbara goldfield, Western Australia, is a schistose group unconformably underlying the Cambrian(?) Nullagine Series. This in turn rests on an older series, the Warrawoona. Both may be considered Algonkian, as the rocks can be recognised as Sediments. At Kalgoorlie the conglomerates are Algonkian, as are those of Goat Island, Tasmania, with mica schists and garnet-zoizite-amphibolites; in the Mount Lofty and Flinders Ranges the rocks of the Houghton magma, so rich in titaniferous iron and diopside, and connected with radium deposits are also probably Algonkian. The Glenelg River schists and Mitta Mitta schists of Victoria may also be Algonkian, as well as most of the mica and quartz schists of Northern Territory.
	Archæan	..	30. Archæan rocks are widely spread in Western Australia in the Musgrave and Macdonnell Ranges, and at Port Lincoln, in South Australia, and between Camooweal and Borraloola, in Northern Territory. The Aguilar Range in Queensland, north of Brisbane, containing glaucophane schists may also be Archæan, as well as the main axis of British and German New Guinea.

(b) Pre-Cambrian System.

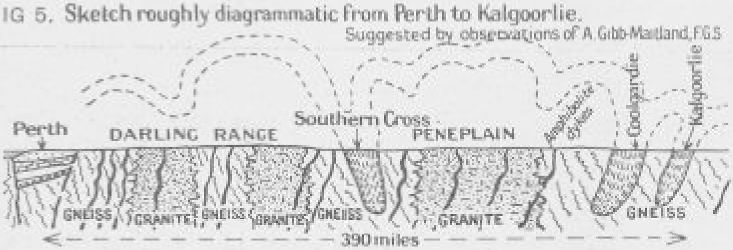
The rocks of this age, comprising both Algonkian and Archæan formations, are developed on a particularly grand scale in Western Australia and Central Australia, in fact, about one-third of the whole area of Australia, namely approximately 800,000 square miles, is occupied by this vast crystalline complex. Pre-Cambrian rocks are also developed in the Kimberley gold-field of Western Australia, as well as at Darwin, extending from the latter at intervals to Camooweal in Queensland. In New South Wales, they are represented by a belt of Garnetiferous mica-schist with amphibolites and gneiss in the Barrier Ranges of the Broken Hill silver-field. They are represented by schists near the Cobar Copper Mines of New South Wales, and

FIG 4. **DIAGRAMMATIC SECTIONS ACROSS COLLIE-STIRLING TROUGH**
Vertical Scale 8000 feet to an inch



by a thick series of crystalline schists in a broad belt of country stretching S.S.E. from Wodonga and Tallangatta, through Omeo and Tongio West in North-east Victoria. Other areas occur in Victoria south of Mount Stavely and in the basin of the Glenelg River. In Tasmania, a well-marked belt of mica-schist and white saccharoidal quartzite, and a very interesting belt of zoisite-amphibolite, are ascribed to this group. With the exception of the last-mentioned rock, all the Pre-Cambrian rocks of Tasmania appear to have been of sedimentary origin, and should therefore be referred to the Algonkian system. In Western Australia, the group is divisible into two portions, or we may say that two groups are present: Firstly, an older form of gneisses and acidic schists with intrusive granite and pegmatite veins with numerous dykes of diorite, norite, dolerite, etc. Secondly, Algonkian rocks formed of coarse conglomerates together with, in places, altered volcanic tuffs and amygdaloidal dolerites, the latter evidently being of contemporaneous origin. The principal gold-fields of Western Australia, one of which alone (Kalgoorlie) has produced to date over £100,000,000 worth of gold, are situated in rocks, probably of this group, occupying deeply infolded basins, partly of Pre-Cambrian basic lavas and tuffs, in the older crystalline complex. As shown on the Section, Fig. 4, these Pre-Cambrian rocks have been intensely folded, the trend of the folds being nearly meridional, but on the whole having the form as shown on the Pl. III. of a very open inverted letter "S." One can distinguish at least four of these great gold-bearing basins from east to west in the following order:—Kanowna, Boulder and Kalgoorlie, Coolgardie, and Southern Cross. In the Pilbara district of Western Australia, there is a considerable development of minerals of the rare earths associated with veins of pegmatite traversing Pre-Cam-

FIG 5. **Sketch roughly diagrammatic from Perth to Kalgoorlie.**
Suggested by observations of A. Gibb-Maitland, F.G.S.



brian rocks. For example, associated with tin-stone are found in this region tantalite in sufficient quantity to control the whole of the tantalum market of the world. The mineral gadolinite, associated with well-crystallized monazite, and occasionally the rare radio-active mineral pilbarite, a lead-bearing uranium ore, are also met with within this area. At Mount Painter between the head of Spencer's Gulf and Lake Eyre, the Pre-Cambrian rocks comprise remarkably massive deposits with coarse mica-schists, containing an abundance of sapphire. These rocks are traversed by a huge lode containing radio-active minerals, such as monazite, torbenite, autunite, etc., together with a considerable amount of fluorspar. This lode has been traced along a continuous outcrop of over a mile, and in places is said to be over 20 yards in width—in places as much as 50 yards. At present the lode is only being prospected. At the Radium Hill, at Olary, on the railway line from Adelaide to Broken Hill, there is a considerable deposit of uranium-bearing titaniferous iron ore. At the surface outcrop this is stained lemon-yellow to orange by carnotite. The ore from this mine is at present being successfully treated at Woolwich, Sydney, and it is expected that it will soon be possible to produce not less than a gramme of radium bromide annually from this mine alone. In the MacDonnell Ranges, associated with the pegmatite dykes are large crystals of muscovite mica, from 1 foot up to 18 inches or more in diameter. Beryls in large crystals, but not of commercial value, occur in the same region. A remarkable rock in the Pre-Cambrian group is that known as the ribbon jasper. This rock, often many hundreds of yards in width, is typically a beautifully banded haematitic quartz rock. It can be traced for hundreds of miles along the gold-bearing belts of Western Australia. From its southern gold-fields, as far north as Kimberley gold-field, wherever reefs of quartz intersect it they are usually gold-bearing. Recent petrological research proves that this ribbon jasper is actually a mylonized quartz-dolerite, subsequently altered by silicification. It is singular that in other places as at Boulder, near Kalgoorlie, a similar mylonized quartz-dolerite has been converted into a graphite schist, probably as the result of long-continued emanations of methane. This gas is still being evolved from the gold telluride-bearing graphite-schists at the Great Boulder Proprietary Mine. At Bimbowrie, in South Australia, magnificent crystals of chiastolite, used for jewellery are abundantly developed in the Pre-Cambrian rocks. To the east of the Mount Lofty Ranges, in South Australia, there is a considerable development of andalusite-bearing schists, with which are associated schistose diopside-diorite. The latter rock is very rich in ilmenite, and black sands derived from this ilmenite are plentifully distributed throughout the basalt rocks of the succeeding Cambrian formation. Reference has already been made to the considerable development of Pre-Cambrian rocks in the neighbourhood of the Broken Hill silver mines. No attempt has as yet been made to form even a rough approximation of the thickness of the Pre-Cambrians, but it certainly must be very vast.

(c) Cambrian System.

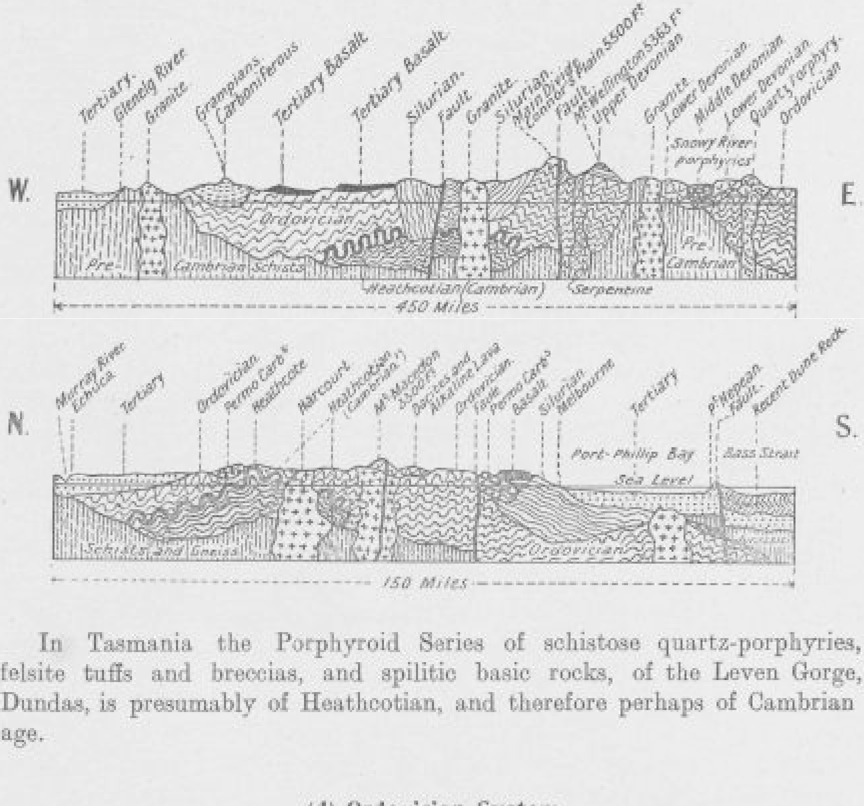
Rocks of this age are developed on a grand scale in the northern part of Northern Territory, as well as between Lake Eyre and Kangaroo Island, to the south of Adelaide. They are also probably represented by the Nullagine series in the Pilbara region. At that gold-field, conglomerates perhaps of Cambrian age overlie quite uncomformably the older schists. These conglomerates contain gold and small diamonds, and are the oldest diamond-bearing horizon as yet proved within the Commonwealth. In the Northern Territory, in Arnhem Land, and in the Barclay Tableland, the Cambrian rocks there, largely formed of limestones, have proved invaluable as a source of supply of sub-artesian water. These limestones in the Northern Territory, at the Daly River, as well as at Mount Panton, in the Kimberley gold-field, are rich in the fossil pteropod—*Salterella hardmani*. Their thickness is certainly several thousands of feet, possibly 7,000 feet. In Arnhem Land and at Kimberley, these limestones overlie thick sheets of basic lavas, apparently contemporaneous in these Cambrian deposits. The two salient points of scientific interest about the system as developed in the Commonwealth are:—First, the development on a grand scale of glacial tillite. It has now been demonstrated that these glacial beds are in places fully 1,000 feet in thickness and extend from the Sturt Gorge, east of Adelaide, at least as far north as Pekina, to the north of Port Augusta, and may extend almost to the tropic of Capricorn, near Lake Eyre. The glacial beds of South Australia cross into New South Wales in the Barrier Ranges, about 20 miles north of Broken Hill. These glacial beds are met with about half-way up in the great thickness of Cambrian strata, and are many thousands of feet below the second feature about to be described, namely, the *Archaeocyathinae* limestones. These rocks are developed on a large scale at Yorke's Peninsula, to the west of Adelaide, as well as near Normanville and the Onkaparinga Valley, whence they extend at least as far north as the Blinnman and Ajax Mines, near Lake Eyre. They contain a rich and exquisitely preserved fossil marine fauna. It may be mentioned that small pieces of similar limestone were discovered by Sir Ernest Shackleton near Mount Darwin, about 360 miles from the South Pole.

The Heathcotian Series.

Shales and mudstones containing the trilolites *Dinesus* and *Notasaphus*, *Protospongia* and other sponge spicules, brachiopods and radiolaria occur about 3 miles north of Heathcote. These were originally referred to the Cambrian and later to the Ordovician. Recent evidence tends to reinforce their Cambrian age. Immediately underlying these beds to the east, come a mixed series of black cherts, cherty shales, and igneous rocks, principally basic lavas, described as diabases, tuffs, and agglomerates, with a few minor dioritic intrusions and a larger intrusive mass of micro-granite. To these rocks the term Heathcotian has been applied, and they have been described as underlying the Dinesus beds with a marked unconformity, and have been referred to the Pre-Ordovician and even to the Pre-Cambrian series. Others have pointed out that there is no evidence of unconformity between them and the overlying Ordovicians, but a gradual passage, and that therefore they cannot be older than Cambrian and may be Cambro-Ordovician in age. Similar rocks, with similar stratigraphical relations, and containing black cherts with *Protospongia* and radiolaria interbedded with diabases occur to the north-east of Lancefield. Probably the diabases and cherts of Mount Major, near Dookie; of Mount Stavely, and of the Hummocks, in the west of Victoria, are also referable to the Heathcotian series.

In Tasmania, Cambrian rocks of the nature of yellow rusty friable sandstones and quartzites occur at Caroline Creek, between Railton and Latrobe, as well as on the Humboldt Divide, and in the Florentine Valley. These rocks, which contain well preserved casts of *Dikellocephalus*, are considered to be of Upper Cambrian age.

FIG. 6.—Diagrammatic Sections across Victoria.



In Tasmania the Porphyroid Series of schistose quartz-porphyries, felsite tuffs and breccias, and spilitic basic rocks, of the Leven Gorge, Dundas, is presumably of Heathcotian, and therefore perhaps of Cambrian age.

(d) Ordovician System.

Two well-marked types, the one littoral, the other probably pelagic, are referred to this system. Shallow water strata of the former type have been described from the Tempe Downs Station and the Levi Range, to the south of the MacDonnell Ranges. These rocks show ripple marks and sun cracks, as well as cubical pseudomorphs in quartzite after rock-salt. Abundant well-preserved fossils, of which the commonest forms are *Orthis leviensis*, *Endoceras warburtoni*, *Asaphus illarensis*, are to be found in this neighbourhood in sandy calcareous shales. The other type of Ordovician rock, the dominant type in fact, consists of black carbonaceous shales and slates, with bands of fine-grained sandstones and quartzites and occasional conglomerates. They are best developed in Victoria where they are closely folded and strike generally in a N.N.W. direction. They are divided into a lower series, in which the black shales and slates on the whole predominate, and an upper series in which sandstones are more prominent, and containing basal conglomerates as at Kerrie, east of Mount Macedon. The lower member has been divided by its graptolite zones into the following divisions from above downward :—

Darriwil series,
Castlemaine series,
Bendigo series,
Lancefield series.

The most productive gold-fields of Victoria, such as those of Bendigo, Ballarat, Daylesford, Maldon, Dunolly, Poseidon, and Steiglitz occur in Lower Ordovician rocks, near intrusions of granodiorite. It has been suggested that the quartz reefs are generally most productive where traversing black shales of the Bendigo series. The Lower Ordovician rocks have so far only been found in Victoria, and with the exception of the Mornington Peninsula, only to the west of a line running north from Melbourne and stretching to the western boundary of the State. The Upper Ordovician rocks are, on the whole, less closely folded than the lower series, are less auriferous, but have a generally similar N.N.W. strike, and occur only to the east of a line running north from Melbourne. Near Melbourne they occur at Diggers Rest, and further north at Kerrie, east of Mount Macedon. Inliers of Upper Ordovician rocks occur near the Woods Point gold-field, and also further east, surrounded by the broad belt of Silurian rocks, while very extensive areas in Eastern Victoria have yielded only Upper Ordovician graptolites.

Northwards from Victoria the Upper Ordovician rocks extend into New South Wales, sweeping in a broad belt to the east of Mount Kosciusko, between the Snowy River and Cooma. A belt of the same rock has been identified at Tallong, near Marulan, where it has been shown there is a great unconformity between this system and the overlying Silurian system. At Cadia, near Orange, there is a great belt of these rocks containing contemporaneous andesite lava, with large deposits of iron ore. Though extensive, these are not as large by any means as the great ironstone mountain deposits—the Iron Knob and the Iron Monarch—to the west of Port Augusta, from which the ore is to be obtained in the near future to supply the large steel works about to be erected at Newcastle. In Tasmania, strata of Ordovician age are represented at the Beaconsfield gold-field, near Launceston.

(e) Silurian System.

Strata of this age appear to be wholly restricted in the Commonwealth to the eastern portion of Australia and to Tasmania. In Tasmania they are well developed in the neighbourhood of the Mount Lyell Mine, where they contain the trilobite *Homalonotus*. The strata in Victoria are divided into the Upper or Yeringian and the Lower or Melbournian series. At Lilydale, in Victoria, there is a well preserved marine fauna in the limestones of that locality. These strata are not so strongly folded as those of the Ordovician System. Perhaps the richest fossil-bearing locality for the Silurians is to be found in the Yass district of New South Wales. The rocks there consist of contemporaneous dacite tuffs with sandy shales, olive coloured to yellowish brown shales and numerous beds of limestone. The limestones are built up of a rich coral fauna. In fact, they are obviously old fringing coral reefs. One of the most common and characteristic corals is the mushroom shaped form, *Mucophyllum*. *Pentamerus* is very plentiful near the limestones in the middle system. *Halysites* is very common and characteristic in the lower limestones of the system, being so abundant at Spring Creek, near Orange, and at Molong, as to constitute by itself coral reefs. In the upper strata the trilobites *Hausmannia* and *Encrinurus* occur plentifully. The famous Jenolan caves of New South Wales have been hollowed out of limestones rich in *Pentamerus*. These are capped by massive black cherts, chiefly composed of radiolaria. At the limestone reefs at Wellington, New South Wales, beautifully preserved siliceous sponges allied to *Astylospongia* may be collected, weathered out of the surface of the limestone. Silurian rocks so far have been identified in Queensland only in the neighbourhood of Chillagoe, where limestones containing *Halysites* are developed. At the same time it is considered probable that a belt of Silurian extends through Queensland, from the south of Boulia to the extreme north-west, and from 20 miles east of Cloncurry to the western boundary of the State. The Stirling Range, in the south-western portion of Western Australia, has been doubtfully referred to this period.

(f) Devonian System.

This is the oldest system in the Commonwealth in which definite fossil plants have been discovered, and such give evidence of a great extension of the land surface of Australia in an easterly direction since the close of Pre-Cambrian time. They occur at intervals all the way round from Kimberley to Cloncurry, the Burdekin basin, the Tamworth area, the region west of the Blue Mountains between Mudgee and Bowenfels, as well as in a parallel strip near Wellington, Spring Creek, near Orange, and Canowindra. They are also represented at the Yalwal gold-field, to the south of the Illa warra District, as well as on a large scale at Burrinjuck, and also in the Pambula regions. In addition, outlying patches of Devonian rock occur at Cobar, Oxley's Tableland, Gundabooka Mountain, and White Cliffs, beyond Wellington. Southwards they can be traced into Victoria, as the Snowy River porphyries and the Buchan and Bindi limestones and the Tabberabbera shales. No undoubted Devonian rocks have as yet been proved in Tasmania, in South Australia, or in Western Australia south of Kimberley. The system is divisible into three series. The lower is often chiefly volcanic, consisting of banded rhyolites and tuffs. These are associated with reddish-purple to chocolate coloured shales. In places the volcanic rocks become basic. In the neighbourhood of Burrinjuck and higher up the Murrumbidgee River, near Taemas, there is a splendid development of folded Lower Devonian limestones. A conspicuous and characteristic large fossil in these rocks is the form *Receptaculites*. Remains of large bony-plated fish, such as *Coccosteus* and *Asterolepis*, have been found in these limestones. In Victoria, the Buchan and Bindi limestones occupy eroded hollows in the surface of the Snowy River porphyries. The Gram pian Range of white, grey, red, and purple sandstones and conglomerates perhaps belongs to the Upper Devonian beds. The conglomerates, sandstones, and shales of Mansfield, Victoria, are perhaps of Upper Devonian age. In New South Wales, Middle Devonian rocks are well represented in the Tamworth region by massive coralline limestone, in which the curious type *Sanidophyllum* is a dominant form. Associated with the limestones is a vast thickness, about 9,000 feet, of tufaceous cherty shales, with concretions of radiolarian limestones. In some of these the radiolaria are exquisitely preserved. Interbedded in the shales are numerous casts of *Lepidodendron australe*. In Queensland the chief development of Devonian rocks is in the Burdekin basin. There they consist of very massive conglomerates at the base, passing upwards into coral reef limestones of vast thickness. On the Manning River they are no less than 7,000 feet thick. The most characteristic fossils are *Pachypora meridionalis* and *Stromatoporella*. With these are associated fossil plants such as *Dicranophyllum*, as well as a remarkable undescribed form. Upper Devonian rocks are mostly represented by reddish to grey quartzites, sandstones, and red shales. They are typically developed at Mount Lambie, Mount Walker, and Spring Creek, near Orange, New South Wales. These strata are very rich in *Spirifera disjuncta* and *Rhynchonella pleurodon*. Lastly, at Kimberley, in Western Australia, there is a belt of marine Devonian rocks containing a fauna which suggests that it may be of Middle Devonian age.

(g) Carboniferous System.

With perhaps the exception of a small belt of rocks at Kimberley, which is rumoured to contain *Lepidodendron*, and the Grampians sandstones in Western Victoria, which have recently yielded forms of *Lingula* and fish remains similar to those of the Mansfield rocks, no rocks of this age are known to be developed in Australia, to the west of a line joining Cape York with Melbourne. No trace of *Lepidodendron* has as yet been found in Tasmania. The genus is widely represented in Queensland, where much of the folded highlands of the north-eastern coast ranges are built up of these rocks.

The latest folding to which the earth's crust in Australia has been subjected belongs to late Carboniferous time. So far no marked unconformity has been traced between the Devonian and Carboniferous rocks. Rocks of true Carboniferous age in the Commonwealth are characterized by the presence in their lower strata of *Lepidodendron volkmannianum*, *L. veltheimianum* and *L. dichotomum*, and in their upper portion by several species of *Rhachopteris* and *Aneimites*. So far no single example of a *Lepidodendron* has been found anywhere in the Commonwealth in rocks of so-called Permo-Carboniferous age. A marine fauna is associated with this system particularly in its lower and middle portions. An important form to distinguish the Carboniferous rocks from the Devonian on the one hand, and the Permo-Carboniferous on the other, is *Phillipsia*. So far no trace of trilobites has ever been observed in any of the true Permo-Carboniferous rocks. *Michelinia* and *Lithostrotion* found in New England are essentially Carboniferous forms which never ascend into the Permo-Carboniferous systems. Less reliance can be placed on the brachiopods, many of which, such as *Productus semireticulatus*, *Orthis*, and *Streptorhyncuhs*, &c., ascend into the Permo-Carboniferous system.

The upper series of the Carboniferous system is characterized by a vast thickness of lavas and tuffs, mostly acidic, such as rhyolites and ceratophyres associated with hypersthene andesites and hornblende andesites and magnetite-sandstones. Intrusions of granites and quartz-porphyries occur on a grand scale in this system, and it may be assumed that the rhyolites and other acid lavas are the volcanic representatives of the granite batholiths. As regards local development, Carboniferous strata formed of reddish shales and sandstones are most typically developed in Victoria, near Mansfield. They there contain *Lepidodendron australe* with an abundance of fossil fish such as *Gyracanthides murrayi*, *Acanthodes australis*, *Eupleurogmus cresswelli*, *Strepsodus decipiens*, *Ctenodus breviceps*, *Elonichthys sweeti*, *E. gibbus*. It may be mentioned that it has been proposed to place these beds in the Upper Devonian, the occurrence of *Lepidodendron australe*, the the most characteristic of our Devonian plants, suggesting this possibility; but at present the Victorian geologists prefer to class these strata as Lower Carboniferous. The occurrence of *Lepidodendron australe* in beds of undoubted Carboniferous age in the Star series of Queensland seems to justify this classification.

In New South Wales the Carboniferous system is about 20,000 feet in thickness, and extends in a wide folded belt from Port Stephens northwards into New England, reaching the Queensland border near the Horton River.

(h) Permo-Carboniferous (Permian) System.

Of all the sedimentary formations developed in the Commonwealth this system is perhaps the most interesting by reason, in the first place, of the wonderful evidence of past ice action; in the second place, on account of the remarkable development of the *Glossopteris* and *Gangamopteris* flora which replaced everywhere within the Commonwealth the *Lepidodendron* flora of the preceding system; and, in the third place, this system is specially interesting on account of its marine fauna, which belongs to two sharply differentiated types—the western, allied to the Permo-Carboniferous fauna of India; and the eastern, a distinct fauna unlike, in many respects, any developed in other parts of the world. It is also interesting on account of the fact that probably nowhere else in the world are the strata of the Permo-Carboniferous system of such thickness, or so rich in diversified forms of animal life. It is not proposed to discuss the Palæontology of this system here, as Mr. W. S. Dun has given a summary of it at the end of this article, and details are given in the handbooks for the various States.

In regard to the upward passage from the Carboniferous strata into the Permo-Carboniferous, it may be said that, while there is little evidence of unconformity in some places, in others the unconformity is fairly strongly marked; as, for example, near Lochinvar in the Hunter Valley of New South Wales. At the same time, the unconformity is not nearly as strong as that developed in the British Isles, between the dolomitic breccias of the Permian system, and the Carboniferous rocks.

It has already been stated that the Carboniferous strata in the Commonwealth are mostly disposed in fairly close folds. On the other hand, the strata in the Permo-Carboniferous system are either perfectly horizontal or disposed in broad open troughs and arches. Only in the case of the strata at Drake and Undercliff in New England and of the Ashford areas in New South Wales, and the Gympie area in Queensland, are the strata of this system highly disturbed near granitic intrusions.

In regard to the term "Permo-Carboniferous," in view of the present state of our knowledge it is somewhat of a misnomer. The term was applied, in the first case, by Messrs. R. L. Jack and R. Etheridge, jun., to certain strata in Queensland, which undoubtedly did unite between themselves forms of life, chiefly marine, partly characteristic of the Carboniferous, partly of the Permian. It is now known that in Queensland these rocks can be sharply divided into two groups, viz.: an older group, in which *Lepidodendron* and *Phillipsia* are present; and a younger group, in which neither of the above fossils ever occur, but which contains a marine fauna distinctly comparable with that of the Hunter River region of New South Wales. In spite of the fact that some of the brachiopods of this Permo-Carboniferous system show affinities with those of the Carboniferous, it appears to the writer that there is no longer need for the retention of the term Peımo-Carboniferous, but that the strata of this system should be considered to be Permian for the following reasons:—

(1) At the very base of the system is a thick and widely developed series of beds of glacial origin, which can be certainly correlated with the Dwyka beds of South Africa in the Karroo system, also with the Talchir beds in India, as well as with the glacial strata known as the Orleans Conglomerate of the Santa Catharina system of South Brazil and of the Argentine.

Now, in South Africa the marine reptile *Mesosaurus* is found in strata conformably overlying the gracial beds of the Dwyka series, so that, presumably, this reptile was more or less contemporaneous with the Dwyka ice age. Similarly, in Southern Brazil, we meet with remains of *Mesosaurus* in strata conformably overlying the Orleans conglomerate. Still further north we encounter the well-marked Permian fossil *Schizodus*, and other marine forms, in shaly strata apparently on the same geological horizon as that containing the above reptile.

If, therefore, *Mesosaurus*, a powerful marine swimmer and therefore a rapid migrator, is really Permian, then the Orleans conglomerate and the Dwyka conglomerate are also of approximately this age.

(2) We find that in Russia, in the neighbourhood of Moscow, a flora rich in *Glossopteris* and *Gangamopteris*, as shown by Amalitzky, overlies sandstones, marls, &c., which at Brasnoborsk contain *Bakewellia ceratophaga*, Schl., and *Schizodus rossicus*, Vern. All the above strata in Northern Dwina are considered by Kohen to be referable to the Zechstein.

But while the term Permian might probably be substituted with advantage for the term Permo-Carboniferous in Eastern Australia, it is doubtful whether it is equally applicable to the so-called Carboniferous rocks of Western Australia, in the Kimberley District In other parts of Western Australia, where so-called Permo-Carboniferous rocks are developed, as at the Gascoyne, Wooramel, and Minilya Rivers, a well-marked glacial horizon the "Lyons conglomerate," underlies the bulk of the so-called Carboniferous strata. There is now little doubt that this glacial horizon is identical with that of Bacchus Marsh, in Victoria, Hallett's Cove, in South Australia, Wynyard, in Tasmania, and Lochinvar, and Kempsey in New South Wales. All the strata above this glacial horizon might fairly be termed Permo-Carboniferous at any rate, if not Permian. In the Kimberley District of Western Australia, the glacial horizon has not been identified definitely, and perhaps does not exist there, but the fossils are essentially similar to those above the glacial horizon of the Lyons conglomerate, and may therefore provisionally be classed as Permo-Carboniferous and even Permian.

While therefore considering that there is much to justify the term "Permian" being substituted for that of "Permo-Carboniferous," the writer proposes to retain temporarily for the purposes of this article the old term "Permo-Carboniferous," chiefly because it has been so widely used, and generally accepted.

As regards geographical distribution, rocks of this system are very widely spread throughout the Commonwealth. In Tasmania about one-half of the island, which is rather bigger than Ceylon but smaller than Ireland, is covered with rocks of this age. They commence with an important series of glacial beds, having a total thickness of about 800 feet. Splendid sections of this can be seen between tide marks on the beach to the east of Wynyard. Several striated pavements occur in the tillite, which show that the ice moved from about S.S.W. to N.N.E. An interesting fact which has lately come to light is that there are at least three, perhaps four distinct tillite horizons, and these are separated from one another by strata perhaps representing inter-glacial epochs. Each tillite horizon can be correlated certainly with those of Victoria, and almost certainly with those of South Africa, and these are succeeded by marine strata belonging to the Lower Marine series, over 600 feet thick at this locality. This series is followed by one of the most important coal-bearing horizons in Australia, viz., the Greta series. In Tasmania, however, the series is represented by only a few seams of coal, from 20 inches up to 3½ feet in thickness. In places this coal passes into kerosene shale, formed largely of the problematical plant considered to be an alga, *Reinschia australis*. Above the Greta series is a considerable development in Tasmania of rocks of the Upper Marine series. In Tasmania the great series of freshwater coal measures developed in New South Wales and Queensland above the Upper Marine series are wanting, and in Tasmania rocks of Trias-Jura or Jurassic age rest conformably on the topmost Marine beds of the Permo-Carboniferous system.

In Victoria there is a wonderful development of glacial beds of the nature of tillites associated with contemporaneous conglomerates and ripple-marked sandstones, together with fine clay shales. The whole series passes upwards into sandstones containing *Gangamopteris*, and is over 2,000 feet in thickness. Hitherto no marine strata nor coal seams have been discovered in Victoria in this system. These glacial beds lie on a surface of low relief, though in places, as at the Werribee Gorge, the tillite fills an old U-shaped valley, perhaps an overdeepened valley. The rocks on which the tillite rests, mostly of Ordovician age, with Post Ordovician granites are very strongly striated and grooved by ice coming from a southerly direction. The sandstone beds between the tillites show strong evidence in places of contemporaneous contortion. As the matrix of the tillite varies with that of the subjacent rock, there can be no doubt that the tillite was formed by an immense sheet of land ice, the main mass of which lay to the south. These glacial deposits can be traced at intervals across Victoria, northwards by way of Heathcote to Beechworth, close to the southern border of New South Wales, and fine striated pavements can be seen at Derrinal, near Heathcote, together with erratics up to 30 tons in weight. Westwards they extend under the level plains of Tertiary rock, having been proved to underlie Nhill. To the south of Adelaide, between that city and the mouth of the Murray River, there are magnificent cliff sections showing the junction of these old glacial beds with the Lower Cambrian strata. Beautiful striated pavements are to be seen in the Inman Valley, Hallett's Cove, etc., which prove that the ice came from a south by east direction. The glacial beds are there, with their associated conglomerates, sandstones, and shales, fully 900 feet in thickness, but so far in South Australia, as in Victoria, no productive coal of this age nor marine fossils have as yet been found. In fact there are considerable patches there of Permo-Carboniferous glacial landscape rediscovered by modern denudation. Still further west, in the south-west corner of Western Australia, there is a small basin, preserved in a deep trough fault, known as the Collie coal-field. This coal-field contains the fossil plant *Gangamopteris,* associated with numerous seams of coal up to over 10 feet in thickness, but the strata are so very porous, that when shafts, bores or tunnels are made in these measures they become veritable artesian wells. The coal itself, contrary to usual experience in strata of this age, is distinctly hydrous. Northwards from Perth the Irwin River region has preserved a small patch of glacial beds immediately underlying richly fossiliferous marine strata including limestones, and conformably overlying brown clay shales. Two seams of coal conformably overlie the marine strata, the main seam 5 feet thick and though not so proved by fossils, presumably of Permo-Carboniferous age. Still further north in Western Australia, the glacial conglomerate has been traced from near the Carnarvon bore at the mouth of the Gascoyne River to the Wooramel River, and almost up to the latitude of North-west Cape. Thus in Western Australia these Permo-Carboniferous glacial beds actually touch the region of the tropics. As evidenced by the nature of the contained boulders, when compared with their nearest parent rocks, it is clear that the ice sheets, which produced this glaciation, moved, on the whole, from the inland plateau westwards or northwards, probably in a north-westerly direction, inasmuch as the glacial boulders become progressively larger the further south they are traced. These glacial beds are known as the "Lyons conglomerate." So far no striated floor has been discovered beneath them. In the Kimberley district of Western Australia there is a considerable development of marine Permo-Carboniferous calcareous sandstones and limestones, and it has been proved that these Carboniferous strata from the Gascoyne River to the Kimberley District contain invaluable supplies of artesian water, though strange to say they are quite wanting in productive coal seams as far as they have yet been tested. Strata of this age extend further east around the Australian coast to the Victoria River. The marine strata at the Victoria River are associated with freshwater shales containing *Glossopteris.* This *Glossoptris* underlies strata which contains *Orthotetes* and *Aulosteges.* This formation has been traced across into Arnhem Land (to the north-east of Darwin), and to the islands of the north-east extremity of Arnhem Land. Groote Island is thought to belong to this system. A remarkable feature is that from the Gulf of Carpentaria around to the Irwin River region the whole assemblage of marine Permo-Carboniferous fossils is distinctly of Indian type. S.S.E. of Cape York is a deep indent in the coast line, marking a prolongation of the trough valley in which lies the Permo-Carboniferous coal-field of the Little River. As the result of heavy downthrows, the strata have been forced into rather sharp zigzag folds, a rare structure in rocks of this age in Australia. Near Townsville is a small development of Permo-Carboniferous strata, which there underlie the coastal plain, and extend out to sea beneath the coral reefs of the Great Barrier. Next we reach the classical coal-field of the Bowen River. There evidence of glacial action, in the form probably of floating ice, is to be found in the shape of numerous small boulders of granite and other rocks foreign to the district embedded in the clay shales of the Permo-Carboniferous system, but nothing approaching a true tillite has ever been observed in this area. Next, on the south, come the extensive and thick coal seams of the Dawson River basin. The thickest seam known in Australia in rocks of this system occurs near Comet, where it is 80 feet thick. Anthracite of excellent quality occurs in a seam 11 feet thick on the Dawson River, about 30 miles south of Duaringa, but unfortunately the coal-field in that area is much broken up by faults. The Permo-Carboniferous system in this important coal-field can be divided up into the following groups arranged in ascending order :—

Lower Bowen:
- At the base, marine beds such as those of Gympie, with boulders presumably transported by ice.
- Next, Lower Marine strata followed by a volcanic series.
- Above this follow sedimentary rocks, with the 11-ft. seam of anthracite already described.
- This is followed by the marine shell beds of Oakey Creek and St. Marys, in turn capped by the *Glossopteris* beds of Oakey Creek and St. Marys.

All these strata are grouped together as Lower Bowen. There follows a slight unconformity and above it are developed the marine shell beds of Claremont and Capella. Above these again, and slightly unconformable to them, are the Tolmie's coal measures. The latter are capped by the old auriferous conglomerates of Claremont. The whole of this last series is grouped together as Upper Bowen. No estimate has, as yet, been formed of the available quantity of Permo-Carboniferous coal in Queensland, but it must be very vast, perhaps, approximating to the 100,000,000,000 of tons roughly estimated to be present in the form of exploitable coal in New South Wales.

South-east of the Dawson field the Permo-Carboniferous strata are represented by the basal marine beds of the Gympie gold-field. It has been the experience there that wherever the quartz reefs, which traverse these strata, come in contact with the occasionally intercalated beds of black carbonaceous shale, they are payably gold-bearing. The Dawson coal-field, traced in a southerly direction, reaches the borders of New South Wales, near Bonshaw and Ashford. At the latter locality a fine seam of anthracite coal, 27 feet in thickness, is to be seen in the left bank of the Severn River. As *Gangamopteris* is the only fossil known to occur in association with this seam, it may provisionally be considered to be of Greta age. This field occupies a narrow fault trough. About 100 miles east of this spot at Undercliff, there are beds of graphite associated with intrusive acid granites. These graphite beds are considered to represent intensely metamorphosed coal seams of Permo-Carboniferous age. These graphitic strata are to be connected with marine beds of undoubted Permo-Carboniferous origin as at the gold-field of Drake, where contemporaneous acid and basic lavas are inter-stratified with the lower beds.

South from Ashford, the region of Gunnedah is reached, from which the principal coal-field of New South Wales extends without a break for fully 300 miles, as far south as the head of the Clyde River, near Ulladulla. The type district in this field is that of Maitland, in the Hunter Valley. The system is there ushered in, at Lochinvar, by reddish-brown clays with numerous glacial boulders, but hardly deserving of the name of a true tillite. These beds are about 300 feet in thickness. They are followed by nearly 4,800 feet of strata, mostly of marine origin, with an exceptionally rich Permo-Carboniferous fauna. The fossil *Eurydesma cordata* is especially characteristic of these Lower Maıine rocks. Its frequent association with coarse conglomerates shows that it was littoral in habit. The fine state of preservation of the marine shells at the classic spot—Harper's Hill—is due to the fact that they were suddenly overwhelmed in showers of contemporaneous volcanic ash, which has effectually preserved them to the present day. Large *Aviculopectens* and vast numbers of polyzoa, belonging to the family of the *Fenestellidae* also abound, and may possibly have some relation to cold water conditions, just as at the present time one sees the icy seas of the Antarctic swarming in polyzoa and pectens. The Greta coal measures, from 100 to 300 feet thick, which conformably overlie the Lower Marine series, are not relatively rich in fossil plants. It is significant that in these measures *Gangamopteris* predominates over *Glossopteris*, whereas in the higher coal measures of this system the reverse is the case. It should here be mentioned that the *Gangamopteris* has been found as low down as 2,000 feet below the Greta coal measures in the middle of the Lower Marine series. The Greta coal measures usually contain about 20 feet of workable coal, and, exceptionally as much as 40 feet. The Upper Marine strata, which follow the Greta, attain their maximum thickness yet proved in the Hunter River region, viz., 5,000 to 6,400 feet. About half-way up in the series erratics, certainly of glacial origin, are very numerous in places, occurring usually in groups. Many of these blocks of rock are one to two tons in weight, and appear to have been derived from the region of Mount Lambie, near Rydal or Bathurst, about 200 miles to the south-west. It is significant, probably, of glacial conditions, that we find an almost total absence of reef-forming corals in the Permo-Carboniferous strata. Such corals as do occur are slender types like *Zaphrentis* and *Trachypora*. Near the top of the Upper Marine series, as well as on certain horizons lower down, are remarkably large pseudomorphs known as glendonite. These crystals attain a length of from 2 ins. to 1 foot. They are best seen on the beach between tide marks at Huskisson, Jervis Bay, about 100 miles southerly from Sydney. The shore here presents the appearance of a medieval battlefield, strewn with spear heads and caltrops. They are pseudomorphs after the double sulphate of sodium and calcium, glauberite. As deposits of sodium sulphate are very common and characteristic in Antarctica, these glendonites may have some climatological significance. They have also been found in Tasmania, close to the horizon of the oil shale known as Tasmanite, in part of the Mersey coal-basin. Above the Upper Marine follow the strata of the Middle Coal measures, known as the East Maitland or Tomago measures. These are from 500 to 1,800 feet thick and contain in the aggregate about 40 feet of coal, which, being more friable than that of the Greta, is not so suitable for export, though useful for household, gas, and blacksmith purposes. A total thickness of about 18 feet of coal is worked. In parts of the Hunter River coal-field, there follows a considerable thickness, in places about 2,000 feet thick, of fresh water strata, with abundant plant remains, but devoid of any coal seams of workable thickness. These beds belong to the Dempsey series. Next, above the Dempsey, comes the Newcastle series, 12,000 to 14,000 feet in thickness, with about 120 feet of coal. The thickness of the seams varies from 1 foot up to about 27 feet. The aggregate thickness of workable coal in this series is from 35 to 40 feet. On the shores of Lake Macquarie, at Awaba, as well as at the southern entrance to Lake Macquarie, known as Reid's Mistake, are fossil forests of coniferous trees. At the latter locality it can be seen that the trees sprang directly from the upper portion of a coal seam being actually in position of growth. The lower parts of the stem are of carbon, but upwards they pass into chalcedony, where they have been buried under showers of very fine volcanic tuff. The tuff has evidently broken down branches of the trees, and resin has exuded from the fractures, and is preserved now in the form of black drops in the tuff, the latter being converted into chert. Some of these coniferous trees can be seen to be over 100 feet in length.

It may be said that, on the whole, the evidence points to the coal seams in the whole of the Permo-Carboniferous system, having formed, for the most part, at the spot where seams are now found. For example, in the under clay, only thin rootlets have been observed. In the clay bands higher up, in the seam numerous specimens of *Vertebraria* can be frequently seen in position of growth. It is only in the actual roofs of the seams that forest trees like the conifer *Dadoxylon* have been proved to exist. In places, but rarely, remains of fossil fish, and of labyrinthodonts have been discovered in the coal measures, from those of Greta age up to those of Newcastle age. For example, a small labryrinthodont has been recorded from the Mersey coal measures (Greta horizon) near Railton, and another was found in the kerosene shale at Airlie, in the western coal-field of New South Wales. *Palaeoniscus* has been obtained from the marine (probably lower marine) Permo-carboniferous rocks of Tasmania, and *Urosthenes* from the Newcastle coal measures of New South Wales. The total amount of exploitable coal in seams not less than 3 feet thick and not more than 4,000 feet in depth in these measures in New South Wales, is estimated to be roughly about 100,000,000,000 tons.

Summary—(1) In regard to Palæogeography the ice which glaciated Tasmania, Victoria and South Australia, came from the south from a land probably a local extension southwards into the Southern Ocean, of the Australian continent. The glaciation of Cambrian time, in Australia, came from the same quarter. In Western Australia, the glaciation is thought to have come from the south-east, from local highlands, near the southern end of Western Australia. In Eastern Australia, the region affected by the glaciation was a landscape apparently of low relief, but we know nothing of the height of the gathering ground of the ice sheets on the now sunken part of the continent, where the eastern end of Jeffrey's Deep shows a depth of 3,000 fathoms. Possibly the great bank recently discovered which lies about 200 miles south of Tasmania, and which rises from great ocean depths to within 500 to 600 fathoms of the surface formed part of a high south-eastern margin to Australia, extending from this bank to Kangaroo Island in Permo-Carboniferous time. This was no doubt in part a gathering ground for the inland ice. In New South Wales, there seem to have been local alpine glaciers. In south-western Western Australia, there seems to have been a local ice sheet.

(2) There were at least three interglacial phases in Australia, probably to be correlated with those of Africa. (3) The fauna especially in disappearance of Carboniferous reef-forming corals suggests general refrigeration of the seas, while the flora of the coal seams is not inconsistent with that of a climate like that of Macquarie Island. (4) Snow line touched sea level probably near 40 degrees S. latitude in Permo-Carboniferous time, and glaciers came down to sea level at about 34 degrees S. latitude. (5) This may demand a fall of temperature as compared with the present of about 10 degrees C.

(i) Trias System.

Rocks of this age are at present known to be developed chiefly in the Sydney and Blue Mountain areas of New South Wales. In Tasmania, however, the Knocklofty Series, variegated sandstones, 1,000 feet thick, which, in the neighbourhood of Hobart, overlie the Permo-Carboniferous strata, have been doubtfully referred to some part of Triassic time. They contain remains of *Acrolepis hamiltoni* and *A. tasmanicus*, and bones of, probably, a labyrinthodont. The occurrence in the sandstones of *Vertebraria indica*, Royle, suggests affinities with the Permo-Carboniferous system. The Ida Bay Series containing *Zeugophyllites* and *Pecopteris lunensis* are perhaps Triassic. In regard to the Fingal Series in the Tasmanian coal-measures, as some doubt exists as to whether they belong to the top of the Trias, or to the base of the Jurassic, they will be described later.

The Triassic strata of New South Wales extend along the coast from the Cambewarra Ranges in the south to Lake Macquarie, near Newcastle, in the north, thence they stretch inland to beyond Gunnedah, on the north-west, and westwards to a little beyond Lithgow.

The rocks in this area have been divided, chiefly lithologically, into three stages which, in descending order, are as follows :—

Wiannamatta shales.—Thickness about 600 feet.
Hawkesbury sandstone.—Thickness about 300 to 1,000 feet.
Narrabeen beds.—Thickness about 200 to 2,000 feet.

The strata of the Narrabeen Stage are largely tufaceous, but the true tuffs do not constitute more than about one-tenth part of the whole thickness of the Stage. In their lower portion they are mostly grey to greenish-grey sandstones, with greenish conglomerates and grey-green and reddish to chocolate-coloured shales. Five hundred feet above the Bulli coal seam (the top of the Permo-Carboniferous System), tufaceous red shales and green tuffs contain innumerable small scales of metallic copper, together with microscopic veins of the same metal. These strata are known as the Cupriferous Tuffs. Over 1,000 feet above these tuffs is a second series of green tuffs and chocolate-red shales. In the latter, at Long Reef, 12 miles north-east of Sydney, beautiful examples occur of plants resembling *Phyllotheca*, with their stems of brittle bituminous coal, held together in a delicate filigree-like network of metallic copper. Where the strata have been much weathered, the metallic copper passes into green and blue carbonates. The copper has obviously been derived from the decomposition of the basic tuffs. The tuffs are traversed in places by small veins of barytes.

The Hawkesbury sandstone, which is typically developed at Sydney and in the Blue Mountains, is chiefly formed of white to yellowish-grey sandstones, very regularly and evenly bedded, diagonal bedding being very conspicious. South of the Hawkesbury River, in the area where this diagonal bedding dips to the north-east, primary graphite is scattered in scales or small pellets through the sandstone. To the north of the Hawkesbury River, the diagonal bedding dips in almost the opposite direction, that is from off the New England tableland, and this part of the formation does not contain graphite. Small garnets are not infrequent in the southern type of the Hawkesbury sandstone. Certain beds in this Stage form a valuable building stone, largely worked in Sydney and suburbs. It weathers, as the result of chemical changes in the iron carbonates, to a pleasing tint of warm sepia. A few bands of dark clay shale are interstratified with the sandstone. These often show evidence of having been disrupted contemporaneously, the fragments being up-ended so that their lamination planes are now vertical. Meanwhile, neither the sandstones above nor those below show any sign of disturbance. This phenomenon, together with that of contemporaneously contorted current-bedding, has been ascribed to the action of ice; but other explanations, such as that of undercutting of the clay shales by stream action are possible. These sandstones weather into picturesque shelter caves, as the result of the removal by capillarity of soluble mineral cement from the inner portion of the sandstone and its transference to the exterior. The Wiannamatta Stage is mostly formed of black carbonaceous shales, with at least one seam of coal, which, with clay bands, is about 4 feet thick. At the top of this stage the beds become sandy and calcareous, ending in a calcareous tufaceous rock, 100 feet thick, containing a very interesting foraminiferal and ostracodan fauna.

As regards fossil plants, *Thinnfeldia odontopteroides* is specially characteristic and abundant throughout the whole series. *Macrotænipteris* and *Phyllotheca* are also typical. *Sphenopteris* is also common, and in places is associated with *Alethopteris* (*Cladophebis*), but this last genus is much more characteristic, in Australia, of the Jurassic rocks than of the Triassic. Near the base of the Narrabeen Stage beautifully preserved specimens of *Schizoneura* are fairly common, and the genus not only extends downwards into the strata which form the roof over the Bulli coal seam, at the top of the Permo-Carboniferous System, but, at the Sydney Harbor collieries shaft at Balmain, Sydney, it has been found associated, in the same bed of clay shale, with *Glossopteris*. *Schizoneura* has never been found in either the Hawkesbury or in the Wiannamatta Stages, but it occurs in Victoria in strata conformably overlying the *Gangamopteris* sandstones and glacial beds at Bacchus Marsh, to the west of Melbourne.

Stems of trees are numerous in the tuff beds near the top of the Stage, as well as forms allied to *Baiera*. Fossil fruit are plentiful in these beds at Long Reef and Narrabeen, to the north of Sydney. Reference has already been made to the abundance of *Phyllotheca*, some stems of which are partly encrusted with metallic copper. The lower part of the Narrabeen Stage, for about 500 feet above the top of the Permo-Carboniferous System, is swarming in small black valves of several species of *Estheria*. Just at the top of the Narrabeen Stage, or possibly a few feet up into the Hawkesbury Sandstone Stage, is a bed of shale at Gosford, which has proved exceptionally rich in remains of fossil fish, together with remains of small labyrinthodonts. The principal forms found are *Palæoniscus*, *Myriolepis*, *Cleithrolepis*, *Apateolepis*, *Dictyopyge*, *Belonorhynchus*, *Semionotus*, *Pristisomus*, *Pholidophorus*, etc.

In the Hawkesbury Sandstone Stage a problematical fossil plant, *Ottelia præterita*, occurs sparingly. In the occasional intercalated shale beds *Oleandridium* has been recorded, while *Thinnfeldia odontopteroides* is very abundant. The leaves are so well preserved that they are sufficiently coherent and flexible to be lifted off the surface of the shale, and when subsequently examined under the microscope, are seen to have preserved much original structure.

At Biloela (Cockatoo Island), near Sydney, a thoracic plate of *Mastodonsaurus* was found, and also, strange to say, at the same spot, a specimen of *Tremanotus*. This Silurian genus on a Triassic horizon may represent either a remarkable survival, or it is possible that the fossil may be an erratic in this formation. It is preserved in ironstone, which may have replaced a small fragment of limestone. In the shales of the Wiannamatta series, most of the fossils are either at the base or near the top of the Stage. Just as the Hawkesbury sandstone usually rests on an eroded surface of Narrabeen beds, so in the case of the junction line of the Wiannamatta shales, with the Hawkesbury sandstone there is in many cases evidence of contemporaneous erosion. A good deal of concretionary clay ironstone has formed in the basal beds of the Wiannamatta shales, and these are mostly fossiliferous. In addition to *Thinnfeldia* and *Phyllotheca*, the *Cycadopteris scolopendrica* has been recorded from these beds. True cycads appear on the whole to be wanting throughout the whole of the Australian Triassic rocks.

In the ironstone concretions referred to above, shells of Mollusca are often very abundant, belonging to the genera *Unio* and *Unionella*. The dwarf character of these shells suggests that the strata containing them were deposited in brackish water. In the brick-pits of Newtown and Enmore, in Sydney, numerous well-preserved specimens of fossil fish have been obtained. These range in size from a few inches up to specimens 6 feet in length.

Labyrinthodont remains have been found on this horizon, both at Enmore and at the Gib Rock Tunnel, near Bowral.

The specimen discovered at the former locality measures about 10 feet in length. Its immense jaws are furnished with three rows of powerful conical teeth. The original specimen, preserved in clay ironstone, has never yet been described. It is now at Brisbane, in the possession of the Government Geologist of Queensland, who also has several as yet undescribed fossil insects, discovered by him in these shales. The Wiannamatta Stage closes with a bed of greenish tufaceous and calcareous sandstone, passing into sandy limestone. This is largely formed of foraminiferal and ostracodan shells. Comment has been made on the fact that, in this horizon of the Wiannamatta Stage, we have a remarkable example of the survival of a Silurian type of ostracod in the genus *Beyrichia endothyra*; also on this horizon is an interesting survivor from the carboniferous fauna. On the other hand, the genus *Haplophragmium*, which also occurs on this horizon, is not known elsewhere to descend so low stratigraphically.

The geographical conditions under which the strata of the Hawkesbury series were accumulated appear to be those of a large shallow lake close to the sea, with which possibly there was intermittent communication. The *Gangamopteris-Glossopteris* Flora of the Permo-Carboniferous Ice Age had, with the exception of *Phyllotheca*, *Sphenopteris*, and perhaps *Alethopteris*, completely disappeared before the earliest strata were deposited in this great lake basin. The eruptions, perhaps of the Kiama-Cambewarra region, or at all events of that zone, were prolonged into Triassic time, as proved by the frequent beds of basic tuff in the Narrabeen Stage. The evidence of ripple-marks and suncracks on many horizons all through the series points obviously to shallow water conditions. The foraminiferal ostracodan sandy limestone and calcareous sandstone at the top of the whole series prove that after a subsidence near the centre of the basin of about 3,500 feet, marine, or at least estuarine, conditions supervened. The flora of these Triassic rocks differs from the Jurassic in the presence in the former of *Phyllotheca* in vast numbers and of *Oleandridium*, while the *Tæniopteris daintreei* and varieties of cycads so common in the Australian Jurassic rocks are wanting in the Trias. Triassic types of *Estheria* do not ascend into the Jurassic, neither do the labyrinthodonts.

Endothyra, *Beyrichia*, *Tremanotus* (?), and *Palæoniscus* all represent Palæozoic forms of life surviving into Mesozoic time in the Trias of Australia.

In reference to the Fingal Series, and other representatives of the upper coal measures of Tasmania, some doubt exists as to whether they are to be classed as Upper Trias, perhaps Rhætic, or Lower Jurassic. As *Tæniopteris daintreei* (*T. spathulata*) regarded as a critical form in Australia for differentiating the Jurassic from the Trias has never yet been found in Tasmania, and the genus *Phyllotheca* is of common occurrence in these Tasmanian coal measures, it is proposed to class them provisionally as Upper Trias, or Passage Beds into the Jurassic proper. *Thinnfeldia odontopteroides*, *Alethopteris* (*Cladophebis denticulata*) *australis*, *Tæniopteris tasmanica*, *T. morrisiana*, *Phyllotheca*, and *Zeugophyllites* (*Phœnicopsis*, or *Podozamites*) *elongatus* are most characteristic. Other forms present are *Ptilophyllum oligoneurum*, *Sphenopteris lobifolia*, *Pterophyllum*, *Baiera tenuifolia*, *Ginkgophyllum australe*, etc. It may be stated generally that these Fingal coal measures are not as rich in fossil cycadaceous forms as are the true Jurassic rocks of the mainland. These measures, about 1,200 feet in thickness, are formed chiefly of yellow, brown, greenish, and bluish-grey sandstones, with coal seams from 4 feet up to 20 feet in thickness. The coal is of fair quality, containing from 1 per cent. up to 4 per cent. of moisture, and from 9 per cent. up to 15 per cent. of ash.

(j) Jurassic System.

Rocks referable to this period belong to what was probably the greatest lake epoch through which the Australasian continent has passed. The principal lake extended from some point south of Dubbo to at least as far north as the far extremity of the Bunya Bunya Ranges of Queensland to the north-west of Dalby. It is probable that the lake extended still further up to the Cloncurry area. Westwards they stretch more or less continuously to Lake Eyre, and still further westwards to Lake Phillipson. The lake would thus have had a total length of 1,200 miles from east to west, with a width from north to south of 700 to 800 miles.

The strata deposited in this lake, or chain of lakes, are the main source of supply of the artesian water in the great artesian basin.

They vary in thickness from 300 to 400 feet up to, at Lake Phillipson, about 3,000 feet. Eastwards the basin extends through a narrow neck near Brisbane (*vide* Plate III.) to the coast at the mouth of the Brisbane River, and also by a wider passage to the east coast, along the basin of the Clarence River, between Ballina and Woolgoolga. That there is no outlet of consequence, if any, for the artesian basin in this direction is proved by the fact that a bore has been put down to a depth of over 3,000 feet at Grafton, and only a feeble trickle of artesian water has been tapped. The same remark applies to the bore at the race-course at Brisbane. As details of this artesian basin are given by Mr. E. F. Pittman in his chapter in this volume, only very brief references will be made to the subject here. The section (Plate VI.) shows somewhat arbitrarily the line of junction between the Jurassic and the Cretaceous rocks, and is to be regarded as provisional only, as, on account of most of the bores being carried out by percussion, the fossils in the strata passed through are usually in such a fragmental state that identification is often very difficult.

The section (Plate VII.) shows the hydraulic grade descending from Charleville as a centre northwards to the Gulf of Carpentaria, and south-westwards to Lake Eyre. This fall in the hydraulic grade is difficult of explanation. The difficulties are obvious from the section, which shows that at its south-western end the basin is apparently blocked by impervious Pre-Cambrian or older Palæozoic rocks, so that apparently it has no outlet in that direction. Then, too, towards the north, a sill of older rock rises so high above the general floor of the basin that it would seem to go far towards checking any important underflow and outflow to the sea in this direction also. The explanation of the fall of the hydraulic grade seawards from Charleville, in Queensland, would seem to be either (*a*) that there are narrow subterranean outlets (which have not yet been tapped in the bores), both in the direction of the Bight and in that of the Gulf of Carpentaria ; or (*b*) that before the bores were sunk the chief outlet for the artesian water was through those natural artesian wells—the Mound Springs. These are very numerous on the Lower Flinders River in the north, and near Lake Eyre towards the south-west end of the basin.

PLATE VI.

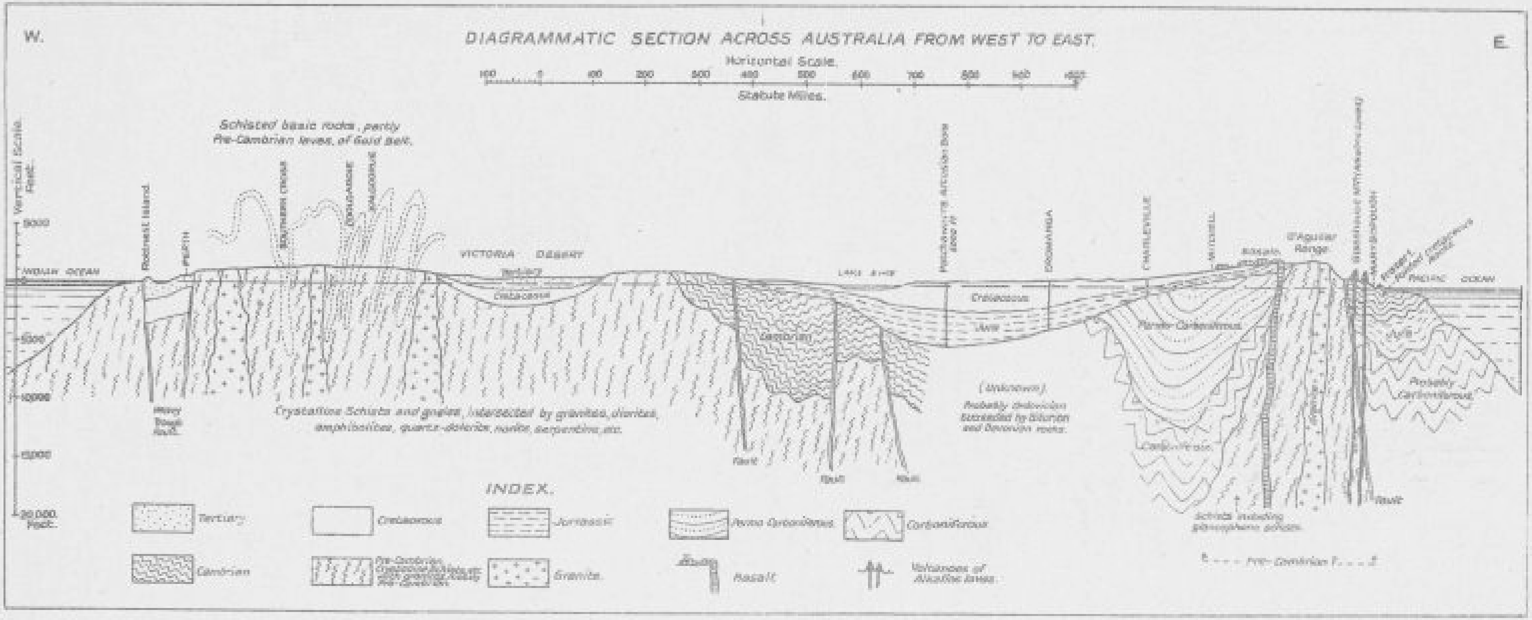
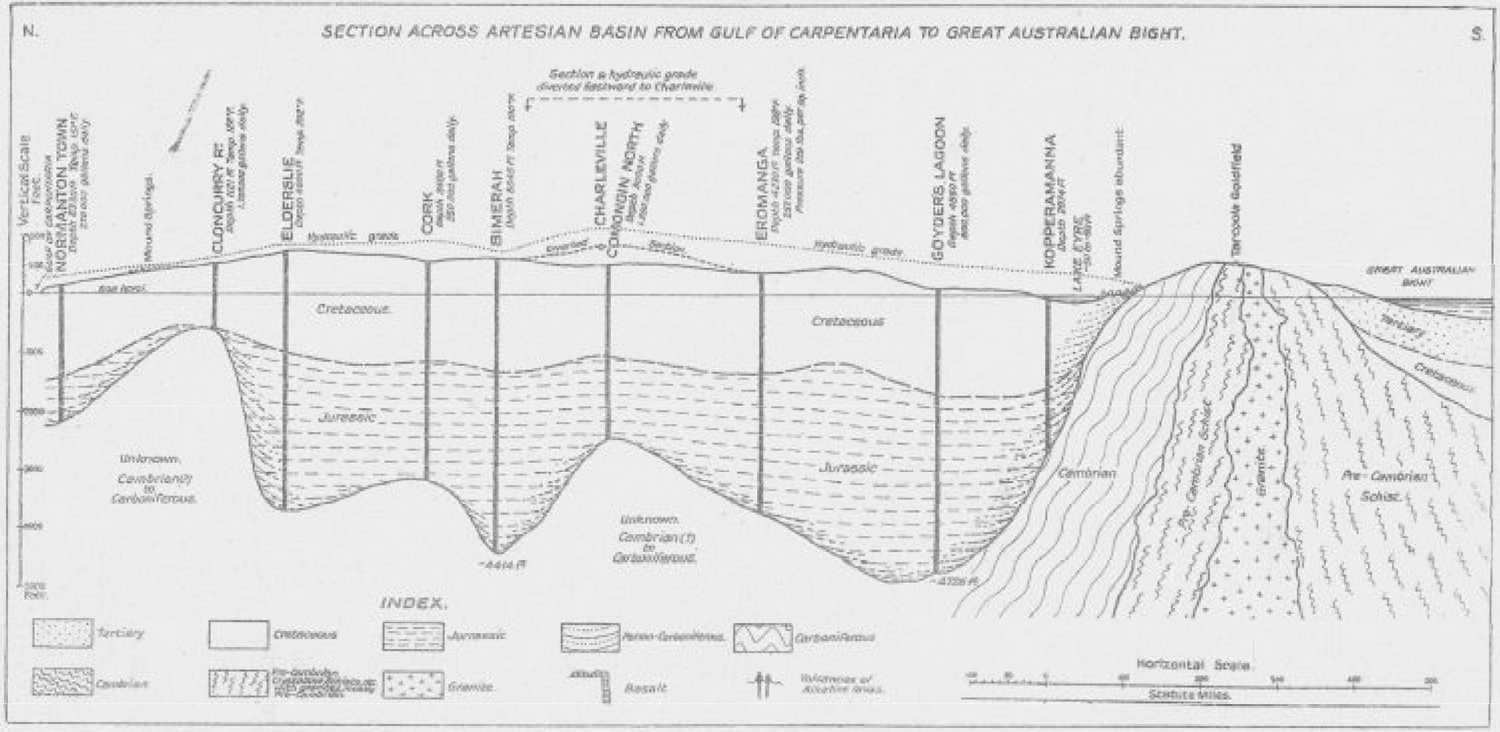

W.
E.
DIAGRAMMATIC SECTION ACROSS AUSTRALIA FROM WEST TO EAST.
Horizontal Scale.
Statute Miles.
Vertical Scale. Feet.
Schisted basic rocks, partly Pre-Cambrian lavas, of Gold Belt.
INDIAN OCEAN
Rottnest Island
PERTH
SOUTHERN CROSS
VICTORIA DESERT
Tertiary
Cretaceous
Crystalline Schists and gneiss, intersected by granites, diorites, amphibolites, quartz-dolerite, norite, serpentine, etc.
Fault
Cambrian
(Unknown)
Probably Ordovician succeeded by Silurian and Devonian rocks.
CHARLEVILLE
MITCHELL
D'Aguilar Range
Permo-Carboniferous
Basalt
PACIFIC OCEAN
Probably Carboniferous
Schists including glaucophane schists.
INDEX.
Tertiary
Cretaceous
Jurassic
Permo Carboniferous
Carboniferous
Cambrian
Granite.
Basalt
Volcanoes of Alkaline lavas.

PLATE VII.


N.
SECTION ACROSS ARTESIAN BASIN FROM GULF OF CARPENTARIA TO GREAT AUSTRALIAN BIGHT.
S.
Vertical Scale Feet.
NORMANTON TOWN
CLONCURRY R.
ELDERSLIE
CORK
SIMERAH
CHARLEVILLE
GOYDERS LAGOON
KOPPERAMANNA
LAKE EYRE
EROMANGA
Hydraulic grade.
Cretaceous.
Jurassic
Unknown.
Cambrian(?) to Carboniferous.
Cambrian
Granite
Pre-Cambrian Schist.
Tertiary
GREAT AUSTRALIAN BIGHT
INDEX.
Tertiary
Cretaceous
Jurassic
Permo-Carboniferous.
Carboniferous
Cambrian
Granite.
Basalt
Horizontal Scale
Statute Miles.

That springs connected with faults supply part of the artesian water is obvious; but it is probable that by far the larger proportion has a meteoric origin, being derived from rain falling direct on to the outcrop of the porous beds, or leaking into them from the channels of rivers.

This supposition receives some confirmation from the Cainozoic analogue of the artesian basin at Perth, in Western Australia, where the interdependence between rainfall and the outflow of artesian water has been distinctly proved; but the conditions in the Perth artesian basin are not in every respect analogous to those in the central Jurassic basin. For example, in the latter the factor of gas pressure is very important in helping to force the artesian supply to the surface. Over 90 per cent. of the gas concerned in producing this pressure is nitrogen; gases like CH_4, CO_2, H_2S, etc., are present in far smaller proportion. This nitrogen is almost certainly not of plutonic origin, but is probably derived from the alteration of organic material, such as lignite or coal, by the action of anærobic bacteria. As, however, the temperature of the artesian water is in some cases up to 204 degrees Fahr., even when the water arrives at the surface, it is difficult to understand how bacteria can live under such conditions. But, so far, the waters from the chief bores which evolve nitrogen have much lower temperatures than the above. This interesting problem, as indeed that of the whole physics, chemistry, and geology of the great artesian basin, still awaits solution. The total depth of all the artesian bores of Australia, according to the latest figures available to the writer, is almost exactly 500 miles, and the potential daily yield about 680 millions of gallons.

Strata of Jurassic age are also found on the eastern periphery of Australia and in Tasmania, as well as in the coastal regions of Western Australia.

In Queensland the principal localties are Ipswich, Clifton, Callide Creek west of Gladstone, Stanwell, and Rosewood west of Rockhampton, and Broadsound to its north. The strata are there from 2,000 to at least 3,000 feet in thickness, and consist of sandstones, conglomerates, and shales, with massive beds of quartz-trachyte tuff at the base of the Series at Brisbane. Basic lavas are present on a higher horizon and contemporaneous trachyte lavas. These are found between Brisbane and the Macpherson Ranges, on the borders of New South Wales and Queensland. The seams of coal in the Queensland Jurassic rocks range from a few feet up to a maximum of 30 feet in thickness. In the Ipswich basin the seams vary from about 6 feet up to 8 or 10 feet in thickness. The principal fossils are *Tæniopteris daintreei*, *Thinnfeldia odontopteroides*, *Alethopteris australis*, *Sagenopteris*, *Ptilophyllum*, *Podozamites kidstoni*, *Otozamites*, *Brachyphyllum*, etc. The fossil fauna comprises *Estheria mangaliensis*, *Unio ipsviciensis*, *Unio eyrensis*, while insects are represented by *Mesostigmodera typica* and several as yet undescribed forms.

In the Clarence Basin of northern New South Wales, strata of this age are probably at least 4,000 feet in thickness. They are divided into Upper Middle, and Lower Clarence Stages respectively. The Lower Clarence Stage contains several seams of coal, up to a maximum thickness of about 37 feet, but the seams are so full of clay bands that they are not at present worked commercially. The Middle Clarence Stage is a strongly marked horizon of massive diagonal-bedded sandstone. The Upper Clarence consists of clay, shales, and clayey sandstones. A rich flora is contained in the Lower Clarence Stage, but it has not yet been described. *Tæniopteris daintreei* and *Thinnfeldia odontopteroides* are the most characteristic fossils.

A small isolated patch of Jurassic rock also occurs at Talbragan, between Mudgee and Dubbo, in New South Wales. These strata, which rest on an eroded surface of Hawkesbury sandstone, contain the following fossils:—*Tæniopteris daintreei, Alethopteris australis, Thinnfeldia falcata, Podozamites lanceolatus*, and *Baiera bidens*. Insects were represented by an ancestor of the true locust, the fossil form being described as *Cicada lowei.*

Amongst the fish, which are very numerous, are *Leptolepis gregarious, Archæomene robustus, Coccolepis*, etc.

In Victoria there are three considerable areas of Jurassic rocks—those of South Gippsland, the Cape Otway District, and the neighbourhood of Merino, in the west.

The strata consist of felspathic sandstones, with abundant fresh fragmental felspar, perhaps of tufaceous origin, besides shales, mudstones, and seams of coal. The seams are worked commercially in the Cape Paterson District, as at the State-owned colliery at Wonthaggi. The coal is of fairly good quality, and the thickness of the seams varies from 2 to 9 feet. The following are among the most characteristic fossils:—*Coniopteris hymenophylloides* var. *australica, Cladophlebis denticulata* var. *australis, Sphenopteris ampla, Thinnfeldia odontopteroides, T. maccoyi, Tæniopteris spatulata* and vars. *daintreei* and *carruthersi, Podozamites barklyi, Ginkgo robusta, Baiera subgracitis, Palissya australis, Brachyphyllum gippslandicum, Unio stirlingi.* The interesting discovery has been made of a tooth of *Ceratodus* from Cape Paterson, *C. avus*. Scales of *Ceratodus* have also been described from the parish of Killak, South Gippsland. *Ceratodus* has of course been recorded from the Stormberg series of South Africa, as well as from the Trias of Europe. Another recent very interesting discovery has been that of a claw of a dinosaur also in the Cape Paterson beds.

In South Australia, to the south of Lake Eyre, there is a small Jurassic coal basin, an outlier of the main Jurassic artesian basin, and preserved in a deep trough fault. This is the Leigh's Creek coal basin. Its strata of sandstone and carbonaceous shales are over 2,000 feet in thickness, and comprise several seams of coal, one of which is 47 feet in thickness. This coal is a hydrous brown coal. The chief fossils are *Thinnfeldia odontopteroides, T. media, Macrotæinopteris wianamattæ, Podozamites lanceolatus*, and an immense number of the fossil pelecypod *Unio eyrensis*. This occurred in almost every foot of the core from the bore for coal, from the surface to a depth of over 1,500 feet. The only marine equivalents of strata of Jurassic age within the Commonwealth are found on the west and south-west coasts of Western Australia. They are chiefly developed in the Northampton District, extending thence by way of the Greenough River to Gingin, about 40 miles north of Perth, in Western Australia. The strata consist of white sandstones, ferruginous sandstones, light-coloured claystones, grits, limestones, and shales, with lignites. Their maximum thickness is quite 3,000 feet. In places phosphatic green-coloured patches in the ferruginous sandstone contain the phosphatic mineral dufrenite. Artesian water has been struck in this formation at Dongara and at Yardarino; but after flowing for a few years, the flow has ceased at the former locality through the bore becoming choked, and at the latter through failure of the supply. The following are the most typical fossils in this area :—*Otozamites feistmanteli*, Zigno, *Pagiophyllum* (?), *Pentacrinus australis*, *Trigonia moorei*, *Teredo* found in its own bores in fossil wood, several varieties of Jurassic ammonites, and remains of large enaliosaurians. The second area commences at Cape Riche, and extends to beyond the Phillips River. The strata, in almost horizontal beds, rise to about 700 feet above sea-level. Perfect specimens of fossil sponges are weathered out from some of the caves in this formation.

A very important unit in the geology of Tasmania is the huge sills of diabase (granophyric dolerite and enstatite-augite dolerite), often over 500 feet thick, which have been intruded into these coal measures. They are almost certainly Pre-Cainozoic. If they are of the same age as the great dolerite sills of the Karroo System of South Africa, and the Antarctic dolerites, which intrude the Beacon sandstone formation of the Ross Sea Region, they should probably be placed at the top of the Jurassic, and perhaps be connected with the breaking up of Gondwana Land, at the close of Jurassic time.

(k) Cretaceous System.

This system is divided at present into the Rolling Downs formation below, and the Desert Sandstone above. The lower formation is almost wholly marine, except in the case of the Burrum coal-field of Queensland with the adjacent Frazer Island, or Great Sandy Island, and intermediate islands, which consist partly of fresh-water beds. The Desert Sandstone is mostly of fresh-water origin ; but in places, as at Croydon, in Queensland, it contains in abundance *Rhynchonella croydonensis*, and at Fanny Bay and adjacent areas at Darwin is represented by a radiolarian shale, and by cherts containing casts of small *Belemnites*. As regards thickness, the Desert Sandstones vary from about 150 feet up to a maximum of 500 feet, while the Rolling Downs beds are known to be in places about 2,000 feet in thickness, perhaps more. The exact thickness is not always easy to determine, on account of a nearly conformable downward passage from the Rolling Downs beds into the Jurassic strata. The vast extent, about one-third, of the whole area of Australia, formerly covered by the rocks of the Cretaceous system, shows that an enormous transgression of the ocean took place at this time, so as to develop a distinct epicontinental sea over the whole of the east central portion of Australia. Cretaceous rocks are also known to be developed on the north-west side of the Victoria Desert in Western Australia, as well as under the Tertiary limestones of the Nullarbor Plains fronting the Great Australian Bight, as lately proved in the Madura artesian bore. They are also represented by a narrow strip, some thousand feet below sea level, at Perth, as shown by the Clermont Bore as well as by a similar strip extending along the coast from north of Geraldton towards North-west Cape.

Mr. W. S. Dun, in his palæontological notes in this article, comments on the fact that the marine fauna from this west coast belt of Western Australia is closely allied to the Pondicherry Cretaceous fauna of India, whereas that of the great artesian basin represents a peculiar type locally developed within this Australian Mediterranean. Lithologically the Desert Sandstone rocks consist mostly of coarse sandstone, passing in the arid regions into quartzite, as well as of very siliceous white shales graduating superficially into porcellanite, and in places containing valuable deposits of precious opal. The latter are associated with remarkable large forms, known to the miners as "pineapples," formed of common opal pseudomorphous after glauberite, together with concretions locally known as buns of barytes. Near Port Mackay, in Queensland, trachytic tuffs are said to be associated with the lower beds of the Desert Sandstone. This is the only record of contemporaneous volcanic activity in the whole Cretaceous System in Australia. Small seams of coal, too thin to be workable, and numerous silicified trees occur in places in this formation. The Rolling Downs strata are mostly friable sandstones rich in foraminifera, and rendered green by glauconite. In addition, at the Burrum coal-field and at Maryborough and Frazer Island, sandstones and shales, with fossil plants and seams of productive coal, are now considered to be of Cretaceous age. The whole series is approximately 3,000 feet thick. The Burrum coal seams, of which about four are of workable thickness—that is,from 3 feet to 4 feet thick—contain coal of a brittle, bright, black, bituminous character, and remarkably free from ash, but too friable for export. The fossil plants recently recorded from this Cretaceous coal-field show that forms like *Trichomanites laxum*, *Thinnfeldia media*, and *Tæniopteris daintreei* survived over from Jurassic time. *Corbula burrumensis* and *Rocellaria terræ reginæ* are associated with the Burrum coal measures. This recent discovery of the survival of part of the Australian Jurassic fauna and flora into Cretaceous time is obviously of considerable importance. As regards the fossil fauna in the Rolling Downs beds, well preserved remains of infusoria belonging to the *Tintinnoidæ* associated with diatoms and radiolaria have been found in fine-grained limestones at Mitchell, on the Maranoa River. The following is a list of specially characteristic fossils:—Foraminifera, in which the *Lituolidae* are strongly represented, *Purisiphonia clarkei*, *Pseudavicula australis*, *Maccoyella barklyi*, *Nucula quadrata*, *Cytherea clarkei*, *Belemnites australis*, *Crioceras australe*, *Lamna daviesii*, *Aspidorhynchus sp.*, *Belonostomus sweeti*, *Notochelone costata*, *Ichthyosaurus australis*, *Plesiosaurus macrospondylus*, *Æschna flindersensis*, etc.*

The general evidence points to a progressive submergence of the Australian Continent in Cretaceous time leading to an encroachment of the sea southwards through the direction of the Gulf of Carpentaria across to the Australian Bight. It is just possible that there may have been a narrow neck of land joining east Australia to Western Australia to the south of Lake Eyre. At all events the isolation, when the submergence was at its maximum, of east Australia from Western Australia, must have been nearly complete. The wide spread of the comparatively thin beds of the Desert Sandstone, mostly of fresh-water origin, indicate that, in Upper Cretaceous time, the Cretaceous seas were retiring from the Continental area, and lacustrine conditions were taking their place everywhere, except locally, as at Croydon and Darwin. It may be added that Melville Island and Bathurst Island, to the north of Darwin, are formed of Cretaceous rocks, apparently of Rolling Downs type,

* This insect is probably an *Æschnidium*. Mention may here be made of an extraordinary fossil perhaps allied to *Æschnidium* now to be seen at the Geological and Mining Museum, Sydney. It is a well preserved wing in the heart of an immense selenite crystal found at over 600 feet underground in the Mt. Elliott copper mine, near Cloncurry, Queensland.

but little is as yet known of their fossil contents. The fact that Lower Cretaceous fossils, especially small specimens of *Scaphites*, are being constantly washed up on the beach at the Point Charles lighthouse, Darwin, shows that Lower Cretaceous rocks underlie the strait which separates Melville Island from the mainland. It may be suggested here, very tentatively, that the vast transgression of the Cretaceous sea was perhaps causally connected with two other important geological events, viz.:—Firstly with the sinking in of Gondwana land leading to compensating uplifts of the sea floor, and secondly with the wholesale injection of the vast dolerite sills, which probably further contributed towards shoaling the ocean basins.

(I) Cainozoic Era.

The classification and correlation of the rocks of the Commonwealth belonging to this era present many difficulties.

It is harder in Australia than in Northern Europe to separate the Post Tertiary from the Tertiary rocks, as whereas in Northern Europe glacial deposits, chiefly of Pleistocene time, are widespread, in Australia such glacial evidences are wholly restricted to an area of less than 500 square miles, which has its centre at Mount Kosciusko. Only in Tasmania can evidences of Pleistocene ice action be traced over a large area. Then in regard to the correlation of the Australian Tertiaries with those of Europe, the statement of an Australian palæontologist still applies :—"Many attempts have been made to fit the Tertiaries of Southern Australia into the British Procrustean subdivisions, and I do not know that the results are any more satisfactory to the strata than they were to the guests of Procrustes himself."

Direct comparison of Australian Tertiary forms with those of Europe may prove fallaceous, unless supplemented by other evidence, for there is no direct proof of the existence of any highway for migration of marine organisms from the seas of the Southern Hemisphere into the Tethys area in early Tertiary time.

Tested by the Lyellian method—the determination of the percentage of recent Mollusca in the series—the Tertiary marine faunas of Australia can be compared with the recent fauna of Australian seas, but it is now clear that some Australian palæontologists who worked on these lines did not recognise the fact that in many of the older Tertiary deposits of Australia the marine molluscan fauna is not, as was originally supposed, littoral in habit, but belongs to a moderate depth ; and recent dredging operations have demonstrated the fact that many forms in the older Australian Tertiaries, formerly thought to belong to extinct species, are now living at some depths off the Australian coasts. If one relies for correlation on the evidence of wide-ranging and rapid-moving types, like sharks and whales, it may be noted that *Carcharodon angustidens* and *C. megalodon*, of the older Australian Tertiaries, are characteristically Miocene in the Northern Hemisphere. Then, too, the toothless whales of the Victorian older Tertiaries belong to a group which in the northern hemisphere appears to be chiefly Pliocene.

On the whole the tendency of late has been to refer the so-called Eocene strata of Southern Australia to some part of Miocene time. Recently it has been proposed to divide the Tertiary rocks of Victoria into three systems, details of which are given in this article. It will be seen that reliance is largely placed for purposes of correlation on various species of *Lepidocyclina*. Meanwhile the sequence of events in Cainozoic time in Southern Australia and Tasmania, from the close of Cretaceous time, may be briefly stated as follows :—

1. Accumulation of plant-bearing strata, developing in places into thick beds of lignite. These plants have been considered to be Eocene, but may be Oligocene or Lower Miocene. A primitive marsupial fauna was probably already in occupation of Tasmania, as a nearly complete skeleton of *Wynyardia* has been found in the marine strata of No. 3, which conformably follows No. 2, No. 2 being conformable to No. 1, and all being separated from one another by no great time interval. *Wynyardia bassiana* was a generalized form neither distinctly polyprotodont nor distinctly diprotodont. (The original is now in the Hobart Museum.) The older " deep leads " of Eastern Australia belong here.

2. Extensive flows of the so-called " older basalts," and development of basic tuffs passing into laterite and covering the older deep leads.

3. The Pre-Miocene Bassian landbridge between Tasmania and the mainland became broken down, the old bridge becoming involved in a general submergence, which affected the whole of the southern shores of Australia. In the Nullarbor Plains area of the Great Australian Bight, strata of white chalky limestones, with flints, and often rich in *Gryphaea*, were developed over a large area. Similar strata occur at intervals all along the southern shores of Australia. In the Lower Murray area, as well as in Victoria and Tasmania, the polyzoon *Cellepora gambierensis* is extremely characteristic, and in the cliffs of the Lower Murray forms sub-spherical masses, each of the size of a man's head. These strata attain a thickness of about 80 feet at Table Cape, Tasmania, and on the coastal plains of Southern Australia are usually 200 to 400 feet thick, with a maximum thickness of about 1,000 feet under the Nullarbor Plains. The Purari series and the oil-bearing strata of British New Guinea probably are of this age.

4. The *Ostrea sturti* beds, which overlie the *Cellepora* limestones of the Lower Murray, perhaps Upper Miocene.

5. The immense belt of alkaline lavas and tuffs, which extend from Casterton, in Victoria, through Mount Macedon to Clermont and Springsure, in Queensland, perhaps belongs to this horizon.

Possibly the nepheline-basanite of Table Cape, the melilite basalt at Sandy Bay, near Hobart, and the nepheline melilite basalt and nepheline eudialyte basalt of Shannon Tier, in Tasmania, were erupted about this time.

6. In British Papua the Port Moresby series probably belongs to the older Pliocene. In Australia Marine Pliocene strata, to a thickness of about 1,000 feet, were deposited in the neighbourhood of Adelaide, as proved by the Croydon bore (2,296 feet deep). In all other areas in Australia and Tasmania, strata of this age are of freshwater or of volcanic origin. Possibly the lake beds of the Launceston Tertiary Basin, 1,000 feet thick, are of Pliocene age, as they contain fossil fruits, such as *Spondylostrobus smythii*, *Plesiocapparis leptocelyphis*, *Pentrune allporti*, etc., fossils more characteristic of the Kalimnan than of either the Janjukian or of the Balcombian age.

7. Vast sheets of basalts, proceeding from dyke eruptions, flooded the nearly even surfaces of the east and south-east Australian and Tasmanian peneplains. In South Australia they are represented at Kangaroo Island, and in Western Australia at Bunbury, the Lower Blackwood River, and at Black Point upon the coast. The fact that the flora of this period shows scarcely any trace of differentiation suggests that the land had a low relief. These extensive basaltic outflows appear to date near to the close of Pliocene time.

8. (*a*) In either very late Pliocene, or early Pleistocene time, the earth's crust, in the Australian and New Guinea region, was subjected to considerable diastrophism. The eastern periphery of Australia, including Tasmania, was warped up to altitudes of over 3,000 feet above the sea. The movement being differential carried an area, such as Kosciusko, to a height of 7,000 feet above sea level. In New Guinea the Cretaceous to Pliocene strata underwent intense orogenic movements, mountains being produced up to and over 15,000 feet in height.

(*b*) A glacial age supervened, which had many phases. Kosciusko was capped by an ice calotte from its summit to about 5,000 feet above sea level. In Tasmania the glaciation was naturally very heavy on the west coast and western highlands, the modern heavy rainfall, coming from the west, being at that time largely replaced by snowfall. Not only were the Western Tiers of Tasmania and the highlands of the west coast covered with firn-fields and glacier ice, but at the township of Gormanston glacial boulder clays were formed only a few hundred feet above sea level, and on the west side of the Craycroft Range the moraine material descends to within 250 feet of sea level. This glaciation affected, probably synchronously, New Guinea, and it was probably during a phase of this glacial age that the rhododendron migrated from Papua to the Bellenden-Ker Range, of Queensland (over 5,000 feet high), where it has since become isolated through the amelioration of the climate. The phenomena of the maximum glaciation seem to call for a lowering of temperature of approximately 9 degrees Fahr., as compared with that of the present day.

(*c*) Partly synchronous, if not wholly synchronous, with this Ice Age, or possibly its interglacial phases (if there were any such), was an epoch when the central plains of Australia had a good rainfall, and the present area of internal drainage was only beginning to come into existence. Great herds of herbivores, of much larger size than their nearest modern allies, roamed over what are now the arid regions of the lower steppes of Australia, near Lakes Eyre, Frome, and Callabonna. This fauna comprised *Ceratodus*, *Megalania prisca*, *Meiolonia*, *Pallimnarchus pollens*, *Diprotodon*, *Nototherium*, *Macropus*, and *Sceparnodon*, with the probably carnivorous form *Thylacoleo*, and the carnivorous *Thylacinus*, *Sarcophilus*, and *Canis dingo*, while *Sus papuensis* found its way southwards from Papua, as far as the Darling Downs, of Queensland. Thus during this Kosciusko epoch Papua was still united to Australia, and the recent discovery of a *Nototherium* (*N. tasmanicum*, Scott) at Mowbray Swamp, in the north-western part of Tasmania, taken in conjunction with other evidence, suggests that Tasmania was once more united to Australia by way of the Bassian Bridge. At least one gigantic ancestor of the emu *Genyornis* was associated with this fauna. This bird was probably about 13 feet in height. A fine collection of this fauna is in the Adelaide Museum.

(*d*) Subsidences complementary to the uplift no doubt commenced with the uplift, but became much more pronounced after the uplift ceased. The rift valleys, Torres Strait, Port Curtis, of Cairns, of Cooma, of Bass Strait, Hobart, Port Phillip, St. Vincent and Spencer's Gulfs, and Lake Torrens, and of the west coast of Western Australia gradually developed, together with those many faults traversing the highlands of the warped peneplains of Australia and Tasmania, whose unreduced scarps attest their comparatively recent origin. The recent volcanic craters of Mount Gambier, Tower Hill, etc., may be referred to this epoch. Possibly negritoid man entered Tasmania by way of the Pleistocene Bassian Bridge before its final collapse. Ever since the Kosciusko epoch canyon cutting has been proceeding down to the present day in the elevated peripheral portions of Australia and Tasmania, this process tending to push the divides further inland.

Amongst recent formations may be mentioned the dune rock, partly cemented by lime, of Fremantle, and the south-western coast of Western Australia, of Cape Northumberland, near the border of South Australia and Victoria, and the dune rock of Warrnambool, Sorrento, etc. At Sorrento this dune rock is about 1,000 feet in thickness, and near Perth, in Western Australia, is at least as thick. The heavy silting along the Victorian coast, which has produced the Gippsland Lakes, as well as silting off the Maryborough coast, where the dunes are 800 feet high, and the silting between Sharks Bay and North-west Cape, in Western Australia, are all connected with the cusps of slack water formed next the shore, where great ocean currents meet. Mention may also be made here of the sand dunes of the lower steppes of Australia, and of the Victoria Desert. The latter are only superficially formed of loose sand, to a depth of a foot or so, and then the formation passes into a tough calcareous rock. The Transcontinental railway from Perth, by way of Kalgoorlie to Adelaide, will have to be cut through a vast number of these dune ridges, which are from 30 feet up to 80 feet high in places. In the Lake Eyre region the sand dunes again are only superficially loose sand. Inside they are formed of a certain amount of loamy material, especially near the old deltas of Cooper's Creek, and of the Diamantina River. In most parts of Central Australia these dunes derive their sand from the breaking up of the Upper Cretaceous desert sandstone.

In addition to the alluvial plains and rivers, mention may be made of the laterites (pindan gravels) of Western Australia, the nodular tufaceous limestone (" kunkar ") of South Australia, the saline deposits of the inland plains, and the coastal salinas. Subsidence has evidently been recently in progress at the southern end of Tasmania, and the large " bank " recently discovered 200 miles further south, is obviously an immense sunken segment of a once greater Australia. Submergence has also taken place for a great distance along the east coast of Australia. As already stated, this is partly due to the recent melting of ice and snow in Antarctica, bringing about a eustatic positive movement of sea level; but it cannot be entirely due to this, as the recent submergence is in places of the order of fully 200 feet, and it is doubtful whether the ice of Antarctica, from the great ice age down to the present time, can have affected sea-level to the extent of more than about 100 feet.

The so-called raised beach of about 15 feet is so general around Australia, that it is probably due to a recent eustatic negative movement of the sea surface. The 50 feet raised beach near Darwin is probably connected with recent orogenic movements in Papua. These recent movements have caused a local emergence of the coral reefs in south-eastern Papua of 1,000 up to 2,000 feet. The Great Barrier Reef of Queensland, some 1,200 miles in length, represents, in its uppermost portion, a marvellous area of growing reef The bulk of the reef appears to be formed of coral.

Earthquake shocks, most frequent in the area between the gulfs of South Australia, Bass Strait, and Kosciusko, show that coastal readjustment is still in slow progress in those regions. In New Guinea sharp shocks proceed from near the active volcanic zone, near Mount Victory. Most of the earthquake shocks which reach the eastern side of Australia emanate from the deep trench to the east of the Tongan and Kermadec Islands. Western Australia is practically free from earthquakes.

5.—Pre-Historic Man.

As is well known, the aboriginal inhabitants, now unfortunately extinct, of Tasmania belonged to the negrito and were in a palæolithic state of civilization. They had no knowledge of producing a cutting edge on stone by grinding it down on a hone stone, all their instrunents being of the rudest possible type, and roughly chipped. Neither had they any knowledge of building canoes of the sea-going type, being satisfied to construct them from the bark of trees stripped off in long sheets, then sewn up at the ends and plugged with clay. In this frail craft they navigated their own rivers and lakes. No trace has been found in Tasmania of aboriginal man considerably antedating the coming of the white man. On the mainland of Australia the aboriginal attained to neolithic stage of civilization as far back as we have any traces of him. Up to the present the following appear to be the only evidences of man in Australia attaining to anything approaching high geological antiquity :—

1. The Tasmanian aborigines probably crossed Bass Strait (as they were ignorant of the art of making sea-going canoes) by an almost continuous, if not continuous, land bridge.

2. On the mainland of Australia there is possible evidence near Warrnambool of impressions attributable to human bodies and feet in some of the old cemented sand dunes. Many have doubted the genuineness of these imprints. In New South Wales several stone tomahawks were dug up a few years ago in cutting a canal at Shea's Creek, between Botany Bay and Redfern. These tomahawks were embedded in peat many feet in thickness underlying marine estuarine beds at a total depth of 15 feet below the high water. It may be concluded that the whole of our coast-line has subsided by 15 feet, or else, as the result of the melting of ice and snow in the Antarctic regions, sea level has risen by that amount since the time when the aborigines lost their tomahawks in this swamp. In either case a

considerable lapse of time, perhaps of the order of several thousands of years, would be needed to account for this change in the relative level of land and sea.

3. Statements have frequently been made that stone tomahawks have been discovered in the deep leads of Victoria. The following, as far as is known, is the only case where the stone tomahawk may possibly be considered as the same age as a deep lead:—Near Maryborough, Victoria, in 1855, a basalt axe head was found at a depth of 4 feet from the surface in one of the tributaries of the main Bet Bet lead. The main lead is covered by basalt believed to be of Pleistocene age, but, as the tributary lead in which the axe head was found is not covered by basalt, the finding of an axe head at a depth of only 4 feet does not necessarily imply any great antiquity for it.

6. Australian Graptolites.

By T. S. Hall, M.A., D.Sc., Lecturer in Biology in the University of Melbourne.

Graptolites are found at innumerable localities in Victoria where Silurian or Ordovician rocks occur, but so far none have been found west of the meridian of Ballarat. The belt of old rocks is continued from eastern Victoria along the inland slopes of the Divide far into New South Wales, and during the last few years have yielded graptolites from a few places. Tasmanian records are vague, but some identifiable forms have been obtained from boulders in the Permo-Carboniferous glacial beds at Wynyard. There are no records from the other States, but Lower Ordovician species have been found in New Zealand.

Apparently the whole range of the fauna can be illustrated from Victoria, with perhaps the exception of Devonian and Cambrian forms. We can recognise the following subdivision of the rocks:—

Ordovician	Upper	
	Lower	Darriwillian
		Castlemanian
		Bendigonian
		Lancefieldian.

SILURIAN.—*Retiolites australis* McCoy and two or three species of *Diplograptidæ* and *Monograptus*, including *M. turriculatus*, have been found in Victoria, and *Monograptus* occurs in New South Wales.

ORDOVICIAN.—It has not been found convenient as yet to recognise the three usual subdivisions accepted in Europe, and we need only consider an upper and lower division.

The UPPER division is characterised by *Dicranograptus, Dicellograptus, Leptograptus, Nemagraptus, Didymograptus, Diplograptus, Climacograptus, Cryptograptus, Glossograptus, Lasiograptus, Retiograptus*, and *Retiolites*. The series is well represented in the eastern part of the State, and passes north into New South Wales, where Lower Ordovician is not as yet known to be represented. A large number of the species are new, but many northern hemisphere forms have been recognised. No detailed stratigraphical work has been done in these rocks.

The LOWER division has had more attention given to it, as it is displayed on many of our goldfields.

DARRIWILLIAN.—No good exposures are known and specific records are few. *Dicranograptidae* are absent. The following genera are represented :—*Didymograptus*, *Tetragraptus*, *Loganograptus*, *Diplograptus*, *Climacograptus*, *Trigonograptus*, *Glossograptus*, *Lasiograptus*, and others not determined.

CASTLEMANIAN.—The fauna is rich. *Didymograptidae* are well represented. *D. caduceus* Salter (= *D. gibberulus*) is abundant throughout, and passes up. *D. bifidus* and its allies are found only in the lowest beds, and pass down into the top of the next division. The relative position of these two species is peculiar and well proved in various localities.

BENDIGONIAN.—The most abundant fossil is *Tetragraptus fruticosus*. *Bryograptus* occurs in the lowest beds, though it is generally regarded as Cambrian in Europe. *Tetragraptus approximatus* Nicholson is also found at the base, and is in one locality associated with Lancefieldian forms. It is thus of stratigraphical importance. The Bendigonian fauna is rich in species.

LANCEFIELDIAN.—*Bryograptus*, several species of *Clonograptus* and *Dictyonema* occur. Lithologically similar rocks with the same fauna have been recognised by me from the south-west corner of New Zealand, more than 1,000 miles away.

There are several apparent inversions of the European sequence of species, and Ruedmann has shown that the Australian sequence is practically that of New York, and both agree in differing slightly from the European.

7. Notes on the Palæontology of Australia.

By W. S. Dun, Lecturer in Palæontology in the University of Sydney.

The general character of the fauna of the Palæozoic of Australia as a whole, is its cosmopolitan nature, no definite Australian fauna being presented until the Permo-Carboniferous.

CAMBRIAN.—Fossiliferous limestones and shales of Cambrian age occur in Western Australia, South Australia, Northern Territory, Victoria, and Tasmania. *Olenollus* beds with *Salterella* occur in the Kimberley District (W.A.). In Yorke's Peninsula (S.A.), Archæocyathinæ limestones are well developed, also beds containing *Micromitra*, *Kutorgina*, *Obolella*, *Nisusia*, *Eoorthis*, *Huenolla*, *Stenotheca*, *Ophileta*, *Salterella*, *Hyolithes*, *Dolichometopus*, *Conocephalites*, *Olenollus*, *Microdiscus*, *Ptychoparia*. At Beltana occurs the most important horizon of Archæocyathinæ so far discovered; eight genera and thirty-two species have already been described.

In the Northern Territory, from Ekeldra, *Agnostus*, *Paradoxides*, *Microdiscus*, and *Ptychoparia* have been recorded.

In Victoria, in north-eastern Gippsland, near Mount Wellington, occur limestones with *Plectorthis*, *Lingulella*, *Scenella*, *Agnostus*, *Ptychoparia*, and *Crepicephalus*.

The Heathcotian beds containing *Dinesus* and *Notasaphns* may prove to be either Cambrian or Cambro-Ordovician. In Tasmania Archæocyathinæ occur and quartzites yielding *Dikelocephalus* and *Concephalites*.

ORDOVICIAN.

In Central Australia Ordovician limestones contain *Endoceras, Orthoceras,* Asaphus spp., *Ctenodonta, Raphistoma,* and *Ophileta.*

In Tasmania the Gordon River limestones with *Cyrtodonta, Ctenodonta, Tellinomya, Bellerophon, Helicotoma, Hormotoma, Raphistoma* may prove to be of Silurian age. Ordovician brachiopods and trilobites are also found in the Florentine Valley.

SILURIAN.

The Silurian of Australia occurs entirely in the eastern States, and is of a true cosmopolitan type, and the fossiliferous limestones and shales of New South Wales and Victoria may be correlated with the Wenlock and Ludlow in part. There is an abundant molluscan, brachiopod, trilobite, and cœlenterate fauna, the main characteristics being the great variety of *Halysites* in New South Wales; of *Tryplasma, Spongophyllum,* and *Rhizophyllum,* and the presence of endemic rugosa such as *Mucophyllum, Mictocystis, Arachnophyllum, Vepresiphyllum,* etc.; *Conchidium* and *Barrandella* horizons are well developed in New South Wales.

DEVONIAN.

Devonian strata occur in Western Australia and the eastern States. In Western Australia, the Kimberley, Napier Range, and Gascoyne river beds contained a Lower or Middle Devonian fauna—Stromatoporoids, *Cyathophyllum, Phillipsastrea,* tabulate corals, *Atrypa reticularis.* Certain of the fossils recorded from these beds, however, belong to adjacent Permo-Carboniferous areas.

In Victoria, in Gippsland, Middle Devonian limestone with *Spirifera yassensis* and *Receptaculites* are well developed. Freshwater Upper Devonian or Lower Carboniferous beds contain *Archæopteris, Sphenopteris,* and *Cordaites*—these beds also occur in southern New South Wales.

In New South Wales the Lower Devonians are well developed in the Murrumbidgee District and are characterized by a great development of *Receptaculites,* one species attaining a diameter of at least a foot. Tabulate corals are abundant. The typical fossils are species of *Actinocystis, Diphyphyllum,* and *Spirifera yassensis.*

The Middle Devonian are developed in the Western Districts, and contain varieties of *Spirifera cristata* and pterinoid bivalves, etc.

The Upper Devonian sediments of New South Wales are of two types, the arenaceous of the Western Districts containing *Rhynchonella pleurodon, Spirifera disjuncta,* and *Lepidodendron, Lepidodondron australe,* and that of the New England District composed of coralline limestones, claystones, and cherts.

The limestones contain such corals as *Favosites, Heliolites, Sanidophyllum, Spongophyllum, Diphyphyllum,* and *Syringopora*—all species distinct from the Silurian and little in common with the Lower Devonian series. The limestones and cherts comprise a great development of interbedded Radiolarian rocks. The upper mudstones contain *Lepidodondron australe* in abundance.

In Queensland the Fanning River and Burdekin limestones are corralline and contain abundance of *Alveolites*, *Aræopora*, *Campophyllum*, *Stringocephalus*, *Atrypa*, etc.

CARBONIFEROUS.

Beds of this age occur in New South Wales, Victoria, and Queensland.

The Mansfield beds of Victoria, regarded as Lower Carboniferous, contain *Lepidodendron australe* and fish—*Gyracanthides*, *Acanthodes*, *Strepsodus*, *Elonichthys*, etc.—it is possible these beds may prove to be in part Upper Devonian.

In New South Wales, marine and freshwater Carboniferous beds occur. The marine fauna is of the mountain limestone type, and consists mostly of cosmopolitan types of brachiopoda, *Productus semireticulatus*, *Orthis resupinata*, *Spirifera striata*, *Phillipsia*, *Griffithides*, and *Brachymetopus*.

The coral fauna is typical—*Zaphrentis*, *Cyathophyllum*, *Lithostrotion*, *Michelinia*, etc.

Mesoblastus and *Tricoelocriuus* occur in Queensland.

The freshwater beds have a Middle Carboniferous facies with *Aneimites ovata*, *Cardiopteris*, and *Lepidodendron veltheimianum*.

In Queensland the Star beds, well developed around Rockhampton, have a fauna very similar to that of the New South Wales series.

Doubtful Carboniferous beds containing *Lepidodendron* occur in Western Australia.

A fact of importance in Eastern Australia is that no Carboniferous species extend into the overlying Permo-Carboniferous, and that there is a well-marked unconformity between the two systems.

PERMO-CARBONIFEROUS.

Of the Australian Palæozoic faunas that which attracts most attention is the Marine Permo-Carboniferous, and the interest is twofold, due in the first place to the change which without doubt in great part effected the glacial phase which occurred at the initiation of sedimentation, and the effect of land barriers hindering migration between the eastern and western Permo-Carboniferous shores.

The Eastern Australian Permo-Carboniferous fauna may be regarded as exhibiting the typical Australian facies, containing as it does the development of many purely Australian types. The two main divisions of the marine sediments—the Lower and Upper Marine series (separated in typical localities by a freshwater phase—the Greta coal measures) vary little in character in New South Wales, Queensland, and Tasmania.

The principal elements of the fauna are—

FORAMINIFERA.—*Nubecularia*, *Pelosina*, *Hyperammina*, *Haplophragmium*, *Lituola*, *Endothyra*, *Lagena*, *Nodosaria*, *Genitzina*, etc., etc. *Nubecularia* is in great abundance and the arenaceous and sub-arenaceous types preponderate. Horizons occur in both Lower and Upper Marines and in association with the Pokolbin (Lower Marines) horizon, and also in the Wollong (Upper Marine) are glacial beds, indicating the cooling of the water.

SPONGIDA. — Sponges are rare, the anchoring spicules of *Hyalostelia*, *Lasiocladia*, and certain burrowing sponges (*Clionolithus*) are found in the Lower and Upper Marines of New South Wales.

CŒLENTERATA.—One of the noticeable features of the Permo-Carboniferous of eastern Australia is the impoverished Cœlenterata fauna, due without doubt to the glacial conditions at the initiation of sedimentation. A few species of Zaphrentoid corals, close to Hinde's genus *Plerophyllum*, occur showing an extravagant development of stereoplasma. The tabulate *Trachypora* forms a well-marked zone fossil in the Upper Marines.

ECHINODERMATA.—This phyllum is of particular interest. Blastoids and cystoids are absent; the Crinoidea are represented by the giant *Phialocrinus princeps* of the Upper Marines, 4½ inches in diameter. *Tribrachiocrinus*, a dicyclic form with large radianal and "X" plate, three double branchia and two single—this genus is peculiar to Eastern Australia. A large *Archæocidaris* and several species of Palasterids (*Etheridgeaster*, *Monaster*, and *Palaeaester*) occur in the Lower Marines, one, *Etheridgeaster giganteus*, having a span of 7 inches.

BRYOZOA.—The great development of the trepostomatous *Stenopora* is a characteristic of this period in Eastern Australia. The massive *S. crinita* forms irregular polyzoaria of from 1 to 2 feet in size. Dendroid and flabellate types are also common and present many species as yet undescribed.

The Fenestellidæ are also well developed. *Fenestella* is rare, but such types as *Phyllopora*, *Polypora*, and *Protoretepora* being extremely abundant, and in some cases form distinct limestones in the Lower Marines. Fenestellidæ are equally developed in the Lower and Upper Marines and in all provinces.

BRACHIOPODA.—This may be regarded as a *Martiniopsis* fauna. This protean genus is extremely abundant in all suitable sediments. Associated with it are winged *Spiriferæ*, all strongly ridged, *Spiriferina dielasma*, *Chonetes*, *Productus*, *Strophalosia*, Aulosteges, Lingula, and Orbicula. In Queensland, in the Bowen beds, we get as well Derbyia senilia. It must be noted in contradistinction to the Permo-Carboniferous Brachiopod fauna of Western Australia and the Northern Territory that Carboniferous species are entirely absent and that there is an absence of the Orthidæ and *Leptæna* group, *Athyris*, *Cyrtina syringothyris*, and *Reticularia*.

PELECYPODA.—It is in this group of the Mollusca that what may be termed the Pacific facies of the Australian Permo-Carboniferous asserts itself with purely endemic genera as *Cleobis*, *Mæonia*, *Astartila*, *Pachydomus*, *Notomya*, *Aphanaia*, *Merismopteria*, *Clarkia*, *Deltopecten*—a giant form, a transition between *Aviculopecten* and *Pecten-Stutchburia*, an edentulous variant of *Pleurophorus*. *Chænomya* (Meek) of the Nebraska-Permian is very characteristic of certain estuarine deposits. The most interesting type is *Eurydesma*, mainly characteristic of the Lower Marines, noteworthy for its absence from Western Australia and its presence in the olive shales of the Himalayas, and the Marine Karoo of German West Africa. The fauna is noteworthy for the preponderance of edentulous gaping types. Cosmopolitan genera, such as *Nuculana*, *Scaldia*, *Cardiomorpha* (?), *Solecurtus*, *Aviculopecten*, *Solenopsis*, *Modiolopsis* also occur. The fauna is evenly distributed along the east coast.

GASTEROPODA.—There is nothing distinctive in the eastern Gasteropod fauna which includes *Platyschisma*, *Straparollus*, and various *Pleurotomarioids*—*Keeneia*, *Ptycomphalina*, *Mourlonia*, and a Naticoid type, together with a patelloid genus and *Orthonychia*.

PTEROPODA AND CONULARIDÆ.—*Hyolithes* is common, and a giant *Conularia* reaching a length of 20 inches, occurs in the eastern provinces.

CEPHALOPODA are uncommon, *Orthoceras* and *Agathiceras* (*Goniatites*) being abundant in the Ravensfield sandstone of New South Wales.

THE WESTERN AUSTRALIA FAUNA.

In Western Australia it has been customary to class certain formations as Carboniferous and certain as Permo-Carboniferous, but there is good reason to believe that the entire series, developed in the Irwin, Gascoyne, Mingenew, Minilya, Lyons River Districts, and Kimberley is more properly Permo-Carboniferous as regards the mingling of the faunas.

One of the prominent features of the Eastern Australian Permo-Carboniferous fauna is the absolute absence of any Carboniferous species, whereas in the west, together with Indian species and local varieties, there are Carboniferous types such as *Orthis resupinata*, *Rhipidomella*, *Productus semireticulatus*, *Leptæna analoga*, *Phillipsia*, etc.—forms which in Eastern Australia are confined to the Star beds of Queensland and New South Wales, beds separated from the Permo-Carboniferous of that region by a well-marked unconformity. Taking into consideration the fact that the so-called Permo-Carboniferous sedimentation of both eastern and western Australia was initiated by glacial stages which must be regarded as synchronous, this mingling of faunas in Western Australia points to a direct communication with the Permo-Carboniferous coast line of the Himalayan and Salt Range Region. The fact that certain Producti, Pectinidæ, Terebratulidæ, and Spirifeidæ of the West have a close resemblance to Eastern Australian types may, perhaps, be regarded as instances of parallel development, rather than of specific identity.

The Permo-Carboniferous of the Northern Territory has western affinities.

As regards the flora of the Permo-Carboniferous, nothing need be said other than that a Lower Gondwana flora is preserved in both Western and Eastern Australia. The earlier beds are characterized by Gangamopteroid types. the upper by *Glossopteris* and *Phyllotheca*, more especially.

MESOZOIC.

The Mesozoic rocks of Australia, fresh water and marine, range from Trias to Cretaceous.

The freshwater beds present in all the States are of Trias and Jurassic age, and in Eastern Australia there is good reason to regard the so-called Jurassic (Ipswich) system as being the freshwater series directly succeeded by the Marine Cretaceous.

In Western Australia fresh water beds of Jurassic age occur at Mingenew with *Otozamites* and *Plagiophyllum*. At Champion Bay *Belemnites*, *Dorsetensia*, *Stephanoceras*, *Trigonia*, etc., occur. At the Greenough River are Oolites yielding *Alectryonia Marshii*, *Ctenostreon pectiniformis*, *Radula duplicata*, *Trigonia*, etc. It is possible that the Gingin chalk is of Cretaceous age. The fauna of the Marine Mesozoic of Western Australia exhibit marked affinities (and identity) with European and Asiatic species.

In the Northern Territory, at Point Charles, there is evidence of an abundant Cretaceous fauna *Aucella*, *Scaphites*, *Histrichoceras*, etc., dwarfed forms in almost every case, and having Gault affinities.

Almost as marked as the difference between the eastern and western Permo-Carboniferous fauna is the lack of community between the Marine Mesozoic fauna of the east and west. Stratigraphical evidence points to the fact that there is a continuity of sedimentation from at latest Jurassic to the end of Cretaceous time, and this has led to an apparent mingling of faunas. The Cretaceous Mediterranean occupied portions of the States of Queensland, New South Wales, and South Australia, and is characterized by numerous species peculiar to the region and many endemic genera among the Mollusca. The most typical forms are *Maccoyella*, *Pseudavicula*, and *Fissilunula*, all endemic types occurring in both Lower and Upper Cretaceous. The cephalopodan fauna is not larger, but is noteworthy for the great size of the *Crioceras* and *Ancyloceras* group. *Icthyosaurus*, *Plesiosaurus*, and *Cimoliosaurus* are represented by several species. The nature of the fauna points to the fact that the barrier which prevented the mingling of the Eastern and Western Permo-Carboniferous faunas persisted into late Mesozoic time.

The Mesozoic flora of Eastern Australia may be divided into three groups —(1) the Ipswich flora of Queensland, the Clarence basin of New South Wales, the South Gippsland basin of Victoria, and the Lake Eyre basin of South Australia; (2) the Tasmanian Upper coal measures; and (3) the Hawkesbury series of the Sydney–Blue Mountain District.

(1) The Ipswich, etc., series.—These beds possess the cosmopolitan Jurassic vegetation with *Cladophebis denticulata*, various species of *Thinnfeldia*, *Tæniopteris daintreei*, *Podozamites*, *Baiera*, etc., etc. They occupy the lower portion of the great artesian basin and are succeeded conformably by the Marine Cretaceous shales and sandstones. The rather scanty evidence at present available points to the fact that the sagging of the Mediterranean region was associated in its early stages with lacustrine conditions leading up to an invasion of the sea and marine sedimentation. These conditions on the coastal district ceased at the close of fresh water sedimentation, except in the Maryborough district, Queensland, where both fresh water and marine sedimentation took place

(2) The Upper coal measures of Tasmania may be correlated with the Gippsland measures of Jurassic age. *Tæniopteris daintreei* is wanting, but *Cladophebis denticulata* is abundant with *Thinnfeldia*, *Phyllotheca*, etc.

(3) In the Sydney area occurs the Hawkesbury series, made up of the Narrabeen, Hawkesbury, and Wiannamatta Stages. The Narrabeen shales succeed directly after the Upper coal measures (Permo-Carboniferous) with no break in sedimentation, and a mingling of the Glossopteris and Lower Mesozoic flora—*Glossopteris* and *Schizoneura*.

The Narrabeen, Hawkesbury, and Wiannamatta Stages have a well developed flora with *Thinnfeldia odontopteroides*, in several varieties, *Macrotænopteris*, *Alethopteris*, conifers, and *Phyllotheca*; there are distinct differences from the flora of the Ipswich Series, which are possibly due to more arid conditions. The Hawkesbury sandstones and Wiannamatta shales have a well-developed fish fauna—*Cleithrolepis*, *Gosfordia*, *Semionotus*, *Dictyopyge*, *Belonorhynchus*, etc., together with Labyrinthodonta, Platyceps, *Bothriceps*, *Mastodonsaurus* in part of Palæozoic and of Rhætic affinities. A depauperate foraminiferal horizon occurs in the Wiannamatta shales. It is usual to regard these beds of Triassic age in part, possibly slightly older than the Ipswich.

At Talbragar, New South Wales, beds with *Tæniopteris daintreei*, *Podozamites*, *Palissya*, *Alithopteris*, contain a distinctive fish fauna—*Leptolepis*, *Coccolepis*, *Aphnelepis*, etc., etc.

TERTIARY.—Terrestrial beds containing plant remains occur in the various States—the oldest series occur in the deep leads which may date back to late Eocene or early Miocene time. The vegetation of these deposits in Eastern Australia bears considerable resemblance to that of the modern "brushes" and afford evidence of more humid conditions.

In the late Tertiary and Pleistocene time, the inland plains supported a giant marsupial fauna, together with Ratite birds—*Diprotodon*, *Nototherium*, members of the Phascolomidæ, *Thylacoleo*, Macropodidæ, Monotremes, such as *Proechidna* and *Ornithorhynchus*; Birds—*Dromornis*, *Genyornis*, etc.; Reptilia—*Megalania*, *Crocodilus*, *Meiolania*, etc.

The giant members of this fauna have been found in all the states, but are most abundant in the great central plains of Queensland, New South Wales, and South Australia, where their remains are found in old lake basins, mud springs, and river beds. Their destruction was due to great diminution of rainfall which took place in late Pleistocene time.

8. Australian Cainozoic System.

By F. Chapman, A.L.S., Palæontologist to the National Museum, Melbourne.

The Australian Cainozoic system is remarkable for its great development of Miocene sediments. These are interposed between an important but locally developed Oligocene series below, and a more widely extended Pliocene series above.

In Victoria and South Australia, where the Cainozoic system is best developed, the beds can be subdivided into four principal series, for they are really more than stages, as time and further research may show. Local terms to denote these series have been suggested, as shown in the following table, which also gives the probable equivalent to the corresponding European formations, according to the several authors quoted.

McCoy and Chapman.	Hall and Pritchard.	Tate and Dennant.
Pleistocene		
Upper Pliocene (Chapman)	Werrikooian (Pliocene)	Pleistocene (Tate) Pliocene (Dennant)
Lower Pliocene	Kalimnan (Miocene) ..	Miocene
Oligocene	Balcombian (Eocene) ..	Eocene
	Janjukian (Eocene) ..	? Oligocene (Tate) Eocene (Tate and Dennant)
Miocene	Aldingan (Eocene in part)	Eocene in part

BALCOMBIAN SERIES.

General Characters.—Commencing with the Balcombian, these beds for the most part consist of sands and shelly marls, largely foraminiferal in places, and containing in the shallower deposits a very rich molluscan fauna, together with the remains of fishes, crustacea, especially ostracoda, polyzoa, echinoderms, gorgonids, corals, sponges, and the foraminifera aforesaid. Intercalated with the sandy clays and marls are beds of brown coal, which at Altona Bay and Newport, in Victoria, have been proved of considerable thickness. At one bore near Laverton (parish of Truganina, Section VII.), a bed of brown coal was struck at 347 feet, having a thickness of 74 feet. A bore at Morwell, in Gippsland, 1,000 feet deep, passed through 888 feet of brown coal. Although the actual age of the latter occurrence has not been proved, it is probably similar to the brown coal of the Port Phillip area.

Chief Fossils.—(B. = Balcombian; J. = Janjukian; K. = Kalimnan). *Lamna apiculata, Carcharodon, Megalodon, Aturia australis* (B.—K.), *Ancilla pseudaustralis* (B.—K.), *Voluta hamiltonensis, Fasciolaria lamellifera, Eburnopsis aulacœssa, Cypræa ampullacea, C. eximia* (B. and J.), *Turbo hamiltonensis, Pecten murrayanus* (B.—K.), *Barbatia celleporacea* (B.—K.), *Crassatellites dennanti* (B. and J.), *Chama lamellifera* (B. and J.), *Magellania coriœnsis* (B. and J.), *Clypeaster gippslandicus* (B.—K.), *Echinolampas gambierensis* (B. and J.), *Placotrochus deltoideus* (B.—K.), *Platytrochus vacuus, Bactronella parvula, Amphistegina lessoni* (B.—K, most abundant in J.).

Localities.—The number of outcrops and exposures of the Balcombian series is seen to be very limited when the faunas have been carefully examined. The best-known and most accessible localities are Balcombe's Bay, near Mornington and Grice's Creek, near Frankston, both in Port Phillip. The gash made through superficial beds by the Muddy Creek, near Hamilton, reveals the lowest beds of the district at Clifton Bank, where they are brought up by a slight monoclinal fold in the otherwise nearly horizontal strata. The beds here have their basement in blue clay containing a rich gasteropod fauna, the clay sometimes containing much glauconite and rolled fragments of polyzoa and cetacean remains. The presence of glauconite points to a fairly deep water origin for this bed. This dark clay bed passes rather rapidly into a brownish sandy marl with a rich molluscan fauna, gradually becoming more polyzoal in character towards the top, where, as recently found at 20 chains up stream in the Muddy Creek, it passes into the pink and yellow polyzoal limestone of true Janjukian character, and with foraminifera of a Burdigalian type.

The important bore at Sorrento, near the eastern head of Port Phillip, did not at its greatest depth, of 1,693 feet, reach the bottom of the Balcombian Series, which is here between 300 and 400 feet thick, so far as proved. On the other hand, bores at Altona Bay and Williamstown have proved the basement bed as a gritty quartz sand passing up into typical shell marls and blue clays with brown coal. The intercalated terrigenous and estuarine beds of the Balcombian, entitle it to be classed as a fluviomarine series in the areas just named, as much as those beds of similar age in Europe as in the Isle of Wight and Belgian Oligocene; whilst the North German Oligocene, being largely marine, may be classed with that of the lower beds at Muddy Creek and Sorrento. The Balcombian Series appears to be confined to the State of Victoria.

JANJUKIAN SERIES.

General Characters.—This is by far the most important group in the Australian Cainozoic system, and presents some remarkable and variable phases. On the terrestrial side, the leaf-beds with *Cinnamomum*, *Laurus*, and *Sterculia* probably come within this series, since stratigraphically the Maddingley leaf-beds seem to graduate into the limestones and marls of the Moorabool River area, finding their place in the Janjukian Series. So that in one area alone, the Geelong—Ballarat gulf and valley, we have fairly deep and clear water deposits, terrigenous shell-bearing beds formed closer inshore, and lacustrine accumulations.

The Corio Bay, Bairnsdale, and Fyansford fossiliferous deposits probably represent the basal part of the Miocene, to the middle of which period I have referred the Janjukian of Torquay and Batesford where, at the former place *Spirulirostra* occurs, and at the latter, Burdigalian foraminifera as *Lepidocyclina tournoueri* and *L. marginata*. In all probability, the general polyzoal facies properly belongs to the Middle Miocene.

At Bird Rock, Torquay, a magnificent cliff section is exposed, showing a vertical succession of 273 feet. The beds form a dome-shaped anticline, the centre of which is at Bird Rock. Forming the lowest of the series in this area, they can be traced either way along the shore where they pass up into a polyzoal and echinoid limestone with *Heteropora*, *Selenaria*, *Cellepora* (with large ramose and rod-like zoaria), and with *Echinocyamus* (*Scutellina*) *patella*.

In other localities enormous deposits of both hard and friable limestone are developed, which point to deposition in a rapidly subsiding marine basin at moderate depths, as witnessed by the presence of the larger shelled foraminifera. These local foraminiferal deposits, as compared with those in coral reef areas at the present day, seem to indicate any depth between 20 and 60 fathoms, whilst the polyzoal rock must have accumulated at a depth averaging 100 fathoms, as borne out by recent dredgings in the Southern Ocean by the Federal Trawler *Endeavour.*

As was seen from the previous list of Balcombian fossils, many species range throughout the Cainozoic. Other species are peculiar to that series, but they are very rare. In the Janjukian Series, however, a great accession to the number of new forms takes place; although where the argillaceous conditions of the underlying Balcombian have continued, those older species persist into the newer strata. The limestone facies brings in quite a new population, for that condition of deposition was markedly absent from the Balcombian. The rule which governed the maximum development, generally in the Miocene, of certain fossil types in Europe, as *Clypeaster* for example, obtains here, since in one species, *C. gippslandicus*, the test is of medium-size in the Balcombian, gigantic in the Janjukian at Bairnsdale, and small again in the Kalimnan. Many other examples could be added, as those of *Linthia* and *Spondylus.*

Chief Fossils.—Cetacea—*Ziphius geelongensis, Parasqualodon wilkinsoni.* Fishes—*Carcharodon auriculatus, Carcharoides totuserratus.* Mollusca—*Spirulirostra curta* (only two other species known, and both from the Miocene, *viz., S. bellardii* and *S. hœrnesi*), *Voluta macroptera, Volutilithes anticingulatus, Eburnopsis tesselatus, Morio wilsoni, Cypræa consobrina, C. platyrhyncha, Cerithium pritchardi, Turritella septifraga, Turbo etheridgei, Pleurotomaria tertiaria, Spondylus gæderopoides, Pecten eyrei, Limopsis insolita, Crassatellites oblonga.* Brachiopods—*Terebratula aldingæ, Acanthothyris squamosa.* Crustacea—*Lepas pritchardi.* Vermes—*Ditrupa cornea* var. *wormbetiensis, Serpula ouyenensis.* Echinoids—*Cidaris australiæ, Cassidulus australiæ, Brissopsis archeri, Eupatagus rotundus.* Corals—*Flabellum distinctum, Deltocyathus subviola, Stephanotrochus tatei, Graphularia senescens* (J. and K.). Sponges—*Ecionema newberyi, Plectroninia halli, Tretocalia pezica.* Foraminifera—*Gypsina howchini, Rotalia calcar, Amphistegina lessonii, Cycloclypeus pustulosus, Lepidocyclina tournoueri, L. marginata.*

Localities.—In Victoria—Spring Creek Series, Torquay (glauconitic and yellow marls, and polyzoal limestone); Waurn Ponds (polyzoal limestone and marls); Moorabool River and Batesford (*Lepidocyclina* and polyzoal limestone); Curlewis (polyzoal limestone and marls with calcareous sponges); Grange Burn, Hamilton (polyzoal limestone with *Lepidocyclina* and *Amphistegina*); Flinders (polyzoal limestone with calcareous sponges); Flemington, lower beds (fossiliferous ironstone); Keilor (foraminiferal limestone); Aire coastal series (marls and lignitic clays); Birregurra (grey and yellow marls); Bairnsdale (*Amphistegina* limestone and yellow fossiliferous marls); Corio Bay and Fyansford (yellow marls); bores in Mallee (white, polyzoal limestone and glauconitic marls).

In South Australia—Mount Gambier (white polyzoal limestone); Aldinga, lower beds (clays, glauconite marls, and limestones); banks of Murray River (polyzoal limestone); Murray desert.

Tasmania—Table Cape, near Wynyard, includes *Crassatellites* bed and overlying *Turritella* bed.

Probably the New South Wales leaf-beds (Dalton and Gunning) belong here. Their flora is largely that of Bacchus Marsh, Narracan, Berwick, Pitfield, Cobungra, Dargo, and Bogong.

KALIMNAN SERIES.

General Characters.—In the Sorrento bore the Janjukian marls pass insensibly upwards into the Kalimnan, without much lithological change; and by their containing a considerable amount of glauconite, denote that they were formed in moderately deep water. At Beaumaris, however, where these beds are well exposed in the cliff face, the rock is a yellow sandy marl, with numerous shells and sharks' teeth and occasional bands of fossils. The beds at Beaumaris are shallower in character, and evidence of current action is afforded by a nodule bed with numerous fish-teeth and rolled fossils at the base of the series. This nodule bed exactly corresponds in stratigraphical position with that at Muddy Creek and Grange Burn. The Kalimnan series at the latter localities consist of quite shallow water deposits, with *Mytilus*, *Natica*, *Nassa*, and *Barnea;* whilst the thick-shelled *Trigonia howitti* is further evidence in support of its shallow water origin. By the presence of *Scaldicetus* and other cetacean remains, the Lower Pliocene age of this series as stated originally by McCoy, is substantiated.

Chief Fossils.—Cetacea—*Scaldicetus macgeei*, *Physetodon baileyi*. Fishes—*Oxyrhina hastalis*, *Galeocerdo aduncus*, *Cestracion cainozoicus*, *Diodon formosus*. Mollusca—*Ancilla papillata*, *Voluta fulgetroides*, *V. masoni*, *Fusus gippslandicus*, *Natica cunninghamensis*, *Eglisia triplicata*, *Dentalium largicrescens*, *Pecten antiaustralia*, *Perna percrassa*, *Glycimeris halli*, *Trigonia margaritacea* var. *acuticostata*, *Sunetta gibberula*, *Mactra hamiltonensis*. Corals—*Trematotrochus clarkei*, *Notophyllia gracilis*.

Localities.—Upper beds, Muddy Creek; upper series at Shelford; lower Glenelg River; Beaumaris; Gippsland lakes; bores in Mallee, at 100 to 250 feet; Sorrento bore, at 585 to 741 feet (circ.); upper Murray cliffs; Adelaide; Haddon, Vict. (deep leads with plant remains).

WERRIKOOIAN SERIES.

In Upper Pliocene times the southern part of the continent had risen considerably, and corresponding denudation took place. The country must have supported a rich fauna, largely marsupial, of which we have evidence in *Phascolomys pliocenus*, of the Dunolly Gold Drift. The type locality of the Werrikooian is Limestone Creek, Glenelg River, where a rich marine molluscan fauna, with a large percentage of living species is found. The Upper beds of Moorabool Viaduct appear to belong here.

PLEISTOCENE.

The inland and coastal deposits such as cave floors, volcanic tuffs, and consolidated dunes afford evidence of many extinct and living marsupial genera, among the former being *Nototherium*, *Diprotodon*, *Procoptodon*, and *Palorchestes*; while the giant emu—*Genyornis*—occurs in the *Diprotodon* swamps of Lake Callabonna, South Australia, and also at Mount Gambier, and in Queensland. Remains of *Dromornis*, a struthious bird as large as the moa, occurs in the Pliocene of Queensland, New South Wales, and South

Australia. The volcanic tuffs of Tower Hill, Victoria, must be very late Pleistocene, for they overlie beds of marine shells identical in species with those now found living a short distance away on the sea-coast.

The physiographical results of a study of the Cainozoics show that in Oligocene times the land suffered much oscillation, subsidence being sometimes in evidence, at others elevation. The climate was then warm-temperate to sub-tropical. With the Miocene was ushered in a great steady movement of subsidence, as shown by the great limestone series, with only occasional elevation, when the dynamical movements expressed themselves in volcanic outbursts, the older basalt filling up the valleys both inland and coastal, as at Dargo and Flinders respectively. The climate was probably warm-temperate. In the Lower Pliocene or Kalimnan times, elevation re-commenced, and gave rise to the shell-banks and shallow-water marls. The molluscan genera at this time indicate a climate similar to that now enjoyed. In Upper Pliocene and Pleistocene times, there is evidence for the belief that the climate became even colder than now, due probably to uplift, for estuarine sands found in the Mallee borings, perhaps 300 feet above sea level indicate a sub-temperate faunal character.

9. Igneous Rocks.

By T. W. Edgeworth David, C.M.G., D.Sc., F.R.S., and *Ernest W. Skeats, D.Sc., A.R.C.S., F.G.S., Professor of Geology in the University of Melbourne.*

PRE-CAMBRIAN.

The oldest known volcanic rocks in the Commonwealth are those of the Norseman and other regions of the great gold-bearing belts in the southern part of Western Australia. These are of the nature of amygdaloidal dolerites associated with contemporaneous tuff. Further north, as at Kalgoorlie and Coolgardie, these volcanic rocks have been altered into hornblende and chlorite schists, commonly spoken of as the "greenstone" schists, and it is in them that most of the payable gold-bearing belts occur. In the Pilbara district, rocks of this type belong to a lower division of the Algonkian group, known as the Warrawoona series. This is followed by a later Algonkian series—the Mosquito series—in which the Pre-Cambrian group terminates in that district. Plutonic rocks are also widely represented in the Pre-Cambrian group. For example, in Western Australia there are huge belts of granite passing into gneiss and traversed by veins of pegmatite. In places the granite intersects older diorite rocks. In other places, as at Kalgoorlie, serpentine occurs in the same group. The interesting observation has been made, at the Phillips River gold-field, on the south coast of Western Australia, that the local granite is of a very marked albite type, in fact it is almost devoid of any potash, but relatively high in soda. In the same region a quartz-ceratophyre has been identified, and the interesting question here suggests itself as to whether we may not have representatives of the third great division of igneous rocks—third in relation to the well recognised alkali and calcic types, namely the spilitic suite. From the Blyth Range, a myrmekite granite has been described, showing gridiron structure of quartz-felspar intergrowth, not original, and like that of similar granites, probably Archæan, in Sweden and Finland. It may be added that in the Phillips River gold-field albite-pegmatite is of common occurrence, in which coarsely crystalline spodumene is associated with the albite. All these rocks are of Pre-Cambrian age.

In reference to its Pre-Cambrian igneous rocks, the State of South Australia is considered to be a petrographical province, the characteristic feature of which is the high percentage of titanium oxide, and, to a less degree, the abundance of soda. The rock which has given rise to these Pre-Cambrian igneous rocks may be termed the Houghton magma. From it have been produced ilmenite-diopside-diorite, ilmenite-diopside-syenite, ilmenite-sphene-actinolite-pegmatites, and ilmenite-felspar-quartz pegmatites with ilmenite quartz-veins.

The rocks of this Houghton magma are traversed by veins of "yatalite," a pegmatite formed of uralitic actinolite (after diopside) albite containing microcline, titaniferous magnetite, sphene and quartz. The actinolite is in large subidimorphic paramorphs after diopside. Gneissic normal granite pegmatite is associated with the "yatalite."

At Olary, a highly-titaniferous uranium-bearing mineral, davidite, occurs in a pegmatite vein, intruding Pre-Cambrian quartzite.

In addition there are present in this area epi-granites, diopside-diorites, granodiorites, hornblende-diorites approaching monzonite, mica-diorite, biotite-syenite, epi-syenite, and diopside-quartz-syenite with epidote.

The most typical rock of this series—the diopside-diorite—is interesting in view of its high content of soda (5·34 per cent.), and titanium oxide (3·11 per cent.)

The magmatic name is tonalose.

In the Pre-Cambrian rocks of Tasmania, it is a singular fact that as far as is at present known, there is an entire absence of any kind of igneous rock whatsoever, with the single exception, perhaps, of the garnet-zoisite-amphibolite, which occurs just above Hamilton, on the left bank of the River Forth in the north-west of Tasmania. In Victoria, gneisses intruded by granitic rocks occur near the western border of the State, in the county Dundas, as well as in Gippsland, in north-eastern Victoria. At Broken Hill, on the south-western border of New South Wales, the augen-gneisses are Pre-Cambrian. In the Macdonnell Ranges, augen-gneisses traversed by very coarse pegmatites, with mica crystals in places up to 2 feet or more in diameter, are widely distributed. Large crystals of beryl, and occasionally tinstone, are associated with the pegmatite. These rocks are traversed by micropegmatites, granulitic pyroxene diorites, diorites, gabbros, dolerites, and amphibolites—all are probably Pre-Cambrian.

CAMBRIAN.

Perhaps the most extensive lava flows as yet recorded from the Commonwealth belong to this system. They are represented at Nullagine, in the Pilbara gold-field, where they occur a short distance above the basal gold-bearing and diamond-bearing conglomerates. They are partly acid rocks, and partly dolerites. In the Kimberley district, there are very large areas covered by what is called the great Antrim plateau basalt. At Mount Panton, this series of basic lavas and tuffs is capped by beds of somewhat phosphatic *Salterella* limestone. In Northern Territory there is a great series of basalts and dacites associated with beds of volcanic tuff and agglomerate, the blocks of which are up to 4 feet in diameter. The thickness and full extent of this vast series and its petrological character is as yet almost wholly unknown, but there is little doubt that it is part of the great Antrim plateau group.

In the account of Cambrian rocks, reference has been made to the Heathcotian series of igneous rocks in Victoria. In the type locality altered basic submarine lavas or diabases predominate and are associated with altered submarine diabase tuffs, schalsteins, agglomerates, and minor diorite intrusions.

Interbedded with the diabases are black cherts, some containing radiolaria and at any rate in part derived by metasomatic alteration of diabase ash, while the diabase is in places silicified to jasper. At Heathcote, these rocks are invaded by micro granite, which may be genetically related to the diabase series. Near Heathcote, the diabase at its margin passes into "selwynite," a green alteration product containing a green chrome-bearing micaceous mineral, chromite, pyroxene, together with corundum. Corundum also occurs with chromite in the serpentine area, near Mount Wellington in North Gippsland, which is pre-Upper Ordovician, and may be Heathcotian in age. The quarries on Mount William, north of Lancefield, from which the aborigines manufactured tomahawks, occur in a similar diabase with interbedded black cherts and cherty shales, containing *protospongia* and radiolaria. Similar associations of diabase and cherts occur at Mount Major, near Dookie, and at Mount Stavely, while serpentinous diabase occurs at the Hummocks, north of Casterton, in Western Victoria. The whole assemblage of these Heathcotian series is strongly suggestive of a spilite suite, but chemical analyses of the rocks are not yet available. In Tasmania, probable equivalents of the Heathcotian volcanic series of Victoria are developed at North Dundas, Zeehan, the Leven gorge, etc., in the north-west and west of the island. These are known as the porphyroid series, and consist of dynamically altered quartz and felspar porphyries, amygdaloidal diabase (spilite ?), breccias tuffs, and tufaceous slates, together with intrusive syenites and granites.

ORDOVICIAN.

Igneous rocks possibly of this age have been described in South Australia from the Blinman mining field as melaphyres, olivine-diabase, granulitic-diabase, gabbro-diabase. These are perhaps related to the dykes of amphibolite with scapolitised felspar from the New Era mine, near Woodside. In Victoria, if the Heathcotian series is of Cambrian age, there are no known igneous rocks of Ordovician age. Basic agglomerates from Mount Arrowsmith, in New South Wales may also be Ordovician. At the Lyndhurst gold-field, near Mandurama, in New South Wales, there is an immense development of contemporaneous basic tuff in the Upper Ordovician black cherty graptolitic and radiolarian rocks. In the same state, at Cadia, near Orange, two sheets of andesite lava, 30 feet thick, interbedded in the upper Ordovician graptolite slates give evidence of contemporaneous volcanic activity. They are associated with a deposit of iron ore, estimated to contain about 40,000,000 tons of ore. At Forest Reefs, near Orange, this group of lavas and tuffs attains a great thickness.

SILURIAN.

In Victoria no definite evidence of contemporaneous igneous rocks of Silurian age has yet been forthcoming. It is possible that the alkali granites of Victoria, which as far as is known intrude the Ordovician and older rocks but not the Silurian series, may be of Silurian age.

DEVONIAN.

Lower Devonian.

In Victoria there occurs a wonderful development of igneous rocks, which have been referred to this period. It was a time of great earth movement in Victoria, when the older Palæozoic rocks were much folded, and it is probable that the intrusion and extrusion of igneous magma accompanied the movement of folding while the gold deposits appear also to be genetically related to the igneous intrusions and the gold quartz veins filled fissures which resulted from the folding movements or igneous invasions. Volcanic, dyke, and plutonic rocks are abundantly represented.

The Volcanic Rocks.—These include the following series :—

The Snowy River Porphyries.—These are acid lavas, mostly rhyolites and tuffs, in places over 2,000 feet in thickness. They were erupted from a chain of volcanoes, perhaps comparable to the Andes, and situated on a probable line of fissure trending nearly north and south through Eastern Victoria, near and along the Snowy River. Their worn-down stumps are now preserved in mountains like the Cobberas, Wombargo, Mount Hotham, etc., while the granite porphyries of Mount Taylor, Mount Alfred, etc., near Bairnsdale may represent the plugs of some of the volcanoes of this series. Probably of similar age are the rocks of Noyang, on the Tambo River, in Eastern Gippsland. These include intrusive as well as volcanic types, and consist of quartz porphyrites and quartz granophyrites. These rocks show a great preponderance of soda over potash and may be described as ceratophyres and quartz-ceratophyres

The Dacite, Quartz-porphyrite Series.—This series is developed in Central Victoria from sporadic centres. Fragmental rocks are scarce, except in the Lilydale district, and no volcanic necks have been located. The rocks consist of thousands of feet of rocks, mainly volcanic, but probably in part intrusive. The chief areas are Mount Macedon, the Dandenong Hills, Healesville, and Warburton. the Cerberean Range, the northern part of the Strathbogies, and near Whitfield, in Delatite. At Mount Macedon, the Dandenongs, Healesville, and Warburton, the rocks consist of hypersthene-biotite dacites, biotite dacites, and quartz-porphyrites. In the Strathbogies and in Delatite, garnet accompanies the quartz porphyrites, and here they are overlain by Lower Carboniferous sandstones. Probably the most complete sequence occurs near Lilydale, where fragmental rocks are abundant, and the earlier eruptions consisted of alkali dacites or toscanites, with about 7 per cent. of alkalies equally divided between potash and soda, quartz porphyrites followed, and the volcanic activity concluded with the eruption of normal hypersthene biotite dacites.

Hypabyssal Rocks.—Many of the granites and grano-diorites have marginal apophyses of quartz porphyry, pegmatites, etc., penetrating the invaded sediments. Of more economic importance are the altered types of dykes, some of which carry gold-quartz veins which have proved highly auriferous. Among these are the propyitised hornblende porphyrite of Woods Point and Gaffney's Creek, and the sericitic quartz-porphyry of the Diamond Creek mine, near Melbourne. The periodotites of Aberfeldy, the cupriferous hornblende amphibolites of the Thomson River, and the hornblende picrite of Sheep Station creek, near Omeo, may belong to this period.

Plutonic Rocks.—As stated in the stratigraphical part, the alkali granites, so far as is known, do not penetrate Silurian rocks, and may be of Silurian age, but there are petrographic grounds for associating them with the grano-diorites and adamellites, many of which are Post Silurian, and some of which, possibly all, are Pre-Lower Carboniferous.

The alkali granites, in which orthoclase predominates over plagioclase and potash generally over soda, include the masses of Mount Buffalo, Cape Woolamai, Gabo Island, and certain masses near Geelong, such as the You Yangs, the Dog Rocks, and an area near Ceres.

Certain diabases or epidiorites occur at Ceres and the Dog Rocks, which were formerly referred to the Heathcotian, but since they are probably genetically related to the alkali granites of these areas are now included with them in this place. Adamellites are known to occur near Violet Town and Nillahcootie, in north-eastern Victoria; at Trawool, Ingliston, north of Bacchus Marsh, and at Broadmeadows, near Melbourne.

The grano-diorite masses, with which many of the gold-fields appear to be genetically related are represented among other areas by the big mass south of Bendigo, including Harcourt, from which the rock is quarried for building stone, by an area near Pyalong, Bulla, Macedon, south of Mount Dandenong, and south of Warburton. In the three latter areas the grano-diorite is genetically related to the dacites, but is intrusive into them.

In New South Wales in the type district for Silurian rocks, that of Yass, dacitic tuffs containing contemporaneous corals and siliceous sponges are developed on a large scale. Individual beds aggregate several hundreds of feet in thickness. They are intruded by sills of porphyrite and granodiorite. Again, at Jenolan Caves, there is a considerable development of basic and intermediate tuffs with lavas, immediately underlying the *Pentamerus* limestone in which the caves are situated. Corals and crinoids are scattered through these tuffs. Most of these limestones of Jenolan, Yass, etc., represent old fringing coral reefs, and it is clear that these grew partly over banks of volcanic tuff and lava, The granites of the southern tableland of New South Wales, like that of Cooma, which are Post Ordovician and Pre-Devonian, probably belong here, as do the miarolitic granites of Parkes, which are Post Ordovician, and capped by Devonian rocks.

Middle Devonian.

In the Buchan series of Victoria there is a considerable development of felsite lavas called felsitic tuffs and breccias, which pass upwards into the Buchan limestone series. These vary from 750 up to 1,000 feet in thickness. Diabases and andesites also occur. In New South Wales, in radiolarian rocks of this age, there is a great thickness of tuff now proved to be of spilitic origin, like the pillow-lava of the British Isles. These Tamworth rocks also contain basic spilites. The whole series, including some marine beds of coral reef limestone, is estimated to be about 9,000 feet in thickness.

Upper Devonian.

In Victoria, at Mount Wellington, a great thickness, up to 2,000 feet, of acid lavas, rhyolites, and quartz-porphyrites, extend north-westward towards Mansfield. These lavas are proved to be probably Upper Devonian by the presence of the fossil *Lepidodendron australe*. Melaphyres, quite subordinate in importance to the rhyolites, are also met with in this series.

In New South Wales, rhyolites and basalts of this age occur at Yalwal.

Devonian Plutonic.

In Tasmania large masses of serpentine and granite were intruded, perhaps in Devonian time.

The serpentine is generally a peripheral mantle of serpentinised gabbroid and ultrabasic rocks surrounding the granite masses on the west coast. Occasionally between the granite and serpentine is an aureole of actinolitic rock. There is the clearest evidence that the ultra-basic rock consolidated before the granite.

This granite, unlike that of the porphyroid series, is uncrushed.

This granite is mostly tin-bearing. A remarkable feature about the serpentine is that it not only contains nickel and osmiridian, but, at Dundas, has tin ores associated with it.

CARBONIFEROUS.

In Victoria, the granodiorites and granodiorite-porphyrites of Mount William, in the Grampians, have recently been shown to be intrusions into the Grampians sandstones. In addition, sills, dykes, and possibly lava flows of quartz porphyry occur in the sandstone. These igneous rocks there are post Lower Carboniferous in age, and include the youngest series of plutonic rocks known in Victoria. Possibly the quartz-porphyries of Grangeburn, near Hamilton, and other localities in Western Victoria, may belong to the same period of intrusion.

In New South Wales there is a wonderful development of lavas and tuffs, all through this massive system which aggregates at least 20,000 feet in thickness. Its upper portion is formed very largely of rhyolite lavas and coarse acid tuffs, passing in places into hypersthene andesite. Immense sills of quartz-porphyry intersect this bedded series. Beds of arkose-like tuffs of great thickness, which at first sight appear to be granite but which are really acid tuffs, contribute considerably to the thickness of the system. It would appear that acid eruptions were in progress on a very grand scale in New South Wales during this period. Mount Spiriby, the highest point of Mount

Capoompeta in New England, is formed of rhyolite of this age. The andesites and rhyolites of the Drake gold-field are possibly Carboniferous, but may belong to the base of the Permo-Carboniferous system. In Queensland, lavas of the nature of amygdaloidal dolerites and agglomerates, in places containing metallic copper and carbonate of copper in the steam holes, are interstratified with sedimentary rocks at Mount Toussaint, in the Bowen coal-field.

Plutonic.

In New England, the immense belt of serpentine which stretches in a nearly continuous belt for fully 150 miles from Bingara to Nundle, is either of very late Devonian, or of Carboniferous age, and forms a mantle curving sympathetically with the huge intrusive batholiths and sills of granite of the New England tableland. On the eastern margins of the New England granites are large outlying masses of serpentine, on the Manning, Hastings, and Clarence Rivers. There is clear evidence here, as in Tasmania, that the granite has consolidated within a discontinuous ring of serpentine. In New England, there are three varieties of granite belonging perhaps to this period, the oldest being a bluish-grey biotite-hornblende-pyroxene granite-porphyry. This occurs perhaps as a huge sill: it was followed by widespread intrusions of sphene granite, full of dark, basic segregations. This in turn was intruded, probably in Permo-Carboniferous time, by an acid granite, containing up to 80 per cent. of SiO_2. The silica percentage in this group ranges from about 65 to 80. Most of the granites of Queensland may belong to this period.

PERMO-CARBONIFEROUS (PERMIAN).

Plutonic and Hypabyssal.

The intrusion of the acid granites, as already stated, had taken place in Permo-Carboniferous time. Possibly some of the Queensland tin-bearing granites belong to this age, as well as the diorite dykes which have intruded the Lower Permo-Carboniferous rocks of the Gympie gold-field, also in Queensland.

Volcanic.

In New South Wales, the great coal basin which separates the New England massif from the Bathurst-Monaro massif was the scene of eruptions of lavas and tuffs in Permo-Carboniferous time. At Harper's Hill, 7 miles west of West Maitland, coarse andesite tuffs and agglomerates are interstratified in the Lower Marine Series, and hyperstheneandesite, as well as natrolite basalt with datolite are intercalated in the upper part of this series below the horizon of the Greta coal measures.

An important group of alkaline eruptives occurs in the Cambewarra–Kiama districts, to the south of Sydney. This is partly contemporaneous with the top of the Upper Marine Series (shells of *Cleobis grandis* and *Chenomya* occurring abundantly in the basal tuffs, and partly with the Bulli coal measures. The series of lavas and tuffs, about 1,000 feet thick, shows the following sequence, the oldest being mentioned first:—orthoclase-basalts, or latites, the total alkalies ranging up to over 9 per cent., of which from 2 per cent. to nearly 5 per cent. are potash. These lavas range in composition from shoshonose to monzonose, having points of resemblance to the rocks of the Yellowstone region, United States of America, the trachydolerites in part, and also being comparable with the "Ciminites" and "Vulsinites" of Italy. These earlier eruptions of alkaline, not very basic rocks, were associated with sills of monzonite, and possibly as the result of progressive differentiation) produced later, perhaps in Triassic time, peralkaline rocks like nepheline-syenite and tinguaite, as sills (the alkalies being 10 per cent. to 15 per cent.) on the one hand, and monchiquite dykes (alkalies under 4 per cent.) on the other. Both these types intrude the Permo-Carboniferous and Triassic rocks, and may be related to the Mittagong Post-Triassic Series, to be described later.

Still later basalts were erupted of a much less alkaline type. At Murrurundi, in New South Wales, there were extensive eruptions of basic tuff and lavas near the horizon probably of the Newcastle coal measures, the latter containing much chert formed by the alteration of powdered felspar and volcanic glass.

TRIASSIC.

Volcanic.—In New South Wales there is a considerable development of more or less fine volcanic tuff in the lower division of the Trias, known as the Narrabeen stage. These tuffs are distinctly basic in character, and like the lavas of the Permo-Carboniferous, contain metallic copper. Through redistribution in water the tuffs have passed into the characteristic chocolate shale, so well seen at Long Reef and Narrabeen, etc., to the north of Manly.

JURASSIC.

At Brisbane there is a considerable development of coarse rhyolite tuff, in the heart of the city itself, as at the Leichhardt quarries. Fossil trees completely carbonized are found embedded in the tuff. The tuffs are followed by basic lavas. It is as yet uncertain whether the Brisbane tuffs belong to the Trias or to the Jura system. To the south of Brisbane, in the direction of Mount Flinders and the Macpherson Ranges, trachytes are interbedded in the Jurassic rocks and are associated with *Tæniopteris daintreei.*

In Victoria, the Jurassic rocks were penetrated in a bore to a depth of over 3,000 feet, 60 miles easterly from Melbourne. The Jurassic strata, chiefly felspathic sandstones, are uniform in character over the state and have been shown to contain abundant fragments of undecomposed felspar, presumably of tufaceous origin. The source of all this tuff has not yet been discovered.

JURASSIC (?) (POSSIBLY TRIASSIC).

Tasmania.—Rocks of foyaitic magma are represented by the Port Cygnet series. These rocks are considered to be perhaps of Lower Mesozoic age.

At Regatta Point, Port Cygnet, the following occur :—Augite syenite, poor in quartz; nepheline syenite, essexite, jacupirangite facies of nepheline syenite, melanite-hauy-syenite porphyry, garnet-bearing mica solvsbergite, tinguaite, garnet tinguaite porphyry, nephelinite, etc. These rocks are all strongly intrusive into the Permo-Carboniferous series. but their relations to the Jurassic sedimentary rocks and to the diabase have not yet been clearly demonstrated.

Hypabyssal.—The close of Jurassic time was marked by one of the most wonderful manifestations of eruptive force of which we have evidence anywhere in the Commonwealth. The vast sills of dolerite, partly hünne-diabase, that is an enstatite-augite diabase, partly konga-diabase, the latter containing normal pyroxene and granophyric intergrowths, probably may be referred here. These rocks have disrupted the Jurassic strata of Tasmania on a grand scale, and as individual sills are in some cases fully 500 feet in thickness and of immense lateral extent, portions of the Jurassic sandstones overlying them must have floated on this heavy magma like icebergs in a polar sea. As already suggested, these intrusions may have accompanied the breaking in of the big land bridges of Gondwana Land, which formerly joined Australia to India, South Africa, South America, and Antarctica.

Cretaceous.—No volcanic rocks of this age are known anywhere in the Commonwealth, with perhaps the single exception of the so-called Desert sandstones, like those of Port Mackay, in Queensland. It has been stated that part of these sandstones is built up of trachytic tuff.

CAINOZOIC.

A great variety of volcanic rocks belong to this era, especially in Eastern Australia and Tasmania. In lower Cainozoic time there were extensive outflows of basalts and eruptions of basic tuff. These are spoken of by the Victorian geologists as the older basalts. Probably the older basalts of New South Wales, and perhaps Queensland belong to this series. It is doubtful whether the series is represented either in South Australia, Tasmania, or Western Australia. In Victoria, where they have been most fully described they are developed at Melbourne itself at Royal Park, Essendon, Broadmeadows, and Keilor, where they occur underneath the lower Cainozoic fossiliferous sediments. They occur also near Geelong, as at Curlewis, at French Island and Phillip Island. At Cape Schanck, a bore penetrated them for over 800 feet, while at Flinders another bore was discontinued after passing through no less than 1,300 ft. of older basalt. They are widespread in south-east Gippsland, as at Buln Buln, Leongatha, Neerim, Mirboo, etc., while in north Gippsland they cap the plateau sometimes at elevations of 5,000 feet as at Mount Feathertop and Dargo high plains. Their chemical composition, so far as is known is normal, but occasionally crystals of anorthoclase are present. In texture, they range from tachylyte to coarse dolerites and their decomposition provides rich soils. In the fresh state they are quarried in places for road metal. Although in part apparently sub-marine, they do not, as far as is yet observed show affinities with the spilites. In New South Wales, there is a considerable development of older basalts overlying leaf beds first considered to be of Eocene age, though later there have been adduced strong reasons for considering that these leaf beds may be of somewhat newer age. They are typically developed in the New England district of New South Wales, where for the most part they consist of reddish decomposed amygdaloidal basic lavas, passing in places into dense columnar basalts. Frequently these New England lavas are capped by beds of laterite passing into bauxite and in places into pisolitic iron ore. These laterites mostly represent basalt tuffs.

MIDDLE CAINOZOIC.

This is a most remarkable group of volcanic rocks which, in eastern Australia and Tasmania, is distinctly of alkali characters. Rocks of this age and character extend at intervals from Casterton and Coleraine in western Victoria, through Mount Macedon and Omeo. In New South Wales they are met at Bowral, the Canobolas, Warrumbungle Mountains, Nandewar Ranges, the MacPherson Ranges. In Queensland they trend through Mount Flinders, the Fassifern districts, East Moreton, Wide Bay, the Glass House mountains. Mount Larcombe, Yeppoon to Clermont and Springsure, in North Queensland. The total distance over which they have been traced is over 1,200 miles.

Victoria.—In the Western District anorthoclase-aegirine-trachytes occur in a number of areas, including the neighbourhood of Carapook, Coleraine, Mount Koroite, Koolomert, and " the Giant Rock," at Wotong Vale. The hills of Adam and Eve, near Coleraine consist of anorthoclase olivine basalt traversed by a trachyte dyke, but at Mount Koroite and at Koolomert, the basic lavas appear to rest upon the trachytes.

The Mount Macedon alkali province in Central Victoria has been more closely studied than any similar area in Australia. Fragmental rocks are practically absent and the lava flows and intrusives were poured out over or intruded into a Palæozoic complex of Ordovician sediments, and Devonian dacites and grano-diorites. The sequence from below upwards appears to be as follows :—Anorthoclase aegirine trachyte, volcanic plugs or mamelons of solvsbergite, anorthoclase basalt and two new rock types, macedonite and woodendite, followed by anorthoclase-olivine trachyte, olivine anorthoclase trachyte and limburgite, the volcanic history of the area terminating with the pouring out of calcic newer basalts of probably Pleistocene age. The new types, macedonite and woodendite, present similarities to the orthoclase basalts, and closer resemblance to the mugearites. They contain alkali felspars associated with biotite and olivine, and have a high content of phosphorus and titanium.

Possibly the monchiquite dykes which come up the axes of the anticlines in the mining fields of Bendigo and Castlemaine, etc., may be genetically related to these alkali rocks.

In north-eastern Victoria alkali rocks probably of similar age to those of Mount Macedon, occur near Mansfield, Omeo, and Mount Leinster, in Benambra.

About 15 miles north-east from Mansfield, in the Tolmie highlands, Gallows Hill has recently been shown to consist of a volcanic hill with lava flows of nepheline phonolite. At Barwite, east of Mansfield, a similar nepheline phonolite appears to occur as a dyke, but its field relations have not yet been studied.

At Frenchman's Hill, just north of Omeo, a volcanic hill with central core of solvsbergite has on its flanks flows of anorthoclase trachyte, and a more or less radial system of dykes, including pegmatites, quartz veins, bostonites, diabase, trachytes, and nepheline phonolite. They have been described as of Palæozoic age, but are almost certainly Cainozoic. The phonolites of Omeo, Gallows Hill, and Barwite are the only ones as yet known in Victoria.

In Benambra at Mount Leinster, another volcanic hill includes solvsbergites, anorthoclase trachytes, and interesting dyke rocks, some allied to variolite, and as in the case of Frenchman's Hill, this series has been regarded as of Palæozoic age, but is probably Cainozoic.

In the Mittagong–Bowral district of New South Wales, there is an important suite of eruptive alkaline rocks, all of which are intrusive into the Triassic sediments. They are chiefly developed at Gib Rock, and Mount Jellore respectively, 2,830 feet, and 2,734 feet high, both of which represent probably the denuded plugs of old volcanoes or dome eruptions, probably the latter. The sequence has been as follows: the oldest rocks being mentioned first:—

1. Alkaline rocks of intermediate composition—(a) Syenite, allied to bostonite, magmatic name boxanolose, containing fluorspar and occasional hydro-carbons, in addition to orthoclase, arfvedsonite aegirine, magnetite and ilmenite; (b) Ægirine-arfvedsonite-quartz trachytes. The total alkalies in the above two rocks range from 10 per cent. to 12 per cent.
2. Basic sub-alkaline rocks, with 46 per cent. SiO_2, total alkalies about 5 per cent. These rocks are essexites, with primary analcite.
3. Basic rocks—
   (a) Basalts and dolerites, SiO_2, 43 per cent., alkalies 3 per cent.
   (b) Picrites SiO_2, 40 per cent, alkalies 2 per cent.

Next on the western side of the Blue Mountains there lies a series of very perfect laccolites in the form of dome-shaped hills, like Mount Stormy and others, which are formed largely of nepheline, aegirine, a little anorthoclase, and a considerable amount of analcite. These have been described as syenitic tinguaites. Still further west, in the locality of the Canobolas, near Orange, there is a great development of alkaline lavas and tuffs, extending in a general northerly direction to the Warrumbungle Mountains, between Dubbo and Coonabarabran, and thence trending in a north by east direction into the Nandewar Ranges. From thence at intervals, the alkaline volcanic belt can be traced further into the McPherson Ranges dividing Queensland from New South Wales, through the Mount Flinders and Fassifern districts to East Moreton and Wide Bay; thence the belt trends northerly through the Glass House Mountains, near Maryborough. Still further north it has been identified at Mount Larcombe to the south of Rockhampton, as well as in the hills at Yeppoon, to the north-east of Rockhampton. Though this immense belt has been proved to extend in a north and south direction for a distance of about 800 miles, the belt is characterized physiographically by a number of dome-shaped or cylindrical hills, in many cases over 4,000 feet high, and very abrupt, marking the sites of old volcanic necks. In the Warrumbungle Mountains, at Wantialable Creek, the alkaline trachytic tuffs are interstratified with diatomaceous earths, the latter containing fossil leaves. These tuffs are formed of snow white, often perfect, crystals, of anorthoclase-felspar. The frequent association of diatom aceous earth with these volcanic rocks suggests a causal connexion. Meteoric waters, with their temperature raised through contact with heated volcanic rocks, and therefore capable of dissolving a relatively large amount of silica, together with the water of hot springs, probably favour the development locally of the diatoms. The usual sequence seems to have been first, leucocratic trachytes (sometimes preceded by rhyolites) commencing with riebeckite arfvedsonite comendites passing upwards into pantellarites, followed by solvsbergites, phonolitic trachytes, and melanocratic trachytes. These are followed by alkaline andesites, and these in turn by basalts, either olivine basalts or olivine fayalite-melilite basalts. The sequence in most cases has been from acid to basic.

These volcanic rocks are associated with intrusive hypabyssal rocks of the nature of porphyrite, tonalite monzonite, soda andesite, etc. The whole group shows Eastern Australia to be an alkaline and titanium-rich petrographical province.

The melilite fayalite basalts and tuffs (alnoites), which break through the konga-diabase at One-Tree Point, Hobart, and the melilite-eudialite basalts of Shannon Tier, and the nepheline basanites of Table Cape, Tasmania, are perhaps to be grouped here. Their occurrence recalls that of the alnoites which have intruded the diabase of South Africa. Perhaps to the closing phases of these alkaline eruptions belong the leucite lavas of Byrock, Capitan, Harden, and Lake Cudjellico, the essexites of Prospect, near Parramatta, the nepheline basalts of Capertee, Mount Royal, etc., in New South Wales, the nepheline basalts of Mount Beardmore, and the leucite-basalts of the Normanby Reefs in the Cooktown district in Queensland.

It is possible, however, that the above lavas are Newer Cainozoic.

NEWER CAINOZOIC TO RECENT NEWER BASALTS.

These rocks form physiographically very extensive plains, stretching from Mount Gambier in South Australia, through the western district of Victoria to Melbourne, in several places, as in the Loddon Valley, running long distances to the north of the main divide. These basalt plains are diversified by hundreds of small volcanic cones or "puys," in various stages of preservation or dissection, and probably the most recent cone is the compound one of Tower Hill, west of Warrnambool. Much of the lava forming the plains probably proceeded from fissures now concealed beneath the lava flows. In places shallow broad depressions of the lava surface have led to the formation of extensive lakes over these plains, while in places the present streams have trenched deep and sometimes wide valleys through them. The rocks are mainly normal calcic olivine basalts, but in places, as at Ballarat and Melbourne, occasionally contain a few crystals of anorthoclase, while analcite has been recorded from a coarse type of olivine-augite dolerite or essexite, occurring as boulders in the tuffs at the base of the volcanic series at Lake Bullenmerri, near Camperdown. The eruptions appear to be connected with extensive movements of subsidence and of faulting which affected Victoria at intervals from post Pliocene to recent times, and in some places the sequence of rocks was first tuffs, then lava flows, while the later volcanic cones, many with perfectly preserved craters, consist mainly of scoria and tuffs. The texture of the basalts varies from coarse dolerites, through finer varieties to the glassy form—tachylyte, such as is found at the Lal Lal Falls and the Merri Creek, near Melbourne. The rock is extensively quarried as a building stone, and constitutes the road metal of Melbourne and many other localities. These newer basalts in Victoria frequently sealed up old river valleys, the deep leads which contained rich deposits of gold-bearing sands and gravels, as at Ballarat, Ararat, and the Loddon Valley.

In South Australia, Mount Gambier, Mount Reid, Mount Leah, etc., represent recent olivine basalt cones and craters. The basalt flows of Kangaroo Island probably belong here, as may those of Bunbury, in the south-eastern part of Western Australia. Probably most of the basalts of Northern Tasmania, including at Sheffield the tachylytic variety, belong here. In New South Wales, the newer basalts are widely distributed and in places form the cappings of deep leads. Basalts are abundant in the New England district, and on the border of Queensland occur at Tweed Heads. In Queensland, there are some nearly perfect craters, enclosing crater lakes, preserved on the flanks of the Bellenden-Ker Ranges. From their perfect state of preservation, it is probable that they too belong to a late stage of newer basalt series.

In Papua, basalts and agglomerates, some 3,000 feet in thickness, overlie a peneplain cut out of the highly-folded Pliocene Port Moresby beds. Mount Victory, in British Papua, over 6,000 feet high, is the only lava producing volcano at present known within the territory of the Commonwealth. This has not yet been explored.

10. Metamorphic Rocks.

By Prof. T. W. Edgeworth David, C.M.G., D.Sc., F.R.S., and Prof. Ernest W. Skeats, D.Sc., A.R.C.S., F.G.S.

Contact Metamorphism.—Apart from the normal developments of hornfels, andalusite mica schist, cordierite mica rocks, etc., where granitic rocks have invaded shales, rocks such as garnet-rock, wollastonite rock, epidote rock occur at the contact, chiefly between acid eruptives and limestones, and ophicalcites where the latter have been intruded by ultrabasic pyroxene rocks belonging to the peridototes or picrites. Contact metamorphic rocks of special interest occur at the Mount Bischoff tin mine in the north-west part of Tasmania. There a quartz-porphyry, which has broken through slaty rocks, probably of Ordovician age, has had the whole of its felspar converted by pneumatolysis into fibrous radial topaz (pycnite). The rock at the same time has been tourmalinised, with a development in places in a massive form of tourmaline veins and irregular lumps, of the dark-green ferriferous variety zeuxite. An interesting type of contact alteration is produced by the intrusion of granodiorite into dacite, near Selby, in the Dandenong hills, at Warburton, and Mount Macedon, in Victoria. The dacite becomes slightly schistose. Hypersthene is converted into secondary biotite, ilmenite reacting with felspar forms fringes of secondary biotite, the ground mass is re-crystallized on a larger scale and some secondary blue tourmaline is developed. Near Selby, local development of crystalline biotite gneisses from the hypersthene dacite occur near the granodiorite contact. In this case it is possible that dynamic metamorphism reinforced the contact effects. Adinoles have been recorded amongst the cherts in the Heathcotian series of Victoria, but the analysis suggests that they do not vary much from the normal cherts in spite of the fact that their association with albite-diabase flows, schalsteins, tuffs, and radiolarian rocks suggests a local development of the spilite suite, with which adinoles are often associated.

Dynamic Metamorphism.—Under this heading may be included the phyllites and the crystalline schists.

Phyllites.—Argillaceous sediments altered to phyllites occur in the districts of Kosciusko, Cooma, and Cobar, in New South Wales, and in Victoria are represented near Yackandandah, and in several other localities in the metamorphic belt of north-eastern Victoria, and in Dundas in western Victoria. The precise age of many of these rocks is undetermined, but some have been referred to the Pre-Cambrian Series.

Crystalline Schists.—Very little work has as yet been done in the way of classifying these rocks on the principles of Grubenmann. There is here an enormous field for research, more than a third of Australia, including large parts of Western and South Australia, western New South Wales, and areas in western and eastern Victoria, and a large portion of Tasmania being formed of these rocks. Rocks of Grubenmann's upper, middle, and lower (deep) zone are well represented. Typical of the upper zones are chloritoid schist, talc schist, chlorite schist, talc schist, the schistose amphibolites and serpentinized areas of the Broken Hill area in New South Wales, the epidiorite, the glaucophane rock and glaucophane-epidote rock, albite-chlorite-sillimanite schist of Leahy's Creek, in the D'Aguilar Range area, north of Brisbane, in Queensland; the sericitic quartzites, magnetitic quartzite, conglomerates, talcose slates, and epi-magnetite slates of Northern Territory, the Algonkian (?) quartz-schists of Tasmania, and crushed quartzite conglomerates of Goat Island, near Ulverstone, in Tasmania, muscovite schists, quartz schists, chlorite schists of the Mount Lofty to Murray Bridge region to the east of Adelaide, chlorite, amphibolite graphite schists, siliceous mylonites (ribbon jasper), and crush conglomerates of felspar porphyry of Kalgoorlie, in Western Australia.

Amongst rocks which characterize the middle zone are the staurolite gneisses, staurolite mica schists, zoisite schists, and tremolite schists of the Broken Hill area, the tremolite schists, actinolite schists, muscovite-biotite schists, andalusite schists, and "paringite"* schists of the Mount Lofty to Murray Bridge area, the muscovite and biotite schists of western and north-eastern Victoria; the muscovite-biotite schists, garnet-zoisite amphibolite rock of Forth River, Tasmania; cyanite-rutile granulite, epidote-actinolite topaz schist, anthophyllite schist from D'Aguilar Range area, Queensland.

Possibly to this middle group may be referred the remarkable sapphire schists of Mount Painter. At Mount Painter, 300 miles north-west of Broken Hill, there occurs a rock formed of corundum, often as sapphire, cordierite sillimanite, pleonaste, magnetite, and abundant apatite, monazite and tourmaline.

These schists are traversed by an immense lode containing radio-active minerals such as autunite, torbernite, monazite radio-active fluorspar, etc. To the lowest or middle zone may belong the epidote-cordierite-chlorite

* A moderately coarse friable silvery muscovite-biotite schist with very wavy lamination, and with very prominent "knots" or "eyes" of impure andalusite, which may be upwards of an inch in diameter.

schist, the cyanite-rutile granulite, the granulitic mica schist, and the muscovite granulite of the D'Aguilar Range area, and the muscovite-sillimanite chiastolite schist, with andalusite schist, of the Mount Lofty to Murray Bridge area.

The following types, perhaps belonging to the deepest zone, have been identified in Australia :—Kata-biotite orthoclase gneisses, sillimanite gneiss. garnet-sillimanite schist, cordierite-granulite, scapolite-gneiss and plagioclase pyroxene rocks, from the Broken Hill area, and scapolite-amphibolite rocks and amphibolites, with sphene and vesuvianites from the Mount Lofty Ranges, to east of Mount Lofty. The sillimanite schists and gneisses near Tallangatta, and elsewhere in north-eastern Victoria, may belong here.

The following metamorphic rocks seem of special interest :—

(1) The mylonized granophyric quartz-dolerites of Western Australia, passing at one end of the series by introduction of silica and formation of haematite into red ribbon jaspers and haematite schists, and at the other end, as the result of the introduction of plutonic carbon, as methane, etc., passing into graphite schists, as at the Great Boulder mine at Boulder, adjacent to Kalgoorlie, where methane is still being given off in the deep levels of the mine, at 2,000 feet below the surface. The ribbon jaspers and haematite schists can be traced for fully a thousand miles, at intervals from the extreme south to the extreme north of Western Australia. Where quartz reefs traverse these metamorphosed mylonized rocks they are generally gold-bearing.

(2) The remarkable belt of sapphire schists adjacent to the great radium-bearing lode of Mount Painter.

(3) The glaucophane schists of Mount Mee in the D'Aguilar Range area of Queensland, to the north of Brisbane.

(4) The important belt of the Broken Hill area, with its sillimanite gneiss, scapolite gneiss, pyroxene-amphibole rocks, etc., characteristic of Grubenmann's deepest zone.

(5) The wonderful chiastolite belt of Bimbowrie to the west of Broken Hill. These chiastolites, often 5 to 6 inches in length, and over an inch in diameter, have in some cases suffered paramorphism, and pass into aggregates of pinite, with occasional grains of corundum. The important "paringite" belt of Mount Lofty may also belong to this horizon.

11. Papua.

New Guinea, 1,500 miles long, with an extreme width of 380 miles, and an area of 306,000 square miles, is one of the biggest islands in the world.

Apart from Polar regions, perhaps, no portion of the world has been so little explored, and yet it probably yields to no other part in scientific interest. If it were possible to travel from the coast inland in a bee line for from 30 to 100 miles,* one could pass from the dense, steaming, tropical atmosphere of the lowlands, with its rattan-tangled jungles and bright scarlet creepers to the bracing air of the open forest glades, where the pink rhododendron forms a

* So dense is the growth of the jungle that it took the Goodenough-Rawling expedition no less than five weeks to travel inland five miles.

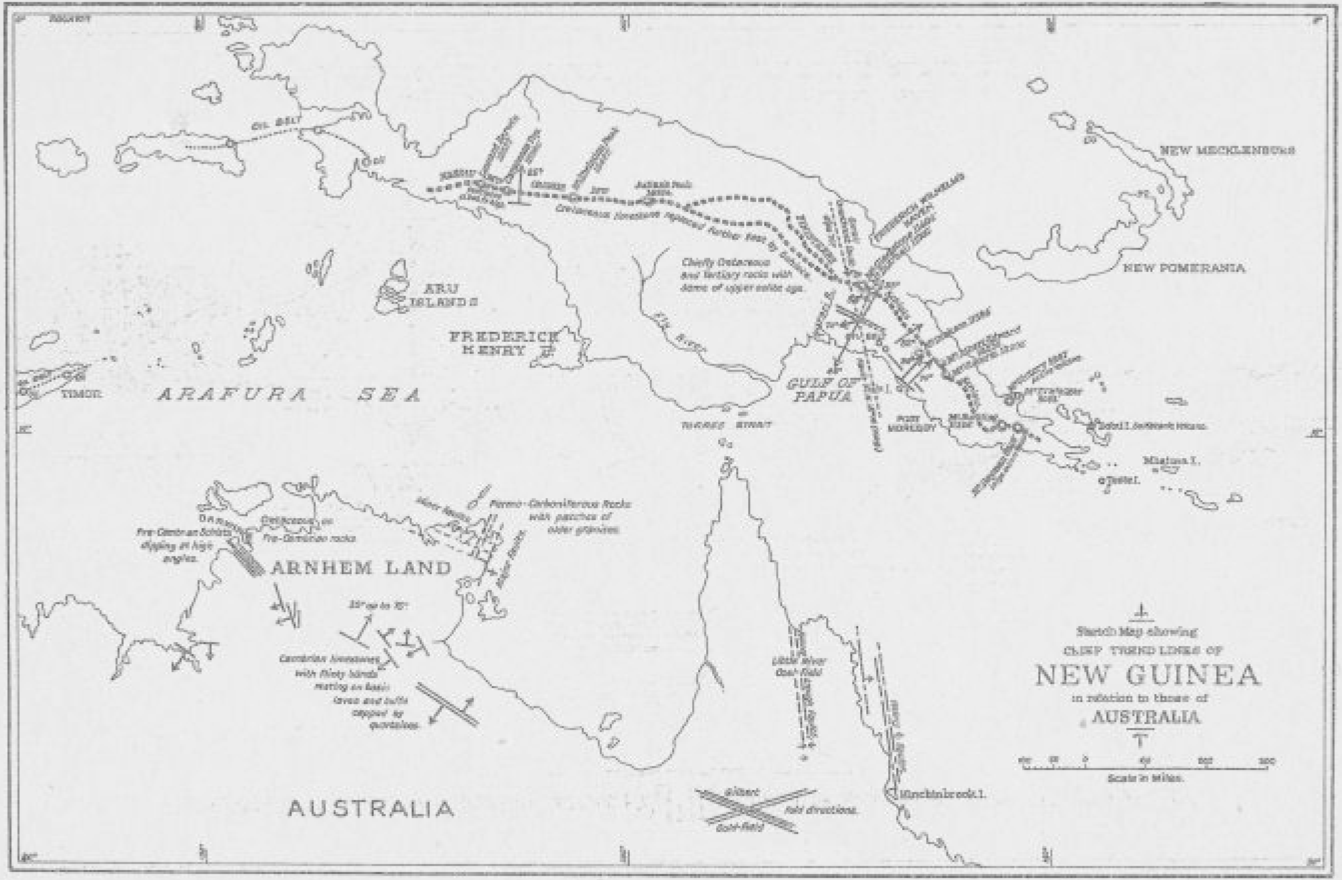
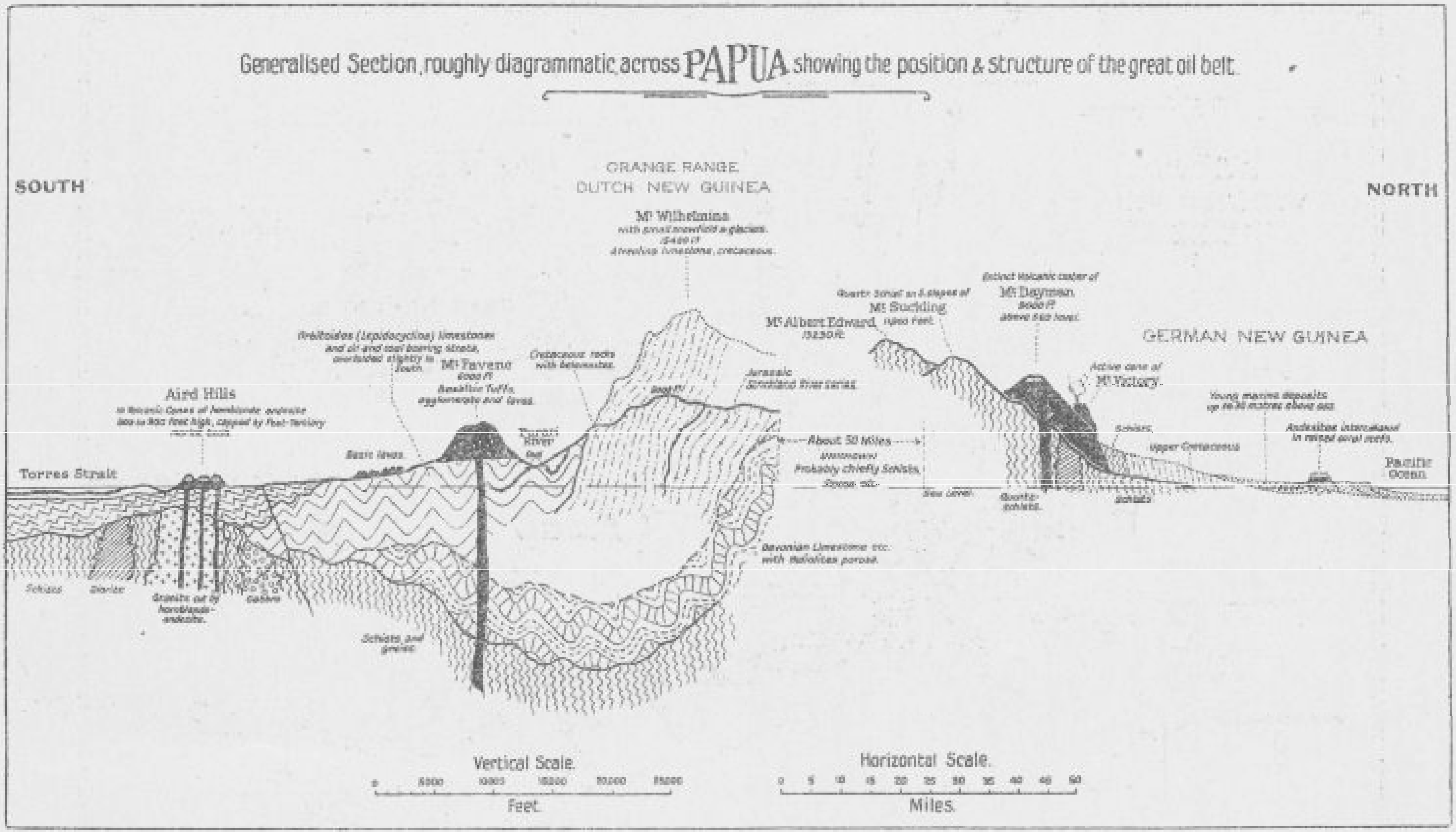

NEW MECKLENBURG
NEW POMERANIA
OIL BELT
ARU ISLANDS
FREDERICK HENRY I.
TIMOR
ARAFURA SEA
GULF OF PAPUA
TORRES STRAIT
PORT MORESBY
Misima I.
Permo-Carboniferous Rocks with patches of older granites.
Cretaceous on Pre-Cambrian rocks
Pre-Cambrian Schists dipping at high angles.
ARNHEM LAND
Cambrian limestones with flinty bands resting on basic lavas and tuffs capped by quartzites.
Little River Gold-field
Gilbert Gold-field
fold directions.
Hinchinbrook I.
AUSTRALIA
Sketch Map showing
CHIEF TREND LINES OF
NEW GUINEA
in relation to those of
AUSTRALIA
Scale in Miles.

PLATE IX.


Generalised Section, roughly diagrammatic, across PAPUA showing the position & structure of the great oil belt.
SOUTH
NORTH
ORANGE RANGE
DUTCH NEW GUINEA
GERMAN NEW GUINEA
Torres Strait
Aird Hills
Mt Wilhelmina
Mt Albert Edward
Mt Suckling
Mt Dayman
Mt Victory
About 50 Miles
Probably chiefly Schists
Sea level
Pacific Ocean
Schists
Diorite
Gabbro
Schists and gneiss
Devonian Limestone etc.
Upper Cretaceous
Vertical Scale.
0 5000 10000 15000 20000 25000
Feet.
Horizontal Scale.
0 5 10 15 20 25 30 35 40 45 50
Miles.

Index to Geological section of Papua.

Pre-Cambrian (?)

- Quartz and Mica Schists and gneiss (Ialokite).

Probably all Post-Pre-Cambrian

- Granite
- Diorite
- Gabbro

The relative ages of these are not at present known.

- Devonian Beds (Tauri Limestones etc.) with Heliolites porosa
- Upper Oolite. Strickland River series with Stephanoceras and abundant other jurassic ammonites in indurated calcareous shales.
- Upper Cretaceous. Bluish limestones and dark green Sandstones with Inoceramus, Gryphœa, etc.
- Miocene (Lower ?) Purari series. Lepidocyclina limestones, plant-bearing bluish grey to greenish grey mudstones clays and sandstones. Brown coals. Rock oil with natural gas and saline and iodine water, forming gas and mud springs
- Older Pliocene (?) Port Moresby beds. Marine Calcareous shales with radiolaria and flinty concretions, siliceous limestones sandstones and conglomerates. This series is strongly folded.
- Post-Tertiary Hornblende Andesites and basalts, and agglomerates.
- Post-Tertiary marine beds including raised coral reefs.
- Delta deposits.

glowing fringe to the sombre mantle of pine and cypress which clothes the higher slopes. In British New Guinea, one may climb above the tree line to the Alpine grasses and flowers, and extinct glacial lakes of the great horst, where, even in midsummer, in early morning the grass and wild strawberries are white with frost, and all the shallow pools are crusted with ice. Higher still, bare peaks and pinnacles of dark schists pierce the clouds. Among their sharp serrated ridges and spurs the mountain torrents gather for their leap down steep ravines into the valleys far below. In Dutch New Guinea there are even perennial snows and glaciers in the Nassau and Orange Ranges, the latter reached in 1905 by Dr. Lorentz and his comrades.

The association in New Guinea of *Dendrolagus* and *Prœchidna* with the cloven-footed *Sus papuensis*, of *eucalyptus* and *casuarina* with the oak and rhododendron, are typical of that commingling of Indo-Malayan with Australian forms which makes New Guinea so happy a hunting ground for the botanist and zoologist. The aborigines, including the pygmies, with their primitive pile dwellings recall the lake dwellers of Europe, and present a most fascinating study for the anthropologist. Geologically as well as biologically New Guinea shows a commingling of Oriental with Australian elements.

Papua tectonically and palæontologically is an oriental element in the Australian region. It is part of the Himalayan-Burmese arc, prolonged through the Malay Peninsula, Sumatra, Java, and Timor.* It is specially linked up with the Burmese arc by the great oil belt lately found in Dutch New Guinea and British New Guinea. The limestones, so rich in *Orbitoides* (*Lepidocyclina*), recently discovered at Bootless Inlet, to the east of Port Moresby, are probably of Lower Miocene age, and appear to be close to the horizon of the Papuan oil belt. Its trend lines are continuous with those of the Malay Peninsula; and the direction and age of the folding, extending as it does into late Pliocene time, agree with those of the Burmese arc. In Australia, on the other hand, the latest strong orogenic movements, though prolonged in places into the Lower Permo-Carboniferous age, ceased for the most part in Carboniferous time. The trend of the main folds in New Guinea is in a west to east direction from the Charles Louis Range and Mount Leonard Darwin to the north-west end of the Finisterre Mountains. Thence the trend is nearly south-east, to near Mount Suckling, and thence to the Louisiade Archipelago east-south-east. A probable virgation of the main trend line is indicated by the great promontory of New Guinea, opposite New Pomerania, and by the long axis of that island.

This strongly marked Burmese trend line is crossed by minor trend lines, subordinate folds and faults, more or less meridional, coming from Australia. These manifest themselves where the strong faults at the north-east end of Arnhem Land, running north by east, pass over into Frederick Henry Island, and also in the faults and small cross folds inland from the Gulf of Papua, in the neighbourhood of Port Moresby, and at Ware (Teste) Island, etc. On the Purari River there is evidence of minor overthrust faults with the overthrusting coming from west-south-west, as well as of the dominant north-west to south-east trend lines. On the whole, evidence up to the present suggests that the overfolding of New Guinea has been directed in the western half of

* The Timor trend line marks a N.E. trend of the arc of new folded rocks bending away from its E.W. direction owing to the resistance set up by the great crystalline massif of Darwin and Arnhem Land, whose trend lines are directed to the N.W. or N.

the island from north to south, and in the eastern half, from north-east to south-west. In other words, New Guinea has been overfolded towards Australia.

The physiographic geology of New Guinea is unique. The backbone of New Guinea appears to be a horst mostly part of an old peneplain. This, from the south-east extremity of the island as far as to, and including, the Finisterre mountains is formed of crystalline schists and gneisses, probably Pre-Cambrian. At some spot, not yet explored, to west of the Finisterre mountains, and between them and Mount Wilhelmina Peak (15,420 feet), the divide is formed of Cretaceous *Alveolina* limestone. Further west, and south of Carstensz Top and Mount Leonard Darwin, Rawlings has described perhaps the most stupendous precipice known anywhere in the world, recalling the fractures of the lunar Apennines. He estimates its height at 10,500 feet, and considers that it is of tectonic origin. The precipice faces the south, and is no doubt evidence of a powerful inthrow in that direction. Possibly folding has contributed to this gigantic displacement, but to what extent, if at all, is not at present known, but from the evidence further east, on the Purari River, it may be inferred that the disturbance is in part, at any rate, due to folding.

On the northern slopes of Mount Suckling, at an altitude of 8,000 feet, an immense sheer cliff of quartz schist faces the north-east, and perhaps indicates a downthrow in that direction.

The nearly uniform height of the main Divide in the eastern part of the island, rising to from 11,000 to 13,000 feet above sea level, as well as the profile of the ranges, strongly suggests an old peneplain, which has been block-faulted and subsequently deeply dissected.

This peneplain has been carved partly out of Pre-Cambrian schists, partly out of Devonian, Upper Oolitic and Cretaceous rocks. As the Cretaceous transgression probably covered nearly the whole of the island, the peneplain composed partly of steeply dipping Cretaceous rocks must obviously be Post Cretaceous, though it is possible that the schist portion of the peneplain belongs to a Pre-Cretaceous peneplain re-discovered in Post Cretaceous time.

The coastal region and foot hills inland from the Gulf of Papua for a distance of 50 or 60 miles belongs to a second peneplain, carved out of Miocene to Pliocene estuarine and marine strata. The Miocene transgression was far less extensive than the Cretaceous, and the Pliocene less extensive than the Miocene. Even the Pliocene beds (Port Moresby beds) have been intensely folded, and these folded rocks have subsequently been reduced to the level of this second peneplain. This lower peneplain has been covered in Post Pliocene time partly with basalitc and andesitic tuffs and lavas to a depth of from 1,000 to 2,000 feet. A recent transgression has carried horizontally bedded coral reefs over the top of some of the Post Tertiary volcanic rocks, while in other places the coral rock rests directly on the Pliocene beds. These recent coral-reef limestones are now found up to altitudes of 1,000 feet, and exceptionally up to 2,000 feet, above sea level, on the south-east side of Papua. This proves that a negative movement of the strand line of the order of 1,000 to 2,000 feet took place in south-eastern New Guinea in recent geological time.

This recent emergence of the land has been the cause of modern canyon cutting like that of the canyon of the Laloki River, near Port Moresby.

Another alternative explanation of the physiographic geology is that the whole country from sea to sea, up to the top of the divide, belongs to one and the same peneplain, which has been heavily block-faulted in late Pliocene or even Pleistocene time.

Against this interpretation may be adduced the facts—(1) that so far no rocks newer than Cretaceous have been encountered in the region of the divide or anywhere above a level of about 4,000 feet. (2) The main divide portion of the peneplain is so deeply dissected that Post Pliocene time alone may not have sufficed for the work.

Probably connected with the lines of block faulting was the manifestation of volcanic energy, which produced basaltic lavas and tuffs like those of Mount Favenc, and built the volcanic cones and craters respectively of Mount Dayman, 9,305 feet, and of the active volcano, Mount Victory, about 6,000 feet high—the only lava producing volcano within the Commonwealth—as well as the cones of the solfataric volcanoes of the D'Entrecasteaux Group such as that of Dobu, etc. The sharp shocks of earthquake occasionally experienced in British Papua obviously have relation to crustal readjustments connected with the volcanic zones, or movements along fault planes. That New Guinea was not exempt from the great Ice Age of Pleistocene and in part Recent time, which affected south-eastern Australia at Mount Kosciusko, the highlands of Tasmania, and the cordilleras of New Zealand, Patagonia, and Tierra del Fuego, is proved by the evidences of past glacial action observed by Dr. Lorentz, below Wilhelmina Peak, extending downwards to at least 13,200 feet, where glacial lakes with striated rock surfaces were observed. The numerous small lakes and tarns on Mount Albert Edward and Mount Victoria, both of which are over 13,000 feet high, make it nearly certain that these peaks were also at one time glaciated.

One of the latest phases in the evolution of the Papuan landscape has been the reclamation of shallow portions of the continental shelf by river deltas. This is specially to be noticed in the Gulf of Papua, where vast amounts of silt are washed into the sea annually by the Fly, Kikori, and other rivers.

The sequence and character of the formations represented are shown on the diagrammatic section. This section shows that there is a large area in Central Papua as yet mostly unexplored.*

Little is as yet known of the crystalline schists and gneisses, which form the backbone of most of the island, beyond the fact that quartz mica-schists, talc schists, and chlorite schists are represented. These are intruded in places by granites, diorites, and gabbros. Gold-bearing quartz-reefs are associated with these intrusive rocks, and copper deposits are developed

* Not only is the geological structure unknown, but even the zoology has been only very partially studied, as is evident from the following facts:—It has been recorded by Mr. C. G. W. Monckton that near the lakes of Mount Albert Edward he observed, at over 12,000 feet above sea level, footprints of an unknown animal with cloven hoof, the footprints measuring about four inches by four and a half inches—the imprints were quite unlike those of the *Sus papuensis*. He adds that the description given by the natives of the creature that leaves these footprints suggests an animal like the hog-deer (*Sus babirussa*) of the Indian islands.

in connexion with the gabbros. So far the existence of Devonian rock has been proved only on the Tauri river, to the east of Purari river, and 29 miles from the coast. The Upper Oolites are represented by calcareous shales, 75 miles up the Strickland river, above its confluence with the Fly river. These contain *Stephanoceras blagdeni*, *S. lamellosum*, and an ammonite, of *A. lingulatus*, from the White Jura, together with an *Aucella* or *Inoceramus*.

The Cretaceous strata, mostly dark-green calcareous and glauconitic (?) sandstones and limestones, contain *Alveolina*, *Orbitolites* (*Flosculinella* Schu.) *Inoceramus*, *Gryphæa*, *Modiola*, *Aviculopecten*, *Protocardium*, *Cidaris*, *Belemnites*, etc.

The oil belt, without doubt a continuation of the Burmese oil belt, is part of a vast delta or estuarine deposit, consisting of freshwater beds alternating with marine limestones. The limestone of Bootless Inlet to the east of Port Moresby, formed chiefly of beautiful shells of *Orbitoides* (*Lepidocyclina*), probably belongs to the oil belt.

In places the Miocene limestones are formed chiefly of *Globigerina*, like the well-known *Globigerina* limestone of Noumea. Some of the friable sandstones are extremely rich in mollusca, of which 32 genera have been identified by Mr. W. S. Dun and Mr. C. Hedley, the latter being of the opinion that the greater proportion are species new to science.

Seams of brown coal occur at intervals, the thickest seam so far proved being 2 feet 9 inches. The brown coals from British Papua have approximately the following composition:—

Hygroscopic moisture	13	per cent.	to 21	per cent.
Volatile hydrocarbon	37	,,	,, 42	,,
Fixed carbon	34	,,	,, 41	,,
Ash	3	,,	,, 9	,,
Sulphur	3	,,	,, 2	,,

The whole series has been strongly folded along E.S.E. to W.N.W. lines or north-west to south-east lines, crossed by north and south lines.

The oil is associated with anticlinal arches in a bluish-grey mudstone and clayey sandstone, in which it occurs as yellowish-brown globules. This is found in the neighbourhood of the Vailala and Purari Rivers, a short distance above their mouths, to the west of Port Moresby.

Crude petroleum oil collected by Mr. J. E. Carne, F.G.S., was analysed by Mr. J. C. H. Mingaye, F.C.S., with the following results:—

	P. in 100 parts.	Sp Gr.
Petroleum spirit below 150° C.	Nil	..
Burning oils distilled below 300° C.	20·8	0·9283
Intermediate and lubricating oils with solid hydrocarbons	74·2	0·9733
Coke	5·0	..
	100	

That the petroleum spirit had evaporated from these superficial strata as the result of weathering is proved by the fact that light volatile oils have lately been obtained in a bore 300 feet deep on the west side of the Vailala River near its mouth.

The water associated with the rock oil was found to have the following composition:—

	Grains per gallon.	P. in 100 parts.
Total solid matter (dried at 220° F.) ..	842·60	12·038
Chlorine as chlorides	424·62	6·066
Sulphur trioxide as sulphates	Nil	Nil

The solid matter was chiefly sodium chloride with some sodium carbonate, magnesium carbonates, silica, etc. Calcium carbonate, 9·64 grains per gallon; magnesium carbonate, 1·60 grains per gallon; silica, 1·80 grains per gallon. A strong reaction was obtained for the presence of iodine and boric acid in the water. It is thought possible that this iodine water may later prove of value for the extraction of iodine from it, like that of Golnosk Soerabaia Island, Java.

Port Moresby Beds.—These strata, radiolarian in places, and marked by large onion-like concretions of chalcedony up to several feet in diameter, are as strongly folded, mostly overfolded, as are the lower Cambrian rocks of the Mount Lofty Range, near Adelaide, and yet these Port Moresby beds are probably not older than Pliocene. Thus the orogenic movements which have produced the cordillera of Papua must have been acute down to as late in geological time as the Pliocene period.

Post Pliocene.—These are largely composed of volcanic rocks. The volcanic rocks of this age in British Papua have as yet been very little studied. They are known to consist of hornblende andesites and basalts. In the island of Misima (St. Aigan) are thin flows of trachyte. The Papuan lavas appear to belong to two volcanic zones as shown on the section, in which the Aird Hills (about 200 miles north-west from Port Moresby) belong to the southern zone facing Torres Strait and the Arafura Sea, and the other parallel and adjacent to the northern coast of British Papua. The great extinct crater of the unexplored volcano, Dayman, 9,305 feet high, belongs to the northern belt, as does Mount Victory, 6,000 feet high, which still produces lava.

That incandescent lava is present in the crater of Mount Victory is proved by the fact that Mr. A. Gibb Maitland observed on two occasions that the steam clouds hovering over that mountain were seen, after nightfall, to be brilliantly illuminated.

Mount Victory, as far as is known, is the only lava-producing volcano in the territory of the Commonwealth. It has never been geologically examined. The small island of Dobu (Goulvain) in the D'Entrecasteaux Group is a volcanic cone, from which steam is still emitted. This is also situated on the northern volcanic belt. In regard to the broad tectonic features of Papua it may be suggested, very tentatively, that the mainland of Australia has functioned as a "forland massif," Torres Strait, the Gulf of Carpentaria, the Arafura Sea, and the deep Mesozoic and Tertiary basins, with their thick strata as a senkungsfeld. Possibly the crystalline schists forming a great part of the backbone of the island have played the part of an inner, or "rück-land massif," which has helped to roll up the Mesozoic and Tertiary sediments. The chief fracture zones, on which the present active volcanoes of Mount Victory and Dobu are situated, appear to lie on the inner limb of the fold region, just the portions which have been put in tension as the result of the southerly creep of the Papuan area towards Australia.*

The latest crust movements have caused an emergence of the land to the amount of 1,000 feet on the northern coast, and over 2,000 feet on the southern coast in Post Pliocene time.

* If this interpretation is correct their situation would be analogous to that of the Vesuvian volcanic zone in regard to the folds of the Apennines, the lavas of Hungary in reference to the folds of the Carpathians, the lavas of the Great Basin region of the United States of America in regard to the folds of the Rockies and Sierra Nevada, etc.

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