TRANSACTIONS

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Art. 1.—*Palaeozoic and Mesozoic Seas in Australasia.*

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Contents.

The Stratigraphic and Structural Relationships of Australia and New Zealand: an Historical Sketch.

More than forty years ago Hector (1879) delivered in Sydney an address on the "Geological Formations of New Zealand compared with those of Australia," which was used by Suess (1888) in his comparison of the relation of the eastern part of South America to the Andean zone on the one side of the Pacific with that of western Australia to eastern Australia and New Zealand on the other. The former unity of these two last regions had already been indicated in Neumayr's (1883) chart of the

Jurassic world, in which, in place of the Tasman Sea, a restricted southward opening, "Queensland Gulf," lay between the continental mass of Australia and a long promontory stretching from New Guinea through New Caledonia and New Zealand, where is now a somewhat elevated region of the ocean-floor. This feature has characterized most of the later palaeogeographic maps of Australasia drawn at various periods by David (1893), Koken (1893–1907), Frech (1897–1902), Lapparent (1900–6), Arldt (1907), Hedley (1909), Haug (1911), Schuchert (1916), but is not present in those of Lemoine (1906), while Walkom (1918) recognizes the presence of the gulf in Triassic but not in Jurassic times.*

As a geologist trained in Australia, the writer, when settling in New Zealand, was naturally attracted to the problem Hector set himself, and especially towards its palaeogeographic aspect, and he has attempted in the sequel to summarize once more our modern knowledge of the broader features of Australasian stratigraphy. As Walkom (1918) has clearly indicated, "the palaeogeography of the Australasian region involves a consideration of the structure of the western Pacific region"; and we shall therefore commence the discussion by giving a brief *résumé* of the conceptions that have been advanced concerning this broader problem in whole or in part.

Basing his opinions on sections drawn through Canterbury and Westland by von Haast, and through Otago by Hector, Hochstetter (1867) stated that "only the eastern half of a complete mountain chain has been preserved [in New Zealand], while the western half is buried in the depths of the main." Hutton (1875) suggested that the Otago region in Devonian times was depressed beneath the sea, and emerged again in Permian times, when New Zealand formed a very subordinate part of a large continent which stretched far to the northward. Subsidence of all but the southern part followed, succeeded by a slight elevation, deeper subsidence, and this again by the great Alpine folding, believed by Hutton to have occurred in the Middle Jurassic times. This was part of a large movement which probably resulted in the upheaval of an Antarctic continent extending to South America, as shown by the fact that all the formations later than this upheaval contain fossils identical or closely connected with those of Patagonia and Chile. Subsidence followed, New Zealand was reduced to a chain of islands, and has since remained isolated from any large continental area.

Clarke (1878) pointed out that there are no marine Tertiary rocks on the eastern coast of Australia or Tasmania, and that this may indicate that the eastern extension of Australia has been cut off by a general subsidence. "This has some support in the fact that there is a repetition of the Australian formations in the Louisade Archipelago, New Caledonia, and New Zealand. The intervening ocean may therefore be supposed to cover either a great synclinal depression or a denuded series of folds" (Clarke).

Hector's (1879) correlation of the geological formations of Australia and New Zealand is a close approximation to modern conclusions, as may be seen from the accompanying table. Hector held that New Zealand

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* Among other palaeogeographic maps or summaries dealing with Australia as a whole or in part with several or with single formations are those of Jensen (1908, 1912), Basedow (1909), Gregory (1910), David (1907, 1911, 1914, 1919), Walkom 1913), Süssmilch (1919), Andrews (1916), Benson (1921).

TABLE OF CORRELATIONS OF GEOLOGICAL FORMATIONS IN AUSTRALIA AND NEW ZEALAND SUGGESTED BY HECTOR IN 1879.

New Zealand.			Australia.	
Formation.	Age assigned by Hector.	Modern Age-determination.	Coeval Formation according to Hector.	Modern Age-determination.
Amuri limestone, greensand, &c., and coal-measures (also West Coast coal)	Lower Cretaceo-Tertiary and Lower Greensand	Danian and Senonian (Upper Cretaceous) (Eocene)	Possibly in Queensland—*e.g.*, Flinders Range	Lower or Middle Cretaceous (?).
Mataura and Putataka ..	Upper and Middle Jurassic	Neocomian and Tithonian, also Middle Jurassic	Clarence River coal-measures, N.S.W. Jerusalem coal-measures, Tasmania	Lower Jurassic. Lower Jurassic (?).
Catlins and Bastion ..	Liassic	..	Unknown	..
Otapiri .. .. .. Wairoa and Oreti	Rhaetic and Lower Triassic	Noric and Carnic .. .. (Upper Triassic)	Wianamatta and Hawkesbury series, N.S.W.	Rhaetic or Upper Triassic. Lower Triassic (?).
Kaihiku	Permian	Base of the Upper Triassic ..	Newcastle coal-measures ..	Permian.
Maitai limestones, &c ..	Lower Carboniferous ..	Permian or Permo-Carboniferous	Hobart, Tasmania .. Gympie, Queensland .. Port Stephens, N.S.W. ..	Permian or Permo-Carboniferous. *Lower Carboniferous* and Permo-Carboniferous. Lower Carboniferous.
Reefton	Lower Devonian	Silurian	Murrumbidgee, N.S.W. .. Carcoar and Belubela, N.S.W.	Middle Devonian and Silurian. Silurian.
Baton River	Silurian	Silurian	Yass beds, N.S.W. .. Gordon River, Tasmania ..	Upper Silurian. Lower Silurian.
Graptolitic slates	..	Lower Ordovician ..	Auriferous slates, Victoria ..	Lower Ordovician.

and the Chatham Islands were the remnants of a large continent, formerly extending far to the east, which must have been connected in the Temperate Zone with South America, but there was no evidence of its having been connected with Australia during Tertiary times. The Jurassic flora he recognized as occurring also in Australia, while Deslongchamps (1864) had shown that the Triassic fauna of New Zealand had representatives in that of New Caledonia. The "Lower Carboniferous" beds appear "to have been common to Australia and New Zealand, and to have been deposited in both areas under the same physical conditions, and within a common biological province" (Hector). Haast (1879) repeated Hochstetter's conception of the Southern Alps, held that the sedimentary rocks to the east of the gneissic core of this range were derived in Palaeozoic times from a large continent lying east of New Zealand, of which the Chatham Islands form a remnant, and agreed that New Zealand became a string of islands in Cretaceous and Tertiary times. Hector (1885), however, dissented from Hochstetter's conception of the Southern Alps, and mapped them as synclinal, with a gneissic western margin, followed by Permian rocks on either side of a Mesozoic central zone. Hutton (1885) also concurred with Hochstetter's interpretation of the structure of the New Zealand Alps, but, comparing the manganese-bearing bands in the Maitai system with modern deep-sea deposits, he was led to infer very deep depression during the Carboniferous period. He further noted the resemblance between the graptolites of Australia and New Zealand.

Suess (1888) summarized in the following order the sequence of rock-formations observed in passing eastward from the desert of Western Australia, the depressed zone of Lake Eyre and Spencer Gulf, the Flinders, Mount Lofty, Barrier, and Grey Ranges, and the alternating members of the Australian cordillera. For a long distance the farther extension of the continent is now concealed by the sea, but beyond it, in New Zealand, the Mesozoic series is completed, and with this completion we reach the great ranges and at the same time a region of much more recent folding. "All the chains from the Flinders to the Australian cordillera, including the longer of the two syntactic mountain-segments of New Zealand, must equally be regarded as constructed on a common plan."

Stephens (1889), from an Australian standpoint, made a second interesting correlation of Australian and New Zealand strata. The Australian Carboniferous *Lepidodendron* beds he places by the Devonian (?) Te Anau breccias, and following a break, which is not now recognized as existing here, the greywacke and fossiliferous Maitai limestone are grouped with the Permo-Carboniferous coal-measures and marine beds in Australia. Following another break, the Kaihiku series is grouped not in the Permian, where Hector placed it, but with the Triassic Narrabeen beds, the lower part of the Hawkesbury series. In correlating the overlying Oreti beds with the Triassic Hawkesbury sandstone Stephens was obviously embarrassed by Hector's statements that they show evidence of glacial action and of the presence of *Glossopteris*, both of which are no longer accepted. The succeeding Otapiri–Wairoa beds, which Hector rightly considered Triassic, are grouped with the Upper Clarence beds, which are now known to be Jurassic, and the "Lower Jurassic" Mataura series is grouped with the Rhaetic Wianamatta beds of the Sydney district. Stephens further held that the Tasman Sea persisted throughout these epochs, that eastern Australia and New Zealand were independent groups of islands, both united with Antarctica by emergence during Permo-Carboniferous times, and connected with Asia by temporary land-bridges during Lower Triassic times ("when *Hatteria* entered New Zealand").

Professor David (1893) further summarized the pre-Mesozoic geological history of Australasia. He inferred the proximity of land in various regions and periods, but did not offer palaeogeographic charts. Thus he stated that the land which must have supplied the detritus of which the New Zealand Silurian rocks were formed must have existed near the present west coast, but has since been removed by denudation. Portion of it may possibly be represented by the crystalline schists of Otago, but it may be doubted whether there was any land at all within the present area of New Zealand before the commencement of the Mesozoic period, when, for the first time, coarse conglomerates and a land-flora made their appearance.

During the next decade evidence was accumulating which indicated the former extension of Australia to the east and south of its present limits. The former eastward extension, originally deduced by Clarke (1878) from the abundance of the epicontinental Mesozoic deposits and absence of Tertiary marine rocks near the present eastern shore-line, was confirmed by the discovery that there frequently occurs current-bedding in the Newcastle coal-measures, which indicates their deposition by currents flowing towards the west (see David, 1907A). The southward extension, which had been first suggested by Tate's (1879) announcement that the glacial beds near Adelaide contained erratics which appeared to have come from the south, was confirmed when in 1895 it was shown that the most abundant of the recognizable types were derived from near the mouth of the Murray River, fifty miles to the south of their present position. At the same time the glaciation was proved to be pre-Miocene, and was referred to the Cretaceous by Brown, and to the Permo-Carboniferous by Howchin and David, who collaborated with Tate (1895). Further evidence was obtained that the supposedly contemporaneous ice-sheet in Victoria and Tasmania moved to the north-north-east, and that a large elevated land area must have existed to the south-west of the present limits of the three States mentioned.

Hutton (1900, pp. 180–81) again summarized the geological history of New Zealand, in effect saying that of the early Palaeozoic era in this region we know but little; but towards the close of the Devonian period land certainly existed, though its outlines are uncertain. It subsided beneath the sea during Carboniferous times, but subsequently was raised so that in Permian times, after folding had taken place, New Zealand lay near the shore of a continent stretching away towards Tasmania and Australia, to which perhaps it was joined. He concurred with Stephens (1889) in recognizing the fossils of the Maitai series as of Australian Permo-Carboniferous types. Middle Jurassic orogeny was believed by him to have been accompanied by the subsidence of the crust with the formation of the Tasman Sea, though leaving a broad strip of land west of the Southern Alps, which extended northwards to New Caledonia and New Guinea. This connection he believed was broken in the Upper Cretaceous movement of crust-subsidence, and was not renewed in the early Tertiary emergence, with the discussion of which this paper is not concerned.

Lemoine (1906), discussing the former limits of Gondwanaland, considered that it extended across Australia and the Tasman Sea, and that along its northern and eastern shores there migrated the Tethyan forms from India, through the Malayan region, to New Guinea, New Caledonia, and New Zealand. The gneissic rocks of western Otago were considered as being a fragment of this old and largely subsided continent. Fraser and Adams (1907), while remarking on the difficulty of determining whether the sediment forming the Mesozoic greywackes of New Zealand was derived from the west or east, inclined to the latter alternative (at least for the Coromandel region), but Morgan (1908) supported the former view (as regards the West Coast region), citing, but not committing himself to, Lemoine's opinion. He was opposed, however, to the hypothesis of the anticlinal structure of the Southern Alps, declaring that the rocks forming the western slopes are portions of an older chain striking to the north-west, and separated by overthrust faults and a zone of granitic intrusions from the newer Alpine chain.

Arldt (1907, p. 456) recognized the greater part of Australia as a portion of an Archaean massif, a fragment of Gondwanaland, adding that this "appears from the Carboniferous to the beginning of the Tertiary to have had an important extension to the east, even to the margin of the inner island arc of Melanesia, including the Fiji Islands, Tonga Islands, and New Zealand. Obviously these regions were repeatedly flooded over by the sea. On the other hand, the sea had very early appeared thrusting in between Tasmania and New Zealand, existing here during the Jurassic, but probably at various earlier periods also."

Suess's (1908) last volume contained a modification of his earlier discussion of the structure of Australasia. He now recognized three island arcs about Australia. The first comprised New Guinea, New Caledonia, and North Auckland Peninsula, with the New Hebrides, Solomons, and Loyalty Islands as an outer zone. The second arc was a group of coral atolls running north-westwards from Fiji (a rather unsatisfactory grouping); and the third arc ran from Tonga, through the Kermadec Islands, into New Zealand. "The arcs . . . seem to whirl towards the bifurcation of northern New Zealand. . . . At the same time there are many doubtful points. First among these is the question whether the Australian cordillera along the recent down-break on the eastern coast may be recognized as an inner arc. If so, the whole structure would be concentric about an ancient vertex [or nucleus]. But the manner in which the cordillera is continued across Torres Strait scarcely favours that view. [Various conjectures may be made] . . . but in the hope of solving our problems we create new ones."

Gregory (1908) adopted Suess's comparison of the structure of South America and Australia, but took the section across the former through Brazil, instead of the northern Argentine as did Suess, claiming as the counterpart of the Thompson Trough the comparatively small depression (Lake Titicaca) between the eastern cordilleras of South America and the main range. Marshall (1909) urged the close relationship between Tonga and the North Island of New Zealand, drawing attention to the submarine ridge connecting them (Suess's third arc), adding that it was not unreasonable to regard it as an anticline, and the adjacent trough as a syncline (in which crust-movement is still in progress: Angenheister, 1921). This was supported by Speight (1910) in a paper drawing attention to the existence of continental rock (hornblende-granite) beneath the volcanic accumulations (andesite-lavas and tuffs) of the Kermadec Islands, rocks which are closely analogous to those of New Zealand. A useful summary of the problem of ancient land-extensions in the Pacific is given in this paper, and in a later one by Marshall (1912). The investigations of Speight (1909) and Marshall (1909) in the subantarctic islands adjacent to New Zealand had led to the discovery of continental (plutonic) rocks therein, suggesting a former extension of New Zealand to these islands, which may have been continued till it united with Antarctica (itself a fractured continent), as the investigations of biologists have indicated.

Park (1910) supported Lemoine's view of the relation of New Zealand to Gondwanaland, declaring that "the Palaeozoic areas in Nelson, Westland, and Otago are merely the remnants of the fringe of the submerged Indo-African continent which appears to have existed up till near the close of the Secondary period." Professor Gregory (1910) was equally emphatic concerning the former unity of Australia and New Zealand. "Australia," he said, "is essentially a fragment of a great plateau-land of Archaean rocks. It consists in the main of an Archaean coign which still occupies nearly the whole of the western half of the continent, outcrops in north-eastern Queensland, forms the foundation of southern New South Wales, and is exposed in western Victoria and Tasmania, and in the western flanks of the Alps of New Zealand. These areas of Archaean rocks were doubtless once continuous, but they have become separated by the foundering of the Coral Sea, and of a band from the Gulf of Carpentaria to the lower basin of the Murray. The breaking-up of the old Archaean foundation began in Cambrian and Ordovician times . . ." These remarks prefaced a short outline of the palaeogeographic evolution of Australia. It might be remarked, however, that the Archaean age of the basement schists (to which might have been added those of New Guinea, the Louisades, and New Caledonia) cannot be considered as proved in all cases. Thus Browne (1914) has adduced evidence of the Ordovician age of the schists in southern New South Wales, and a like age for those of western New Zealand seems not improbable (*cf.* Benson, 1921).

Marshall (1911) pointed out that the comparison of the lithology of the Mesozoic rocks on the east and west of New Zealand did not give any clear indication of the direction from which the detritus forming them had been derived. He recognized the New Zealand–Tonga line as the boundary of the south-western Pacific, but, omitting all of Suess's second Australian arc except Fiji—in which Woolnough (1903, 1907) had found a continental basement of granite and slates with a north-north-east strike—Marshall drew the continuation of the margin of the Pacific along the outer zone of Suess's first Australian arc from the New Hebrides to New Britain, a palaeogeographic scheme for which there is zoogeographical support (Hedley, 1899).

In the same year Professor David (1911) discussed the structure of Australia and its gradual growth. His map illustrates a remarkable bending of the trend-lines about a Western Australian nucleus, being meridional in the south-eastern region, bending to the north-north-west in the centre of New South Wales, to the north-west in Queensland, and to the west in the ranges of central Australia and the Northen Territory. This simple scheme is complicated by the presence of a secondary nucleus or cross-folding in the Kimberley region (W.A.), and by a north-easterly branch of the virgation in South Australia, which strikes through western New South Wales and Queensland into the central portion of the coastal ranges of Queensland near Townsville. Briefly summarizing the geography of the past, he drew attention to the collapse and subsidence in early Mesozoic times of the collecting-ground of the great Permo-Carboniferous glaciers south-west of Tasmania, Victoria, and South Australia, and to the foundering of the eastern extension of Queensland in late Tertiary times, when "nearly the whole of the eastern watershed of the old Divide to the east of Cairns was sunk beneath the sea." He recognized that New Guinea was a lately folded region, where Cretaceous and even Tertiary rocks are highly disturbed, and that even in Australia tectonic movements are newer as New Guinea is approached. There is need for "a vastly extended series of observations both on land and sea before any satisfactory theory can be advanced as to the plan upon which this island-continent has been built."

Jensen (1911), acknowledging his indebtedness to Professor David's teaching and discussions, concluded that the Australian "continent moved in an easterly direction throughout the Palaeozoic, and by the end of the Permo-Carboniferous had captured more than the whole of the present continent, including many deep-ocean parts. . . . The sediments of one geological period became raised into a marginal buttress of mountain-ranges in the next geological period, the continent advancing a few hundred miles in the direction of the former sea in each geological period." He held that the dominant folding-force came in each period from the sea towards the land.*

Professor David (1914) again summarized the geology of Australia, and also that of Papua, and drew attention (David, 1914A) to the eastward movement of the basins of deposition of sediments in New South Wales, and of the axes of folding and of plutonic intrusions, in the three main Palaeozoic epochs of orogeny recognized by him.

Morgan (1915) was quite uncertain of the position of the land to which New Zealand formed the foreshore or continental shelf in Mesozoic times. As a result of Arber's declaration concerning the absence of *Glossopteris* from New Zealand he "regretfully dismissed" the idea that the continent lay to the west and was indeed the margin of Gondwanaland, though in Seward's (1914) opinion it was not yet necessary to do so. (See footnote, p. 41.)

Andrews (1916), while recognizing the easterly growth of Australia from the western gneissic massif (obviously only the eastern extremity of a still larger continental area), urged that the successive marginal foldings were due to the action of centrifugally (not centripetally) directed forces. His view is thus more or less in accordance with Suess's conception of the growth of the Asiatic continent and his suggestion in regard to Australasia, rather than that advanced by Hobbs (1914), which had been foreshadowed in regard to Australia by Professor David and Dr. Jensen. Andrews, moreover, suggested that New Guinea, New Caledonia, and New Zealand (Suess's first Australian arc) should be considered as distinct units, New

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* In regard to this, reference should be made to Oldham's (1921) comment: "The question of the direction from which the pressure came to which movement is attributed . . . involves a widespread fallacy that pressure can be one-sided. It permeates the great work of Suess, in which we find repeated reference to earth-waves advancing against resistant blocks." In the conceptions put forward by Oldham the word "overthrust" loses its old meaning, and may perhaps be replaced by the more closely applicable term "under-crawl." Oldham continues, "It may be convenient, however, to accept the common usage, incorrect though it be, when referring to the cause from which the displacements are due, so long as the language is understood to be merely descriptive." This criticism seems to go far to reconcile the divergence of statement in the views of David, Andrews, and Jensen.

Guinea having apparently grown from north-east to south-west, and New Zealand from south-west to north-east, though these areas are situated peripherally in regard to the Australian nucleus, and were affected in a measure by the same tectonic forces. In a later paper Andrews (1922) states that "New Guinea, the Solomons, New Caledonia, and New Zealand form the base of a great island knot which has its north-eastern extremity in Samoa. The individual island loops of this knot appear to be separated from each other and from the central portion, but are continental and confluent at the southern and western extremities. The knot itself would appear to arise as the result of the mutual interference of the Tethyan and Pacific controls." Schuchert (1916) declared that eastern Australia and New Zealand were separate geosynclines in Palaeozoic times, and that the latter remained such during Mesozoic, and (he unexpectedly adds) during Cainozoic times also. The area now occupied by the Tasman Sea he considers to have been mostly land at the commencement of Palaeozoic times, but that the sea steadily encroached thereon, advancing northwards, the connecting ridge between New Guinea and New Caledonia - New Zealand having been first sundered during Triassic times, when, by a curious error, he believes the last two regions to have been entirely land areas.

Wilckens (1917), acutely summarizing many contradictory accounts, suggested a comparison between the structure of the European Alps and those of New Zealand, which appeared to him as probably asymmetric and thrust to the south-west and west against the gneissic massifs of western Southland and Fiordland, and to the north-west against a foreland of folded Palaeozoic rocks, now mostly foundered beneath the Tasman Sea, except for the area forming the mountains of the north-western portion of the South Island, thus supporting part of Morgan's (1908) conception of the structure of the Southern Alps. A somewhat similar hypothesis was independently formulated by the writer (Benson, 1921).

Walkom's (1918) careful discussion concerns Mesozoic times chiefly. He conceives that at the commencement of this period a single undivided continental mass extended throughout Australasia, New Guinea, and Fiji, and that its fragmentation with permanent enlargement of the Pacific Ocean commenced at this time. Epicontinental Triassic rocks were deposited in New Zealand and New Caledonia, and a temporary northward extension of the southern ocean formed a gulf extending towards Sydney. The sea regressed somewhat in Jurassic times, the above-mentioned gulf disappearing, and the great subsidences with the formation of the Tasman Sea apparently are considered to have been somewhat later. This wide extent of land, which is assumed to have extended east of the present coast-line of Australia, has recently been named "Tasmantis," the term being defined as indicating "those portions of New South Wales and Queensland cut off from the remaining parts of Australia during the Carboniferous period [which] were parts of a separate land area which existed to the east of the Australian continent at least as far back as the beginning of the Devonian period, and probably as far as the beginning of the Palaeozoic era. This land became permanently united to the mainland of Australia towards the close of the Carboniferous period" (David and Süssmilch, 1919). In this conception of an important geosyncline separating, until the close of Carboniferous times, the Australian nucleus from that now subsided beneath the Tasman Sea we have a marked accord with Schuchert's (1916) suggestions.

Bartrum (1920) called attention to the widespread occurrence of pebbles of gneissic and plutonic rocks in the Mesozoic and later rocks of the North Island of New Zealand, and supported Park's (1893) inference that an ancient complex of plutonic and metamorphic rocks formed a land-mass near this region during Mesozoic times. The comparison of the work of Piroutet and Trechmann made by the present writer (Benson, 1921) supported the suggestion that the remarkable community of characters of the successive Mesozoic marine faunas of New Zealand and New Caledonia was such as to indicate that these regions were then part of a continuous coast-line. Farther north the former continuity of the islands of the Louisades Archipelago with the central chain of Papua as indicated by Clarke (1878) is confirmed by Stanley's (1921) researches.

The Tectonic Relationships of Australasia and Antarctica.

We may here pass on to consider the geological hypotheses of a former connection between Australasia and Antarctica, but omit, as in the above, the discussion of zoogeographic and phytogeographic evidence. The problem has been treated briefly by Mawson (1911) and Gregory (1912), and in more detail by David (1914B). All the region of South Victoria Land extending as far as Adelie Land appears to consist of an ancient gneissic or metamorphic complex, with some early Palaeozoic beds overlain by horizontally bedded Upper Palaeozoic and possibly Mesozoic sandstones invaded by immense sills of dolerite. The structure is thus somewhat analogous with the structure of Tasmania on the one hand, and of Brazil on the other. The Andean zone of folded mountains, with its eastern continental foreland and western zone of fragments of an ancient complex, appears to be represented in the Antarctandes, running through Graham's Land between the western fringe of islands and the eastern area of continental rocks for the most part foundered beneath Weddell Sea. The question as to the position of the representatives of the Antarctandes on the Australasian sector of the Antarctic has been variously answered. Though emphasizing the complete divergence in structure between the Antarctandes and the very continuous though narrow horst, the Royal Society Range, west of Ross Sea, Professor David supports Amundsen's suggestion that the latter may represent the continuation of the Antarctandes, and be in turn continued into southern New Zealand, the fractures bounding them being perhaps part of the same system as the Te Anau line of fracture. "Tectonically," he writes, "but not as regards folding, the evidence seems favourable for considering the great horst of South Victoria Land, in spite of the dissimilarity of its eruptive as well as of many of its sedimentary rocks with those of the American Andes, to be partly related to that great range, and possibly its fractures are not only continuous with those of the South American Andes on the one hand, but also with those of the subantarctic islands, like the faulted area of Campbell Island, and with those of the Alps of New Zealand on the other." The same suggestion had previously been made by Arldt (1907, pp. 497–98), who had, moreover, extended the range through New Zealand to incorporate the Kermadecs, Tonga, and Fiji.

Mawson (1911), while supporting the above view as the most probable, put forward an alternative conception. The Antarctandes of Graham's Land may continue towards King Edward VII Land as a folded range, and be separated by a comparatively low zone from the mighty ranges of South Victoria Land. "The dynamics which have effected the land-building of Tasmania and eastern Australia correspond more strictly with those whose sequence is illustrated in the plateau-massif of South Victoria Land; on the other hand, New Zealand and the archipelagoes of the adjacent Pacific Ocean are illustrations of the Andean tectonics in the Australasian region." With this second view Professor Gregory (1912) is in accord. "The information now available," he writes, "shows that South Victoria Land is more similar in structure to eastern Australia than New Zealand. Hence it appears most probable that the continuation of New Zealand and of the primary Pacific coast lies through King Edward VII Land towards Graham's Land." Subsequently Wilckens (1917) declared that the truncated fold-axis of Otago was the continuation of the "Antarctandes" of Graham's Land—the formerly continuous folded margin of the South Pacific Ocean. This view is also adopted by Kober (1921), who suggests, moreover, that an orogenic zone now submerged separates Antarctica from Tasmania and South Africa. This conception is opposed to previous ideas, and is put forward only tentatively, but finds some support in Du Toit's (1920) hypothesis of the conditions of intrusion of the dolerite sills in these three regions.

If we recall the twofold origin of the New Zealand Alps, these diverse views may be reconciled. While, with Gregory and Wilckens, we may consider as most probable the continuation of the axis of late Mesozoic orogeny through the Antarctandes and King Edward VII Land to New Zealand, we may well correlate the Cainozoic block-faultings and crust-fracturings which, crossing obliquely the older structure-lines (Cotton, 1916), have raised the New Zealand Alps as "a concourse of earth-blocks," with the fracturing, elevation, and subsidences that have separated Antarctica from Australasia and New Zealand, isolated the subantarctic islands, and caused the formation of the horst of the Royal Society Range and the trough of Ross Sea. This correlation is the more easy if we accept Henderson's (1917) view that the movements of block-faulting occurred at intervals during the Cainozoic period in New Zealand, which is not in any way incompatible with the trend of physiographic evidence in eastern Australia, as interpreted by Andrews (1910).

Professor David's (1914B) map of the trend-lines of the circumpolar region supports the suggestion that we may take the zone of the Otago schists and New Zealand Alps as representing the continuation from King Edward VII Land of the circumpacific folds. Such a zone would leave on the one side the plutonic rocks of the Campbell, Auckland, Snares, and Stewart Islands, and of the south-western extremity of New Zealand as representing fragments of the Australasia-South Victoria Land platform, while the schist of the Chatham Islands, and *perhaps* the granitic rocks of Bounty Island,* might be classed as the fragments of ancient lands corresponding with those which along the west coast of South America lie between the Andean zone and the Pacific. This hypothesis would not, therefore, attach much significance to Hector's (1870) comparison of the mica-schists of Chatham Islands and Central Otago. An alternative and perhaps preferable explanation would regard the crystalline rocks at least of the Chatham and Bounty Islands, together with the schists of Central Otago, as portions of the circumpacific orogenic zone.

* Speight compares this rock with that of Auckland Island, and believes that these two formed parts of a single massif.

Park (1910) has suggested that the Chatham Island ridge "is the eastern wing of the great synclinal in the trough of which lie the folded Mesozoic rocks that compose the Alpine divide and the parallel ranges of the Dominion lying to the eastward." The importance of the fracture-lines traversing and often limiting the New Zealand area, and their general obliquity to the axes of the Cretaceous folding, have been emphasized by Cotton (1916, 1917) and others. In particular we may note the continuance of the direction of the Tonga–Kermadec trench by the White Island–Tarawera–Ruapehu zone of volcanic activity. Indeed, the above-noted seismic activity in the Tongan trench and in the eastern suboceanic slopes of New Zealand (Hogben, 1914) may afford evidence of the continuance at the present day of the conditions that led to the formation of the south-western margin of the Pacific. Marshall's (1911) outline of the margin would bring into accordance with this the seismic activity in the New Hebrides indicated by the Rev. E. F. Pigot's seismometric investigations at Riverview, Sydney.

Turning to the palaeontological evidence of the relationships of Australasia through the Antarctic with South America, we note that Taylor (1914) has recognized close allies of South Australian species of Archaeocyathinae in a limestone from South Victoria Land, and Gordon (1920) has noted the presence of this group of organisms in a limestone dredged from a depth of 1,775 fathoms off the South Orkney Islands. Seward's (1914) recognition of *Glossopteris indica* in the specimens collected by Captain Scott and Dr. Wilson permits us to class Antarctica as part of the congeries of continents known as Gondwanaland, and to infer its close association in Permian times with Australia on the one hand, and on the other with the Falkland Islands and eastern South America, where the same form occurs. Professor David (1914) indicated that "the close affinity of the flora of Graham's Land to that of Australia implies a land connection between Antarctica and Australia in Jurassic or Trias-Jura time." Arber (1917), while declaring that *Glossopteris* was absent from New Zealand, and that therefore the New Zealand area did not in Permian times contain a land-mass connected with Gondwanaland, added that there was in Trias-Jura times so great a community between its flora and that of Australia and Graham's Land as to indicate that all three land areas were intimately connected. With this Walkom (1918) concurred. Woods (1917) showed that some community occurred between the Senonian faunas of New Zealand and South America, but this was emphasized in the papers of Trechmann (1917) and Wilckens (1920), the latter declaring that South America, Antarctica, and New Zealand formed at that period part of the continuous southern coast of the Pacific Ocean.

We may here note without discussion Wegener's (1922) remarkable hypothesis. In a sketch-map of the Carboniferous world he shows Antarctica, South America, Africa, peninsular India, and Australia crowded together, while a marginal shallow sea covers the region of New Guinea and New Zealand. This connection, he indicates, was maintained up to the Jurassic times, while that of Australia, Antarctica, and South America persisted until as late as Eocene times. "The general westward movement of the continents is evidenced by many striking features . . . Since the frontal resistance must have a much greater influence for smaller masses than for large, these smaller masses will be left behind in the general westward movement. Thence comes . . . the separation, long ago completed, of the former Australian coastal chain which now forms New Zealand."

THE POSSIBILITY OF DETAILED STRATIGRAPHICAL CORRELATION OF AUSTRALASIAN GEOLOGICAL FORMATIONS.

Before discussing the history of the various geological epochs in Australasia it seems well briefly to consider how far this is or may be determined in detail, for opinion has varied on this point among workers on Australasian fossils. McCoy (1866) believed in "the fact of the specific identity of the marine fauna of the whole world during the most ancient Palaeozoic periods." De Koninck (1877), while recognizing endemic Australian species, supported McCoy by referring also many Australian forms to European species of Silurian, Devonian, or Carboniferous age. The validity of these identifications is, however, often open to grave doubt, and Etheridge (1891) advised that no Australian fossils be referred to European species unless on the clearest possible evidence, and that, moreover, great caution should be exercised "in assimilating our geological subdivisions strictly with those of the Old World." Johnston (1887) argued that fossil plants can afford *no* satisfactory clue to the correlations of strata with those of a distant region: "All that palaeontology can prove is local order of succession." Tate (1901), while arguing against homotaxy, inclined to the extreme view that each of the "permanent" continents had originally the same primitive fauna, the approximately parallel and *pari passu* evolution of which produced the present provincially specialized yet broadly similar faunas, though exact intercontinental age-correlations were impossible. Hall (1902A) gave a general support to the latter statement, concluding that "It is possible in most cases to refer our Australian strata definitely to one or other of the great European periods, but it is not always so. Terms such as 'Permo-Carboniferous' and 'Trias-Jura' express a mingling of faunas representing two distinct northern systems, and are not cloaks to hide our ignorance. This mingling is not necessarily due to the Australian systems being intermediate in age, and being the representative of the great unconformities of the Northern Hemisphere, but probably in a great part follows from differential rates of migration and points to a northern or southern place of origin of the transgressing forms." Later (1909) he remarked, "At present we are unable to subdivide the Upper Ordovician of Australia. It is quite unsafe to apply the facts of distribution of Europe and America to our rocks, in spite of definite opinions to the contrary." Somewhat similar views have been current in New Zealand. Thus Hector (1886) and Park (1910) held there was "a curious commingling of Permo-Carboniferous and Upper Triassic forms"; while Marshall (1912) emphasizes the association of the Jurassic forms *Trigonia* and *Gryphaea* with an apparently Triassic assemblage. As recently as 1919 Etheridge, in describing the Cambrian trilobites of Australia, purposely refrains from adopting the terms "Lower" and "Upper" Cambrian to indicate their horizon, "believing that we know too little as yet of the Cambrian strata throughout Australia and Tasmania to warrant the use of stratigraphical subdivisions employed either in Europe or America," and therefore he records merely "the opinion of others." Dun also (1919) cites several instances of the apparent mingling of forms—the occurrence of Jurassic and Cretaceous types in the Rolling Downs beds, the wide range (Carboniferous to Triassic, *fide* Woodward, 1908) of affinities of the fossil fish in the probably late Triassic shales near Sydney, &c.—reaching the conclusion that "in this region the European standard of palaeontology cannot be followed."

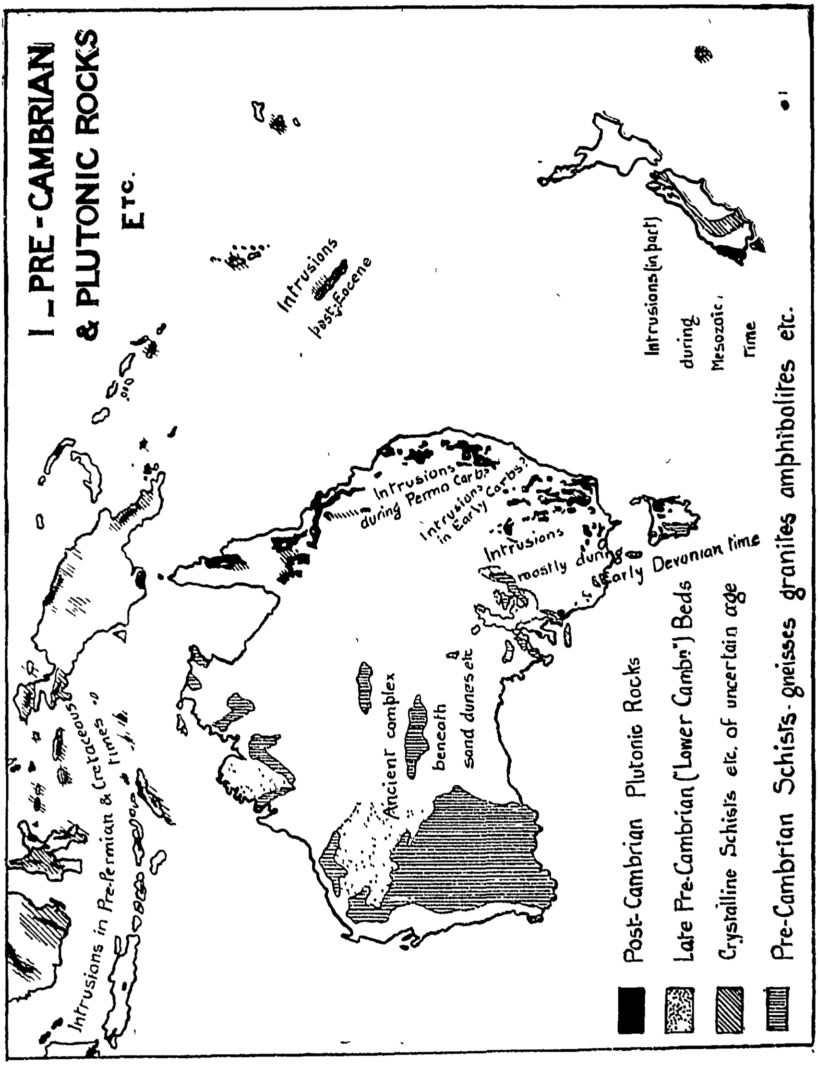
But, while we must not be unmindful of the difficulties, it may be questioned whether the emphasis placed on them has not unduly discouraged workers from attempting careful zonal collecting and investigation of faunas, more fully to test the possibility of detailed interpretations of the Australian geological record. Such recent work as has been done seems full of promise. Walcott's (1916) comparison of the Lower Cambrian fauna of Australia with that of eastern Asia, and Keble's (1920) elaboration of Hall's graptolite zoning of the Lower Ordovician, are cases in point. Ruedemann (1904) has indicated that the zonal sequence of the graptolite fauna of New York in so far as it departs from that established in Europe approximates to that of Victoria. Further, though, as Schuchert (1910) has pointed out, the older generalized determinations of fossils and their reference to cosmopolitan species are not of great value to the modern palaeogeographers, and are usually much modified on revision, the facts, such as they stand at present, in regard to the Devonian period are at least strongly suggestive of many interesting conclusions. The need for the compound term "Siluro-Devonian" has vanished. So, too, the term "Permo-Carboniferous" is gradually succumbing to the detailed inquiries of Professor David and his associates; while the term "Trias-Jura" has been robbed of the significance Hall attached to it (as indicating a real admixture of forms) by the important work of Trechmann and Wilckens on the Triassic marine rocks of New Zealand, of Piroutet on those of New Caledonia, of Arber on the Mesozoic flora of New Zealand, and of Walkom on that of Queensland ("the most significant publication of the year's general palaeobotany"),* which have shown that when the fossils are accurately determined on modern lines, and the erroneous identifications have been eliminated, age-determinations and stratigraphical correlations may be made with considerable precision. So, too, in New Zealand the Cretaceo-Tertiary hypothesis seems to have been overthrown, and the work of Woods, Wilckens, Trechmann, Chapman, and Marshall has indicated the presence of an Albian fauna, and much more definitely a Senonian fauna also, quite distinct from the Tertiary fauna. It must nevertheless be recognized that the provincial character of Australasian stratigraphy has been established for some periods, and the correlation of stratigraphical subdivisions, with extra-Australasian strata, is still very difficult in the Upper Ordovician rocks, the "Permo-Carboniferous" and "Lower Cretaceous"; while in the Cainozoic the local specialization of the stratigraphical and palaeontological record seems to prevent as yet even the detailed comparisons of strata in Australia and New Zealand.

We may nevertheless keep well in mind the words of one under whom the writer was privileged to study: "In the case of stratigraphical geology, if we were compelled to be content with the correlation of systems only, and were unable to ascertain which of the smaller series or stages were contemporaneous, but could only speak of these as homotaxial, we should be in much the same position as the would-be antiquary who was content to consider objects formed by the Romans as contemporaneous with those of mediaeval times. Let me urge my countrymen to continue to study the minute subdivisions of the strata, lest they be left behind by the geologists of other countries to whom the necessity of this kind of study is apparent, and who are carrying it on with great success" (Marr, 1896).

In the present paper the writer, who can make no claim to expert palaeontological knowledge, has considered merely the literature as it now stands, without attempting to revise the data or to discuss pros and cons,

* M. C. Stopes, *Science Progress*, vol. 14, p. 347, 1919.

and has drawn from it such tentative inferences as seem justifiable at the present time, in the hope that such a summary may help to direct attention to this broad aspect of geology. The immediate need is for careful revision of much of the palaeontological data, the more exact determination in the field of the horizon or stratigraphical range of the various fossils, and the palaeogeographic consideration of the lithology of the rocks which contain them.



THE GEOLOGICAL HISTORY OF AUSTRALASIA.

The foundation of the Australasian region is indicated as far as possible by map 1, which shows the areas of exposed definitely pre-Cambrian rocks, the probably late pre-Cambrian Nullagine rocks of Western Australia and the possibly late pre-Cambrian or so-called "Lower Cambrian" of South

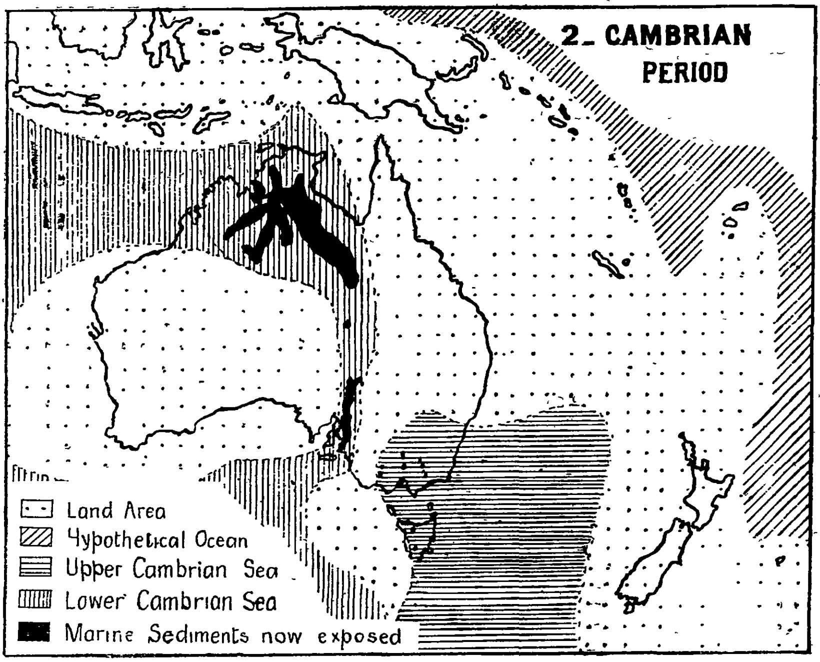
Australia, the metamorphic complexes of uncertain age, and the post-Cambrian granites and diorites. In the palaeogeographic maps 2–11 there is inevitably great uncertainty concerning the former distribution of sea and land in the vast and now submerged areas east of Australia, and the outlines are merely suggestions which accord with some of the facts of distribution of fossils or rock-types, and are not opposed by any other facts known to the writer. These do not depart more than seemed desirable from the earlier suggestions of Schuchert for the Palaeozoic times and Walkom for the Mesozoic. The bulk of the literature concerning the particularly intricate region of the Malay Archipelago and New Guinea, especially the fine work of Abenadon, Brouwer, Molengraaff, Verbeek, Wanner, and Wichmann, has not been accessible to the writer, and the sketches are based on such literature as is cited herein.* Since the oldest rocks in this region of which the age is definitely determinable are Permian, the palaeogeography of earlier periods in this region is purely speculative. Under the most favourable circumstances the accurate palaeogeographic charting of this region would be wellnigh impossible. We have but to recall Professor David's (1914) comparison of the relation of New Guinea to Australia with that of the Himalayas to India, or Brouwer's recent summary (1921) indicating the alpine character of the overthrust-folding of the eastern Malayan islands, to realize that the region must have been formed as a series of anticlines in a broad geosynclinal zone, in which, as in its prototype, extensive and frequent geographic changes must have occurred during successive orogenic movements. The same was probably the case in the Solomon Islands and New Hebrides where "cordilleran" rocks have been found.

Cambrian.

In the Cambrian period a continental mass stretched from the west of the present coast of Australia at least to the western borders of the four eastern States. This continuous mass was, however, broken by a broad syncline which extended meridionally throughout the central zone of the present area of South Australia, flanked by the ancient complex of Eyre Peninsula to the west and that of Broken Hill and Tasmania to the east. This synclinal zone seems to have continued from pre-Cambrian times. In the Adelaide region, unconformably on a probably Algonkian complex of schists invaded by diorites and syenites, there is a thick series of sediments, basal grits, phyllites with interstratified limestones and quartzites followed by thick tillites, banded possibly "varve"-like (Tapley's Hill) shales, and further limestones and shales. All of these Howchin (1918) considers of Lower Cambrian age, believing them to be conformably overlain by the Archaeocyathinae limestones, which he considers of Upper (or possibly Middle) Cambrian Age, and shows to transgress beyond the limits of the sediments mentioned, and to lie on basal grits following directly on the ancient crystalline complex at Ardrossan, in Yorke's Penisula, directly west of Adelaide (Howchin, 1918A). Schuchert (1914) holds that the tillites, &c., are pre-Cambrian, and that a disconformity must exist between these and the Archaeocyathinae limestones, which he considers to be definitely Lower Cambrian. This last is the view of Walcott (1916), who has examined

* While this paper was in the press access was obtained to the valuable summaries of the geology of the eastern and western portions of the Malay Archipelago by Brouwer (1919) and Van Es (1919) respectively. Time has not permitted a complete study of these, but some data therefrom are incorporated below.

a representative collection of fossils, and it must therefore be considered the more probable.* The fossiliferous limestone makes a large reef-like mass at Blinman, four hundred miles north of Adelaide, and also occurs to the south of that city. Here flourished some thirty-seven species of Archaeocyathinae, *Kutorgina*, *Nisusia*, *Micromitra*, *Eoorthis*, *Huenella*, *Obolella*, *Stenotheca*, *Ophileta*, *Hyolithes*, *Salterella*, *Olenellus ?*, *Redlichia*, and *Ptychoparia* (Etheridge, 1890, 1919; Taylor, 1910; Walcott, 1916; Howchin, 1918). No fossils are found in the overlying sandstones, the current-bedding and red colour of which suggest that they were laid down as the Lower Cambrian sea regressed from this South Australian trough.



Besides this transgression and regression of the sea into and from the South Australian trough there was a far more extensive flooding of the northern portion of the Australian continental massif. This appears to have been somewhat irregular in the commencement of Cambrian times, and there was laid down a very extensive series of conglomerates, grits, and sandstones, with some shales, followed by limestones now more or less dolomitic and silicified. This generally slightly undulating but locally strongly warped series extends from the Kimberley district, in the northern part of Western Australia, across the Northern Territory into western Queensland. The sediments contain *Salterella*, *Agnostus*, *Microdiscus*, *Ptychoparia*, and a *Redlichia* formerly described as *Olenellus ? forresti* (Etheridge, 1895, 1897, 1919; Woolnough, 1912; Basedow, 1914–15; Jensen, 1915; Maitland, 1919). There is no evidence to indicate whether the sea extended farther east than the Barkly Tableland, but it was

* Compare also the relationship of the Lower Cambrian rocks on the Yangtse-kiang to the underlying glacial beds, which are "very probably" of Algonkian age (Walcott, 1914).

probably connected with that in the South Australian trough. The possibility that this sea extended south-westwards to the Macdonnell Ranges was suggested by Howchin (1914) on account of the occurrence therein of *Cryptozoon* in dolomitic limestones which according to Chewings lie unconformably beneath fossiliferous Ordovician rocks.

In regard to the origin of this fauna the evidence is as yet rather fragmentary; indeed, Reed (1910) and Haug (1911) considered that no palaeogeographical conclusions of much value could be based on it. Since they wrote, however, Walcott (1913, 1916) has examined representative Australian forms, and made valuable comments on the bearing thereon of the Cambrian faunas of Asia. "The Lower Cambrian Man-t'o *Redlichia* fauna . . . is, so far as known, very distinctive, and confined to the Asiatic continent and Australia. Its transgression over eastern and south-eastern Asia was somewhat later than the transgression in the Siberian area now occupied by the Lena and Yenesei Rivers. . . . The distribution of the *Redlichia* of the *R. noetlingi* form serves to demonstrate that the transgressing Lower Cambrian sea that contained *Redlichia* was confined to eastern and south-eastern China and northern India. The presence of *Redlichia*-like trilobites in southern and western Australia indicates that there was a direct connection between the Punjab Lower Cambrian sea of India and the shallow seas about the Australian area. There is no record pointing to a connection between the Punjab-Man-t'o sea and the Lower Cambrian seas of northern Siberia or western North America." In another sentence, however, he states, "The Siberian fauna is, however, that of the Lower Cambrian of Australia, Sardinia, and North America" (in which Archaeocyathinae are present). According to H. Mansuy's (1912) work, the Lower Cambrian *Redlichia* fauna is present also in Yun-nan. The fact that the Archaeocyathinae are more abundant in South Australia than in any other part of the world may suggest that it was a centre of evolution and dispersion for these forms, but this is not certain.

It was perhaps during the middle part of the Cambrian period (Tilley, 1919) that there occurred these extensive crust-movements and plutonic intrusions which are most strongly indicated along the eastern slopes of the Mount Lofty Ranges, and possibly have affected the region stretching then north-eastward to the western side of the Broken Hill area, though the main orogeny here may have been more ancient. Certainly the coast-line of Australia in Upper Cambrian times ran from western Tasmania into western Victoria, and then probably turned north-east or eastwards. In Tasmania littoral sandstones are found in the Florentine Valley in the centre of the southern half of the island (*Ptychoparia* and *Dikellocephalus* occurring in these), while near Latrobe (Caroline Creek) there is a friable sandstone containing the same genera together with *Leptaena, Orthis, Raphistoma,* and *Ophileta* (Etheridge, 1882, 1919; Twelvetrees, 1909).

The Upper Cambrian (Heathcotian) rocks of Victoria are more widespread, and were laid down in deeper water and farther from the littoral. They consist of shales and radiolarian cherts with *Protospongia* associated with spilitic lavas and tuffs. Limestone is rarely present. The fossils present include the purely Cambrian forms *Lingulella, Acrothele, Billingsella, Eoorthis,* and *Huenella,* together with those of a more Ordovician aspect, *Leptobolus, Herbertella, Eostrophomena,* and *Clitambonites.* The trilobites are represented by *Agnostus, Dinesus, Crepicephalus, Notasaphus,* and

Ptychoparia. These beds are strongly folded and followed conformably by Lower Ordovician rocks (Skeats, 1908; Chapman, 1904, 1911, 1918A; Teale, 1920)—indeed, it is very difficult to draw a line of separation between them. Keble (1920) holds that the lower part of the Lancefieldian beds, considered by Hall to belong to the base of the Ordovician series, is in reality Upper Cambrian. It contains *Bryograptus* and *Clonograptus* as the chief fossils, with some *Tetragraptus,* while in the upper part of the same beds *Tetragraptus* and *Didymograptus* are the dominant genera. Chapman (1918A) has noted the presence of *Acrotreta,* usually a Cambrian brachiopod, in both the Heathcotian and lower Lancefieldian beds.

In regard to the source of this fauna little can be said at present. The Upper Cambrian faunas in general were much less provincial than those of Lower Cambrian times, and in particular there was a merging of the North American and Asiatic faunas (Walcott, 1913). It is noteworthy that *Dikellocephalus* is as generally characteristic of the Upper Cambrian of America as is *Olenus* of that of Europe, so that the Australian fauna may thus be less related to the European than to the Asiatic-American fauna.

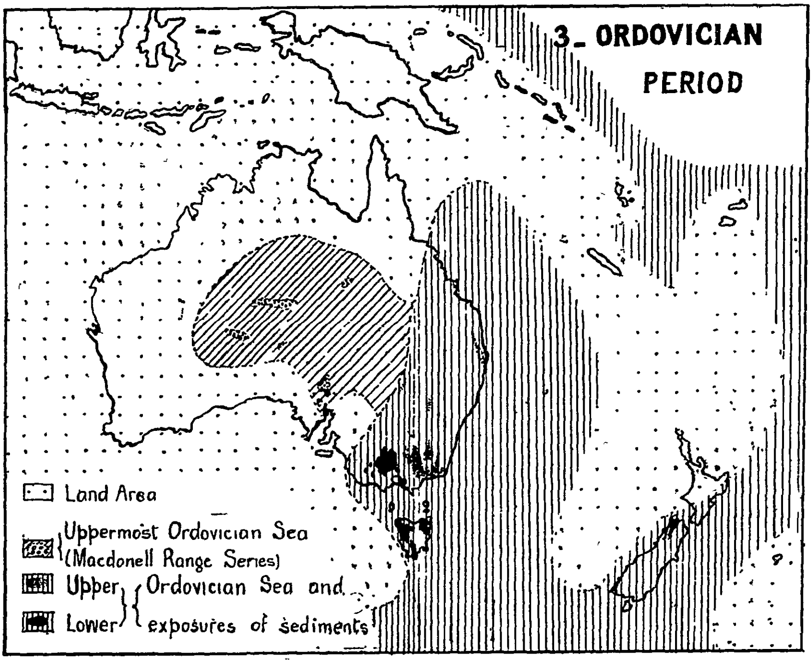
No New Zealand rocks have been proved to be of Cambrian age on definite palaeontological grounds, though if the Upper Cambrian age of the basal Lancefield beds is sustained it is probable that the graptolite slates of Preservation Inlet, in the south-western extremity of the South Island—which Hall (1915) referred to the basal Lancefield beds because of the occurrence of *Bryograptus, Clonograptus,* and *Tetragraptus* in them—should also be of Upper Cambrian age. According to Park (1921), an extensive series of unfossiliferous sediments lies stratigraphically beneath these.

Ordovician.

The coastal zone now passed through western Tasmania, Victoria, and New South Wales, bending north-eastwards into Queensland. In Tasmania the littoral deposits were breccias and sandstones and slates with indefinite graptolitic markings (*Callograptus ?*). In the Permo-Carboniferous glacial till at Wynyard, in the north-west of the island, erratics presumably derived from these contain *Tetragraptus, Phyllograptus,* and *Diplograptus ?* as determined by Hall (Twelvetrees, 1907), also *Siphonotreta,* and *Caryocaris* (Chapman, 1907), while farther to the east the unfossiliferous slates of the north-eastern portion of the island may be the off-shore deposits of the same age. Extensive masses of intrusive and effusive keratophyric porphyroids, &c., form the closing members of this series. They run meridionally through the western portion of the island, and these effusive rocks appear to have been in part submarine, in part subaerial. Hills considers them the product of a coastal volcanic zone (private communication*). In Victoria the littoral deposits are scarcely recognizable, but the Lower Ordovician graptolitic slates are well developed in the western half of the highlands of Victoria, being for the most part covered by the Upper Ordovician slates in the eastern half of the highlands. Both upper and lower slates in several regions contain remarkable phosphatic breccias in which wavellite has been found. In New South Wales we may perhaps consider as littoral Ordovician rocks the strongly folded series of conglomerates and sandstones at Cobar merging eastward into more slaty and even cherty

* See also Hills (1921). The writer is greatly indebted to Mr. Hills for furnishing him with a *résumé* of this useful paper in advance of publication.

rocks, which Andrews (1913) considers to be pre-Silurian. These are followed eastwards by a widespread series of graptolitic slates and (rarely) radiolarian cherts, which, however, belong entirely to the Upper Ordovician. In the north-eastern corner and extending thence into Queensland are the very altered phyllitic rocks known as the Brisbane schists, and these, together with some slaty rocks near Rockhampton, contain phosphatic minerals which, in the absence of better evidence, has caused them to be grouped with the Ordovician rocks of Victoria (Dunstan, 1916). The graptolitic Lower Ordovician rocks in Victoria were divided by Hall (1899, 1914) into four major groups, termed, in ascending order, the Lancefieldian, Bendigonian, Castlemainian, and Darriwillian beds respectively. Harris (1916) and Keble (1920) have divided parts of this succession into numerous subzones, the latter finding these to be of considerable economic



significance in the study of the Bendigo region. Characteristic genera of the Lower Ordovician beds are *Clonograptus*, *Bryograptus*, *Tetragraptus*, *Didymograptus*, *Phyllograptus*, and *Loganograptus*. Of these the first two abound in the (possibly Upper Cambrian) lowest portion of the Lancefieldian beds, wherein the second two are subordinate, but the first pair also ascend as high in the series as the Castlemainian beds, which is on a higher horizon than the highest to which they ascend in Europe and America, where *Clonograptus* barely enters the Ordovician formation. The Upper Ordovician faunal succession has not yet been so closely studied and subdivided, but is well exemplified in eastern Victoria—see Whitelaw (1916). Harris and Crawford (1921)—and is the only type of fossiliferous Ordovician rock in New South Wales. Slates, more or less cherty, and jasperoids occasionally radiolarian, occur with andesitic (or spilitic) lava-flows. The chief fossils are *Protospongia, Climacograptus, Dicellograptus, Dicranograptus, Didymograptus, Diplograptus, Glossograptus,* and *Retiolites;* while *Obolella, Hyolithes, Trinucleus,* and perhaps *Agnostus* are present (Hall, 1900, 1902, 1909, 1920).

Lower Ordovician rocks form the oldest fossiliferous formations in New Zealand, and consist of greywackes, some limestone, and graptolitic slates apparently merging into mica-schists. In the south-western extremity of New Zealand (Preservation Inlet), originally described by McKay (1896), the slates contain *Clonograptus, Bryograptus,* and *Tetragraptus,* for which reason Hall (1915) correlates them with the lowest portion of the Lancefieldian beds in Victoria and considers them of basal Ordovician age, though, as pointed out, it is possible they should be classed as uppermost Cambrian. The slates seem to pass down into mica-schist and these in turn into the so-called "granitic gneiss," a sillimanite-paragneiss which Park (1921) suggests may represent Cambrian sediments, but in such complexes the appearance of superposition and relative degree of metamorphism cannot safely be taken as proving relative age. In the north-west of the South Island of New Zealand the Lower Ordovician rocks are much more widespread, though similar in lithological character (Bell, 1907). The genera present in the fossiliferous rocks are *Bryograptus, Dichograptus, Didymograptus, Loganograptus,* and *Tetragraptus.* The determinations made by Mrs. Shakespear (1908) and Hall (1915) concur in indicating the presence here of two zones belonging to the middle portion of the Lower Ordovician. Recently Professor Park has discovered a further series of graptolitic slates at Cape Providence, twelve miles north-west of the older graptolitic slates at Preservation Inlet. His preliminary determinations of the forms present indicate that they are approximately coeval with those last mentioned in the northern end of the Island, and with the Castlemainian beds of Victoria. (Private communication.)

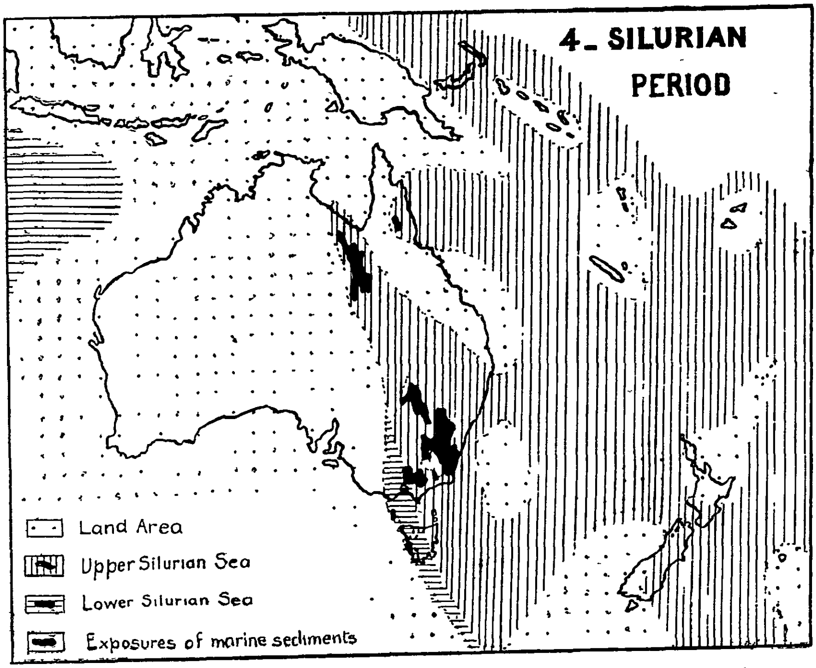
In regard to the derivation of the Australasian graptolitic fauna, it may be said at once that the forms present are those of the cosmopolitan pelagic types found in Europe, New York, Bolivia, and recently in Peru (Lapworth, 1917), but that in those features in which, according to Hall, the Victorian (and also the New Zealand) zonal succession of forms departs from the European succession it accords with that proved by Ruedemann (1904) to be present in New York. It would appear, therefore, that the conditions obtaining in Upper Cambrian times were not wholly reversed during the Ordovician period.

It is difficult yet to trace the sequence of events in the latter part of the Ordovician period. A strong folding doubtless occurred, and land was subjected to erosion extending throughout the present region of Australia, for where the Silurian rocks are seen in contact with the Ordovician rocks in New South Wales—*e.g.*, the Shoalhaven River, as described by Woolnough (1909)—there is a marked unconformity between them. Indeed, connected with this folding there appears to have been a considerable intrusion of granites which have caused profound metamorphism, and according to Browne's observations (1914) in the south-eastern angle of that State have converted extensive masses of the Ordovician slates into mica-schists. The relationship of these to the supposed pre-Cambrian schists of eastern Victoria is not yet definite. The unconformity between the Ordovician and Silurian slates in central Victoria is not so marked. Loftus Hills (1921) has made clear their relationship in western Tasmania. The basal West Coast Range conglomerate, a thick and continuous series, rests unconformably on the Ordovician slates and porphyroids, fragments of which it includes, and is followed by a thick annelid-bearing sandstone; above this is the fossiliferous Gordon River limestone, the fauna of which indicates an age transitional between the Ordovician and Silurian. To this we return shortly, noting, however, that its presence indicates that the orogeny occurred during Upper Ordovician time, and the subsequent transgression commenced in the concluding part of the Ordovician period. This transgression was at first very extensive: indeed, it covered at first an area perhaps as widespread as the Lower Cambrian transgression. A shallow sea extended through south-western Queensland (Jack, 1897) and the Macdonnell Ranges, where it laid down a short cycle of gently flexed sediments. The basal sandstones are followed by fossiliferous argillaceous limestones and mudstones, which are succeeded in turn by ripple-marked and current-bedded sandstones (Tate and Watt, 1896). The quartzites, &c., north of Spencer Gulf in South Australia may also be part of the same series. According to Maitland (1919), we may perhaps group as probably coeval with these the almost horizontal unfossiliferous sandstones, dolomitic limestones, &c., of the Nullagine series, which, overlying a crystalline complex, cover the greater part of the northern moiety of Western Australia, but for the present they are omitted from consideration herewith. The fossils present in the Macdonnell Ranges include the following genera: *Hyalostelia, Orthis, Isoarca, Palaearca, Pteronites, Eumena, Raphistoma, Ophileta, Orthoceras*, and *Asaphus*. Tate (*op. cit.*) thought that these indicated a "Caradocian" (uppermost Ordovician) age, and that they were approximately coeval with the Gordon River limestones, though possessing little faunal community therewith. Concerning them Reed (1910) remarks, "Though we are not able at present to judge precisely of the affinities of the Australian Ordovician neritic forms, for they are not very marked, yet the relations of the species seem to be with north European forms." It would seem, therefore, as if the late Ordovician orogeny had been accompanied by such changes in the geography of the other parts of the world as to open the Australian seas to the stream of European life-forms which dominated the fauna of the succeeding Palaeozoic periods. The marine incursion into central and western Australia was, however, but brief, and regression must have occurred by the close of the Ordovician period, but the sea continued in the eastern States, where a continuous succession of Silurian rocks was laid down.

Silurian.

The Gordon River limestone, with its transitional Ordovician-Silurian fauna, appears as the oldest of the Silurian fossiliferous formations in the eastern States. Among the forms present are *Favosites, Tetradium* (which was at first referred to *Archaeocyathus*), *Halysites, Pleurodictyum, Dalmanella, Camarotoechia, Pentamerus, Trematospira, Rhynchotreta, Trochonema, Raphistomina, Tentaculites, Orthoceras, Asaphus, Illaenus, Cromus*, and *Calymene*. These fossiliferous beds are succeeded by sandstones and slates with *Orthis, Spirifera, Pentamerus*, and *Cardiola*, which are probably equivalent to the Lower Silurian beds of Victoria (see Etheridge, 1882, 1896; Dun, 1910; Chapman, 1919). Silurian beds are represented in northern Tasmania by the Chudleigh limestone, which contains *Halysites* (Etheridge, 1898).

The extensive fauna of the Silurian rocks of Victoria has been studied in detail by Chapman (1908, 1913, 1916). The Lower Silurian (Melbournian) beds occur in the centre of Victoria, running northwards from Melbourne. They consist of mudstones and sandstones exhibiting a mixed Wenlock and Llandovery fauna. Some 135 species have been recorded. The archaic trilobite *Ampyx*, and an *Illaenus* allied to an Upper Ordovician form, are associated with *Monograptus priodon, Botrycrinus, Palaeaster, Palaeechinus, Camarotoechia, Lingula, Nucleospira, Rhynchotreta,* and many molluscs. The Upper Silurian (Yeringian) beds lie rather more to the east than the former, extending into Gippsland. They comprise sandstones, mudstones, and limestones, from which 200 species of fossils have been obtained with the facies of



the Wenlock limestone and Ludlow shales. *Monograptus riccartonensis* and *M. convolutus, Favosites, Heliolites, Clathrodictyon, Actinostroma, Atrypa, Chonetes, Orthis, Pentamerus, Platystrophia, Stropheodonta,* numerous molluscs. *Bronteus, Cheirurus, Encrinurus, Phacops,* and many ostracods occur in this rich fauna.* In the west of Gippsland there are shales containing *Panenka, Styolia, Tentaculites,* and *Kionoceras* in a small fauna of eighteen species which may represent a still higher horizon in the Silurian series; but Whitelaw (1916) has shown that these are overlain by

* An interesting feature in the Upper Silurian (Yeringian) beds is the abundance therein of corals such as *Michelinia* and *Phillipsastraea*, which are more abundant in the Devonian than in the Silurian rocks of the Northern Hemisphere, and especially of *Pleurodictyum*, which is there confined to the Devonian beds. "This constrains us to assume that certain forms of life appeared among the Gothlandian and Wenlock facies earlier in the Southern than in the Northern Hemisphere, and migrated thence during the transition period between Silurian and Devonian epochs" (Chapman, 1920).

further conglomerates, grits, sandstones, and shales with a very late Silurian fauna, if not actually transitional into the Devonian. Chapman (1913) compares the fauna of the last two formations with that of the Helderberg series in North America.

Silurian rocks form the most widespread of the Palaeozoic formations of New South Wales, and include representatives of both the lower and upper divisions, as was pointed out by De Koninck in 1877, and these correspond to Melbournian and Yeringian series respectively of Victoria. The palaeogeographic conditions, however, seem to have been somewhat complex, and we will not here attempt a detailed analysis of them. The eastern margin of the continental nucleus extended through the region of the Western Plains, and littoral conglomerates lying unconformably on the Ordovician (?) rocks are widespread near Cobar (Andrews, 1913). They also occurred farther to the south-east in the Forbes-Parkes district (Andrews. 1910A), and the Yass district (Shearsby, 1911), but are absent elsewhere, "while the general occurrence of alternating sandstones, claystones, and limestones indicates tranquil deposition in a comparatively narrow sea" (Süssmilch, 1914). The most extensive sequence of fossiliferous beds is in the Yass district. In the shales, sandstone, and limestone of the lower portion, *Tryplasma, Pachypora, Cyathophyllum,* and *Halysites* occur, with some brachiopods; while in the upper portion there is a very extensive Wenlock fauna, enumerated by Shearsby, containing many genera of corals, brachiopoda, mollusca, and trilobites, of which the following are present: *Phacops, Dalmanites, Hausmannia, Calymene, Cheirurus, Ceratocephalus, Crotocephalus, Sphaerexocus, Staurocephalus, Odontapleura, Cyphaspis, Harpes, Illaenus, Bronteus, Lichas, Proetus* (see De Koninck, 1877, 1898; Etheridge and Mitchell, 1891–1917; Harper, 1909; Shearsby, 1911). To the north-east of this littoral zone is one in which the dominantly phyllitic Silurian beds are intercalated with lenticular masses of limestone, notably those in the south-east of the State, and at Wombeyan, Jenolan, Bathurst, Orange-Molong, and Wellington. These are probably all to be referred to the Upper Silurian period. *Pentamerus (Conchidium) knightii* var. *stricta,* which Tscherneyschew compares to *P. vogulicus,* is characteristic of these, and with it are abundant stromatoporoids, *Favosites, Heliolites, Halysites, Pleurodictyum, Zaphrentis, Tryplasma, Cyathophyllum,* &c., sometimes with *Orthoceras* and *Astylospongia.* Some forms had a wide range, whilst others were confined to limited areas; but the meaning of this distribution has not yet been fully investigated (see Süssmilch, 1906, 1914).

In Queensland the only definite evidence of Silurian rocks has been found near Chillagoe, where the limestones contain *Favosites, Heliolites, Halysites, Cyathophyllum, Campophyllum,* and *Spongophyllum,* with *Rhynchonella* and *Pentamerus.* Ball (1918) thinks the slates and limestones of the Cloncurry district of north-western Queensland may also be of this age. They contain *Actinoceras* and *Orthoceras, Orthoceratites* and *Stromatopora* (Etheridge, 1911; Dunstan, 1920).

Silurian rocks are known in New Zealand also. At Reefton, in the north-west of the South Island, they are of a varied littoral character (Henderson, 1917); but at the Baton River, eighty miles to the north-east, are found the deep-water sediments, calcareous argillites. Thomson (1913) has enumerated Hector's provisional determinations of the fossils of these localities. There is naturally some difference in the faunal facies in the two regions, but so far as is indicated by the provisional (unpublished) determinations of Dun and Chapman both are comparable with the Upper

Silurian faunas of south-eastern Australia. The presence of a *Pleurodictyum* allied (*fide* Chapman) to *P. megastomum* Dun of the Australian Upper Silurian beds is an interesting connecting link. The earlier attribution of the Reefton beds to the Lower Devonian period seems to be quite unwarranted.

Summarizing the features of the Australian Silurian faunas, Reed (1910) remarks, "The mixture of Periarctic and Bohemian forms is the distinctive mark of the Silurian fauna of this region, while in New Zealand there is an intermixture of European and North American species with local elements."* As the latter statement rests only on Hector's provisional determinations made forty years ago, judgment concerning it must be suspended.

Devonian.

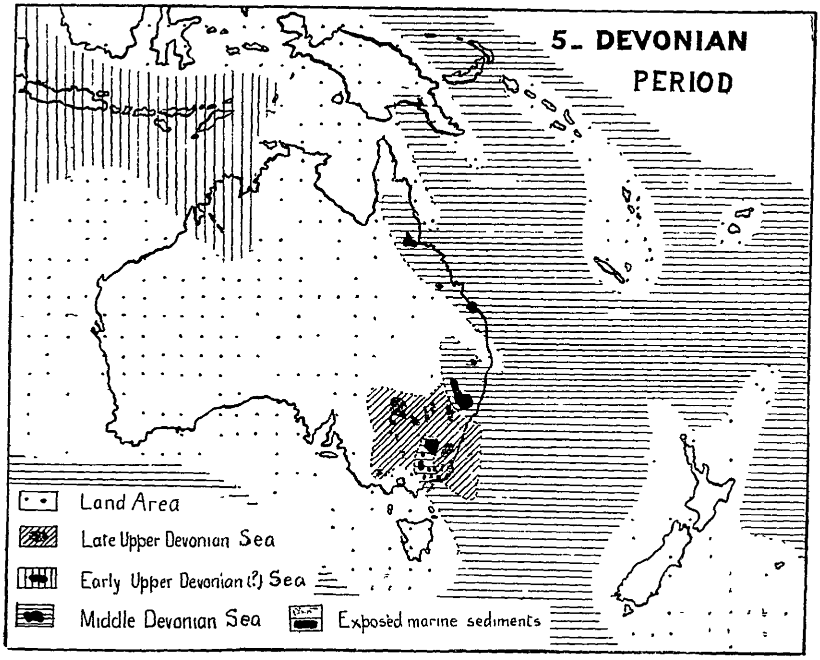
The distribution of marine Devonian formations throughout Australia has been discussed at length by the present writer (Benson, 1921), whose conclusions are here summarized. Intense folding occurred throughout the eastern States at the close of Silurian times, with intrusion of granites during the early part of Devonian times in Tasmania, Victoria, and probably south-eastern New South Wales. Land then extended to the east of the present coast. In the last two States the widespread outpouring of acid lavas which seems to have been associated with this plutonic intrusion was followed in Middle Devonian times by the formation of a long narrow trough by which the sea entered into Gippsland and southern New South Wales, where a thickness of at least 12,000 ft. of shales, limestones, and tuffs was formed. These beds contain over one hundred species of fossils, the characteristic members of the varied fauna being *Receptaculites australis* and *Spirifera yassensis*, while *Diphyphyllum gemmiformis* and various cephalopods are also important. There is not yet sufficient evidence to indicate whether this fauna should be classed with the lower or upper portion of the Middle Devonian rocks. It is not, however, followed conformably by the Upper Devonian rocks, for strong orogenic movement caused the retreat of the sea in the latter part of Middle Devonian or early Upper Devonian times, and gently inclined subaerial Upper Devonian sandstones, &c., rest with marked unconformity on strongly folded Middle Devonian rocks.

A second and larger depression occurred farther to the north, and may have been formed at an earlier date, while it certainly continued to a much later one. Andrews (1914) and David (1919) would apparently invest this trough with very considerable tectonic significance, indicating that it separated the mainland of Australia from the north-eastern land-mass, "Tasmantis," the tectonic history of which has been very different from that of the rest of Australia. How far it extended to the north-west through Queensland we cannot say, as its sediments are hidden beneath Permian and Mesozoic rocks; but there is some reason for believing that it did not continue as an open channel between New Guinea and the Northern

* An interesting instance of the wide geographic range of Australian Silurian species is afforded by Yabe's (1915) study of the genus *Halysites*. Several species originally described in Australia are found by him to be represented elsewhere: *H. sussmilchi* in Gothland, *H. australis* in Dudley, England, and *H. pycnoblastoides* in China near Ychang. (Yabe is, however, inclined to explain the similarity of the Canadian, Baltic, and Australian forms as the result of parallel evolution under analogous conditions from a common stock, rather than by a continuous intermigration of derived forms.)

Territory. To the east it may have been limited at first by the ridge now shown by the Brisbane schist, but Ball's (1921) discovery of *Heliolites* at Warwick beneath the strongly folded Permo-Carboniferous beds indicates that this barrier was flooded over at least in the latter part of Middle Devonian times, when a commingling occurred of the forms in this (the eastern) and the Queensland (or north-eastern) gulf. Richards (private communication) has found that the Devonian limestones near Warwick are associated with radiolarian claystone and tuffs like those which are so widespread in north-eastern New South Wales, as the writer's investigations have shown (*e.g.*, Benson, 1915).

The Middle Devonian beds in the eastern gulf have no visible foundation. They are an extensive series of radiolarian claystones with much tuff and three intercalated widely extending coral limestones. The lowest of these,



which may be referred to the early Middle Devonian period, contains *Favosites basaltica* var. *moonbiensis*, *F. multitabulata*, and other species, together with forms which are more characteristic of Silurian rocks, such as *Heliolites interstincta* and *Tryplasma* spp. The fauna of the next and less continuous limestone horizon is not stratigraphically distinctive. It is characterized by *Heliolites porosa*, a large *Phillipsastraea*, abundant stromatoporoids and pentamerids. The uppermost limestone may be correlated with considerable probability with the later Middle Devonian formations elsewhere. It contains a large coral fauna characterized by *Heliolites porosa*, an endemic form *Sanidophyllum*, *Spongophyllum*, *Endophyllum*, *Actinocystis*, *Microplasma*, *Litophyllum*, and the characteristic Givetian brachiopod *Stringocephalus*. In the radiolarian mudstones associated with this limestone, casts of *Lepidodendron australe* are frequently present, and continue to abound throughout the great thickness of Upper Devonian mudstones which succeed. The sediments appear to have been formed in a widespread but comparatively shallow sea, in which explosive eruptions may have frequently built up temporary islands, especially in later Middle Devonian times.

The Devonian rocks of Queensland are less fully known, and lie for the most part in the highland regions to west of Rockhampton and Townsville. There is a very great thickness of conglomerates, sandstone, shales, and limestones, the fauna of which resembles the Upper-Middle Devonian fauna in the eastern gulf in the presence among it of *Heliolites porosa*, *Litophyllum*, and *Stringocephalus;* and, as indicated above, the two gulfs may have at one time opened into one another; nevertheless, *Lepidodendron australe* is as yet unknown in the Queensland Devonian rocks. Possibly Upper Devonian rocks succeeded these conformably, but nothing is known definitely concerning them. According to Professor David (1914), Devonian beds are represented by a grey limestone containing *Heliolites porosa* on the Tauri River in Papua (approximately 146° E., 8° S.).* Stanley (1921) states that his own observations have not confirmed this, the rocks of the region indicated being chiefly Middle Tertiary. "At the same time, there is a great chance of isolating Palaeozoic rocks in the stupendous gorges prevailing in these parts." To the north of this region is the Owen Stanley Range, in which there are phyllite sandstones and quartzites, with the blue apparently unfossiliferous limestone which, he suggests, is of Algonkian age.† Perhaps they may be the more disturbed portion of a Devonian series, and the metamorphic rocks on which they rest may be the fragment of the old "Tasmantis," but at present we can merely speculate concerning this.

Probably in the close of Middle Devonian times, or the beginning of the Upper Devonian, the sea entered the northern (Kimberley) division of Western Australia, and this movement of the strand may thus have been approximately coeval with the regression of the sea from the south-eastern trough. On a basal conglomerate was laid down a thick mass of limestone containing *Spirifera* cf. *verneuilli* (*S. disjuncta*) and *Rhynchonella* (*Hypothyris*) *cuboides*, together with stromatoporoids.

The relation of the western to the eastern Australian Middle Devonian fauna leads to interesting speculations. Reed (1910) has pointed out that among a great majority of Rhenish forms in the latter region there are a few of American affinities, and that such American influence may also be seen in the Devonian fauna of southern China, though not of Burma, nor is it present in the smaller fauna of Western Australia. This suggests that the great Tethyan migration of European forms through Asia was divided by the northern end of an ancient Cambodia-Malayan continental mass—perhaps the Aequinoctia of Abenadon (1919)—the

* See also Maitland (1905).

† In a private communication dated 24th October, 1922, Stanley says, "During my travels through the main ranges I have discovered massive crystalline limestone forming escarpments in altitude of 7,000–8,000 ft. The same features have recently been met with in the Saruvaged Mountains, Central (German) New Guinea, by Captain Retzner. These are not Tertiary, but appear to be coterminous with the Dutch occurrences (the *Alveolina* limestone of the Wilhelmina Range), and may, therefore, be Cretaceous. I have not seen any fossils in these yet." The *Alveolina* limestones, however, formerly thought to be Cretaceous, have now been placed by Rutten (1914) in the Eocene. In addition to this, we may note that Hubrecht is of the opinion that large masses of crystalline limestone in the south-west of New Guinea are really Permian (Brouwer 1919).

western division passing through Burma to Western Australia, while the other, receiving in China an influx of American forms arriving by the circumpacific channel, passed south-eastwards towards the then Tasman Sea. The complete absence of Devonian marine beds in New Zealand and New Caledonia has led the writer to suggest the land-boundaries in map 5.

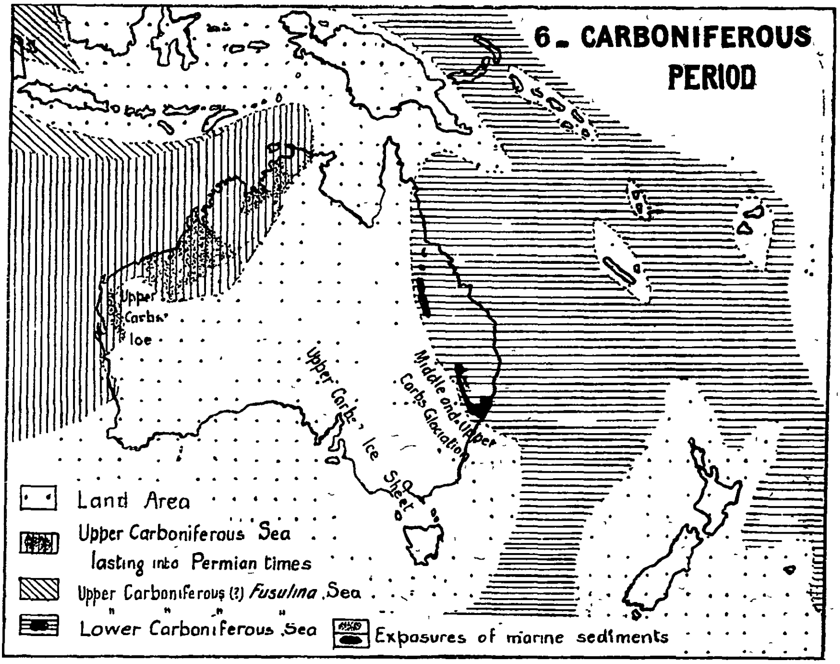
Considerable changes occurred in the closing parts of Devonian time. The sea had withdrawn from Western Australia, Queensland, and the south-eastern gulf, but now emerged from the eastern gulf and transgressed widely, covering almost the whole of New South Wales, flooding over the eroded but still uneven surface of the regions which had been folded at the close of Middle Devonian times, and depositing a series of conglomerates, sandstones, and shales, which are calcareous only near the margin of the eastern gulf, where they also reach their maximum thickness of 10,000 ft. In New South Wales these beds are largely of marine origin and contain *Lingula gregaria. Rhynchonella pleurodon, R. primipilaris,* and *Spirifera disjuncta,* with many lamellibranchs. Specimens of *Lepidodendron australe* are frequent, and towards the south-east the plant-beds are more abundant and varied, and the formation passes in eastern Victoria into lithologically similar rocks containing Upper Devonian plants only, beyond which an overlapping series passes up into sandstones and shales containing a fish-fauna which Woodward (1906) declares to be of Lower Carboniferous age. Similar red sandstones and shales occurring in western Victoria, formerly thought to be Devonian, have been declared by Chapman (1917) to be of Lower Carboniferous age on account of the occurrence of *Lingula squamiformis* var. and fragments of a fish referred to the genus *Physonemus.* Since, however, *L. squamiformis* is known to occur in the Upper Devonian rocks of Wales (*cf.* Dixon, 1921, p. 50), Chapman's conclusion as to the age of these rocks may be somewhat weakened. We may, however, regard this deposit as indicating the limit of the marine transgression reached before the rapid regression which occurred in the early part of the Carboniferous period.

While this transgression appears to have proceeded from and receded into the eastern gulf, there is a remarkable absence of its characteristic fauna in the sediments, chiefly radiolarian mudstones, in the gulf. Only along its western margin do we find a special faunula, which is apparently a mingling of the later Middle Devonian fauna remaining in the gulf with the immigrant Upper Devonian fauna, just as there is also here a mingling of the two lithological facies.

The nature of this transgressing fauna is of interest. It has frequently been pointed out how cosmopolitan is the Upper Devonian fauna, and many of the cosmopolitan forms are present in New South Wales. Nevertheless, the work of Dun (1898) and Gürich (1901) indicates the strong affinity this fauna bears, not so much to the European developments as to the Chemung fauna of the eastern States of America; so that we may conclude that the circumpacific faunal migration became especially effective in Upper Devonian times, and in this we may perhaps see evidence that the periodicity of faunal migrations between the Asiatic and American coasts of the Pacific Ocean, which Smith (1904) declared to be a feature of Cainozoic and Mesozoic times, held good also in the Palaeozoic. If, however, in opposition to Schuchert's (1910) hypothesis that the Portage-Chemung fauna migrated directly across the Atlantic from Europe, it be supposed with Clarke (1898) that it came across the Arctic and spread south-eastwards by way of the cordilleran sea, it would follow that the analogous eastern Asiatic and Australian Upper Devonian fauna was due mainly to an offshoot from this which passed along the western shores of the Pacific. It is worthy of note, however, that there is in the Australian Devonian faunas no community whatever with the (Lower ?) Devonian fauna of South Africa and South America, of which Clarke (1913) has given a comprehensive account. This may indicate that the Antarctic marine channel of migration, which was to become important in Upper Cretaceous times, was not yet in existence.

Carboniferous.

The characteristic Lower Carboniferous (Burindi) beds are confined to the eastern gulf in New South Wales. They follow in apparent conformity on the Upper Devonian mudstones at all points which the writer has observed along a line of contact of over one hundred miles in length (Benson, 1918),

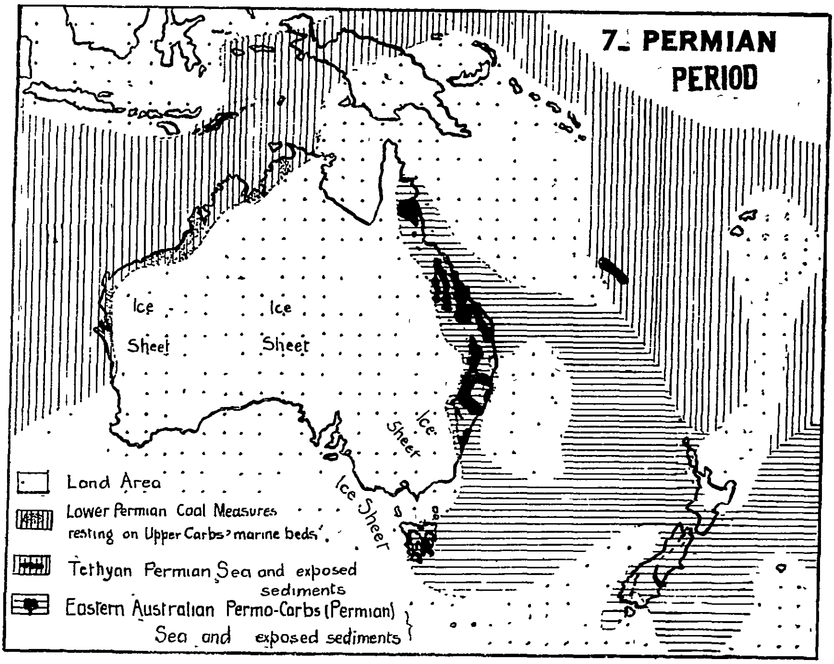


though it is possible that some disconformity may exist between them, as the faunal change is so marked; indeed, the absence of any sign of the late Upper Devonian fauna between the Middle Devonian and the Lower Carboniferous fossiliferous beds is in itself suggestive of the existence of a break in this apparently continuous series of sediments. This would accord with the view of Süssmilch (1914, 1921), though it is opposed to the writer's former belief. Süssmilch, indeed, believes that away from the region of deposition of the Lower Carboniferous marine sediments there was marked orogeny at the close of Devonian time, accounting for the intrusion of granites into the Upper Devonian quartzites west of the Blue Mountains, which granites have been since laid bare and covered by Permo-Carboniferous (Permian) sediments.

In Queensland there is no clear evidence of the existence of Upper Devonian rocks, and the widely extending Lower Carboniferous (Star) beds probably represent a transgression over a region from which the Devonian sea had regressed. There is not yet available, however, any evidence of an unconformity below them. The Lower Carboniferous fauna in Queensland is a small one, and has not yet been critically analysed; but, while it contains several forms not present in the larger fauna of New South Wales, there is no need at present to doubt the contemporaneity of the two faunas. We devote attention, therefore, to the better-known fauna of New South Wales, the information concerning which has been summarized and analysed by the writer (Benson, 1921A). It is a typical example of the cosmopolitan Culm fauna, representing the transgressive Viséan series or upper moiety of the Lower Carboniferous formation. It contains about three hundred species, of which only half a dozen are found in the Upper Devonian. Characteristic forms in it are various zaphrentids and brachiopods such as *Orthotetes crenistria, Chonetes laguessiana, Productus cora, P. semireticulatus, Leptaena analoga, Orthis resupinata, Spirifera bisulcata, S. striata, Spiriferina octoplicata, Reticularia lineata*, and *Actinoconchus planosulcatus*. It is perhaps remarkable for the great rarity of foraminifera, a feature which it shares with the developments of the Culm fauna in south-eastern Asia, as shown by Reed (1920) and Mansuy (1912). Though this fauna appears to have come to Australia from the Asiatic Tethys by way of the eastern Malayan route, it contains very few distinctively American elements, and thus differs markedly from the preceding fauna. That there was at this time a definite connection between the faunas of China and western North America is clear, and we shall await with interest the further light thrown on this by the investigation of the Lower Carboniferous fauna recently discovered in Japan by Yabe and Hayasaka (private communication). The relationship, however, seemed to be greater in Upper Carboniferous times. The crust-movements during the Middle Carboniferous Altaid orogeny made such geographic changes that there is a marked community between the Upper Carboniferous fauna containing *Fusulina* in western North America and eastern Asia, and perhaps to a less degree the Urals also. The American element has been clearly recognized as far to the south-east as Yun-nan (Mansuy, 1912) and Sumatra (Fliegel, 1901) mingling with Himalayan forms. The same series of crust-movements also produced most important results in Australia, which have been discussed by Professor David (1919). Briefly, these involved in the east an extensive elevation of the land, and the withdrawal of the Lower Carboniferous sea from the eastern gulf, along the margin of which a series of very active volcanoes broke out, permitting the accumulation of an immense zone of tufaceous conglomerate, lavas, and sills, extending almost meridionally throughout its whole length. Here appeared the earliest portions of the great ice-sheet that subsequently enveloped much of the whole southern part of Australia, glacial tills and seasonally banded "varve" rocks being intercalated between the tufaceous beds. There then followed the advance of the "Permo-Carboniferous" or Permian sea, which extended far beyond the limits of the Carboniferous rocks in New South Wales and submerged almost the whole of Tasmania, though Victoria remained emergent. Though this appears clear in the two States mentioned, the relationship of the Lower Carboniferous to the "Permo-Carboniferous" (or, as we shall subsequently term it, the Permian) system in Queensland is still incompletely understood, though the misconceptions involved in the institution of the Gympie series (Jack, 1892) are now fairly clear. To this region we return, but digress here to consider events in the west.

" Permo-Carboniferous " or Permian.

Towards the close of Carboniferous times the sea entered the north-western region of Australia, in which were laid down tillites, shales, gypsiferous claystones, mudstones, and limestone, followed by *Glossopteris*-bearing coal-measures. Etheridge's (1914) investigations of the fauna of these mudstones and limestones has been recently analysed by Professor David (1919) with interesting results. There appear in it typical members of the Lower Carboniferous fauna mingled with members of the Himalayan or Salt Range fauna, such as *Hexagonella crucialis,*



Derbya senilis, Orthotetes crenistria, Productus subquadratus, Spirifera musakheylensis, and *Sp. marcoui.* Professor David concludes that it represents the fauna of a gulf extending from the main Tethyan channel in late Carboniferous times, in which survived a large group of Culm forms. As we shall see, the eastern Australian Permian fauna was also derived from the Tethyan channel, but it is, nevertheless, markedly different from that just noted. " One must emphasize the extraordinary effectiveness of the Darwin-to-Adelaide mountainous land-barrier which in ' Permo-Carboniferous ' or Upper Carboniferous times so completely isolated the Western Australian and Northern Territory seas on the one hand from those of eastern Australia on the other. Out of about two hundred species recorded in the Permo-Carboniferous marine fauna of eastern Australia and Tasmania, only about nine are at present known to be common to the two " (David, 1919).

No less marked is the want of community between the Permian marine fauna of eastern Australia and the preceding Lower Carboniferous fauna. There are only twelve (or possibly nineteen) species common to the two series, and we have, therefore, to discover a different source for the two faunas. While the eastern Australian Permian fauna has not very much in common with the *Fusulina* Upper Carboniferous fauna of eastern Asia, it has a marked affinity with the Salt Range fauna, an affinity which does not, however, amount to identity of species (*fide* Dun), and there are several endemic genera. Among the brachiopods *Martiniopsis* is very abundant; also alate Spiriferidae, *Productus* and *Strophalosia*. The mollusca include *Agathiceras* and the typical Salt Range genus *Eurydesma*, which is absent from Western Australia; *Choenomya*, which is very characteristic of the Permian of Nebraska; and endemic genera such as *Cleobis*, *Moeonia*, *Notomya*, *Deltopecten*, and *Aphanaia*, with some cosmopolitan genera. There is little, however, distinctive among the gasteropoda (Dana, 1849; De Koninck, 1877; Johnston, 1888; Etheridge, 1891, 1892; Etheridge and Dun, 1906, 1910; Dun, 1914) nor among the foraminifera (Chapman and Howchin, 1905).

Piroutet (1917) has found the Australian species of *Aphanaia gigantea* in the argillites of the eastern portion of New Caledonia, while farther west, in the gritty littoral beds of the same formation, there are the typically Tethyan cephalopods *Waagenoceras*, *Stacheoceras*, and *Popanoceras*, which occur at intervals between this region and Sicily.

In New Zealand also is a faunula showing Australian affinities, though containing nothing typically Tethyan. Trechmann (1917) described from the Wairoa Gorge, near Nelson—the fossiliferous locality found by McKay (1878) and taken by Hector as proving the Carboniferous age of his Maitai series—the following group of forms: *Rhynchonella* cf. *pleurodon*, *Martiniopsis subradiata*, *Spirifera* cf. *bisulcata*, *Strophalosia* (? cf. *gerardi*), *Platyschisma* sp., *Pleurotomaria* sp., and an obscure form (previously termed the "Dun Mountain *Inoceramus*") which he refers to *Aphanaia*, though according to Mr. Dun (verbal communication) this is not a member of that genus, but differs widely from it, and is apparently without parallel among the described Australian species. Attention may, however, be directed to the form occurring in the Permian ("Carboniferous") rocks of Hobart, which R. M. Johnston termed *Inoceramus elegantula*, though his illustration of it (*Geol. of Tasmania*, pl. xv, fig. 13) does not suggest affinity with either the "Dun Mountain *Inoceramus*" or *Aphanaia*.

Omitting at the moment further discussion of eastern Australasian palaeogeography, we turn to consider the source of this fauna. Along the Tethyan route, Timor would seem to have been in the stream of migration. The Permian fossils found in this island by Rothpletz (1892) and Boehm (1907) contain several forms, notably *Streptorhynchus* cf. *crenistria*, *Reticularia lineata*, *Cleiothyris roysii*, *Productus semireticulatus*, *P. abichi*, *Spirifera musakheylensis*, and *Lyttonia* sp., which are present in the Upper Carboniferous rocks of Western Australia and the *Productus* limestones of India.* The first four of these are represented by closely allied forms in the Lower Carboniferous but not in the Permian of eastern Australia, the latter having no direct representatives in the Timor Permian

* If it should be that the attribution of *Rhynchonella timorensis* to the Devonian rather than to the Upper Carboniferous of Western Australia is mistaken (Foord, 1890), we should have yet another link between the Western Australian and Timor fauna.

fauna. The Himalayan affinities of the latter are emphasized by the presence of *Chonetellus nasuta*, *Productus asperulus*, *P. gratiosus*, *Stacheoceras* sp., and indicate close relationship with the fauna of Chitichun, on the Thibetan frontier, which is the open-sea equivalent of the littoral fauna of the Middle *Productus* limestone (Haug, 1911, p. 805–8; Schuchert, 1906). We may thus recognize a stream of Tethyan forms undergoing considerable evolution as they migrated south-eastwards. The development in Timor indicates the region from which an epicontinental extension of the fauna branched out to north-western Australia; while the main stream, perhaps passing between the shattered residual portions of an ancient continental mass stretching to the north-westwards from Australia—the Aequinoctia, which Abenadon (1919) believes broke up at this time—spread into the seas on the eastern margin of Australia, and there evolved during the closing part of the Carboniferous period into the provincial fauna which characterizes the region (compare Dun, 1914; David, 1919).

Since the above was written access has been obtained to the summaries of the geology of the eastern and western portions of the Malay Archipelago by Brouwer (1919) and Van Es (1919) respectively. These are of such importance for Australasian geology that the following abstract of the portion dealing with the Permian rocks has been incorporated here. Permian rocks are represented in south-western New Guinea by littoral sandstones containing fragments of crinoids, *Spiriferina?*, *Orthis?*, a rhynchonellid, and *Proetus*, originally described by Martin (1911), and a large thickness of shales and limestones in the Snow and Hellwig Mountains, farther north. Crinoidal remains are found in Luang and Babar, and also in Letti, where Molengraaff (1915) found that the series of fossiliferous littoral sediments in the south of the island pass northwards into schists. The fossils consist chiefly of brachiopods and crinoids, with Fusulinidae and ammonites such as *Agathiceras* (a genus represented by *A. micromphalum* in both Western Australia and New South Wales). Broili's (1915) account of the brachiopods indicates the presence of the following Himalayan forms: *Productus cora*, *P. spiralis*, *Spirifera fasciger* (= *S. musakheylensis*), *Reticularia lineata*, *Martinia nucula*, and *Chonetes strophomenoides* (all but the last two being also present in Western Australia), and *Spirifera rajah*, which is closely allied to the characteristic eastern Australian form *S. tasmaniensis*.

In Timor itself the littoral deposits are more richly fossiliferous, but detailed accounts of the fauna are not here available. There is a great wealth of mostly endemic echinoderms described by Wanner (1916), and of cephalopods (Haniel, 1915); the latter include, besides those mentioned above, *Gastrioceras* (which, with *A. micromphalum*, marks a definite zone in Western Australia), *Waagenoceras*, *Popanoceras*, *Cyclolobus*, *Medlicottia*, and other Himalayan genera, together with a large series of brachiopods described by Broili (1916) "which give less definite evidence of age" (*cf.* Schuchert, 1906). Haniel (1915), on the basis of the ammonite fauna, has recognized four stages in these rocks. The lowest is coeval with the lower part of the Artinsk beds (Lower Permian), but contains some Carboniferous elements; the second is Upper Artinsk-Sosio; no analogy is suggested for the third, which is placed in the lower part of the Upper Permian series; the fourth is compared with the Middle and Upper *Productus* limestone of Upper Permian age. Schubert (1915) considers the Fusulinidae indicative of an Upper Carboniferous age, but Van Es (1919) believes them to be Permian, to which period also Brouwer (1919) refers the whole series. "The nearest relatives of all the Permian faunas investigated up to the present are to be found in the Permian of the Alps, of Sicily, of the Urals, of the Salt Range, and in the Himalayas, while the Permian sediments of Timor also correspond in a great degree with the Wichita formation in North America. We thus see that the Tethys geosyncline, of the duration of which in Mesozoic times we usually think, was marked in the Permian and extended from the Mediterranean area to the East Indian Archipelago. But a certain independence appears in the development of the faunas, so that the connection between them was not completely open . . . and it is not remarkable that littoral sediments should have been formed [here] in this geosyncline" (Brouwer, 1919).

The presence of fossiliferous Permian beds in Rotti and Savu has also been noted, but in Java the oldest exposed formations are Cretaceous. An important Permian series is developed in western Sumatra, of which Van Es's (1919) discussion is very illuminating. The lowest exposed members of the series are cherty limestones containing foraminifera, notably *Sumatrina annae*, *Schwagerina verbeeki*, and *Doliolina lepida*. These three forms Deprat (1912) found to abound in the upper term of a threefold series in Yun-nan, of which the middle and lower terms contain Lower Permian and Upper Carboniferous brachiopods, &c., and rest unconformably on Middle and Lower Carboniferous strata. Above the foraminiferal beds in Sumatra lie further limestones with a diversified fauna in which Fliegel (1901), who thought them to be Upper Carboniferous, described a number of new species which have since been found in the Permian of Timor. Locally coal-measures occur interbedded with these, and contain *Pecopteris*. Rather noteworthy, according to Fliegel, is the absence of such Himalayan genera as *Lyttonia*, *Richthofenia*, *Oldhamia*, *Aulosteges*, and *Strophalosia*, most of which occur in Timor.

Exactly where the line should be drawn between the Carboniferous and Permian rocks is a problem of long standing. The diversity of views thereon, as expressed in the "Report on Nomenclature of the Carboniferous, Permo-Carboniferous, and Permian Rocks of the Southern Hemisphere," presented to the British Association in 1915 and 1917, and in Professor David's (1919) last discussion of the question, is indicated in the following diagram :—

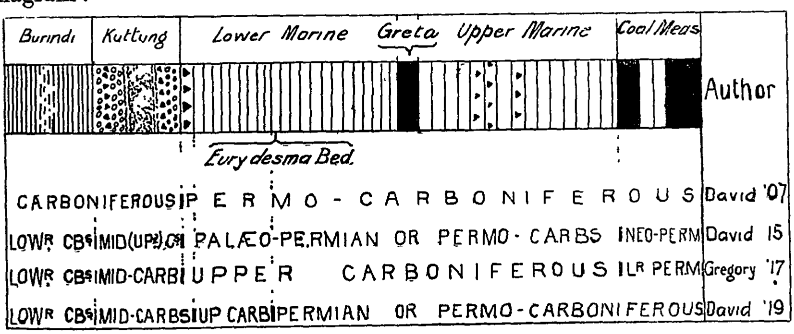


Diagram showing various classifications of the Carboniferous and Permo-Carboniferous beds of New South Wales. (Relative thicknesses not to scale)

The palaeogeographic features of eastern Australia during the period have long been studied by Professor David (*e.g.*, 1907), and are also being studied by Dr. Walkom, whose preliminary conclusions concerning north-eastern New South Wales have already been stated (1913). We shall not, therefore, anticipate further work, but shall briefly summarize our present knowledge of the region.

The marine beds are grouped into a lower and an upper series, deposition having been interrupted by a regression, when lagoons or "inland seas" existed, in which the Greta coal-measures, or their equivalents, were deposited in New South Wales, Queensland, and Tasmania. In each of these States also a second series of coal-measures was formed during the final regression of the Palaeozoic seas from eastern Australia. The marine deposits throughout give evidence of their formation in comparatively shallow seas, and there are many indications that they were laid down between the Australian mainland and an eastern land-mass that is now submerged.

The ice-sheet which had first gathered on the mainland in Middle Carboniferous times probably reached its maximum at the close of that period, and fluctuations of the ice-front during early Permian times seem to be indicated by the presence of unusually abundant erratics dropped from floating bergs, at several horizons in the marine rocks (see, *e.g.*, David, 1907A).

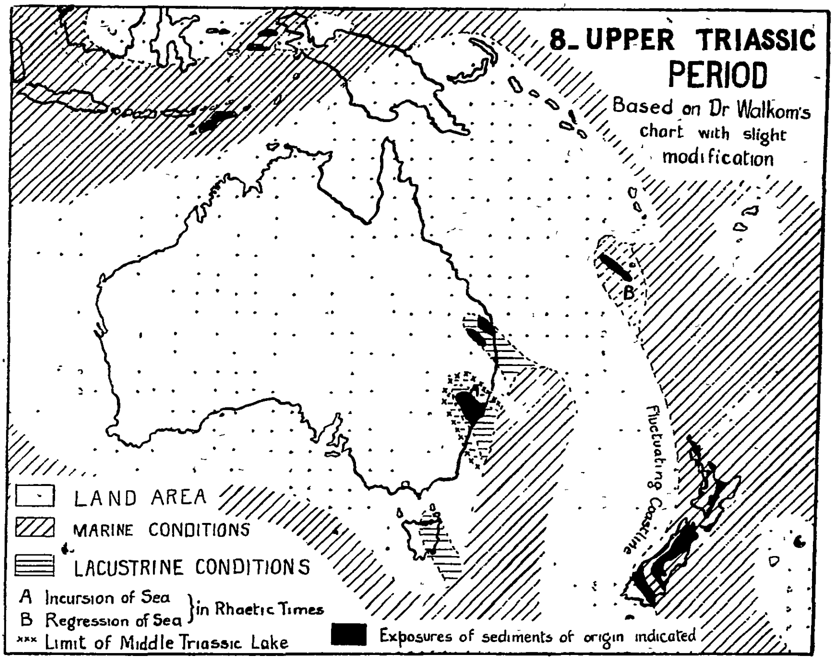
Crust-movement occurred during Permian times in north-eastern New South Wales and southern Queensland. Dr. Walkom's (1913) palaeogeographic maps indicate that this region, though an area of deposition during the Lower Marine period, became a promontory against which the second marine invasion was divided, and the westerly portion of it transgressed considerably farther on to the continent than did the first marine transgression. This crust-movement was apparently a prelude to the intrusion of the extensive series of granites in north-eastern Australia. The details of the distribution of the "Upper and Lower Marine" (Permian) series in Queensland form a very difficult study, concerning which comparatively little is yet clear, though much useful work has been done (see, *e.g.*, Dunstan's tabulation, 1916); and the discussion of the palaeogeographic significance of this, and also of the occurrences in Tasmania, must await fuller treatment by other writers. We must note merely that at the close of this period the sea withdrew completely from Australia, and we find that the land-masses of "Tasmantis" had become united to the Australian continent by the commencement of Triassic times.

As noted above, the discovery of *Glossopteris indica* near the South Pole permits us to infer that a part at least of Antarctica formed one of the groups of closely connected continental masses which made up the Permian or Permo-Carboniferous Gondwanaland, and affords us the first intimation, since Lower Cambrian times, of communication between Australia and Antarctica and the inception of that with South America. It is therefore of interest to inquire the extent to which the varied Indo-Australian fauna on the littoral of Gondwanaland is represented on either side of the South Atlantic, the Devonian fauna of which is so strikingly different from the Australian. Though Haug (1911, p. 817) indicates that Upper Carboniferous marine rocks form a rather widespread sheet transgressing from the Andean geosyncline on to the continental massif to the east, the only account of these rocks accessible to the writer is that of Douglas (1914), who determined fourteen species from South Peru and Bolivia, most of which "appear to belong to an Upper Carboniferous or Permo-Carboniferous fauna showing affinities with types . . . from the Urals, while a few seem more nearly related to Permian forms from the Salt Range of India, and from the Guadalupian fauna of New Mexico." No eastern Australian forms are present. In Keidel's (1922) recent work (for the translation of which the writer is indebted to Professor Elder) the marine beds in the Pre-Cordillera of the western Argentine, supposed by Stappenbeck (1910) to be of Upper Carboniferous or later age on account of the presence of a form resembling *Spirifera supramosquensis*, are shown to be interstratified with tillite, and to contain a number of other species of *Spirifera*, *Dielasma*, and other brachiopods, *Pleurotomaria*, and several other gasteropods, all rather imperfectly preserved and not yet specifically determined. This group of glacial and marine beds has been traced for about a hundred kilometres north and south, and throughout has been thrust to the east on to the Gondwanan continental massif. It appears, however, to have been deposited unconformably on the Lower Carboniferous and earlier Palaeozoic beds that form the western margin of that massif. Keidel terms these glacial and marine beds the Tontal series, and correlates them with the Permian beds of Australia. Some unnamed marine fossils of this age have been found by Oliveira and recorded by Woodworth (1912) from Rio Negro in south-eastern Brazil, and in south-western Africa *Conularia* and the Indian form *Eurydesma globosum* have been found by Schroeder (1909) associated with the Dwyka tillite. There is thus no clear evidence of the migration of marine forms during the Permo-Carboniferous period along a hypothetical Southern Pacific Gondwanaland coast between Australasia and South America.

We return to consider the Permo-Carboniferous or Permian record in New Zealand. It may be remarked parenthetically that the author's substitution of the term "Permian" for "Permo-Carboniferous" as the age of the Maitai series was at first influenced by the supposed presence of *Aphanaia* therein, a form belonging to the "Upper Marine" series of New South Wales, in which also the other New Zealand forms are represented, excepting *Spirifera* cf. *bisulcata*, which occurs in the Lower Marine beds but more usually in the Lower Carboniferous, and *Rhynchonella* cf. *pleurodon*, which occurs in the Upper Devonian and but rarely in the Lower Carboniferous. It may perhaps be doubted whether these determinations are quite correct, as the best specimens available were not good; but, such as they are, they seem to suggest that it would be preferable still to employ the term "Permo-Carboniferous," as Trechmann proposed, to indicate the age of the Maitai series, rather than "Permian" merely, as the writer has done. Little can be stated definitely in regard to the distribution of this series in New Zealand. Fragments of a thin prismatic shell presumed to be the Dun Mountain "*Inoceramus*" of McKay, or the "*Aphanaia*" of Trechmann, are widespread in the greywackes throughout the South Island, and in default of better evidence may be taken as characterizing "Maitai" rocks in several regions in South Canterbury and North Otago, and in the western parts of Southland. Professor Park (1921) has recently recorded some limestones, probably belonging to the same series, at the northern end of the Livingstone Range, west of Lake Wakatipu. In these he noticed the presence of *Productus*, *Spirifera*, and obscure corals and gasteropods. The suggestion that eastern Southland made a resistant crust-block at this period (Benson, 1921) has been considered in preparing the map herewith. It may, however, also have been submerged. Distinct though the affinity is between the faunas of eastern Australia and New Zealand, there is also evidence of a considerable independence, and perhaps the New Zealand area may have been littoral to a Southland–Chatham Island continent, not glaciated, nor supporting *Glossopteris*, rather than to the Australian mainland. Neither drifted erratics* nor *Glossopteris* have been proved to occur in the Maitai series; but, as no fresh-water beds are known in the Maitai series (in its restricted sense), this last point may not be very significant, and does not appear to vitiate the suggestions in the map.

Triassic.

Directly following on the "Permian" Maitai beds, and generally referred to the upper portion of that series, is a thick group of often more siliceous shales and greywackes, extending into the North Island near Wellington, and containing an annelid referred to *Torlessia mackayi* (Bather, 1905–6). Jaworski (1915), however, refers it to *Terebellina* sp., and considers it to be Triassic. We may, perhaps, tentatively accept this view



as to age, and class it with the Lower Triassic beds of New Caledonia, which also follow conformably on the Permian rocks. What followed the deposition of these is not clear. Various writers have claimed a perfect conformity; a disconformity, or an extensive folding with plutonic intrusions, is indicated between the Lower and Upper Triassic beds (see discussion, Benson, 1921). Marshall, however, who in 1912 strongly upheld the first view, has concluded (1917A), since Trechmann's description of the Maitai fossils, that a break of some kind must occur between these

* Professor Park (1920) has discovered striated boulders in a breccia in eastern Otago which may be either of dynamical or glacial origin. He inclines to the latter explanation. They appear to be in "Maitai" rocks.

and the Triassic fossils; and Park (1921) has revived Hutton's view that this was a period of great orogeny and intrusion of plutonic rocks, including among them the diorite-gneisses and associated plutonic rocks of south-western New Zealand and the peridotites, &c., of Nelson. In New Caledonia a regression of the sea in Middle Triassic times is indicated (Piroutet, 1917).

The relationships of New Zealand and New Caledonia during the Triassic period are of great interest. While *Terebellina* (?) *mackayi*, with *Dentalium huttoni*, and possibly other forms, seem the only representatives yet known of the life in New Zealand during Lower Triassic times, in New Caledonia there were present characteristically Tethyan (mostly Himalayan) Lower Triassic forms such as *Pseudomonotis* aff. *painkhandana*, *Ophiceras*, *Flemingites*, *Meekoceras*, *Aspidites*, *Koninckites*, *Danubites*, and *Dorycranites*. An analogous series of forms occur in Timor in beds following conformably on the Permian sediments (Brouwer, 1919). These are also represented to some extent in eastern Asia, whence they apparently migrated into California, since the community of character of the forms on either side of the Pacific was very marked in Lower Triassic times, indicating an intimate connection of the two regions, which became interrupted during the crust-movements of Middle Triassic times (Smith, 1904). We see, therefore, that the extension of the Tethyan coast to New Caledonia, but not to New Zealand, was a feature of Lower Triassic as well as of Permian times. Regression occurred during Middle Triassic times. Beds of this age are absent from Sumatra (Volz, 1899) and Rotti, but are present in Timor containing a neritic cephalopod fauna more like that of the Alpine than the Asiatic Tethys (Brouwer, 1919), and in New Caledonia are represented by an incomplete series on the western slopes containing *Daonella arctica* (a Siberian form); but on the east Upper Triassic rests directly on Lower Triassic (Piroutet, 1917). The crust-movements which occurred at this time in New Caledonia, and probably in New Zealand, joined the two lands so intimately that in Upper Triassic times they formed a well-marked province in the south-eastern extremity of the Tethys. This, Wilckens (1920) suggests, may be termed the Maorian province. It possesses features distinguishing it from the Himalayan and Malayan fauna (with which, nevertheless, it has much in common); and, moreover, the fauna is not yet known in New Guinea, so that Walkom's suggestion (1918) that a northward extension of Australia projected into Malaysia—which would prevent the free south-eastward migration of the Tethyan fauna—accords well with the conclusions we have formed concerning earlier epochs. Nevertheless, the Upper Triassic transgression was felt throughout the whole region considered. Volz (1899) found Upper Triassic forms resting directly on the Permian sediments in Sumatra. In Timor and Rotti, Carnic forms (*Daonella* and *Halobia*) and Noric (*Pseudomonotis ochotica*) are present (Wanner, 1907); and other islands of the archipelago —Misol, Ceram, &c.—show also a development of Upper Triassic marine beds, though as a result of a general regression at the close of Triassic times no Rhaetic sediments appear to be developed throughout the whole archipelago (Brouwer, 1919). The close affinity between the records of Upper Triassic times in New Caledonia and New Zealand has been indicated (Benson, 1921) by a tabular comparison of the recent work of Piroutet (1917) and Trechmann (1917B), modified by Wilckens (in MS.), who, concurring with Trechmann in most points, suggests there is not any good evidence for the Ladinian age of the lowest portion of the mostly

Upper Triassic series in New Zealand. The following table summarizes the facts known :—

COMPARISON OF UPPER TRIASSIC PALAEONTOLOGICAL ZONES IN NEW ZEALAND AND NEW CALEDONIA.

New Zealand.	New Caledonia.
RHAETIC.	
Arcestes cf. *rheticus* ; *Mentzelia* ; *Clavigera*	Marine regression preliminary to orogenic movement.
NORIC.	
Pseudomonotis ochotica (zone locally missing)	*Pseudomonotis* sp. ; cephalopods ; *Rhynchonella* spp., &c.
Pseudomonotis richmondiana (abundant, but zone locally missing)	*Pseudomonotis richmondiana* (abundant).
Spiriferina spp.	*Spirigera, Spiriferina,* &c. ; *Pseudomonotis* sp. ; *Halobia* cf. *varestriata* (zone locally missing).
CARNIC.	
Halobia zitteli var. *zealandica, H. hochstetteri, H.* cf. *austriaca* ; *Myophoria* and gasteropods ; *Spiriferina* sp. ; *Spirigera wreyi* ; *Halorella* sp. ; *Retzia* sp. ; *Discophyllites* sp. ; *Arcestes*	*Halobia hochstetteri, H. austriaca* ; *Spirigera wreyi* ; *Discophyllites* ; *Arcestes* spp. *Myophoria* and gasteropods ; *H. hochstetteri, H. austriaca* ; *Retzia* : *Halorella* ; *Spiriferina*.
" *Mytilus* " *problematicus**	" *Mytilus* " *problematicus*.
Halobia spp.	*Halobia zitteli, H.* spp.
Myophoria nuggetensis ; *Halorella* sp. ; *Spiriferina* sp.	*Myophoria* sp. ; *Halobia* sp.
Spiriferina cf. *fragilis* ; *Daonella indica* ..	*Spiriferina* cf. *fragilis* : *Rhynchonella* sp. ; *Terebratula* sp.

* *Myalina ? (Maoria ?) problematica* Wilckens (in MS.).

It will appear from the above that crust-movement, commencing in Rhaetic times, greatly displaced the coast-line in New Caledonia, which remained raised above the sea-level until near the close of Jurassic times ; while in New Zealand the Triassic conditions were continued into the Jurassic without much permanent geographic change. Near and probably west of both these areas of marine deposition there was a land-mass, and in the minor fluctuations of the strand-line across the coastal shelf there were formed intercalations of fresh-water plant-bearing beds in the predominantly marine strata.

Concerning the palaeogeographic significance of the Upper Triassic fauna, Dr. Trechmann's analysis of that of New Zealand shows that all the forms other than indigenous are represented in the Malay Archipelago, Himalayas, or Alps, except *Pseudomonotis ochotica,* which extends from Timor to Japan and eastern Siberia, and under the name of *P. subcircularis* is found at intervals down the Pacific Coast as far south as the Republic of Colombia. The northern circumpacific channel of migration was, therefore, effective during Upper Triassic times.

Leaving the coastal regions, we turn to consider the conditions of the Australasian continental surface during the Mesozoic times, basing our discussion on Dr. Walkom's (1918, &c.) notable work, supplemented by that of Dr. Arber (1917) for New Zealand. To the former is due the Triassic and Jurassic maps here given (with minor modifications). Extensive fresh-water deposits formed in the neighbourhood of Sydney, comprising the extensive conglomerates, shales, and sandstones of the Narrabeen and Hawkesbury series, of probably early and middle Triassic age. The basin of deposition probably discharged into a northward-extending gulf ancestral to the Tasman Sea. In Rhaetic times the area of sedimentation increased. A second basin formed in south-eastern Queensland (the Ipswich series), and another, probably in Tasmania, discharging into the same gulf, which seemed to have reached a maximum extension at this time, for the deposition of the Rhaetic lacustrine Wianamatta shales above the Hawkesbury sandstone was interrupted near its close by a brief incursion of the sea passing from this gulf as far westwards as the Blue Mountains. Here it deposited an argillaceous limestone containing a small group of ostracods and foraminifera, "a brackish or estuarine fauna having a curious intermingling of Rhaetic and Lower Jurassic types with others more properly referable to the Upper Palaeozoic of Europe" (Chapman, 1909).* It is interesting to note the close approximation in time between this temporary ingression of the sea into eastern Australia and its regression from New Caledonia.

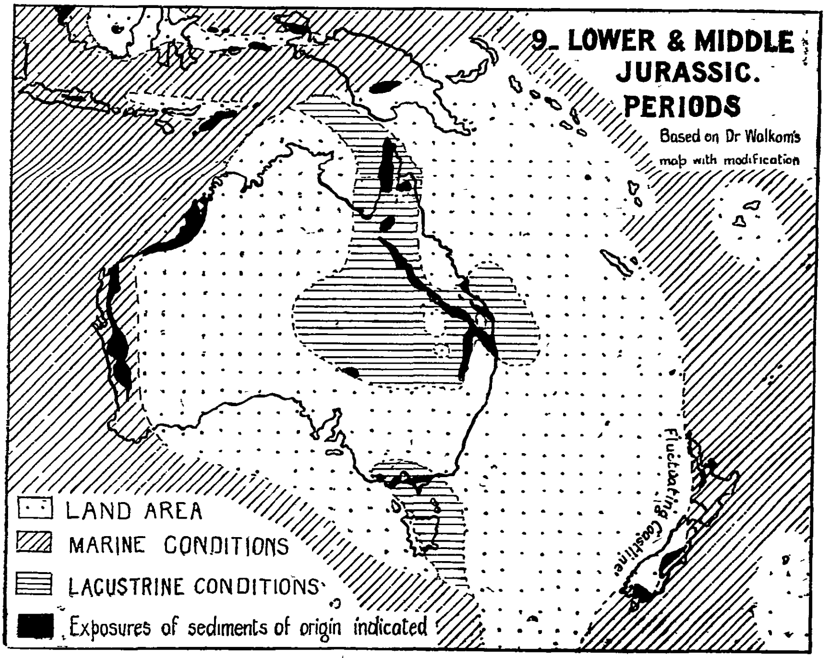
Jurassic.

The Jurassic period witnessed a wider extension of these lacustrine deposits. Walkom (1918) shows them as stretching from the Cape Yorke Peninsula southwards and to the northern parts of South Australia and of New South Wales. He is of the opinion that this basin discharged into the sea by some outlet to the north, and was not connected with a south-eastern sea by a Queensland Gulf such as Neumayr had supposed. A second basin is that comprising the Jurassic coalfields of Victoria and eastern Tasmania, which Walkom thinks may have drained into the Southern Ocean. The intervening region of the present Tasman Sea, he considers, was probably for the most part a land area, the coast of which lay east of New Caledonia (which was land till near the close of Jurassic times), but west of New Zealand, which formed the littoral zone across which the strand fluctuated (until the early part of Cretaceous time), producing intercalated marine and fresh-water deposits, the latter predominating in the latter part of the period. The comparison of the work of Walkom on the Australian flora, and of Arber on that of New Zealand, briefly summarized by the writer (Benson, 1919), indicates a very general similarity, though with comparatively few forms common to the two regions. In general, also, the Australian Mesozoic flora contains four times as many species as that of New Zealand, perhaps due to the unfavourable littoral habitat of the latter, and the modifications which have ensued during their migration back and forth with the fluctuation of the coast-line. The general conditions indicated continued until the commencement of the Cretaceous period, the highest plant-beds in this series in New Zealand being those of Waikato Heads, which Arber considers of Neocomian age; in these, associated with *Cladophlebis* and *Taeniopteris*, appear angiospermous leaves (*Artocarpidium*), which seem to be more related to the figs than to any other modern plants. Of about the same age as these are the much larger floras described by Walkom (1919) from the Burrum and

* It is perhaps more than a coincidence that the time-range of the foraminifera should thus be analogous with that suggested by the fish-fossils in the Wainamatta series (Woodward, 1908).

Styx River beds in Queensland. The former contains thirty-six species, a typical Wealden association, free from angiosperms; the latter, which probably belongs to a slightly higher horizon, contains three angiosperms out of fourteen forms. Both these Queensland floras contain *Microphyllopteris*, a genus instituted by Arber (1917) to receive one of the forms present at the Waikato Heads. Walkom (1919), indeed, remarks on the resemblance of the Styx River flora to that of Waikato Heads.

We thus see the grounds for Arber's conclusion that "in Rhaetic and probably also Jurassic times New Zealand and Tasmania were united with Australia as one large connected land area. The flora of these now separated regions are nearly allied but not identical, but the similarity between them is probably sufficient to allow of this hypothesis." Further,



we must note his remark that "as regards Antarctica, we have no evidence as yet of any Rhaetic land there, but in Jurassic times Graham's Land may have been connected with New Zealand and also with Australia." Nevertheless, we must recall that the Mesozoic flora was a remarkably cosmopolitan one, and accordingly the provincial affinities must be unusually clear to give much support to palaeogeographic hypothesis. Special interest attaches, therefore, to the form *Linguifolium*, which was supposed to belong to *Glossopteris* prior to Arber's investigations.* It occurs in the

* The late Dr. Arber concluded that "there is no evidence that New Zealand formed part of Gondwanaland"; but this, in Seward's opinion, is open to question. "The leaves on which the genus *Linguifolium* is founded are, I believe, generically identical with, or at least closely related to, *Glossopteris*. There is, moreover, a close resemblance shown by several New Zealand species of plants with those of the Rhaetic floras of Tonkin, South Africa, and elsewhere, which contain representatives of *Glossopteris* or other members of the later flora of the Gondwana continent" (Seward, 1914, p. 39). Arber's (1917) reply to this criticism should also be noted.

Rhaetic and Lower Jurassic beds in New Zealand, and Arber believes the genus is represented in the Rhaetic beds of South America and the Jurassic of Australia, though Walkom does not concur in regard to the last. It is perhaps also represented in the Noric beds of New Caledonia by leaves stated by Piroutet (1917) to be " like *Glossopteris*."

Leaving the land area, we return to trace the Australasian coast-line north-westwards from New Zealand. The most extensive development of strata of this age is that of marine and fresh-water beds which cover the south-eastern portion of the Dominion, and in their gently undulating character are so different from the adjacent steeply folded strata of the Hokonui Hills and the Alps farther to the north as to suggest that they represent a transgression of the Jurassic sea over a resistant mass—either a promontory of the ancient continental platform or a foreign block in the broad geosynclinal region splitting apart the Takitimu and Hokonui Ranges. The affinities of this fauna have recently been made more clear by Trechmann and Spath (1921), but an abstract only of their work is as yet available.* The series, which is probably about 10,000 ft. in thickness, ranges from Lower Liassic to Upper Jurassic. The affinities exhibited by the fauna are with forms occurring in the Argentine, Andes, Western Australia, Sula Islands, Spiti Shales, and Kutch, while the ammonites which are referable to the Middle Lias have a typically Mediterranean aspect. The highest portion of the series occurs at Kawhia, and fossils from here have been studied also by Boehm (1911), who recognized, besides the circumpacific types of *Aucella*, *Lima*, *Inoceramus*, and *Phylloceras*, previously noted by Zittel and Hector, additional forms—a *Streblites* and *Perisphinctes*—and stated that the well-known *Ammonites novozealandicus* (Hauer) was a species of *Hoplites* (*Berriasella*). Upper Jurassic marine beds underlie the Neocomian plant-beds of the Waikato Heads, and this association, noted by Hochstetter and Cox, has been redescribed by Gilbert (1921)

On the eastern flanks of the main ranges of the North Island, however, the upper portion of the older Mesozoic series is a considerable thickness of sparsely fossiliferous greywacke containing *Inoceramus*. In the Gisborne district these beds have also yielded an obscure species of *Turritella* which appears to resemble (*fide* Marwick) some forms recently described by

* Since writing the above the author has been permitted by Dr. Trechmann to see and cite from portion of the manuscript of his unpublished paper, from which the following facts are culled. The oldest of the Jurassic fossils in New Zealand were obtained from beds in the Hokonui Hills, in the South Island, apparently transitional between the Otapiri and Bastion series of Hector (see table, Benson, 1921, p. 59). They contained, with *Pecten*, *Astarte*, *Tancredia* (?), and *Oxytoma*, some species of the Hettangian (basal Lias) ammonite *Wachneroceras*. At a higher horizon in the Bastion beds of the same region, the "*Plagiostoma*" (*Pseudomonotis ?*) beds contained some rather obscure lammellibranchs and Rhynchonellidae with a "Callovian" (Middle Jurassic) aspect. These are followed by beds with a fauna analogous to that of Kawhia Harbour, in the North Island, where are developed *Aucella spitiensis*, *Arca* (*Parallelodon*) *egertonensis*. *A. blanfordiana*, *Inoceramus haastii* (allied to *I. galoi*), *Terebratula octoplicata*, and *Rhynchonella pulcherrima*, a group of Bathonian (Lower-Middle Jurassic) forms, together with forms of *Phylloceras* like *P. passati* and *P. malayanum*, described by Boehm from the Oxfordian (Upper-Middle Jurassic) of the Sula Islands. Trechmann's provisional determination, cited by Gilbert (1921), of the fossils in the beds immediately underlying the "Neocomian" flora of Waikato Heads, a short distance to the north, shows the presence of the lamellibranchs of this group. A higher series of beds in the Kawhia Harbour, of Kimmeridgian-Tithonian (Upper Jurassic) age, is characterized by *Streblites* cf. *motutaranus*, *Perisphinctes* spp., and *Belemnites* spp, which are also represented in the Sula Islands. The absence of this fauna from beneath the Neocomian beds of Waikato Heads suggests the existence of a hiatus in the Jurassic series there

Etheridge (1920) from the Rolling Downs beds of Queensland. These rocks are termed the Awanui or East Coast series, and with them we may perhaps group the Manaia series of greywackes and conglomerates in the Coromandel Peninsula. The East Coast series are believed by Mr. Morgan to have been formed during late Jurassic and early Cretaceous times, immediately preceding the retreat of the sea prior to the intense orogeny which occurred in Lower Cretaceous times.

In New Caledonia the land exposed by the retreat of the sea in Rhaetic times endured until near the close of the Jurassic period, when a transgression occurred, the strand-line moving from west to east. The incoming marine fauna contained a *Berriasella* closely allied to *B. novozealandicus* (Piroutet, 1917). Thus regression in New Zealand, with the formations of the plant-beds of Waikato Heads (the prelude to the early Cretaceous orogeny), followed hard on the transgression of the strand in New Caledonia, but the trangression was of short duration. In eastern New Guinea (Papua) a marine trangression occurred in Middle (?) and later Jurassic times. Etheridge (1889) described some poorly preserved forms from the Fly River which he referred to *Stephanoceras* cf. *calloviensis*,* *S.* aff. *lamellosum*, *S.* cf. *blagdeni* (or *S.* cf. *coronatus*), *Macrocephalites* sp., and *Belemnopsis* sp. Haug (1911) reports the occurrence of these forms also, but appears here, as in other cases, to have assigned what seemed to be the most probable names to figured and provisionally determined fossils. In northern and south-western New Guinea the same series appears to extend. Boehm (1906) places the formations as ranging from Callovian to Lower Cretaceous, and has determined a number of better-preserved fossils. Of these, *Macrocephalites keeuwensis* α and *M. keeuwensis* β–γ are believed to be the equivalents respectively of the first two of the above list of forms determined by Etheridge (Boehm, 1913). *Phylloceras*, *Stephanoceras*, *Sphaeroceras*, *Perisphinctes*, *Hoplites*, *Oppelia*, *Hamites* (?), *Belemnites* *Posidonomya* (?), *Inoceramus*, and *Rhynchonella* aff. *moluccana* are also recognized by him. The same geologist has traced this fauna westwards into the Sula Islands, Buru, Babar, Timor, and Rotti, thus surrounding the Banda Sea. In these there is an indication of a distinctively equatorial sea of about Callovian age, an extension of the Tethyan syncline marginal to the Australasian massif (Boehm, 1907). There is, however, an important southern epicontinental extension of the sea which flooded over the western parts of the Australian continent (which must then have extended farther to the west), producing a thickness of about 2,000 ft. of shallow-water deposits, yellow, brownish, or reddish calcareous sandstone, occasionally plant-bearing (Arber, 1910; Walkom, 1921), passing locally into yellow limestone. Moore (1870) recognized twenty European species with nine new forms, and considered the beds to be of Oolitic age. Crick (1894), as a result of his examination of the cephalopods, considered the beds as belonging to the Lower Oolitic period. He recognized species of *Stephanoceras*, *Dorsetensia*, *Perisphinctes*, and also *Belemnites canaliculatus*. Chapman (1904) supported this. Boehm (1907) remarked that the fauna was mid-European in its facies, and considered it to have been deposited in the Callovian extension of the equatorial Tethys. Haug (1911, p. 1045) believed the Bajocian and Callovian strata were represented here. Etheridge (1910) added a few more European forms to the list of Western Australian forms, which was completely tabulated by Glauert in the same year. Trechmann and Spath have noted

* *Kepplerites calloviensis*, according to Haug (1911).

several features of community between the Western Australian fauna and that of New Zealand.

It is interesting to note that Neumayr (1883) was of the opinion that Australasia and China were connected during Jurassic times into a single continental mass; but the discovery of the Malayan developments of the marine fauna has caused certain authors—*e.g.*, Lemoine (1906) and Haug (1911)—to substitute the conception of an Australo-Indo-Madagascan continent, over which there transgressed epicontinental seas into Western Australia and the Runn of Kutch during the Bajocian-Callovian epoch. Uhlig (1911) recognized in this a western development of the Mediterranean-Caucasian faunal province which merged into the Himalayan, of which he regarded as extensions the West African, West Australian, and New Zealand developments. These exhibit marked affinity with the faunas of the Japanese and South Andean provinces, though the contrast they show with the boreal and North Andean province prevents us recognizing a circumpacific geosyncline. The conclusions of Trechmann and Spath (1921) accord with this, and thus are not opposed to the hypothesis of a Jurassic land connection between South America and Australasia suggested by palaeobotanical evidence, and, according to Hedley (1911), by modern biogeography.

A further conception of Neumayr's must also be considered. Hedley (1909) has restated it from a biogeographic standpoint as follows: "A meridional crease in the earth's crust produced in Jurassic times a gulf, which he called the Gulf of Queensland, whose western shore transgressed the present east Australian coast. Enlarging through geological cycles, this gulf grew into what we know now as the Tasman and Coral Seas. . . . As the Mesozoic sink enlarged its periphery it became a dominant factor in land-configuration. First it broke through an inner earth-fold of which New Caledonia and the Louisades are relics. Then, continuing its work to the eastwards, it submerged a younger outer continental ridge on which the Solomons stand. Westerly it crumpled up the former coast of north Queensland, and by a further western effort broke open Torres Straits. While the Coral Sea was yet a prolongation of the old gulf, it offered a refuge to old forms of life. The low latitude afforded a warm unchangeable climate, and the surrounding continental extension (New Guinea–New Zealand) secluded its inhabitants from the incursion and competition of other tropical fauna. When, however, continued subsidence to the east at last burst through the Melanesian plateau, a flood of active competitors must have swept in from the open Pacific. . . . With the opening of Torres Straits, and the consequent outgoing current, the Queensland fauna was spread along north Australia to the Moluccas."

Walkom (1918), in discussing the above, points out that the late Triassic foraminiferal beds near Sydney form the most important piece of evidence of the existence of this gulf, and "there is no evidence at all to show that this gulf transgressed the present east coast of Australia during Jurassic time. . . . The gulf was probably more or less coincident with the present position of the Thomson Trough, but whether this trough is as old as Lower Mesozoic is difficult to determine." His palaeogeographic map (1918, fig. 5) illustrated his conclusion that during Jurassic times the eastern coast of Australasia remained in much the same position as it was in during the Triassic period,* and to the south the Gulf of Queensland disappeared, or was very much reduced.

* Piroutet's conclusion concerning the Jurassic emergence of New Caledonia was not available at the time Dr. Walkom wrote.

Lyman Clarke's (1921) study of the modern echinoderms of Torres Straits has led to the following conclusions:* "Hedley's hypothesis of a Queensland Gulf in Mesozoic time receives no support from the echinoderms. What may be called the original echinoderm fauna was on the north-west side of the present continent, and was of East Indian origin and Indo-Pacific composition. On the other hand, confirmation is afforded for Hedley's view that, as land areas east of New Guinea subsided, the Coral Sea became connected with the Pacific; its western shores also receded until the Great Barrier Reef was formed. This sea was invaded by echinoderms from the Pacific. . . . Continued subsidence on both sides led at last to the formation of Torres Strait, and the East Indian echinoderms then migrated eastward and southward to the Queensland coast, where they mingled with Pacific immigrants. The latter, however, had not passed westward through the straits." (Parenthetically, we may here recall the strong physiographic evidence of the westward retreat of the Queensland coast to its present position in comparatively recent times: *cf.* David, 1911.)

Late Jurassic, Lower and Middle Cretaceous.

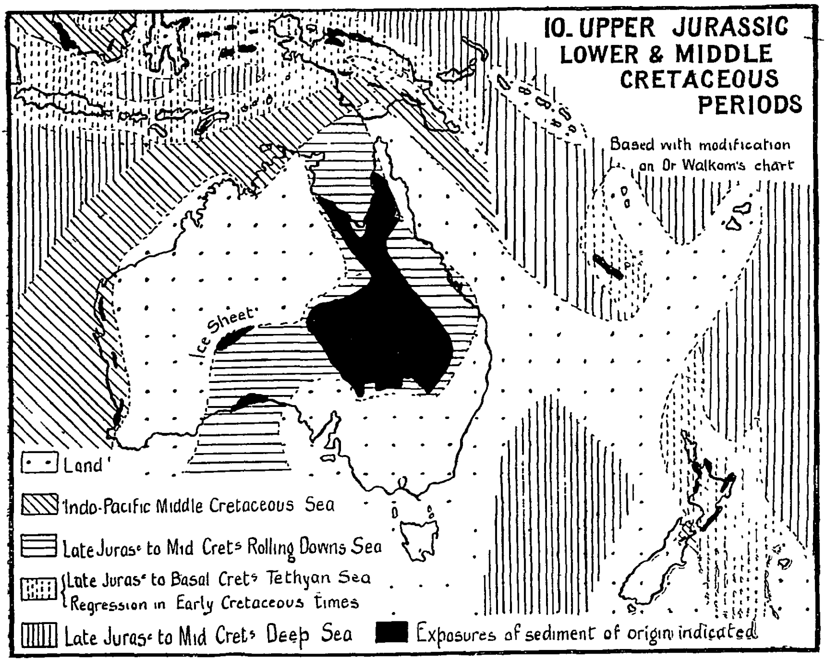
We have already seen that the marine sequence of earlier Mesozoic beds in New Zealand was concluded by the Tithonian or uppermost Jurassic beds at Kawhia, and the possibly early Cretaceous *Inoceramus*-bearing greywackes of the east coast, and, further, that the commencement of the retreat of the sea in New Zealand was approximately coeval with its entry into New Caledonia, which has been emergent throughout the earlier part of the Jurassic period. This sea, which passed from west to east across the island, brought in at first *Berriasella* (*Hoplites* cf. *novozealandica*), together with several species of *Trigonia*, *Alaria*, and undetermined gasteropods. Piroutet has not yet discussed the affinities of these, but apparently European, Indian, and western American forms are represented. A more extensive though still restricted series of three stages follows these Tithonian beds, the uppermost of which is the chief repository for coal in the island. It contains a further species of *Trigonia*, which is compared with a form† in the Maryborough beds of Queensland which Piroutet (1917) thought belonged "d'un niveau très elévé des Rolling Downs beds," but which, as we shall see, are of lowest Cretaceous age or even Upper Jurassic. With this form there occur in New Caledonia shells allied to *Pholadomya elongata* and *Exogyra couloni*, which occur in the lowest Cretaceous beds of southern Europe. This coal-bearing series is followed with but slight unconformity by the Senonian St. Vincent beds, so that here the Mid-Cretaceous emergence was not associated with any orogenic movement.

Jurassic-Cretaceous passage-beds are known also in several localities along the north coast of Dutch New Guinea, and closely resembling these are coeval beds in the Sula Islands characterized by *Phylloceras strigile*, *Lytoceras*, *Bochianites*, *Streblites*, *Hoplites*, *Himalayites*, *Nucula*, *Mytilus*, and *Anopaea*, a facies recalling that of the Spiti shales. Besides these are rather widespread foraminiferal limestones passing into *Globigerina* marl with belemnites, and known as the Buru limestone. It occurs in Buru, Ceram, Misol, Eastern Celebes, and Timor.

* Review by F. A. B. in *Nature*, 4th August, 1921.

† Concerning this species Etheridge (1892, p. 471) remarked that it "has a strong resemblance to a small and peculiar species, *T. semiornata*, figured by A. d'Orbigny from the Cretaceous rocks of South America."

Far more extensive than the above are the marine sediments of the Rolling Downs formation in Australia, concerning which ideas at present are somewhat uncertain. As recently as in 1914 Professor David, in summarizing their occurrence, declared them to be a Lower Cretaceous series of glauconitic sands and clays, almost wholly of marine origin, passing conformably downwards into fresh-water Jurassic rocks, and followed unconformably by the Desert Sandstone, largely of fresh-water origin, though containing marine fossils at Croydon in Queensland, and at Port Darwin. Since then Dunstan (1916, 1920) has shown that the term "Desert Sandstone" has been applied to lithologically similar rocks of various ages, including parts of the Rolling Downs formation itself, such as the Croydon beds mentioned above, and he has therefore abandoned the term altogether, proposing the name "Winton series" for the Upper



Cretaceous and early Tertiary fresh-water beds, which lie conformably on the lower series in Queensland, though with slight unconformity in other regions. Though Jack (1892) at first despaired of reducing to a definite sequence the apparent mixture of Jurassic and Cretaceous forms in the "Rolling Downs" formation, terming the whole Lower Cretaceous, Etheridge (1902), after the examination of many cores obtained from artesian wells, felt that "the time is not far distant when we shall be in a position to break up our continental Cretaceous system into a number of well-defined life-zones." Gürich (1901) had previously discussed the age of a collection from these beds near Wilcannia, and had referred them to the Jurassic on apparently inadequate evidence. Particular interest attaches, however, to the age of the Maryborough plant-bearing marine bed, which at first was classed with the "Desert Sandstones" as Upper

Cretaceous. Out of a described fauna of thirty-two species, eighteen occur in the Rolling Downs beds (Etheridge 1892A, 1901; Chapman, 1913). with which the Maryborough bed has since been correlated. Walkom (1919) has shown that the flora of the Maryborough bed appears to be an Upper Jurassic one, being free from angiosperms, while that of the immediately overlying Burrum beds is of the Neocomian type. He therefore concludes that the Maryborough marine fauna will probably have to be considered as Upper Jurassic, and to this period we may thus tentatively refer the lower portions of the Rolling Downs series.

In north-western Queensland there are widespread water-bearing limestones which Dunstan (1920) considers to be of fresh-water origin and Jurassic age, and to lie conformably beneath the Rolling Downs series. On account of the lithological character of these rocks, Woolnough (1912) has compared them with the adjacent partly silicified Lower Cambrian limestones. Danes (1916), however, states that he has found foraminifera in them, the specimens being referred to *Operculina, Globigerina, Nodosaria, Haplophragmium, Cristellaria,* and *Textularia,* a group of genera which give little indication of the age of the formation. Dunstan (1916) is disposed to agree with Jensen (1914), who suggests that these are merely Tertiary fossils occurring just like the adjacent but rare accumulations of Tertiary mollusca—namely, in small "pockets" in the surface of the Cambrian (?) limestone.

Referring to the fauna of the Rolling Downs beds, among the most distinctive fossils are certain foraminifera, chiefly Lituolidae, and the endemic lamellibranchs *Maccoyella, Pseudoavicula,* and *Fissiluna,* and the large cephalopods *Crioceras* and *Ancyloceras.* According to Etheridge and Dun's (1902) enumeration, the fauna contains 234 species, of which 100 are lamellibranchs, and nearly all are endemic, though out of a score of forms mentioned as having close allies outside of Australia sixteen are represented in India or Europe,* and two recently-described gasteropods resemble Californian forms (Etheridge, 1920).

Among the forms reported with representatives in extra-Australian areas are *Crioceras australe* in the Aptian beds of India, and *Inoceramus crispi,* a world-wide Cenomanian form, with species related to other types in the Cenomanian series with which both Haug (1911) and Woods (1917) correlate the upper part of the Rolling Downs beds. The report (Hector, 1886) that *Belemnites australis,* a Rolling Downs form, occurs also in the Jurassic beds of the Kawhia and Waikato Heads is the result of a mistaken identification, but *B. aucklandicus* in the same series is very like *B. liversidgei* in the Rolling Downs beds (Etheridge, 1892A, p. 491).

In regard to the origin of this fauna, Professor David (1914) and Mr. Dun (1914, 1919) believe that it was developed in an extensive but shallow epicontinental sea, which, extending out from the region of the present Gulf of Carpentaria, covered nearly a third of the continent. It is possible, as Haug suggests, that the transgression may have been more extensive in Middle Cretaceous times than in those immediately prior thereto, but of this there is not yet sufficient proof. The Maryborough

* Haug (1911) remarks, "All these forms have been described as new species with scarcely any identification with European species. It is probable, however, that the differences are more apparent than real." In explanation of this it should be noted that Mr. Etheridge frequently stated his method of nomenclature, which accords with Uhlig's (1911) principle: "I do not consider it wise to identify a form with a species described from a region thousands of miles distant unless the agreement is so close as to leave no room for doubt as to their identity."

fauna is so like that elsewhere in the Rolling Downs series that it appears preferable to consider the former as deposited not in a separate gulf, as Walkom indicates (1918), but as the extension of the sea into and beyond the northern depressed area wherein Jurassic sedimentation had taken place. There is also some doubt (expressed notably by Ward—private communication) as to whether this Cretaceous sea reached as far south as the bight where Cretaceous fossils have been found in strata concealed by overlying Lower Tertiary beds. Ward draws attention to the present absence of any connecting strata crossing the broad area of ancient gneisses and other crystalline rocks between these and the main mid-continental development. That such a connecting zone may have been present, and has now been very largely stripped off, laying bare its foundation, is suggested by the occurrence at Eucla, in beds beneath the Tertiary cover, of typically Rolling Downs genera such as *Maccoyella corbiensis*, *Aucella hughendenensis*, and *Fissiluna*, reported by Maitland (1919). This is indicated on the chart, which is a modification of that suggested by Walkom (1918). In this great mediterranean the fauna developed many endemic forms sharply distinct from those on the north-west coast of the continent, as will be shown. We may here record parenthetically the recent discovery by Talbot and Clarke (1918) of glaciated boulders in these rocks in the south-east of Western Australia, thus confirming an earlier report of a similar discovery by H. Y. L. Brown (1905) in the northern parts of South Australia. Each of the authors considers the glaciation to be of late Cretaceous age, or possibly early Tertiary (see also David, 1907).

Following the Cenomanian period of greatest flooding, there seems to have been an almost complete withdrawal of the sea from central Australia, and a slight crust-flexing and erosion took place before the formation of the Upper Cretaceous or Tertiary flood-plain deposits, so that in Upper Cretaceous times central Australia was mostly emergent, while the sea was transgressing on to the marginal regions of New Caledonia and New Zealand.

The occurrence of Cretaceous rocks in Western Australia is quite different from the above. At Gingin is a small area of chalky limestone, the most richly fossiliferous development of a series of Cretaceous rocks which underlie the coastal lowland near Perth. It contains the sponge *Peronella*, the coral *Coelosmilia*, and the brachiopods *Trigonesmus*, *Magas*, and *Magasella*, forms foreign to the rest of Australia, and allied to those in the Upper Cretaceous beds of India and South Africa. With these are also species of *Inoceramus* and ammonites, which are related to forms in the Rolling Downs beds (Etheridge, 1913). Chapman (1917A) has recognized 134 species of foraminifera in this rock, fifty-nine of which are restricted to the Cretaceous in other parts, chiefly Europe, and of these a fairly large number have hitherto been known only in the Gault (Albian) formations. He therefore concludes that the fauna is, on the whole, not Lower Cretaceous, but Albian-Cenomanian. It thus probably represents a middle Cretaceous expansion of the enlarging Indian Ocean which occurred about the time of the first transgressions of the Indo-Pacific fauna on to the eastern margin of Australasia, and that of the retreat of the sea from its central region. Twenty of the species recognized have also been recorded by Howchin (1893) from central Australia.

Near Port Darwin *Belemnites* beds stated to be of "Upper Cretaceous" age occur in "numerous pockets and patches mostly of slight area along the coastal fringe" (Jensen, 1914). They are composed of cherty sandstones, and contain numerous radiolaria (Hinde, 1893). They appear to overlie a Rolling Downs series, of which, however, no examples can be seen, unless they are exposed on the south of Melville Island, though wave-torn fragments of *Scaphites* and *Rhynchonella* derived therefrom are thrown up on to the beach (Woolnough, 1912). Little has been published concerning the detailed features of this district. It would seem, as pointed out by Dun (1914, 1919), that the Northern Territory in Cretaceous times played a rôle somewhat as in preceding epochs, separating an eastern mediterranean, where local forms developed, from a western region in which there is a more obvious relationship to the Indian faunal facies.

In western Borneo sandstone, claystone, and marl occur, characterized by the Cenomanian ammonite *Cnemoceras*, and adjacent to these are coeval plant-bearing sandstones and limestones with *Orbitolina concava*. Similar limestones appear in the Meratus Range, in the south-east of the island. These seem to indicate a small marine transgression in Middle Cretaceous times.

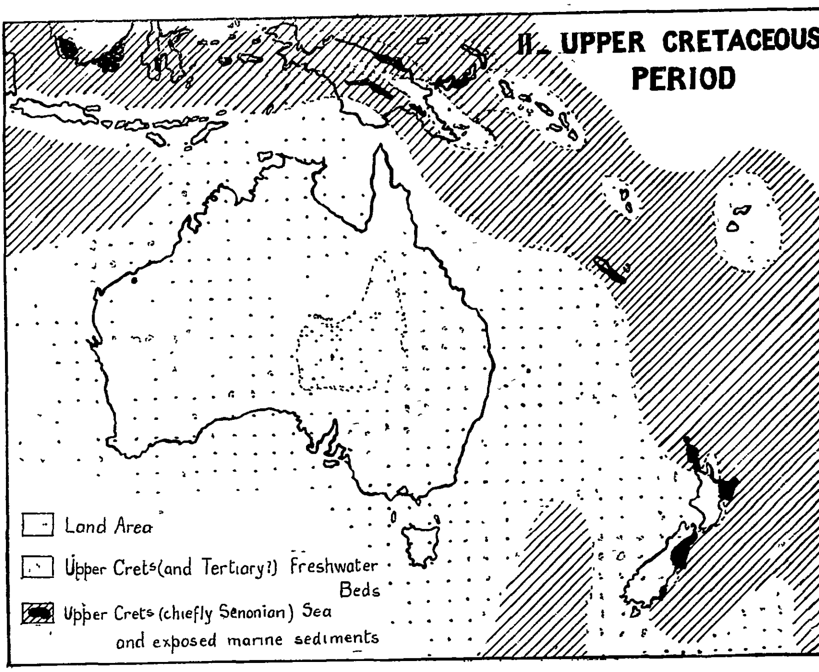
In New Guinea there are rather indefinite evidences of a Middle Cretaceous transgression. In the south, on the Strickland, a tributary of the Fly River, *Inoceramus concentricus* has been obtained (Etheridge, 1889). More recently a considerable extent of these rocks has been found (by the Lorenz, 1907, expedition ?). Professor David (1914) concludes that the Cretaceous transgression probably covered the whole island. The sediments are steeply dipping, and mostly dark-green calcareous and glauconitic (?) sandstones and limestones containing *Inoceramus*, *Gryphaea*, *Modiola*, *Aviculopecten*, *Protocardium*, *Cidaris*, *Belemnites* with *Alveolina* and *Orbitolites*. According to Rutten (1914), however, the two genera of foraminifera are in the Lower Tertiary rather than in the Cretaceous beds. It is the limestone containing these that is so widely distributed throughout the mountain-chain of western New Guinea, and possibly extends into the eastern half of the island. (See second footnote, p. 27.)

No Middle Cretaceous rocks are known in New Caledonia, where Upper Cretaceous beds rest directly upon Lower Cretaceous, so that a long emergence must have been here the feature of Middle Cretaceous time. The same is true in regard to the North Island of New Zealand; but that some depression of the New Zealand area occurred at this time is shown by the entry of Middle Cretaceous sea into the north-eastern corner of the South Island. Here the basement beds rest on an unevenly eroded surface of intensely folded (probably) Lower Mesozoic rocks; and, as there is no evidence of folding during the Mesozoic times prior to the commencement of the Cretceous period, this very intense orogeny must have occurred during Lower Cretaceous times. The Middle Cretaceous sands and clays have a maximum thickness of 8,000 ft., and contain sixteen described species of fossils, mostly lamellibranchs, including *Inoceramus concentricus*, with the cephalopods *Gaudryceras sacya* and *Turrilites circumtaeniatus*, forms widely distributed in the Indo-Pacific Lower Utatúr beds, and probably contemporaneous with the Albian beds and the upper part of the Rolling Downs formation (Woods, 1917). Unless Marshall's (1917) suggestion is correct—viz., that these beds are not really Middle but Upper Cretaceous—or Thomson's (1919), that the immediately overlying flinty limestones bridge the interval between these "Utatúr" beds and the overlying chalky Danian (?) limestone, it would appear that a regression of the strand followed the deposition of these beds, and that the New Zealand area was emergent though quite unfolded during Cenomanian and Turonian times.

Upper Cretaceous.

As in New Zealand, so in the Malay Archipelago, the sea retreated early in the Cretaceous period and great orogeny followed, accompanied by the widespread intrusion of masses of peridotite, gabbro, and perhaps less basic rocks. The last remnant of the Tethyan sea was driven out from the region by these movements. Except for a few forms, the immigrant fauna appearing later in Cretaceous times was of the Indo-Pacific type (Martin, 1914). This Senonian transgression was much more widespread than that of Middle Cretaceous times. Though Van Es (1919) refers merely to the presence of basal Cretaceous rocks in Sumatra, Gregory (1916) mentions the occurrence of *Actinacis sumatraensis* here in Upper Cretaceous beds. Richarz (1910) has summarized the other occurrences of rocks of this age in this region. A small thin-shelled fauna has been found in west Borneo, but more noteworthy are the richly fossiliferous Senonian (Ariyalúr) beds of south-eastern Borneo, in which occur the rudistid *Radiolites* with *Ostrea, Trigonia, Nerinea, Strombus, Nautilus trinchinopolitensis, Acanthoceras, Scaphites*, and a few brachiopods. In Celebes the Upper Cretaceous beds, which apparently merge into the Tertiary, are known as the "Maroro formation." They consist of a generally unfossiliferous series of violet, grey-blue, yellow, or brown claystones, which are intensely folded and invaded by granite and other plutonic rock, by which they have been much metamorphosed. These are rather widespread on the west of the island, but on the east the corresponding beds are more marly in character, with radiolarite and foraminiferal limestone. Unfortunately, Wanner (1919) does not cite any palaeontological data concerning them. In Buru, Wanner found a small molluscan fauna with *Tissotia;* in Obi, the brachiopod *Trigonesmus;* and in the islets south-east of Misol "hard grey marls with banks crammed with large shells of *Inoceramus*," numerous rudistids, and, more rarely, echinoids. The foraminifer *Lacazina* and *Lithothamnium*, which were supposed to indicate the presence of Upper Cretaceous rocks in the Kei Islands, are, however, referred by Rutten (1914) to the Eocene. In the central part of northern New Guinea (the Torricelli Mountains, 142° E., 3° S.) Richarz (1910) has found a small fauna consisting of *Cardium productum* and *Cerithium* aff. *sociale* (forms which may extend down to the Cenomanian, but are also in the Upper Cretaceous series of the Alps, Gosau beds, and have allies in the Upper Cretaceous series of India), associated with indeterminate forms of *Protocardium, Venus, Tapes, Psammosolen, Ostrea,* and *Cypraea,* and with the foraminifera that appear to have Tertiary (Oligocene-Miocene) affinities. Richarz concludes that the whole series is of Upper Cretaceous age, but that it is a curiously provincial fauna, and in particular is unrelated to that in the south of New Guinea. Gregory and Trench (1916) have described the Upper Cretaceous (?) coral *Actinacis sumatraensis* from a limestone pebble obtained high up the Fly River with numerous others containing Eocene forms. Farther east, near Kerema (146° E., 8° S.), occur the supposedly Middle Cretaceous rocks with *Inoceramus, Gryphaea,* noted above. In New Britain there occurred an *Actonella* in a white chalky limestone containing *Globigerina* and other foraminifera, which, however, Brady referred to Recent species. In New Caledonia the St. Vincent series of beds were laid down with minor unconformity on the Eo-Cretaceous coal-measures. They contain *Acanthoceras* and *Douvilleiceras*, with *Kossmaticeras loganianum* and *K. cumshevaense* which are found in the Middle Cretaceous rocks of Queen Charlotte Island (British Columbia). The last two forms are, however, also found in the Senonian beds of Seymour Island, Graham's Land, together with *K. bhavani* and *Trigonia arctica*, which also occur in the St. Vincent beds, where is *Puzozia gaudana*, also found in the Senonian beds of Peru, Pondicherry, and South Africa, with other widespread Senonian genera not specifically identified; nor does Piroutet (1917) discuss the affinities of the fauna, which, however, seems to be clearly representative of the general Indo-Pacific Upper Senonian fauna.

This fauna is also represented in New Zealand, spreading over the greater part of the North Auckland Peninsula, the eastern portion of the North Island, the northern and rather to the south of the central portion of the east coast of the South Island. The presence of *Gryphaea* and "Senonian" types of bryozoa in the Chatham Islands, as reported by



Dieseldorff (1901), may indicate an Upper Cretaceous transgression of the sea over the ancient land-mass of that region, but the information available does not permit us to decide whether the region remained continuously submerged until Middle Tertiary times, or whether some emergence of the land occurred in the interval, the late Cretaceous or early Tertiary times. The investigations of Woods (1917) on the fauna of the north-east of the South Island of New Zealand has shown that the general Indo-Pacific (Ariyalúr) Upper Senonian facies is clearly developed; and this is confirmed by the later work of Trechmann (1918) and Wilckens (1917, 1920, 1922). Very striking, again, is the absence of any noteworthy community with the Australian Cretaceous fauna. Trechmann identifies some shells with the "*Natica*" *variabilis* of the Rolling Downs series, but Wilckens (1922) divides these into two new species.

The strong affinity between the contemporaneous fauna of New Caledonia and New Zealand is shown by the presence of the following common genera: *Kossmaticeras, Baculites, Lytoceras, Anisoceras, Gaudryceras, Trigonia, Arca, Cardium, Alaria.*

Very striking, however, is the close affinity of the New Zealand fauna with that of Graham's Land, Patagonia, Chile, and Peru. Woods (1917) recognized only two or three forms identical with South American species, and four with close affinities thereto. Trechmann (1917A) added to these, and Wilckens (1920, 1922), while revising some identifications, added a dozen species with close relatives among the South American beds. We may now recognize the following species of mollusca as being common to New Zealand and to Graham's Land and South America: *Trigonia hanetiana, Inoceramus pacificus, Panopea clausa, Baculites vagina, Kossmaticeras gemmatus.* In addition the following species in New Zealand are closely related to South American forms: *Cucullaea antarctica, C. zealandica, Malletia cymbula, Calliostoma thomsoni, C. wilckensi, Lahillia* sp., *Trigonia antarctica, T. pseudocaudata, Kossmaticeras haumuriensis, Natica ingrata, Scalaria pacifica, Struthiolariopsis similis, Eriptycha punamutica, Cylichna thomsoniana, Arrhoges haastianus,** *Perissoptera waiparensis, Conchothyra parasitica, Tudicula* ex. aff. *tumida, Pleurotomaria maoriensis, Patella* (?) *amuritica, Cryptorhytis vulnerata.* Dr. Marshall's investigations of the fossils of the North Auckland Peninsula add further evidence of this affinity. So great is it that Wilckens (1920) concludes that New Zealand, Graham's Land, and Patagonia formed part of the southern coast of the Pacific Ocean in Senonian times.

There has thus been obtained within recent years strong palaeontological evidence of the littoral and therefore land connection of part of Australasia with Antarctica and South America at the close of Mesozoic times, a connection of which the probability has long been upheld by students of the distribution of the modern flora and fauna. At the same time, the striking difference between the Cretaceous faunas of New Zealand and Australia indicates that at the close of Mesozoic times there was a marked difference between the relations of South America to New Zealand on the one hand and to Australia on the other, as has been the case, apparently, in succeeding periods up to the present.

Post-Cretaceous.

The circumpacific connection, however, broke down during the Tertiary period, but the stages by which the separation was affected will not be discussed here, though a few remarks may not be out of place. Divergence between the history of New Caledonia and New Zealand appears once more in Danian times. In the former, retreat of the sea occurred during this period, with some contemporaneous crust-folding occupying the early Eocene periods, after which a varied series of Eocene sediments were laid down in three stages, in the last of which the island was completely submerged. These contain *Spatangus, Prenaster,* and various species of *Orthophragmina* and *Lithothamnium,* the last two being genera well known in rocks of this age in New Guinea (Rutten, 1914). This transgression

* Trechmann thought this to be identical with *Aporrhais gregaria.*

was followed by the most intense orogenic movements of which there is record in the island, in which the vast intrusive masses of peridotite came into place. These movements were doubtless connected with those occurring in Miocene times throughout the outer arc of the Malay Archipelago which gave rise to intense folding and alpine overthrusting.* In New Zealand, on the other hand, the Senonian beds are followed by Danian (?) limestones, as suggested by Chapman's 1910 work, and these by a succession of Tertiary beds, for the most part without marked unconformity, though there is some evidence of block-movements, warping, and consequent local transgressions and regressions during that period. In the North Auckland Peninsula, however, the great dislocation of the Upper Cretaceous and early Tertiary beds, clay-stones, hydraulic limestones, &c. (into the latter of which the serpentines of Wade have been injected—*fide* Bartrum), contrasted with the lesser disturbance of the later Tertiary beds, suggests that this region has come within the influence of the New Caledonian early Tertiary orogenic movements. The abundant fauna exhibits but little community with that of the Tertiary rocks of southern Australia. In regard to the brachiopods, Thomson (1918) concludes that those in Australia, New Zealand, and South America originated on the coast of the portion of Gondwanaland that then existed, and were grouped into different faunal provinces by the early Cretaceous crust-movements, for in each area where Recent forms occur they are the diminished remnants of the "Miocene" forms in that area, and give no evidence of communication since that period with adjacent areas. "The communication between New Zealand and Antarctica and New Zealand with the migration of the brachiopods may have occurred as early as in the Cretaceous, and apparently was earlier than the connection of Antarctica with Australia." A like conclusion is reached by Marshall and Murdoch (1920), who state that "the present molluscan fauna of New Zealand seems to be a remnant of a fauna of early or middle Tertiary age." While, therefore, there is some indication of an influx of South American "Miocene" forms into New Zealand (when the New Zealand fauna was perhaps more allied to that of Patagonia than of Australia), it has been completely isolated ever since.

Thus it would appear as if at the close of Mesozoic times the various portions of Australasia ceased to have any striking unity of geological history. The fragmentation of the region became more active, and extending subsidence blocked it out into geographical elements, the remnants of which are now visible. These appear to have had very diverse histories during the Tertiary period, to have been submerged, warped, elevated, or folded at different times, and to have developed provincial faunas with little intermigration. Little has yet been done which permits us to correlate the Tertiary records in these various regions. The end of the Mesozoic period thus appears to be a fitting point to close this attempt to trace in broad outlines the geographical evolution of Australasia, and the source of its successive marine faunas.

* A continuation of the same orogeny occurred throughout the archipelago at the close of Pliocene time, but was then chiefly in the nature of vertical block-movements, though with a considerable horizontal displacement also (Brouwer, 1919, 1921).

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Addendum.

Concerning the relationship of the "Permo-Carboniferous" fauna of Western Australia to that of the East Indies, reference should be made to the following paper read before the Royal Society of New South Wales in December, 1922, by Mr. W. S. Dun and Professor Sir Edgeworth David: "Notes on the Occurrence of *Gastrioceras* at the Irwin River Coalfield, Western Australia, and a Comparison with the so-called *Paralegoceras* from Letti, Dutch East Indies."

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