THE GEOLOGICAL HISTORY OF THE PACIFIC OCEAN. An ADDRESS TO THE GEOLOGICAL SOCIETY OF LONDON AT ITS ANNIVERSARY MEETING ON THE TWENTY-FIRST of FEBRUARY, 1930.

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The Geological History of the Pacific Ocean.

(1) The Supposed Permanence of the Pacific.

The Pacific Ocean, as the greatest geographical unit on earth, with an area greater than that of all the land, presents the difficulties as well as the attractions of its size. Its broad trigonal shape, nearly 10,000 miles wide from New Guinea to Peru, forms a striking contrast to the long trough of the Atlantic, about 1700 miles across from Brazil to Liberia. The differences in size and shape render the continuity of the grain and recurrence of similar structural units, which are such conspicuous features on the opposite coasts of the Atlantic, less likely with the Pacific. Biological differences between Papua and Peru may appear at first sight so fundamental as to debar any former direct land-connexion; but the distance between them is greater than that between western Europe and south-eastern Asia, which are in distinct zoological regions, although parts of one continuous land.

The 3000 islands of the Pacific give little evidence as to its geological history, for most of them are composed of comparatively young volcanic ejecta or coral-rock. They have been piled up from the sea-floor; many of them have been submerged by temporary subsidence, and have received their existing fauna and flora by the drift of organisms through the air or across the sea.

Again, unlike the Atlantic, which consists of three well-marked divisions, the first striking feature of the Pacific is its apparent unity. It is surrounded by lines of volcanoes, its so-called 'girdle of fire', and by an earthquake zone which indicates that its margin is unstable and has undergone recent earth-movement. It is bordered by mountain-chains which for great distances are parallel to the shore, instead of meeting the coast at a high angle and being there cut off abruptly. Hence Suess separated the coasts of the world into two types, the Pacific and Atlantic coast-types. They have been correlated by Prior, Harker, and Becke with petrographic types, the coasts of the Atlantic type being associated with alkaline lavas and those of the Pacific type with lavas richer in lime and poorer in alkalies.

The Pacific Ocean has, therefore, been claimed on the grounds of its geographical and geological unity to have existed throughout geological time. This view, urged by Dana in 1846, has been adopted by many geologists, such as Frech and Schuchert[1]; by palæontologists such as W. D. Matthew (1906)[2]; by many zoologists, from Russell Wallace in his 'Island Life' (1880) to the recent verdict of Prof. P. J. Schmidt,[3] of the Zoological Museum, Leningrad, that 'the Pacific was formed in very ancient times, and has undergone no important changes'; and that its basin in the Mesozoic Era was 'of nearly the same dimensions as now, and preserved a fauna of the same character'. Among oceanographers who have adopted the same theory was H. N. Dickson,[4] who stated that 'the present contours of the open Pacific are almost as they were in Palæozoic times, and in the intervening ages changes of level and form have been slight'.

[1] The literature is so voluminous that complete reference is impracticable. The references here given are only representative: some are to early papers of historic importance, and some to recent literature which refers to previous authorities.

[2] 'Hypothetical Outlines of the Continents in Tertiary Times' Bull. Amer. Mus. Nat. Hist. vol. xxii (1906) and many later papers.

[3] Third Pan-Pacif. Sci. Congr. vol. i (1929) p. 1021

[4] Encycl. Brit. 'Pacific Ocean' vol. xx (1911) p. 435.

This belief in the permanence of the Pacific has been rejected by other authorities. The existence of a Mesozoic Pacific Continent was advocated in his Presidential Address to this Society sixty years ago by Huxley.[1] It was supported by Baur[2] to explain the remarkable fauna and flora of the Galapagos Islands and the distribution of various animals throughout the Indo-Pacific region. Haug[3] inferred from his view of geosynclines that practically the whole of the Pacific basin must have been occupied by a continent during the Mesozoic and until late in the Kainozoic Era. This continent, he remarked, was hypothetical; but he claimed that it must be accepted, since the evidence 'nous l'impose d'une manière absolue'. According to Haug the Pacific Continent was both 'Secondary' and 'Tertiary', and even late 'Tertiary', as he attributed to eastern projections from the Pacific Continent the folding in the Antillean and South Georgian arcs. He reasserted its existence in his 'Traité de Géologie' (vol. i, 1907, pp. 169–70, vol. ii, 1910, p. 1115) as 'très vraisemblable', and as broken up by the Eocene (vol. ii, pt. 3, 1911, pp. 1561, 1563).

That the Pacific is the oldest ocean is accepted by some authorities, as Prof. F. von Huene,[4] who reject its permanence. In 1899, however, after having argued on various grounds against the permanency of the Pacific Ocean, I expressed the view that[5] 'the Pacific Ocean may have undergone great changes later than the other oceans'.

(2) Theories of the Origin of the Pacific.

The view of the unity of the Pacific was strengthened by widely accepted theories of its origin. According to O. Fisher[6] and Sir George Darwin the Pacific basin is the hollow made when the moon was torn away from the Earth. This theory was

[1] Q. J. G. S. vol. xxvi, Proc. (1870) p. lx.

[2] G. Baur, 'New Observations on the Origin of the Galapagos Islands, with Remarks on the Geological Age of the Pacific Ocean' Amer. Nat. vol. xxxi (1897) pp. 661–80, 864–96.

[3] E. Haug, 'Les Géosynclinaux et les Aires continentales' Bull. Soc. Géol. France, ser. 3, vol. xxviii (1900) p. 646.

[4] 'Versuch einer Skizze der Paläogeographischen Beziehungen Süd-Amerikas' Geol. Rundsch. vol. xx (1929) p. 91.

[5] In 'The International Geography' 1899, p. 41.

[6] 'Physics of the Earth's Crust' 1881; 2nd ed. 1889, p. 358.

inconsistent with the figures of size and density: the Pacific basin is calculated at 144,402,000 cubic miles; the moon is about 37 times too big. Nor does the moon consist of the right material: the specific gravity of the continental zone of the Earth's crust is about 2·5, and, as that of the moon is 3·4, it is heavier than it should be if it were composed of the layer which formerly connected America with Asia and Australasia. The lunar origin of the Pacific depression appears no more probable than H. Simroth's[1] explanation of Africa as due to the fall on to the Earth of its second moon, which spread out when melted by the heat of impact.

The standard geological theory of the Pacific Ocean is that of Eduard Suess, who was impressed by its geographical unity, as indicated by the parallel folded mountains around it, and by the frequent occurrence along its margin of marine Triassic rocks. Hence Suess[2] concluded that the Pacific was an ocean in the Trias, was somewhat smaller in the Jurassic Period, and has since been continuously reduced in area. Suess's view encouraged the hypothesis that the Pacific Ocean has been permanent throughout geological history: this belief has been often rejected. Suess himself held that the Pacific block has acted like the peninsular portion of India in resisting the advance of Asia; and many biologists and palæontologists have insisted that the distribution of animals and plants can only be explained by the existence of a continent in the Pacific, or of land-bridges across it.

If the Pacific Ocean has been permanent, we should expect clear manifestations of the persistent unity of its fauna, and that it would be surrounded by the remnants of concentric zones of successive geological systems. It was the evidence in favour of a circum-Pacific Triassic zone which led Suess to his belief in the Triassic Pacific.[3]

Let us consider first, as the most direct existing evidence upon the problem, whether the different geological systems are distributed around the Pacific in accordance with this plan.

[1] 'Die Pendulations-Theorie' 2nd ed. (1914) p. 544.

[2] 'Face of the Earth' vol. ii (German ed. 1888) p. 553. This view has been frequently expressed with various modifications; one of the latest restatements is by L. Kober, 'Der Bau der Erde' 2nd ed. (1928) pp. 352–64.

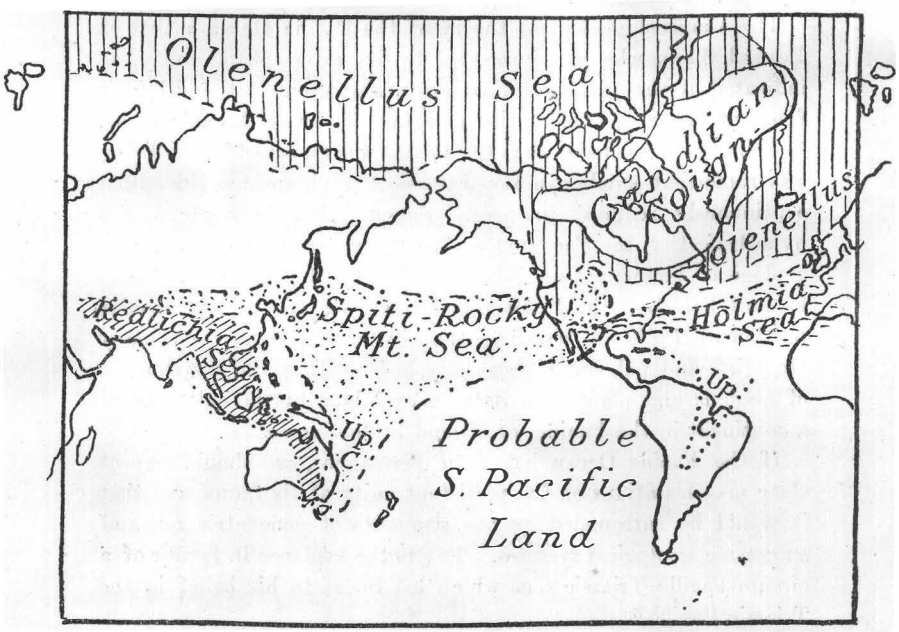
[3] *Cf.* Suess, *op. cit.* vol. ii. pp. 207, 257, etc.

(3) The Stratigraphy of the Pacific.

(i) The Cambrian.

The expectation that the Pacific Ocean had been established by the Cambrian Period is encouraged by resemblances between the faunas of that date in eastern China and western North America, and by Frech's claim for the existence then of a Pacific zoo-

Fig. 1.—*The Pacific Seas in the Cambrian Period.*



Lower Cambrian.
- The Olenellus Sea on the north: vertical shading.
- The Redlichia Sea on the south-west: inclined shading.
- The Holmia-Callavia Sea across the southern United States and England: horizontal bars.

Middle and Upper Cambrian—The Spiti-Rocky Mountain Sea, with extension across eastern Australia: dotted.

An Upper Cambrian Gulf reached Bolivia from the Atlantic.

[*For* 'Candian' *read* 'Canadian'.]

geographical province.[1] Later information as to the distribution of the Cambrian seas in the Pacific area is, however, inconsistent with the existence of a single Pacific province or with an ocean like the present Pacific. As was pointed out by Dr. F. R. Cowper Reed[2] in 1910, Frech's province must be subdivided.

In the Lower Cambrian the Pacific was occupied by three distinct seas. The Olenellus Sea of the North Atlantic spread westwards into the United States as the Georgian Province, which, in Vermont, included the original locality of *Olenellus*. This sea was connected with the contemporary sea of Siberia and with the Waucobian Gulf of California, which was occupied for a short stage by a western form of *Olenellus*. In this gulf accumulated 6000 feet of sediment from land now under the Pacific. The Olenellus Sea in the north of Scotland was separated by land from the Callavia-Holmia Sea of the English Midlands. In the United States the Olenellus Sea in the north was widely separated from the Redlichia Sea of the south-western Pacific and south-eastern Asia. This Redlichia Sea reached the Punjaub, Spiti in the Himalaya, and Mesopotamia; a branch to the south crossed the Kimberley district of north-western Australia to South Australia near Adelaide; and it had a great extension in southern China, in Yunnan, and farther north in eastern China.

Dr. Cowper Reed pointed out in 1910 that the characteristic trilobites of the Middle Cambrian of western North America, for instance, *Olenoides*, *Neolenus*, and *Ogygopsis*, are absent from the Cambrian fauna of northern India,[3] which has no resemblance to the contemporary fauna of northern China.[4]

The Redlichia Sea, according to C. D. Walcott,[5] was not connected either with the Lower Cambrian Sea of southern Siberia or with that of North America. 'The Lower Cambrian *Redlichia* fauna of Asia,' he says, 'is so distinct that there is no probability of

[1] F. Frech, 'Lethæa Geognostica' pt. i: Palæozoicum, vol. ii (1897) pp. 57–58, map 1, represented the Pacific as early as the Middle Cambrian as a continuous sea much larger than at present, and covering the eastern half of Asia, Australia except the two northern peninsulas, and as being continuous with the Atlantic owing to the submergence of Central America and all the Antilles.

[2] 'Himalayan Fossils' Pal. Ind. ser. 15, vol. vii (1910) p. 63.

[3] *Ibid.* p. 64.

[4] *Ibid.* p. 65.

[5] 'Cambrian Faunas of Eastern Asia' Smithson. Misc. Coll. lxiv, No. 1, Publ. 2263 (1914) pp. 62, 69.

its having lived in the same province with the Mesonacidæ fauna of North America.' It is therefore clear that the Redlichia Sea was bounded by land east and north-east of China and Australia, that separated it from the Waucobian Gulf of California and from the North Pacific Sea; and this land may have occupied a vast area in the southern Pacific. By the Middle Cambrian, the northern sea had lost its brief extension to the Waucobian Gulf of California, for *Paradoxides*, its characteristic trilobite in the British Isles, did not reach western North America. The Middle Cambrian of Shantung was still distinct, according to Walcott,[1] from that of Siberia. Some genera of trilobites are common to Spiti and China and to the rich fauna of the Rocky Mountains; Cowper Reed[2] remarks that the Spiti fauna is strongly related to that of western North America, but the Middle Cambrian of China is declared by Walcott to have still had no connexion with the wide-ranging sea on the east. Hence large tracts of the Pacific must then have been occupied by land.

In the Upper Cambrian the faunas of China and western North America have a strong generic community; but the absence of the characteristic European genus *Olenus*, which occurs in North America in Cape Breton, shows that the sea which extended across the North Pacific was separated from the northern and British seas. The Croixian Province of Minnesota contains the trilobite *Dikelocephalus*, which ranges thence through the Rocky Mountain Province to China, and extends south to Tasmania and south-eastern Australia, where it was associated with the Heathcotian genus *Notasaphus*. But, while the Upper Cambrian Sea stretched from the centre of the United States to China and Tasmania, it was bounded on the south and south-east by a South Pacific land, as indicated by the absence of the Cambrian from New Zealand, from the continental islands of the south-western Pacific, and from the whole of the western coast of South America. The Upper Cambrian sea, however, covered parts of eastern Australia that had been, during both the Lower and Middle Cambrian, part of the South Pacific land.

Instead, therefore, of the Palæozoic Era beginning with the Pacific Ocean already in existence, its area was occupied by a varying series of mediterranean seas. In the Lower Cambrian one sea ranged across the North Pacific, with a gulf reaching as

[1] 'Cambrian Faunas of Eastern Asia' 1914, p. 73.

[2] 'Himalayan Fossils' 1910, pp. 64, 65.

far south as California; a second sea lay over parts of southern and south-eastern Asia and western Australia; and a third sea extended from northern China to the north-western United States, and increased until it submerged eastern Australia. An arm of the contemporary sea in the Atlantic reached Bolivia; but there is no evidence of any Cambrian Sea on the western coast of South America, or in New Zealand, or in the intervening area.

The evidence indicates, not a Cambrian Pacific Ocean, but relatively narrow seas, separated by land.

(ii) The Ordovician and Silurian.

In contrast to the isolation of the Cambrian Seas is the cosmopolitan range of the Ordovician and Silurian faunas. Graptolites of the same species and in the same general sequence occur in south-eastern Australia and Europe; the agreement is, in part, even closer between Australia and New York State. Many of the Ordovician and Silurian Australian molluscs and brachiopods have been identified as European species. Dr. Cowper Reed has remarked the close affinities of the faunas. Dr. Bather informs me that the Silurian crinoids of Victoria (Australia) would have been quite at home in the North Atlantic. Mr. Chapman observes that the coral genera appear earlier in Australia than in Europe, where some of them appear first in the Devonian, as if, like some disputed Victorian plants, they originated in the South Temperate Zone.[1]

There is also a marked increase in the community of central Asiatic and North American life. Dr. Cowper Reed[2] has remarked that the Ordovician fauna and the Silurian corals of the Himalaya are American in type, in contrast to the essential difference between the Lower Cambrian faunas of the two areas. The American affinity does not, however, hold throughout the two Periods; for the Silurian fauna of the Central Himalaya, excepting the corals, is described by Dr. Reed[3] as predominantly European.

The spread of part of the faunas has been explained by a widespread increase of the sea. Frech's[4] Pacific had expanded in the 'Lower Silurian' into his 'Pacifisch-amerikanisches Meer', which

[1] F. Chapman, Proc. Roy. Soc. Vict. n.s. vol. xxxiii (1921) p. 218.

[2] 'Himalayan Fossils' Pal. Ind. ser. 15, vol. vii (1910) p. 66; *ibid.* (1912) pp. 164, 167.

[3] *Ibid.* (1912) p. 167.

[4] 'Lethæa Geognostica' pt. i: Palæozoicum, vol. ii (1897) map 2.

submerged most of America and spread the Asiatic Sea over much of Europe. The change also led to the deposition in Central Australia of wide areas of limestone which indicate a clearer sea than the shales of Victoria and New South Wales.

The freer communication between some of the seas does not imply the general extension of the sea over the Pacific region. The southern Pacific made no great advance on South America: the Ordovician of Peru was restricted to the eastern interior, and was due to a transgression from the Atlantic side; and there is no known occurrence of Ordovician rocks along the western edge of South America, south of Colombia. On the other side of the southern Pacific the Australian sea had reached New Zealand. In the northern Pacific, on the other hand, the seas were less extensive than in parts of the Cambrian. According to Dr. W. Grabau[1] the only Ordovician rocks in northern China were due to an advance of the Arctic Sea up the valley of the Lena and thence southwards (on 130° E.) into the province of Chihli; the deposits begin with the Lower Ordovician fauna of the Durness Limestone (northern Scotland) and Beekmantown (New York).

Farther south, an instructive Upper Llandeilo fauna was discovered by von Loczy and Coggin Brown at Pupiao in Yunnan: this fauna is allied to that of Russia and Britain, and not to the American. So also is that at a slightly higher horizon (the *Climacograptus-peltifer* Zone, at the junction of the Llandeilo and Bala) discovered by my son and myself at A-shih-chai; for the graptolites are identified by Dr. G. L. Elles as common British species.[2] In Central China, in Szechuan and west of Hankow, the richly fossiliferous Upper Llandeilo and Bala beds have a Baltic fauna. In Tongking and Annam the Upper Ordovician is known in two localities, and the fauna is again European.

On the American side of the North Pacific the conditions were remarkably different from those of eastern Asia. An Arctic Sea, rich in cephalopods, ranged from the north and north-west of Greenland to Siberia and perhaps to the Baltic, and in America it extended up the Mackenzie Valley to Manitoba and the St. Lawrence. At times, an arm of this sea continued south-west from the upper Mackenzie Valley to the coast of California at its main bend near Los Angeles and Santa Barbara. At times, a

[1] 'Stratigraphy of China' vol. i (1924) p. 66.

[2] In J. W. Gregory & C. J. Gregory, Phil. Trans. Roy. Soc. ser. B, vol. ccxiii (1925) pp. 290–91.

second gulf notched the coast farther south, and crossed the peninsula of Lower California into Mexico. Prof. C. Schuchert's[1] maps show that very little of the western coast of North America was covered by the sea in Ordovician and Silurian times.

During most of both Periods the site of much of the western mountains of the United States and Canada was occupied by land, which probably extended far westwards into the Pacific; but the sea covered the Mackenzie Valley and parts of the Rocky Mountains. Prof. Schuchert's maps show that two or three parts of the western coast of North America were at times submerged by gulfs running eastwards from a continuous North Pacific ocean. If so, and if that ocean had extended westwards to Asia, we should expect the same faunas there as in America. Dr. Grabau[2] remarks of the Pupiao beds that 'there is scarcely any trace of an American element in this fauna'. This statement is true in general of the eastern Asiatic faunas of both Periods: their affinities are European, not American. Hence, between the Ordovician and Silurian Seas of eastern Asia and western North America there was doubtless a sufficient width of land to separate the two faunas.

(iii) The Devonian.

The southern Pacific region underwent a marked change in the Devonian when, so far as is known, the sea first entered its south-eastern quarter, while it receded in the west. In the Lower Devonian the whole of eastern Asia, the Philippines, the East Indian Archipelago, Australia, and New Zealand were occupied by an apparently continuous land. Middle Devonian marine deposits occur in the Shan States of Burma and in Annam; but they are not known to have reached the eastern coast of China. Their fauna is European. So also is that of the Middle Devonian of Chinese Tibet; for the limestone of Janula yielded a fossil identified by Dr. Cowper Reed[3] as a variety of *Uncinulus procuboides* Kayser, and the *Stromatopora* reefs near the great bend of the Yangtze Kiang are formed of species closely allied to those of Europe.[4]

[1] 'Paleogeography of North America' Bull. Geol. Soc. Amer. vol. xx (1910) pls. 55–71.

[2] 'Stratigraphy of China' vol. i (1924) p. 86.

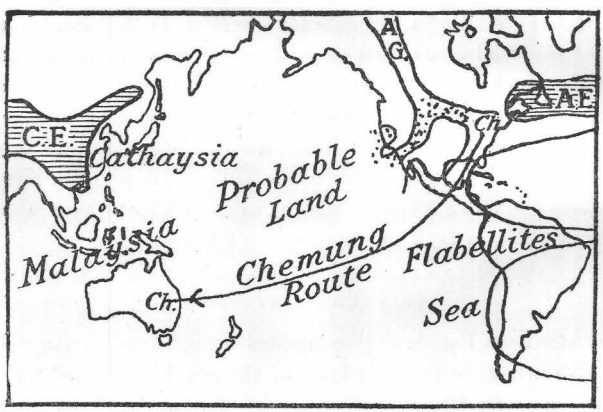
[3] In J. W. Gregory & C. J. Gregory, 'Geology & Physical Geography of Chinese Tibet' Phil. Trans. Roy. Soc. ser. B, vol. ccxiii (1925) pp. 287–89.

[4] *Ibid.* pp. 291–94.

These Chinese Middle Devonian (Eifelian) limestones were formed in a narrow sea which was a precursor of the Tethys, but is not known to have reached the Pacific during the Lower Devonian and the lower part of the Middle Devonian ; but, towards the end of the Middle Devonian, in the Givetian, the sea reached the Gulf of Tongking, and a northern branch entered the Gulf of Okhotsk.

The same arrangement in eastern Asia held in the Upper Devonian.

Fig. 2.—*The Pacific Seas in the Devonian Period.*



C.E. An extensive sea in China, with a European fauna.

A.G. Arctic gulf up the Mackenzie Valley.

Dotted area: California Sea. without the Chemung Fauna.

Ch. Chemung Fauna in New York State and New South Wales, which latter it probably reached across the Pacific.

Flabellites Sea, covering part of western South America, but not reaching Australia.

The Central Pacific—probably land, in extension of Cathaysia and Malaysia, and separating the Chinese from the Chemung fauna.

The extension of the land in Australia and western Asia was, according to F. Frech,[1] accompanied by a survival of the Pacific as an unbroken ocean and nearly of its present extent, except for land having occupied Bering Sea north of the Alaskan Peninsula. But the evidence for the occupation of the northern Pacific by sea is by no means convincing. The western coast of North America, as summarized in Prof. C. Schuchert's[2] maps, was mainly land,

[1] 'Lethæa Geognostica' pt. i: Palæozoicum, vol. ii (1897) map 3.

[2] Bull. Soc. Amer. vol. xx (1910) pls. 73–77.

with a Lower Devonian sea covering the shore near Los Angeles and in northern British Columbia; the sea there was somewhat more extensive in the Middle and Upper Devonian, when the Mackenzie Valley was an Arctic gulf. The faunas of the Middle and Upper Devonian of northern China show affinities to those of parts of North America; but the connexion may have been only by a narrow sea continuing the valley of the Amur, and in the Upper Devonian, occupying part of the Sea of Okhotsk: this sea was probably united with that of northern North America.

The continuity of the Middle and Upper Devonian South China sea with that of America is doubtful. The typical Middle Devonian coral, *Calceola*, ranges from western Europe to Yunnan, but does not occur in America. Some of the Middle Devonian fossils of Yunnan are very similar to those of New York; but, as Dr. Grabau [1] suggests, they doubtless reached the eastern United States across the Atlantic, as they are not known in Western America.

The Middle Devonian is the first date at which there is evidence of the occupation of the south-eastern Pacific by sea. The *Flabellites* fauna of Cape Colony and the Falklands is found in western South America, and extends into the Amazon Valley and Colombia, and into the Mississippi Valley. Hence, while the Flabellites Land of Schwarz (*cf.* Q. J. G. S. vol. lxxxv, 1929, p. cxviii) occupied the South Atlantic, a western sea extended from the Mississippi Valley to the Southern Ocean.

This *Flabellites* fauna did not, however, occur in the south-western Pacific, hence the area between South America and Australia was not a continuous ocean. Prof. W. N. Benson [2] insists that the Australian Devonian faunas had no connexion whatever with those of South Africa and South America, and that no channel between them was then in existence. But by the Upper Devonian New South Wales had been invaded by the Chemung fauna of New York, which does not occur in the Western States.[3] Hence it has been suggested by various authorities that this fauna migrated from the north-western Atlantic to Australia through the Arctic

[1] 'Stratigraphy of China' Geol. Surv. China, vol. i (1924) p. 198.

[2] 'Palæozoic & Mesozoic Seas in Australasia' Trans. N. Z. Inst. vol. liv (1923) p. 29.

[3] W. S. Dun, 'Devonian Boulders at the Opal Fields' Rec. Geol. Surv. N. S. Wales, vol. v (1898) p. 171; G. Gürich, 'Jura- und Devon-Fossilien von White Cliffs (Australien)' Neues Jahrb. Beilage-Band xiv (1901) p. 518; W. N. Benson, Trans. N.Z. Inst. vol. liv (1923) p. 28.

Sea and off the western coast of America; but the route may have been by the Atlantic and the Amazon Valley, and across the South Pacific.

This Chemung fauna, although it ranged from New York to New South Wales, must have been kept out of the north-western and western equatorial Pacific, since the Upper Devonian faunas of China and Yunnan are different.

The Devonian Period in the Pacific was characterized by variable seas separated by broad belts of land.

(iv) The Carboniferous.

In this System the evidence of the marine faunas is supplemented by that of land floras. The distribution of the seas can, therefore, be dismissed briefly. Most of the Pacific coast in North America and Asia was occupied, as during the Devonian Period, by land: but areas in California, Nevada, Montana, and British Columbia were at intervals again covered by the sea. The marine deposits on the eastern coast of Asia, in northern China and south-eastern Siberia, in the valleys of the Amur and the lower Yangtze Kiang, and in Tongking belong only to the Carboniferous or Dinantian. But farther inland, in Yunnan, extensive marine deposits belong to the Lower, Middle, and Upper Carboniferous. The faunas are predominantly European: the Viséan corals and brachiopods of Central China include British species. The Upper Carboniferous (Uralian) fauna of the Caspian is American, and the varied crinoids of the Mississippi Series of the Middle West of the United States belong to genera mostly found also in the Tournaisian in Belgium.[1] The connexion, by whatever route, was doubtless trans-Atlantic.

The Lower Carboniferous fauna of Europe extends across southern Asia and through Malaysia to New South Wales; this fauna does not occur farther east in New Zealand, and is distinct from that in South America. There appears little evidence of extensive marine connexion across the Pacific before the Upper Carboniferous, when American elements appeared in Yunnan[2] and Sumatra.[3]

[1] Dr. E. O. Ulrich maintains the Atlantic origin of the whole of the Palæozoic crinoid faunas, Bull. Amer. Geol. Soc. vol. xxii (1911) p. 502.

[2] H. Mansuy, 'Etude Géologique du Yunnan Oriental: II. Paléontologie' Mem. Serv. Géol. Indochine, vol. i, fasc. ii (1912) pp. 11, 97, 99, etc.

[3] G. Fliegel, 'Ueber Obercarbonische Faunen aus Ost- und Südasien' Palæontographica, vol. xlviii (1901) pp. 124–25.

The marine fauna, therefore, gives no indication of any Carboniferous Pacific Ocean; nor does the land vegetation. T. G. Halle[1] has shown that the Upper Palæozoic (Stephanian and Lower Permian) floras of Shansi in north-central China are as nearly related to those of North America as to those of Europe: D. White had previously remarked that this affinity was to the floras of western North America, so that it was not established across the Atlantic. Hence a broad effective land-connexion, in a suitable climatic zone, must have existed between China and the western coast of the United States.

Farther south is another flora, which is characterized by *Gigantopteris*. This plant was first discovered by F. von Richthofen in the coal-mines of Hunan; it was later found in Yunnan, and described by D. White[2] (1912) from the Wichita Formation of Texas. It occurs in Mexico, southern China, Manchuria, Korea, Yunnan and Fukien, Texas and Oklahoma: its age is Lower Permian and Lower Trias. It is regarded as a member of the Gondwanaland flora, and as having reached Mexico from the west or south-west. As the genus does not occur in northern China and only in the south of North America, there is no indication of its migration around the northern shores of the Pacific, although that route is adopted by White,[3] who assumes great climatic changes to render it possible. Both the northern and the *Gigantopteris* floras imply belts of land connecting Asia and North America.

(v) The Trias.

The evidence as to the condition of the Pacific during the Mesozoic Era is more abundant than for the Palæozoic. Less of the rocks has been removed by denudation, and the life of the land is better known. Nevertheless, opinions have been diametrically opposed: for, while Suess founded his history of the Pacific on its existence in the Triass, Haug's theory of geosynclines requires a Mesozoic Pacific Continent.

Suess's view of the Triassic age of the Pacific Ocean has been

[1] 'Palæontologia Sinica' ser. A, vol. ii, fasc. 1 (1927) pp. 276–78, 293.

[2] 'The Characters of . . . . *Gigantopteris*, & its Occurrence in North America' Proc. U.S. Nat. Mus. vol. xli (1912) p. 511; also H. Yabe, 'Geological & Geographical Distribution of *Gigantopteris*' Sci. Rep. Tohoku Imp. Univ. ser. 2, Geol. vol. iv (1917) map, p. 62.

[3] *Op. supra cit.* p. 513.

widely adopted, as by K. Martin.[1] Frech[2] represents a continuous belt of Trias around the Pacific, broken only from Korea to the Yangtze Kiang and in Australia. His map marks the Triassic Sea as covering all New Guinea, the Philippines, and other areas where there is no evidence of marine Trias. The Pacific Triassic girdle is very incomplete. There is no marine Trias in Australia[3] or in the Philippines, or on the coast of China, and the Pacific margin must be pushed eastwards, as suggested by R. von Drasche[4] in 1879, to the line through New Zealand, New Caledonia, and Japan. The eastern shore of the Triassic Pacific was similarly far west of South America.

Even along this inner line the supposed Triassic girdle is local and variable. New Zealand and New Caledonia both have abundant marine Trias: but in New Zealand there is no Lower Trias, while the Upper and Middle series are well developed. In New Caledonia, on the contrary, the Lower Trias is represented by the Werfenian, the Middle Trias is absent, and the Upper division has a great development. The irregular occurrence of the Trias suggests, not a permanent ocean with a transgressive border, but deposition in the depressions of an irregularly sinking land.

The Trias of New Zealand and New Caledonia are grouped by Carl Diener[5] as the Maori Province, a division of the Himalayan

[1] 'Ein zweiter Beitrag zur Frage nach der Entstehung des Ostindischen Archipels' Geogr. Zeit. vol. xiii (1907) p. 436.

[2] 'Lethæa Geognostica' pt. 11, Mesozoicum, vol. i (1908) Welt-Karte der Trias.

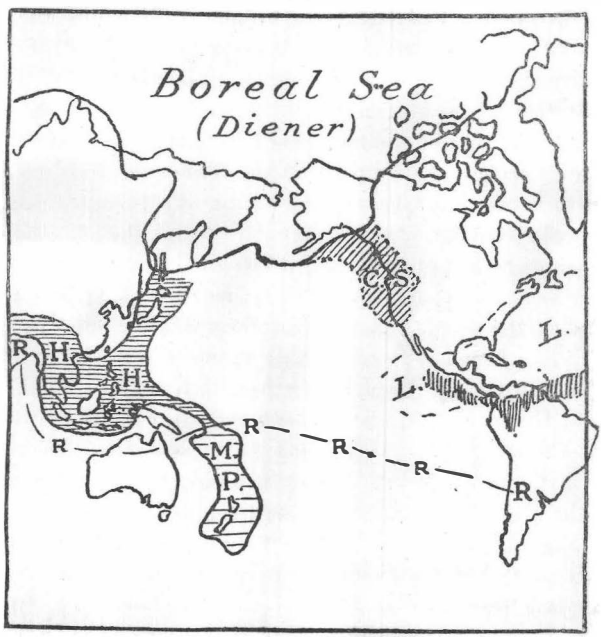
[3] This statement may appear inconsistent with the ostracod-foraminiferal limestone in the Wianamatta Shales of New South Wales, which has been advanced as evidence that the Triassic sea reached the eastern coast of Australia. But (1) that limestone is Rhætic, which I regard as Jurassic; (2) Chapman ('On Some Microzoa from the Wianamatta Shales, N.S.W.' Rec. Geol. Surv. N.S.W. vol. viii, 1909, p. 335) says that the fossils are brackish or estuarine, and are a mixture of Lower Jurassic and Upper Palæozoic; (3) the bed is not accepted as marine by some Australian geologists, such as C. A. Süssmilch (Geol N. S. Wales, 1922, p. 162), who concludes, despite the foraminifera, that it is a freshwater formation. Dr. A. B. Walkom ('Lower Mesozoic Rocks of Queensland' Proc. Linn. Soc. N.S.W. vol. xliii, 1918, pp. 104, 106) suggests that this deposit may have been formed by an extension of Neumayr's 'Gulf of Queensland'; he regards it as post-Triassic, and remarks that 'there is no marine deposit of Triassic age known on the present Australian Continent'.

[4] 'Ueber Paläozoische Schichten auf Kamtschatka & Luzon' Neues Jahrb. 1879, p. 268.

[5] 'Die Marinen Reiche der Triasperiode' Denkschr. Akad. Wissensch. Wien, vol. xcii (1915) p. 494.

Region. This province is regarded as a continuation of the Tethys by some route across south-eastern Asia. Diener's view that the connexion with the Himalayan sea was across Eastern Burma is confirmed: it is not, as shown in some sketch-maps (as, for instance, those by Grabau), across the Ganges delta. The closest affinities of the Maori Province are with the Tethys; but, as the connexion

Fig. 3.—*The Pacific Seas in the Triassic Period.*



Boreal Sea of Diener covering the extensive northern Pacific.

H. The Himalayan Region (horizontal shading), with an arm to Japan and the nearly isolated Maori Province (M P) [wider horizontal lines].

C.S. California Sea.

Vertical shading: Upper Triassic sea in northern South America, south of the Transatlantic Land (L.).

R. *Rhynchosaurus* in southern India and South America, and its probable route of migration.

between the two was apparently narrow and temporary, there are marked differences between the faunas. Prof. W. N. Benson [1] remarks that the Triassic fauna of New Zealand is Himalayan, whereas that of the Jurassic is Andean, although the New Zealand

[1] 'Lower Mesozoic of New Zealand' 3rd Pan-Pac. Sci. Congr. 1929, p. 1698.

Jurassic sea was still connected with the Himalayan through the Sula Islands and across the East Indies. The Triassic sea of New Zealand appears to have been the south-eastern end of the Tethys, and not the opening to a vast Pacific Ocean.

The irregularity of the connexion of the Maori Province with the Tethys was doubtless due to the variable condition of the East Indies. That region had been occupied in the Palæozoic Era by a stable continent, with no marine deposits except Carboniferous and a little Permian. The land broke up in the Trias into an eastern and a western basin. Some parts, such as Java, New Guinea, the Sula Islands, and the Philippines, remained land, and have no Trias. That System begins in Timor with the Ladinic, and there includes some Noric: the oldest in Borneo is Noric, and in northern Sumatra Carnic. Farther north the Trias reappears in Japan, where some marine Lower Trias (with *Meekoceras*) has been discovered recently.[1] Diener[2] has shown that the affinities of the fauna which he collected in the Anisic (lower Middle Trias) beds at Inai on Sendai Bay, on the north-eastern coast of Japan (lat. 38°) were with the south; that Japan formed a subprovince of the East Indian Province; and that its fauna is quite different from that of the Olonek Beds of north-eastern Siberia. The Anisic Trias of Ussuri and Japan he declares to be completely devoid of boreal affinities. The Inai fauna, he explains,[3] has no affinities with that of the North American Trias, which was connected with the Mediterranean and Alpine seas.

In the Ladinic (upper Middle Trias) the *Daonella* sea spread into Japan[4]; but the Carnic of the inner zone of south-western Japan is a plant-bed, and the Noric *Pseudomonotis* Sandstone is due to the re-submergence of Japan beneath the Arctic-North Pacific sea.

Farther north, the mainland south of the Amur and the island of Sakhalin were in part covered by a gulf from the same Arctic sea, which also reached Alaska and extended along the American coast as far south as Vancouver, where there is only the Upper Trias.

On the western coast of North America the Lower Trias is

[1] Y. Ozawa, 'Geological History of South-West Japan in the Mesozoic' 3rd Pan-Pac. Sci. Congr. vol. i (1929) pp. 544–45.

[2] 'Japanische Triasfaunen' Denkschr. Akad. Wissensch. Wien, vol. xcii (1915) p. 30.

[3] *Ibid.* p. 24.

[4] Y. Ozawa, *op. supra cit.* 1929, p. 544.

represented by volcanic rocks in Alaska and the Yukon. The marine Lower Trias occurs inland in Nevada, Idaho, and eastern California, and contains a Himalayan fauna and the East Siberian genus *Ussuria*.[1] Hence, as Perrin Smith points out, this sea in the western interior of the United States was probably connected with the northern Pacific across northern California, and was separated from the trans-Atlantic sea on the south. Some marine Middle Trias occurs in Alaska, and in the interior of British Columbia about Kamloops. The Upper Trias is more extensive both in Alaska and in northern British Columbia; it begins in the Carnic with an Arctic fauna, and its oldest group, the *Dawsonites* Zone, occurs in Bear Island (south of Spitsbergen), and is followed in the *Halobia-superba* Limestone (Chitistone Beds) by a warmer Mediterranean fauna.

The Noric (including the *Pseudomonotis-subcircularis* Beds) had also the warmer California fauna. The Upper Trias occurs also in Vancouver Island and along the eastern front of the Rocky Mountains, and through northern California, Nevada, and Idaho. There it overlies the Lower Trias, which, as remarked above, has a western fauna, so that its basin was separated from the eastern sea; this separation appears to have lasted till later, as the Upper Trias (Carnic) of Mexico has a European fauna with *Cassianella*, etc.

For South America, G. Steinmann [2] states that the marine Trias occurs only in the interior, and there is none along the coast. A little occurs in Chili.

The hypothetical *circum*-Pacific belt of Trias is therefore very incomplete. It is absent from more than half the Pacific border, and, where it occurs, it is due to the advance of relatively narrow seas which had their longest extension west and east.

These Pacific seas formed four groups:—

(1) A northern sea, which ranged from Spitsbergen to north-eastern Siberia and British Columbia;

(2) a north temperate sea with *Ussuria* and a Himalayan fauna, which in the lower Middle Trias was a subprovince of the East Indian sea, but later, in the Upper Trias, extended from northern California westwards to Central Asia;

[1] See R. W. Goranson, 'A Correlation of the Mesozoic Formations of the Pacific Coast of North America' Amer. Journ. Sci. ser. 5, vol. viii (1924) pp. 62–63; and J. Perrin Smith, *ibid.* ser. 4, vol. xvii (1904) p. 218.

[2] 'Geologie von Peru' 1929, p. 284.

(3) the western end of the Tethys, which reached Mexico and South California, and, *fide* Diener, extended farther north in America with an Alpine and pelagic fauna; and

(4) the Maori Province, the south-eastern end of the Tethys in the south-western Pacific.

The Maori Province includes *Daonella indica* and *Halobia zitteli*, and is thereby allied to the northern fauna; a channel may have opened in the Upper Trias across the mid-Pacific, connecting the Vancouver Gulf with the Maori Province. Any such extension would not have lasted through the Trias, according to the view of F. von Huene,[1] that a trans-Pacific land-bridge is required to explain the distribution of the Triassic quadrupeds. He insists that the Rhynchosaurids of Brazil are more nearly related to those of India than they are to the more primitive forms in South Africa. Similarly, the Parasuchians have been found in South and North America, Europe, and India, but not in Africa. As both Rhynchosaurians and Parasuchians are absent from Africa, von Huene reasonably concludes that the land-connexion which they used in their migration was across the Pacific.

(vi) The Jurassic.

The range of the Jurassic Seas in the Pacific Region was varied and complex. The evidence to 1911 was carefully summarized and collated by E. Dacqué,[2] and is in general supported by the additional information obtained since then.

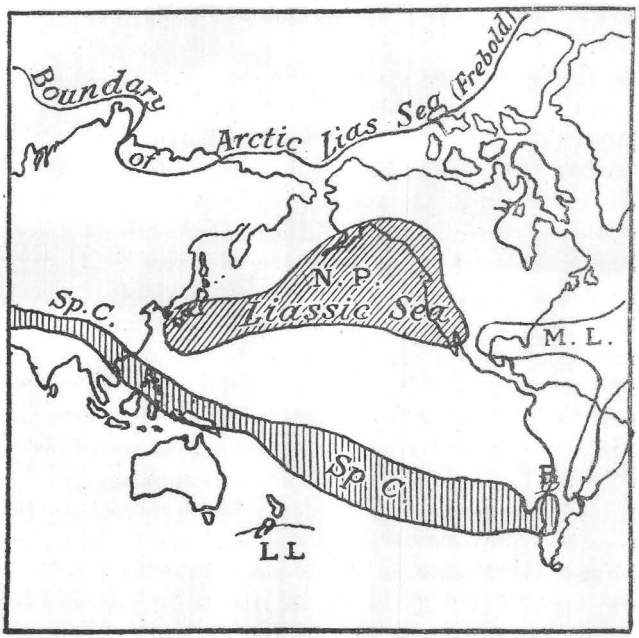
During the Lias eastern Siberia and Alaska were apparently connected by land across Bering Strait; but, on the south, the sea extended across Japan, and reached adjacent parts of Siberia. On the eastern side of the Pacific the Upper Lias is represented by volcanic rocks in the north-west, and by the widespread Hardgrave Sandstone with *Pecten acutiplicatus* of California; this rock ranges northwards to Kamloops in British Columbia. The Liassic sea may have extended westwards across the Pacific to Japan, and its southern shore is indicated by the absence of marine Lias from the coasts of China and the Philippines. In America the Lias re-

[1] 'Versuch einer Skizze der Paläogeographischen Beziehungen Südamerikas' Geol. Rundsch. vol. xx (1929) p. 91. Also 'Ueber *Rhynchosaurus* & andere Reptilien aus den Gondwana-Ablagerungen Südamerikas' Geol. Pal. Abhandl. n.s. vol. xvii (1929) pp. 55–61.

[2] 'Die Stratigraphie des Marinen Jura an den Rändern des Pazifischen Ozeans' Geol. Rundsch. vol. ii (1911) pp. 464–98.

appears on the south in Mexico; but it there has a Mediterranean and Mid-European fauna,[1] which was presumably separated from that of Japan and of the Hardgrave Sandstone. The barrier was probably a remnant of the Permian land occupied by the

Fig. 4.—*The Pacific Seas in the Jurassic Period.*



Arctic Sea of the Upper Lias: southern boundary after Frebold (1929).

N.P. The North Pacific Liassic sea. (Inclined shading.)
M.L. Mediterranean Liassic sea, with an arm to the Argentine.
Sp.C. Spiti-Chile sea—Upper Jurassic (Kimmeridgian-Portlandian).
B. Burckhardt's conglomerate (Kimmeridgian-Portlandian).
LL. Lias (mainly Lower: some Middle) in New Zealand.

Gigantopteris flora. South of this land the Upper Lias is represented in the East Indies in Borneo and Misol, and in south-eastern Asia in Annam; but there is no Lias in Australia. In the South Island of New Zealand[2] it is represented by the

[1] V. Uhlig, 'Die Fauna der Spiti-Schiefer der Himalaya' Denkschr. Akad. Wissensch. Wien, vol. lxxxv (1910) p. 67.

[2] C. T. Trechmann, 'The Jurassic Rocks of New Zealand' Q. J. G. S. vol. lxxix (1923) pp. 256–57; and L. F. Spath, *ibid.* pp. 288, 290–94.

Lower Lias (with the Hettangian *Psiloceras*, often recorded as *Wæhneroceras*) and some Middle Lias; and there is no known Upper Lias. In western South America the Lias is well developed.[1] According to J. Perrin Smith [2] this Lias is an extension of that of California and Nevada; but this view is not applicable to the Lower and Upper Lias of 40° S. in the western Argentine, which show no affinity or special resemblance to the Lias of North America.

The Middle and Upper Jurassic repeat the same lack of continuity of the faunas and beds from north to south. In the far north the Alaska Sea of the Middle Jurassic (Callovian and Oxfordian) had a cold-water fauna which ranged westwards to the Urals. This boreal sea, of which the characteristic fossil was the ammonite *Cardioceras*, covered northern Russia and Siberia from the Oxfordian to the Kimmeridgian and Neocomian. It did not, however, reach India,[3] where the northern Oxfordian fauna was replaced by *Macrocephalites* and *Simbirskites*, and in the Kimmeridgian by the latter with *Spiticeras* and *Himalayites*. The faunas were not always limited to the south by an absolute barrier, for *Cardioceras* itself lived in the Mediterranean during the Oxfordian: but this northern colony did not spread eastwards through the Tethys to the warmer south Asian seas.

In the Upper Jurassic the Arctic Sea which covered the Bering area was rich in the characteristic northern lamellibranch, *Aucella*, which reached Mexico in the Kimmeridgian by a gulf across North America east of the Rocky Mountains. *Aucella* is also found in the Mariposa Beds of California, and one species (*A. spitiensis*) lived in the Himalaya: but it was the only Arctic form there. In America *Aucella* extended even farther south through South California and Mexico; and it perhaps reached Brazil, Peru, and New Zealand.[4]

In Upper Jurassic times the sea of Central America was connected with the Tethys, as it contains the Portlandian fauna

[1] For references, see E. Dacqué, Geol. Rundsch. vol. ii (1911) p. 493.

[2] 'Periodic Migrations between the Asiatic & American Coasts of the Pacific Ocean' Amer. Journ. Sci. ser. 4, vol. xvii (1904) p. 221.

[3] *Cf.* V. Uhlig, 'Die Fauna der Spiti-Schiefer der Himalaya' Denkschr. Akad. Wissensch. Wien, vol. lxxxv (1910) pp. 566–67.

[4] J. F. Pompeckj, 'Ueber Aucellen & Aucellen-ähnliche Formen' Neues Jahrb. Beilage-Band xiv (1901) pp. 351–65, regards these species as doubtful, and removes those of Queensland and the Caucasus to a distinct genus, *Aucellina*.

of the Mediterranean and that of the Stramberg Beds of the northern Alps.[1]

According to Goranson,[2] the Callovian of California was quite distinct from that to the north, and was[3] the last pre-Kainozoic occurrence of a Mediterranean fauna on the western coast of America. This separation of the North Pacific from the western end of the Tethys implies the existence of extensive land west of California, south of which lived a third marine Jurassic Pacific fauna. The East Indies were undergoing disruption and subsidence; the Lias of Misol, New Guinea, and the Sula Islands begin the Jurassic sequence, followed by the Dogger and Oxfordian of Buru and Ceram, with the Portlandian in New Caledonia. In South America the Malm was deposited on the site of the southern Andes, and its fauna was Himalayan, containing[4] many of the Spiti genera, such as *Spiticeras*, *Blanfordia*, *Virgatosphinctes*, *Berriasella*, *Himalayites*, *Kossmatia*, etc. This fauna, according to Uhlig,[5] spread through a sea which had its eastern shore in Brazil and its northern in Texas: its northern boundary must have separated it from the North Pacific Sea, but enabled the faunas to range westwards to the Himalaya.

Further evidence of land west of the Andes is afforded by Burckhardt's account of the sedimentary rocks. They include coarse conglomerates near the coast, and pass into finer beds and sands. He held that the material must have come from west of the present land.[6]

The land that formed the northern border of the Malm sea and connected Chile and India requires only a small part of the 'Secondary' Pacific Continent of Haug.[7] Land-barriers in the Pacific provide the natural explanation of the zoological provinces, which Uhlig classified as four—that of Japan and the Amur, the Maoric or New Zealand, the North Andean (an unfortunate term, as the range of this province is from Southern California to Alaska and to Grinnell Land opposite northern Greenland), and the South Andean from Southern California and Texas to Patagonia and

[1] E. Dacqué, Geol. Rundsch. vol. ii (1911) p. 451.

[2] Amer. Journ. Sci. ser. 5, vol. viii (1924) p. 78.

[3] *Ibid.* p. 77.

[4] See, for instance, V. Uhlig, Denkschr. Akad. Wissensch. Wien, vol. lxxxv (1910) pp. 598, 608.

[5] *Id. ibid.* p. 607.

[6] C. Burckhardt, 'Beiträge zur Kenntniss der Jura- & Kreideformation der Cordillere' Palæontographica, vol. l (1903) pp. 126–28, pl. facing p. 128.

[7] E. Haug, Bull. Soc. Géol. France, ser. 3, vol. xxviii (1900) pp. 633, 646–47.

Grahamland. J. Perrin Smith, however, considers that different biological areas were due to ocean-currents and climate. He says, 'such a simple matter as the periodic opening and closing of Bering Strait by rising and sinking of the land in that quarter will account satisfactorily for all the changes in character and distribution of the marine faunas'.[1]

That view would seem to me improbable, and to be rendered untenable by the range of the land animals as affirmed by F. von Huene, who remarks that the kind of land-connexion required by them is recognized as probable, from the evidence of the marine invertebrates, by Dr. L. F. Spath and Dr. C. T. Trechmann.

(vii) The Cretaceous.

The Pacific in the Cretaceous Period was apparently arranged on much the same plan as during the Jurassic, with narrow seas extending east and west: but, at one time, a depression parallel to the Rocky Mountains and the Andes enabled the northern fauna to spread far to the south. In the Cretaceous we have the advantage of fuller knowledge of the intermigration of land life between America and the lands west of the Pacific.

The Arctic seas continued with a boreal fauna, represented by *Aucella* in the Neocomian of Alaska, which was separated from the contemporary Knoxville Bed of California, as it has a warm temperate fauna including *Phylloceras*, *Berriasella*, and *Neocomites*, with Himalayan and Mediterranean affinities. The Arctic fauna ranged south on the Asiatic side, and the boreal Neocomian fauna of the Torinosu limestone of Japan (Uhlig, 1910, p. 596) may indicate the route by which a few northern molluscs reached New Zealand.

The European seas reached the Pacific from both sides. The Tethys perhaps then had its widest extension, as two crinoids, *Uintacrinus* and *Marsupites*,[2] show that during the Middle Senonian the sea ranged from Kansas to England, Algeria, southern India, and to the Gingin Chalk of Western Australia. On the other side of the Pacific the European fauna reached northern

[1] Amer. Journ. Sci. ser. 4, vol. xvii (1904) p. 233.

[2] T. H. Withers, Journ. R. Soc. W. Austr. vol. xi (1924) pp. 15–18; vol. xii (1926) pp. 97–104. This chalk may include more than one series, as, according to F. Chapman, 'Monograph of the Foraminifera & Ostracoda of the Gingin Chalk' Bull. Geol. Surv. W. A. No. 72 (1917) p. 15, the age is Albian–Cenomanian.

Chile (23° S.),[1] doubtless through the West Indies; and, as the fauna shows no special North American or East Asiatic intermixture, the sea must have been isolated on the west from the other Pacific seas.

The existence of such Pacific lands is indicated by the faunal and stratigraphical differences between the Cretaceous formations in various parts of the Pacific region. For example, the Californian province was at times occupied by a western Pacific and Indian fauna, while the faunas living in neighbouring areas on the north-east and south-east were Atlantic and Mediterranean; at times the Californian province was inhabited by the eastern fauna, which kept its characteristics so distinct that it must have been separated by land from the western sea.

F. Kossmat[2] in 1894 pointed out that the faunas of California from the Albian to the Senonian were closely allied to those of southern India. This view was supported by Prof. C. Schuchert,[3] who remarked that both the Chico and the earlier or Shasta faunas (Valangian and Urgonian) were Indo-Pacific, and differ markedly from those of the contemporary seas in Colorado and Mexico. T. W. Stanton[4] declared that the Upper Cretaceous faunas of the California coast 'are much closer with those found on the opposite side of the Pacific' in southern India, Japan, and Sakhalin than to those in other parts of the United States. Prof. J. Perrin Smith[5] shows that the western coast of America was occupied by the Indian fauna as far north as Puget Sound (48° N.) and suggests migration by a northern route; he remarks that it is 'noteworthy that the Puget Sound, Horsetown, and Chico faunas are even more closely allied to those of India than are those of California. Migration appears to have been free between Asia and America, but the species did not all range as far south as California, thus indicating the direction from which they came'.

E. L. Packard[6] reasserts the Indian affinity of the West American

[1] E. Dacqué, Geol. Rundsch. vol. ii (1911) p. 487.

[2] 'Die Bedeutung der Südindischen Kreideformation . . .' Jahrb. k. k. Geol. Reichsanst. vol. xlvi (1894) pp. 471–72.

[3] In Pirsson & Schuchert, 'Text-Book of Geology' pt. ii (1895) p. 890.

[4] 'The Faunal Relations of the Eocene & Upper Cretaceous on the Pacific Coast' 17th Ann. Rep. Geol. Surv. U.S.A. pt. i (1896) p. 134.

[5] 'Periodic Migration between the Asiatic & American Coasts of the Pacific Ocean' Amer. Journ. Sci. ser. 4, vol. xviii (1904) p. 223.

[6] 'Faunal Studies in the Cretaceous of the Santa Ana Mountains of Southern California' Univ. Calif. Bull. Geol. vol. ix (1916) p. 157; and, quoting F. M. Anderson, Proc. Calif. Acad. Sci. ser. 3, Geol. vol. ii (1902) p. 57.

Cretaceous, for he says that the fauna of the Santa Ana Beds of California is nearest to that of the Ariyalur and Utatur Beds of Southern India.

Great earth-movements in the western Americas were in progress; by the Upper Chico (Senonian) the connexion of the Indian seas with that of California and Oregon had been reduced. The faunas in those States came from the east, from the Missouri Valley; and during the Tejon (Eocene) the affinities of the Californian fauna were with the Atlantic.

The changes in the affinities of the Californian marine faunas indicate that the earth-movements affected lands situated far west of America. The existence of a shallow Upper Cretaceous land-line from Vancouver to New Zealand has been inferred from the resemblances of the fauna, and this migration route is recognized by Dr. P. Marshall,[1] although he has declared against any Pacific land-bridges.

Stronger evidence of trans-Pacific land is given by the quadrupeds.

The western United States and Mongolia shared in the Upper Cretaceous the same fauna of giant reptiles. The continuity of land across the Pacific to permit their passage from Asia was predicted by Prof. W. F. Osborn, and may be regarded as proved by the discoveries of the American Mongolian Expedition under Roy Andrews. Migration overland from northern China to the northern parts of the United States happened at least four times, and was apparently across land that lay south of the Bering Sea. The Upper Cretaceous Sauropods of the Iren Dabasu beds migrated to America, and on both sides of the Pacific they lived between latitudes 40° and 50° N.

'We observe,' says Prof. Osborn,[2] 'that the very richest dinosaur beds of the close of the Age of Reptiles that have been discovered in the United States and Canada during the past half-century are not far distant in latitude from those we have found recently in Gobia' (Mongolia).

The bias in favour of selecting land routes which do not encroach materially on the existing oceans may be illustrated by Prof. Osborn's map of this migration route. Instead of the giant deinosaurs travelling from central Asia to central North America along their own latitude, they were sent north across the

[1] 'Physical & Paleontological Development of New Zealand' C. R. XIIIth Internat. Geol. vol. iii (1926) p. 1593.

[2] H. F. Osborn Asia: Nat. Hist. vol. xxiv (1924) p. 137.

Arctic Circle and Bering Strait,[1] although there is no evidence of their existence beyond a little north of 50°. At three distinct epochs huge land animals must have crossed from Mongolia to the United States, and not one of these faunas, so far as is known, ranged north of about 50°. The Deinosaurs entered Canada, but are only known there near the United States frontier.

The threefold coincidence in latitude of the great quadrupeds of Mongolia and the western United States and absence of these faunas in the far north of Asia and America is in favour of a trans-Pacific passage along the latitude at which their remains are found, and not across Bering Strait, especially since that area was at times covered by the sea.[2]

Hence the probabilities are in favour of these animals having crossed between Asia and America in about the latitude to which they were confined on both continents. The existence of Cretaceous land farther south in the Pacific is proved, according to Prof. F. von Huene,[3] by the Mesozoic reptiles of South America, of which he has brought forward important fresh evidence. He regards the Pacific as the oldest existing ocean, but he is emphatic that it was crossed during the Mesozoic Era by land-bridges or chains of islands, of which one connected South America with Australia and south-eastern Asia, and another independently united North America and eastern Asia. The Cretaceous Titanosaurs are widely distributed in South America, and the species are very nearly related to those of India; they also occur in Madagascar, but not in Africa or North America. The Ceratopsids and Acanthopholids are found in the Upper Cretaceous of Patagonia, Mongolia, and North America; but Prof. von Huene [4] holds that they must have travelled from Asia

[1] H. F. Osborn, Asia: Nat. Hist. vol. xxix (1924) p. 4.

[2] Bering Strait and Sea were submerged in the Lower Cretaceous Period (during the Knoxville age), but were occupied by land in the Upper Cretaceous, Eocene, and probably Oligocene Periods. They were again submerged in the Lower Miocene, and are represented as sea in the Upper Miocene and Pliocene in Schuchert's maps. *Cf.* C. Schuchert, 'Paleogeography of North America' Bull. Geol. Soc. Amer. vol. xx (1910) pp. 93–98; also A. Knopf, 'The Probable Tertiary Land-Connexion between Asia & North America' Univ. Calif. Bull. Geol. vol. v (1910) pp. 419–20.

[3] 'Versuch einer Skizze der paläogeographischen Beziehungen Südamerikas' Geol. Rundsch. vol. xx (1929) pp. 81–96; and 'Ueber Rhynchosaurier & andere Reptilien aus den Gondwana-Ablagerungen Südamerikas' Geol. Pal. Abhandl. n.s. vol. xvii (1929) pp. 55–61.

[4] Geol. Rundsch. vol. xx (1929) pp. 92–93.

to North America and Patagonia by independent land routes, as North and South America were then separated by sea. He concludes that the only available route for the Ceratopsids on their migration from Mongolia to Patagonia was by land across the central and southern Pacific.

The occurrence of Cretaceous land in the southern Pacific is further indicated by the marked differences in the southern Pacific faunas. The Lower Cretaceous (Comanche) fauna of Mexico, the Caribbean, and north-western South America is of Mediterranean type; and it extended to the western coast of Central America: but it is so distinct from that of the Shasta Beds of the Californian coast that the two faunas must have been separated by land. T. W. Stanton recognizes this fact; although he dislikes invoking land west of its present range, he concludes [1] that such a complete lack of common species must have been caused by a land-barrier between the Atlantic and the Pacific throughout North America, and he considers that a continuous land existed from British Columbia to South America also during Upper Cretaceous times.

The Cretaceous in Colombia is persistently Mediterranean in type, as shown by the Barremian faunas described by Paulcke [2] and Collet, and more recently for the Lower Turonian by Fritsche. This affinity had long been known for the echinoids of the northern Andes. But farther south in Chile the Senonian Quiriquina Beds have a fauna distinct from that of the Chico Beds of California, of the Mediterranean, and of the Hokkaido Beds of Japan [3]: it resembles those of Seymour Island in Antarctica and of the Batley Beds of New Zealand. Dr. O. Wilckens [4] in 1922—agreeing with the view of Dr. H. Woods as to the similarity of the Upper

[1] 'Mesozoic History of Mexico, Central America, & the West Indies' Bull. Geol. Soc. Amer. vol. xxix (1918) pp. 605–606.

[2] W. Paulcke, 'Ueber die Kreideformation in Südamerika' Neues Jahrb. Beilage-Band xvii (1903) p. 309; L. W. Collet. 'Sur quelques Ammonites du Barrémien de Colombie' Eclogæ Geol. Helvet. vol. xviii (1924) pp. 485–93; C. H. Fritsche, 'Neue Kreidefaunen aus Südamerika' Centralbl. Min. 1921, p. 277.

[3] *Cf.* P. Marshall, 'Correlation of Mesozoic Formations of the Pacific Region' 3rd Pan-Pac. Sci. Congr. vol. ii (1929) p. 1601.

[4] 'The Upper Cretaceous Gastropods of New Zealand' N.Z. Surv. Pal. Bull. no. ix (1922) p. 31; H. Woods, 'The Cretaceous Faunas of the North-Eastern Part of the South Island of New Zealand' N.Z. Geol. Surv. Pal. Bull. no. iv (1917) p. 14. *Cf.* also O. Wilckens, 'Revision der Fauna der Quiriquina-Schichten' Neues Jahrb. Beilage-Band xviii (1904) pp. 280–84.

Senonian faunas of New Zealand, Patagonia, and Grahamland—advocates a shallow-water and direct land-connexion between them.

The difference between the faunas of Chile and of California cannot be due to distance, in view of the wide range of these faunas. The westward extension of the land accepted by Stanton west of Central America would explain it, and also the occurrence of an outlier of the Turonian Dakota Sandstone flora of Nebraska and Kansas 5000 miles away to the south, at Cerro Guido [1] in the interior of south-western Patagonia. F. H. Knowlton [2] says, that judging from the list of species, that collection might have been made in Kansas. No trace of this flora is known at any intermediate locality, and it apparently spread southwards by land now lost under the Pacific. The western extension of that land would have served for the migration of Prof. F. von Huene's reptiles.

(viii) The Pacific in the Kainozoic Era.[3]

During the Mesozoic Era there had been an apparent increase in the extent and probably also the depth of the Pacific seas. In the Kainozoic this process was continued, although with great interruptions, until about the middle of that Era, when widespread subsidence converted the various seas into the Pacific Ocean.

In the Lower Kainozoic, extensive areas of land still lay over parts of the Pacific area. Indeed, according to Prof. H. von Ihering,[4] the Pacific was a narrow sea extending from Japan to South America, between his Archigalenis, a land joining Central America and California to Siberia, and an extension of southern Asia and Australasia which included nearly all Polynesia, the Ladrone Islands, and southern Japan. This Archigalenis would require some modifications at its American end, in order to serve as the highway between Mongolia and Montana for the giant Sauropods in the Upper Jurassic, *Triceratops* in the Upper Cretaceous, and the

[1] F. Kurtz, 'Sobre la Existencia de una Dakota-Flora en la Patagonia Austro-occidental' Rev. Mus. La Plata, vol. x (1902) pp. 43–60.

[2] 'Relations between the Mesozoic Floras of North & South America' Bull. Geol. Soc. Amer. vol. xxix (1918) p. 612.

[3] For a summary of the distribution of the rocks, see T. W. Vaughan and others, 'Correlations of the Post-Cretaceous Formations in the Pacific Region' 1st Pan-Pac. Sci. Congr., Spec. Pub. B. P. B. Museum, no. 7 (1921) pp. 713–873.

[4] 'Die Geschichte des Atlantischen Ozeans' 1927, Karte ii.

Titanotheres that roamed across it in the Upper Eocene, when the mammal fauna of Irdin Manha of Gobi, says Prof. Osborn,[1] 'bears very strong resemblance' to that of northern Utah.

That this migration route was also open in the Oligocene Period is shown by the resemblances of the *Brontotherium* of the Rocky Mountains to the *Embolotherium* of Mongolia.[2] The land traversed by these animals probably lay within the zone of 40° to 50° N., for none of them are known much north of it: any land-connexion at Bering Strait, in 65° N., may have been inaccessible to this fauna owing to the direct and indirect effects of climate.

The same route may have been followed in the Pliocene Period, when the Bering area was submerged, by *Hipparion* (as the *H. richthofeni* of China 'stands very close specifically'[3] to *H. mohavense* from the Lower Pliocene of southern California), and by *Hycenarctos*, in their migration from eastern Asia to Oregon and the southern parts of the United States.

The southern shore of this land would have provided the warm shallow water required for the diffusion of the marine fauna between India and California. The occupation of the western coast of the United States by an Asiatic and Indian fauna, previously mentioned as notable in the Cretaceous, persists into the Eocene. The molluscan fauna of the Tejon (Eocene) in California is Atlantic, says Perrin Smith,[4] and shows no indications of any connexion with Asia. The Echinoids in the Eocene were however still Asiatic, and W. S. W. Kew,[5] who claims that although they are scarce in California, they are especially significant, says that the Eocene beds of India include all the West Coast genera. This community had become less by the Oligocene, and had disappeared by the Miocene and Neocene, when the fauna was endemic and had no particular affinity to either the Atlantic or the Asiatic faunas.[6]

[1] H. F. Osborn: Asia. Nat. Hist. vol. xxiv (1924) p. 147.

[2] *Id.* Amer. Mus. Novit. no. 353 (1929) pp. 18–19.

[3] Chester Stock, 'Some Mammalian Forms common to the Pliocene of America & Asia' Proc. Pan-Pac. Sci. Congr. 1923, vol. i (1924) p. 881.

[4] J. P. Smith, 'Periodic Migrations between the Asiatic & American Coasts of the Pacific Ocean' Amer. Journ. Sci. ser. 4, vol. xvii (1904) p. 224. R. E. Dickerson, 'Tejon Eocene of California' Univ. Calif. Bull. Geol. vol. ix (1916) p. 479, remarks that the affinity is closer to the Gulf Eocene than had been thought.

[5] 'Cretaceous & Cenozoic Echinoidea of the Pacific Coast of North America' Univ. Calif. Bull. Geol. vol. xii, no. 2 (1920) p. 33.

[6] J. P. Smith, *op. cit.* (1904) p. 225; W. S. W. Kew, *op. cit.* (1920) pp. 33–34.

Kainozoic land must also have existed west of South America. The north-western corner of the continent has Kainozoic beds with a Tethyan or Mediterranean fauna, such as that of the Zorritos Beds of northern Peru (Burdigalian; Lower Miocene). This fauna must have been limited on the west by land, or its eastern character would have been swamped by the Pacific elements. Farther south along the coast there are no marine Kainozoic beds, and that the land extended considerably westwards is suggested by Prof. E. W. Berry's opinion that the flora of the Lower Miocene coal-measures on the Chilian coast at Concepcion and Arauco (37° S.) is not a coastal vegetation. That the land then extended west of the present area the two authors say [1] 'cannot be doubted'.

The claim for the affinity of some Patagonian fossils to the Tasmanian Wolf, *Thylacinus*, which was implied in the name *Prothylacinus*, has been repeatedly denied.[2] It has, however, been reaffirmed by W. J. Sinclair and W. K. Gregory,[3] the latter of whom has placed them in one family, the Thylacinidæ. If these animals be allied, the fact would support a South Pacific land-connexion. Prof. W. B. Scott, in a recent discussion of the origin of the American mammals, concludes that they require land-bridges from Australia to South America, both directly east and west, and through Antarctica.[4]

The existence of a southern Pacific land is supported by the range of *Miolania*, the giant horned tortoise which has been found fossil (Pleistocene) in Queensland and Lord Howe Island, and is represented in earlier beds (Oligocene-Miocene) in Patagonia by the nearly allied genus *Niolania* (Ameghino). *Miolania* and *Niolania* are so similar that they were placed by Sir Arthur Smith

[1] E. W. Berry & J. T. Singewald, 'The Tectonic History of Western South America' Proc. 3rd Pan-Pac. Sci. Congr. vol. i (1929) p. 437.

[2] For instance, C. S. Tomes, from the structure of the teeth, Proc. Zool. Soc. vol. i (1906) p. 57; also C. T. Regan, Brit. Antarctic Exped. 1910, Zool. vol. i (1914) p. 43.

[3] W. J. Sinclair, Rep. Princetown Exped. Patag. vol. iv (1901) p. 333; W. K. Gregory, Bull. Amer. Mus. vol. xxvii (1910) p. 207.

[4] 'The Origin of the Mammalian Faunas of North & South America' Palæobiologica, vol. i (1927) p. 262. That the South American and Australian marsupials are genetically connected is proved, according to Prof. Launcelot Harrison, by their parasites, 'Ectoparasitic Insects & Pacific Problems' Pan-Pac. Sci. Congr. 1923, vol. ii (1924) pp. 1584–85.

Woodward[1] in one genus. Dr. C. Tate Regan[2] regards the genera as quite distinct although similar, and he considers their distribution as having no special significance for palæogeography, as their ancestors may have lived in the northern hemisphere. No trace of them has been found there, although their massive, distinctive bony bosses should have made conspicuous fossils.

The area of the southern Pacific during the Kainozoic Era, in addition to any northern projections of Antarctica—the history of which is not considered in this Address—was reduced by the extension of the lands from west and east, and of the remaining islands as shown by their geological structure, fauna, and flora. This land must have extended sufficiently far westward to have divided the northern and southern seas, for the northern marine fauna is, say Berry & Singewald, so unlike that of the contemporary Navidad Beds of Chile, that the two must have been separated by land.[3]

A continuous land across the southern Pacific from Patagonia to Polynesia and south-eastern Asia is claimed by F. von Huene from the distribution of the primitive mammals. According to him, in the Mesozoic Era the Monotremes and their predecessors the Allotheria (Multituberculata) lived in south-eastern Asia, and at about the end of the Cretaceous they migrated by a land-bridge or chains of islands across the Southern Pacific to the southern end of South America, that is, to the Archiplata of H. von Ihering. In South America the early Kainozoic Marsupials became specialized, and formed the varied Polyprotodonts, while one branch became the Diprotodonts, which are at present known outside of Australia only by the *Cænolestes* of Ecuador. From Patagonia both sections of marsupials, according to F. von Huene, crossed to Australia by some route north of New Zealand, which has neither monotremes nor marsupials. The Marsupials developed in Eastern Australia and New Guinea during the Upper Kainozoic Era into the highly specialized and varied Australian marsupials.

That continental Australasia extended to New Caledonia and New Zealand is generally admitted; but there has been widespread reluctance to admit its extension farther east. The evidence that the Fiji Islands were also part of the Australasian Continent is

[1] 'On Some Extinct Reptiles from Patagonia' Proc. Zool. Soc. vol. i (1901) p. 170.

[2] Brit. Antarctic Exped. 1910, Zool. vol. i (1914) pp. 42–45.

[3] Proc. 3rd Pan. Pac. Sci. Congress, vol. i (1929) p. 437.

increasing in weight. That view was expressed in the title of Woolnough's first paper on the islands, 'The Continental Origin of Fiji' (Proc. Linn. Soc. N.S.W. vol. xxviii, 1903, pp. 437–540): and is reaffirmed in his later paper of 1907 (*ibid.* vol. xxxii, pp. 431–74). It is adopted by Prof. R. W. Brock ('Geology of Viti Levu' Trans. Roy. Soc. Canada, ser. 3, vol. xviii, 1924, pp. 63–83), who describes the oldest rocks as 'strongly metamorphosed' as 'metamorphosed to schists', and including rocks like Archæan schist (*ibid.* pp. 69, 80).

The metamorphism was due to mountain-building on lines trending north-northeast to south-southwest (*ibid.* p. 81), and was connected with the intrusion of plutonic masses (the Tholo Revolution of Brock). The Viti Formation (early Miocene) was formed, according to Brock, during a subsidence of 'several thousand feet' (*ibid.* p. 76), and was followed by the Viti Revolution (probably also Miocene), during which the country was compressed by mountain-building along lines from east-northeast to west-southwest. 'The geology of the island', says Brock, 'proves conclusively that it once formed part of a continental area'. Moreover, the continent must have extended farther north-eastwards into Central Polynesia, for, according to Brock, the pressures of the two periods of mountain-formation acted at right angles (*ibid.* p. 81): the Miocene pressure was from east-northeast and pressed Fiji towards New Caledonia. 'The earlier movement proves that the Fijian mass extended either north or south. Fiji not only contains a base of continental rocks, but was part of a land that extended eastwards or northwards into central Polynesia.

This view is consistent with the conclusions of Sir Douglas Mawson [1] regarding the New Hebrides, with their steeply dipping Eocene limestones and radiolarian shales.

That shallow-water marine deposits were being laid down in various parts of the Pacific during the early and middle Kainozoic is shown by the occurrence of Miocene limestones in their foundations. Thus Mangaia, one of the Cook Islands (22° S., 158° W.), has been shown by Dr. P. Marshall [2] to consist of a base of Cretaceous or Eocene basalt covered by foraminiferal limestone (with *Lepidocyclina*, *Spiroclypeus*, etc.) ranging from the Pliocene or Lower Miocene onwards. *Lepidocyclina* has also been found

[1] Rep. Austral. Assoc. Adv. Sci. vol. x (1904) pp. 215–16; Proc. Linn. Soc. N.S.W. vol. xxx (1905) p. 400–84.

[2] 'Geology of Mangaia' B. P. B. Mus. Bull. 36 (1927) pp. 43, 32, 33.

in the limestone-breccia of Jaluit[1] (7° S., 169° E.), one of the Marshall Archipelago.

Clear evidence of the former extension of South America into the Pacific is given by the abrupt termination of the grain of the land in southern Peru. The Pacific-Coast type of Suess is best developed in South America: but even there the fold-ranges are not consistently parallel to the coast, as they should be to conform to the definition. The sudden north-westward bend of the coast in Southern Peru is the most conspicuous feature in the western side of South America; and, as I pointed out in 1908,[2] this trend is coincident with ancient structural lines, along which the Andes were deflected north-westwards during the Cretaceous folding. Where the coast resumes its normal trend to the north the mountain-structure does not make the same change, but continues north-westwards, and is cut off by the Pacific. The coast from Ica in Peru (14° S.) to Ecuador is, therefore, of the Atlantic type. T. Wolf[3] in 1892 showed that the ranges west of Guayaquil trend approximately east and west. Dr. R. Stappenbeck[4] has found the same in the Chicama Valley in northern Peru; the Cretaceous rocks in places trend nearly due east and west, at right angles to the coast, and are overfolded towards the north. That the coast is transverse to the strike of the rocks near Paita is remarked by Dr. H. de Böckh.[5]

The late Prof. Steinmann,[6] in his last paper, called the former prolongation of the northwest-trending Andes of southern Peru the Chimu-Andes. He represents them as having continued north-west to the Galapagos, and as having subdivided into four: one branch (marked as a fragment of a festoon in my 'Geography', 1908, pl. xxxii, p. 278) passed through Duncan Island, Clipperton Island, Gigedo Island, the Alijos, and Guadalupe as an arc that met the mainland where the coast of California projects with a north-westerly trend. A second branch of the Chimu-Andes curved

[1] H. Yabe & R. Aoki, 'Reef-Conglomerate with small Pellets of *Lepidocyclina* Limestone found on the Atoll Jaluit' Jap. Journ. Geol. & Geogr. vol. i (1922) pp. 39–43.

[2] 'Geography, Structural & Physical' 1908, pp. 245–46 & pl. xxvi.

[3] 'Geografia & Geologia del Ecuador' 1892, p. 243 & map.

[4] 'Geologie des Chicamatales in Nordperu' Geol. & Pal. Abhandl. vol. xvi, pt. 4 (1929) pp. 18, 22: Karte iv, *e. g.* east of Chicama: Karte ii, lowest figure.

[5] In 'The Structure of Asia' 1929, p. 167.

[6] Geol. Rundsch. vol. xx (1929) p. 140.

south-westwards to the Paumotu Archipelago; another passed on a long curved arc to the Marquesas; the fourth branch continued west-northwestwards and joined the North Pacific Chain.

According to Steinmann's 'Geologie von Peru' (1929, p. 301), the Chimu-Andes were cut off from Peru, and sank beneath the Pacific in the early Eocene: and also, according to him, until then the eastern tropical Pacific was traversed by mountain-lands which extended across the part that is now almost island-free, and reached the island-strewn seas of Polynesia and the north-central Pacific.

The former existence and date of disappearance of the Chimu-Andes is consistent with the general geology, for the complete absence of early Kainozoic marine deposits along that part of South America indicates that the land formerly extended farther westwards.

4. The Evidence of Biogeography.

(i) Factors of Distribution.

If, as indicated by the foregoing evidence, large parts of the Pacific Ocean were occupied by land at times up to the Miocene Period, the influence of this arrangement should be traceable on the distribution of those groups of living animals and plants which were in existence in pre-Miocene times. The biological evidence is so bewildering, owing to the diametrically opposite conclusions advocated, that Prof. H. E. Gregory, of Honolulu, recommends that the plants be disregarded until botanists come to some agreement. If this advice be adopted, the renunciation should be extended to Zoology and Palæontology. The biological clues are, however, so illuminating that they cannot be ignored. Caution in their use is necessary since the evidence is fragmentary, and its interpretation is uncertain, as faith in the permanence of oceans and continents influences some biologists in their identifications and opinions as to the affinities of organisms.

The influence of the factors of distribution is also uncertain. Some authorities explain the more glaring anomalies in distribution by the transport of spores, eggs, and larvæ in mud attached to the legs of birds, by ocean currents carrying seeds, and by driftwood conveying menageries of lizards, small mammals, snails, and insects. The resemblance of the lichens of Australia to those of South America has been attributed to the wind having blown the spores across the southern Pacific, and the wide range of some spiders to their webs having been wafted from island to island. Man, in

addition to his deliberate transport of food-plants and domestic pets, is thought to have added to the confusion by carrying reptiles and mice as stowaways in canoes. Volcanoes are invoked, and the presence in Cuba of the Polynesian palm, *Pritchardia*, is explained by its nuts having been hurled to the West Indies from the south-western Pacific by a volcanic explosion.

When all other explanations fail, there is the final appeal to 'convergent evolution' leading to the independent development of the same organism in disconnected areas.

Other students of biogeography attribute less importance to these processes. The formation of a complex organism along two different lines of evolution is rejected as utterly improbable, and the results of accidental distribution are thought to be recognizable, as they produce, to use Baur's term, disharmonic faunas. The accidental factors, it is claimed, do not operate to the extent required to explain the facts. C. M. Cooke,[1] for instance, tells us that the snail *Placostylus* can be transported overseas for 20 miles, but there are no known cases of its survival after a longer voyage, and that oversea drift does not explain the distribution of the land mollusca of the Pacific islands. If the casual agents, such as currents, winds, and birds, were the main agents of distribution, islands should have been inhabited from the nearest land, whereas some of the islands off South America are biologically very distinct from it.

Even birds have not the wide range that would be expected from their powers of flight, for the zoological regions were established in 1858 by P. L. Sclater[2] on the distribution of birds.

Similarly, marine fishes do not spread through the sea open to them. Dr. Tate Regan rejects the widely accepted belief in the connexion of Australia and South America by a southern continent, since the Antarctic fishes belong mainly to one family, the Nototheniiformes, which is almost restricted to the Antarctic and Sub-Antarctic zones, although the fishes have an uninterrupted seaway to South America and Australia.[3]

Some botanists, such as Prof. W. R. B. Oliver,[4] regard the

[1] 'Notes on Pacific Land Snails' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. ii (1929) p. 2282.

[2] Proc. Journ. Linn. Soc., Zool. vol. ii, pp. 130–45: confirmed by W. L. & P. L. Sclater in their 'Geography of Mammals' 1899.

[3] Brit. Antarctic Exped. 1910, Zool. vol. i (1914) pp. 40, 41.

[4] 'Biogeographical Relations of New Zealand' Journ. Linn. Soc., Bot. vol. xlvii (1925) pp. 118, 133.

presence of many species of plants both in New Zealand and in South America as due to the drift of seeds and wood. Other authorities regard the facts as proof of a former direct land-connexion. Marine drift has doubtless helped to spread the coco-nut palm, and planted the tufts of *Casuarina* on the headlands of East Africa. But many authorities agree with Dr. Willis that the migration of an ordinary terrestrial flora, except for short distances, is dependent on continuous land.

Some marine animals have doubtless powers of quick diffusion through any connected tropical and temperate seas: but others, although they may have free-swimming larvæ, do not spread far. Alexander Agassiz objected to my argument that some echinoids cannot cross a deep ocean; but he has himself reported as one of the remarkable features of pelagic life 'the total absence of littoral embryos'.[1]

Evidence of the limited influence of accidental distribution has been summarized by Dr. R. H. Scharff,[2] and that view has received widespread support.

The application of biogeography to the history of the Pacific depends mainly on the affinities of the faunas and floras of the opposite lands, and on distribution of life in the Pacific Islands.[3]

(ii) Biological Trans-Pacific Coincidences.

The biological resemblances between the faunas and floras of the opposite sides are naturally less striking with the Pacific than with the Atlantic, owing to the greater distance. The United States is twice as far from China as from France. The affinities between the life of the opposite shores of the Pacific have therefore often been attributed to migration by way of Bering Strait or Antarctica. Thus Prof. W. A. Setchell,[4] of California University, explains the distribution of the Pacific floras as having been along two routes, one from the east and the other lying north and south, and by

[1] 'Report on the Scientific Results of the Expedition to the Eastern Tropical Pacific, by the "Albatross", 1904–5: General Report' Mem. Mus. Comp. Zool. vol. xxxiii (1906) p. xi.

[2] 'Distribution & Origin of Life in America' 1911, pp. 116–17, 300–301, and 'European Animals: their Geological History & Geographical Distribution' 1907, pp. 2–4.

[3] A brief statement of evidence was given in a lecture at the Royal Institution Jan. 30th, 1925: 'The Mountain-Structure & Geographical Relations of South-Eastern Asia' Proc. R. Inst. Gr. Brit. vol. xxiv (1925) pp. 515–16.

[4] Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) pp. 869–75.

processes applicable to the present arrangement of land and sea. Similarly, E. D. Merrill[1] holds that the elements common to the floras of Asia and North America are due to migration through Alaska, and those common to the floras of South America and Australia or New Zealand are due to migration through a sub-Antarctic land. He holds that, although there are many cases of community of plant life on the opposite sides of the North and South Pacific, they are relatively few across the tropical Pacific.

Bering Strait has often been replaced by a land-bridge connecting Asia and America: but this change does not explain all the migrations, for the bridge was not always there when it is wanted by the biological evidence. It was doubtless available in the Upper Eocene, when *Protylopus*, the ancestor of the Camels, crossed from North America to Asia[2]; but the passage of the later camels, which must have been during the Miocene to allow of their appearance in the Siwalik Beds of India, was probably by a more southerly route (as shown by H. F. Osborn's[3] figure) when the Bering Strait was submerged.

(1) Reptiles and Amphibia.—A well-known occurrence of an animal on opposite sides of the Central Pacific is the alligator. It lives in the warmer regions of America, in the south-eastern part of the United States, in Central America, and tropical South America. Its only other haunt is the Yangtze Kiang in China. There is no trace of its existence in Northern Asia or northern North America. T. Barbour[4] declares that 'the existence of a true alligator in China is one of the most interesting and remarkable facts which has ever been brought to the notice of zoogeographers'. In answer to the enquiry of Dr. G. A. Boulenger whether he shared this view, he replied (June 1923) that he did not, as the case 'is paralleled in batrachians and fishes'.

Dr. A. Gunther told me that some of the lizards of Asia are so like those of the United States that he would have identified them as the same species, if he had not known that they came from such distant localities. Dr. R. H. Scharff[5] has summarized many cases

[1] Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) pp. 389–93.

[2] H. F. Osborn, 'Age of Mammals' 1910, p. 110.

[3] *Ibid.* p. 294.

[4] 'A Note regarding the Chinese Alligator' Proc. Acad. Nat. Sci. Phil. vol. lxii (1910) p. 464.

[5] 'Origin of Life in America' 1911, pp. 123–26. Various cases are mentioned in J. W. & C. J. Gregory, 'To the Alps of Chinese Tibet' 1923, pp. 24–27.

of lizards, such as the blue-tailed skink, which is almost identical in Japan and in the south-eastern United States, and the ground lizard, *Lygosoma laterale*, which ranges in America from Mexico to New Jersey, and lives also in China and Japan. Dr. Scharff refers to various snakes which contribute to that formerly 'insoluble zoogeographical enigma, namely the group of animals and plants peculiar to eastern Asia and eastern America'.[1] This distribution is shared by the fish-like salamanders, the Amphiumidæ, which are found only in eastern China and in the south-eastern United States. The Hellbinder, a giant salamander, living in the eastern United States, has its only close ally in Japan. Among the turtles, the Chelydridæ or 'side-necked tortoises' are found in northern South America, New Guinea, and Australia; but they are less significant, as the family occurs fossil in the European Oligocene. Among snakes, the Aglypha are restricted to south-eastern Asia and the East Indies, except for one genus in Central America; the Amblycephalidæ have much the same range, but are widespread through Central and South America; and the pythons, which range across Africa, southern Asia, and Australia, are represented in America only in a small area on the western side of Central America.[2]

The frogs supply two interesting examples. The Cystignathidæ occur only in Australia, Mexico, and South America, and the Leptodactylidæ live only in Australia and South America; and their parasites are limited to the same range.

The resemblance between animals on opposite sides of the Pacific is most striking with the lower vertebrates, the reptiles, amphibia, and fishes, and is exceptional with the more highly specialized mammals and birds of families which probably developed in or after the Oligocene and Miocene Periods.

(2) Southern India and Tropical America.—W. T. Blanford[3] called attention to numerous animals that range from South India through the East Indies and tropical America, and are not known farther north nor in Africa; such are the Whip-Scorpions (Thelyphonidæ), *Muelleria*, a bivalve living in the rivers of Mysore and belonging to the South American family Æetheriidæ, and

[1] 'Origin of Life in America' 1911, p. 130.

[2] J. G. Bartholemew, 'Atlas of Zoogeography' pl. xix, map 4.

[3] 'The Distribution of Vertebrate Animals in India, Ceylon, & Burma' Phil. Trans. Roy. Soc. ser. B, vol. cxciv (1901) pp. 422–23.

various lizards and snakes. The mammal to which he referred, the Tapir, is of an ancient type.

(3) Invertebrates.—The invertebrates supply many cases of the trans-Pacific range, including the butterflies of the family Morphidæ,[1] which range from Central America through the tropical Pacific Islands to New Guinea and south-eastern Asia, and the Neotropidæ,[2] which inhabit the same countries and also the south-west of North America, Queensland, and New Zealand. The moths, the Castnidæ, range widely through the southern lands, as they occur in Australia and eastern Africa, and, like the Morphidæ, are unknown in south-eastern Asia and North America.

(4) Mammals.—The evidence of the lower vertebrates and of many invertebrates appears opposed to that of the ordinary mammals; for the llamas, vicuñas, puma, etc., of South America are strikingly different from the kangaroos and wombats of Australia, and from the tiger, rhinoceros, and elephant of the Oriental region in south-eastern Asia. There is, on the other hand, much in common between the mammals of northern Asia and those of North America; but that community can be explained by migration over what is now the Bering Sea.

There are, however, a few cases of close affinity between mammals on either side of the tropical Pacific. Oldfield Thomas[3] gave the name *Blarinella* to a shrew from south-western China, because it was more closely allied to the North American *Blarina* than to any Old World genus; he quoted a similar relation in the case of *Zapus*, also from Szechuan. Thomas told me of his surprise at finding that the small rodents of the East Indies agree in the development of the os penis with those of tropical America. The North American Mole (*Neurotrichus*) is a close ally of the Japanese *Urotrichus*.

Migration across the southern Pacific has been claimed for the much discussed *Cœnolestes* of Ecuador. The characteristic mammals of Australia are the Diprotodont marsupials, while the American opossums are all Polyprotodonts. Both sections of

[1] J. G. Bartholemew, 'Atlas of Zoogeography' 1911, pl. xxx, fig. 6

[2] *Ibid.* pl. xxxix, fig. 6.

[3] 'On Mammals from Kan-zu & Sze-chwan, Western China' Proc. Zool. Soc. 1911, p. 166.

marsupials were regarded as derived from a common northern ancestor, until Thomas (1888) proved that *Cænolestes* is a Diprotodont marsupial. Various attempts have been made to reconcile its occurrence in South America with the hypothesis of the northern origin of the mammals. According to one view, adopted among others by W. K. Gregory (1910), R. Broom (1912), and C. Tate Regan (1914), *Cænolestes* and the fossil Patagonian Epanorthidæ were merely Polyprotodonts which had acquired a Diprotodont dentition.

The most detailed recent work on *Cænolestes* by W. H. Osgood[1] emphatically rejects this theory; he considers it a true Diprotodont, with many resemblances to the Australian Bandicoots (*Perameles*), and that it is the direct prototype of the Australian Diprotodonts. He holds that it may be descended from a primitive form, which had a wide range in the northern lands, and so its present habitat would not prove the former existence of a southern land-connexion between South America and Australia. The presence in Patagonia of the fossil Epanorthidæ is, however, opposed to the explanation that these small marsupials reached South America from the north.

(5) Southern Origin of the Mammals.—The theory of the northern origin of most groups of animals, which was mentioned in my address last year, has long been popular; but exactly the opposite conclusion has been reached by Dr. Ernst Schwarz,[2] who traces the origin of the mammals to the late Palæozoic or early Mesozoic Era in a great southern continent, which included Africa, Australia, and South America. These early mammals, he holds, gave rise to two stems: one, the Insectivores, which occupied the Atlantic lands; and the other, the Polyprotodonts, which occupied the Pacific lands, and gave rise to the Marsupials. *Cænolestes* Schwarz regards[3] as an early primitive offshoot of the Austral fauna.[4]

Support to Schwarz's rejection of the northern monopoly of evolution is given by the probable southern origin of various animals and plants, as claimed for some of those of New Zealand by

[1] 'A Monographic Study of the American Marsupial *Cænolestes*' Field Mus. Nat. Hist. Publ. 207, Zool. ser. xiv, no. 1 (1921) pp. 128–29, 150–52.

[2] 'On the Evolution & Radiation of Mammalian Faunæ' Acta Zoologica (Stockholm), vol. v (1924) pp. 415, 417.

[3] *Ibid.* pp. 415, 419.

[4] *Ibid.* p. 420.

L. Cockayne[1] and of Australia[2] by E. C. Andrews, and by Spencer Moore, who repudiated the superiority of the northern plants, and argued that various genera now common in the northern lands are of southern origin.

Dr. C. Tate Regan,[3] from the distribution of the freshwater fishes, the Ostariophysi, says that the view that they 'originated in the north and spread southwards involves so many improbabilities as to be almost unbelievable'.

(6) The Sino-United States Flora.—The occupation of lands now separated by the Pacific Ocean by animals that are not known in the areas which they must have occupied if they had migrated between Australia and Asia and America by way of Bering Strait, is strongly supported by the evidence of the plants. Asa Gray[4] pointed out the surprising resemblances between the flora of eastern China and that of the south-eastern United States. The fact has been reaffirmed and the evidence summarized by Prof. C. S. Sargent in his introduction to E. H. Wilson's 'A Naturalist in Western China' (1913).

There is no evidence that the Chinese flora reached North America by way of Bering Strait, and it probably made the passage farther south across humid lowlands, which once doubtless extended far west from the Antillean Region into the Pacific. The flora probably reached the Lower Mississippi area through the land that served for the passage of the alligator and *Lygosoma* and the numerous snakes and other reptiles, amphibia, and freshwater fishes that occur in the warmer lands on both sides of the Pacific, and which was used by the Upper Eocene mammals, the Titanotheres, when they ranged between the deserts of Gobi and Utah.

Attention has recently been directed by Prof. E. W. Berry[5] to an example that is especially useful from its evidence as to the date of the migration. The genus *Gordonia* is one of many

[1] 'Vegetation of New Zealand' 1921, p. 192.

[2] E. C. Andrews, Amer. Journ. Sci. ser. 4, vol. xlii (1916) p. 218; Spencer Moore, 'Suggestions upon the Origin of the Australian Flora' Nat. Sci. vol. xv (1899) pp. 201–202.

[3] 'The Distribution of the Fishes of the Order Ostariophysi' Bijdr. Dierkunde K. Zool. Genootsch. Amsterdam, pt. xxii (1922) p. 207.

[4] 'Forest Geography & Archæology' Amer. Journ. Sci. ser. 3, vol. xvi (1878) pp. 188, 196.

[5] '*Gordonia* from the Miocene of Idaho & Washington' Amer. Journ. Sci. ser. 5, vol. xviii (1929) pp. 429–32.

which are at present restricted to south-eastern Asia and the warmer regions of America. Its family includes from sixteen to seventeen genera and two hundred species, which live in southern China, Indo-China, Borneo, Celebes, the Philippines, Formosa, Sumatra, Java (not Timor or New Guinea), the south-east of the United States, and Idaho. It was known fossil in the Pleistocene of Java, and now has been identified, from both seeds and leaves, from the Miocene lake-beds of the Payette Formation in Idaho and of the Latah Formation of Washington.

This discovery of *Gordonia* in the Miocene indicates that it and the many other genera with a similar range probably crossed from China or the East Indies to America not later than the Oligocene or early Miocene Period.

(7) The Southern Floras.—Botanical evidence for a migration route across the Southern Pacific is afforded by the many genera and species of plants confined to New Zealand or Australia and South America, of which the Fuchsias and Araucarias are well-known examples. The number, according to E. C. Andrews,[1] amounts to eighty-eight genera and sixty-eight species. Prof. W. R. B. Oliver[2] reports seventy species as common to South America and New Zealand. Mr. R. D'O. Good,[3] after a critical study, enumerates, among the genera of the South Temperate Zone, fifteen found in America, Australasia, and New Zealand, thirteen in America and Australia or New Zealand, and five in America and Australia and/or Polynesia.

The explanation that these plants have spread across a land-connexion between South America and Australasia by way of Antarctica has been widely adopted. But Andrews objects to that view, since this flora shows no signs of adaptation to circumpolar conditions. He rejects the independent evolution of a species in isolated areas, as he calculates that the odds against it for a single species are 250,000 'billions' to one, and that this slight chance vanishes in the case of the eighty-eight genera and sixty-eight species common to South America, and Australia or New Zealand. He concludes that the common element in the Australasian and South

[1] 'The Geological History of the Australian Flowering Plants' Amer. Journ. Sci. ser. 4, vol. xlii (1916) p. 219.

[2] 'Biographical Relations of New Zealand' Journ. Linn. Soc., Bot. vol. xlvii (1925) p. 117.

[3] 'A Summary of Discontinuous Generic Distribution in the Angiosperms New Phytologist, vol. xxvi (1927) p. 257.

due to derivation from a north temperate land; and that its absence from Africa is due to the plants having perished there, on account of a climatic change.

New Zealand, according to those who, like Dr. Andrews, reject the southern land-connexion with South America, has been isolated since the Mesozoic Era; so that it would be strange if a whole group of plants should have survived so long and spread from a northern land to Patagonia and New Zealand without undergoing specific change. Hence the route adopted by Andrews seems less likely than its alternative *via* the Antarctic.

(8) The Evidence of Parasitology.—The improbability that the occurrence of similar and nearly related land-animals and plants on both sides of the Pacific is due to migration from the north has been increased in recent years by the evidence of parasitology. Its use, designated 'the von Ihering method', as that author adopted it in 1891, has been greatly extended by M. M. Metcalf [1] and the late Prof. Launcelot Harrison of Sydney. H. von Ihering showed that the marsupials of Australia and South America are infested by the same rectal parasites. The doctine of 'convergent evolution' is overburdened when called on to explain the independent development of a parasite as well as that of its host.

The Leptodactylidæ is a family of frogs which live only in the southern lands—Australia, Tasmania, Papua and the Bismarck Islands, perhaps the New Hebrides, South and Central America, the West Indies, and the southern coast of the United States on the Gulf of Mexico. They have been called 'the Southern Frogs', and quoted in support of an Antarctic connexion between Australia and South America. Opponents of that view [2] hold that the South American and Australian frogs that have been referred to this family are not closely related, although they look as if they were. The frogs in both these continents are infested by parasites, *Zelleriella* (an Opalinid, one of the ciliate Protozoa), which, according to Metcalf, 'are almost if not quite specifically identical'. *Zelleriella* is absent from the Old World. excepting Australia, and

[1] 'Parasites, & the Aid they give in Problems of Taxonomy, Geographical Distribution, & Paleogeography' Smithson. Misc. Coll. vol. lxxxi, No. 8, No. 3010 (1929) 36 pp.; L. Harrison, 'Ectoparasitic Insects & Pacific Problems' Pan-Pac. Sci. Congr. 1923, pp. 1584–85, and elsewhere.

[2] For references see footnote on p. cxvi.

it is not found in America north of the Gulf Coast of the United States. 'No one can for a moment believe', declares Metcalf,[1] 'that along with the parallel evolution of the American and Australian hosts, there was also a parallel evolution of their Opalinids'. In face of the evidence of *Zelleriella*, he remarks that 'the hypothesis of the northern origin and southward dispersal of the Southern Frogs becomes grotesque'.[2] Launcelot Harrison,[3] the late Professor of Zoology at Sydney University, was equally emphatic. He declared that the evidence of *Zelleriella* shows that the Leptodactylid frogs of South America and Australia 'must have had a common origin', and is 'strong presumptive evidence' that the two continents were joined 'in some way which excluded the northern land-masses'.

The parasitological evidence is especially useful when it throws light on the date of separation of South America and Australia. In the Brazilian Highlands the toad *Bufo* has an Opalinid parasite, *Cepedea*: neither of them shares the wide southern range of *Leptodactylus*, for the Brazilian Highlands were separated from southern South America (the Archiplata of H. von Ihering) until the Middle Miocene. Hence, the spread of *Leptodactylus* and *Zelleriella* must have happened before that date.

Ortmann, in a well-known memoir, has pointed out that the distribution of crayfish, owing to their restricted means of migration, is especially significant. There are two main families: the Potamobiidæ, which ranges across the northern lands, and the Parastacidæ, which is found only in South America, Australia, Tasmania, New Zealand, and Madagascar (but not in Africa). The wide east-and-west range of the Parastacidæ and their absence from the northern lands was considered by Ortmann evidence that both Australia and South America were connected with Antarctica. But, as pointed out by Scharff,[4] a land-bridge across the South

[1] Smithson. Misc. Coll. vol. lxxxi, No. 3010 (1929) p. 5.

[2] *Ibid.* p. 4.

[3] 'Host & Parasite' Presidential Address to the Linn. Soc. N.S. Wales, Proc. vol. liii (1928) pp. ix, xvi. He considers that the connexion of South America and Australia is supported by the evidence of the parasites of the ostriches and rheas, of *Temnocephala*, and of the lice on the marsupials, *ibid.* pp. ix, xvi, xviii, xxvii. See also his 'Ectoparasitic Insects & Pacific Problems' Proc. Pan-Pac. Sci. Congr. 1923, vol. ii (1924) pp. 1584–85.

[4] See R. F. Scharff (1911) *op. cit.* p. 426. Hutton abandoned his belief in Antarctica, and believed that the connexion was across the South Pacific.

Pacific equally well explains these facts, and is free from the serious objections [1] to the Antarctic route.

The evidence of the southern crayfish (Parastacidæ) for some sort of South Pacific land-connexion is greatly strengthened by their parasites. The southern crayfish are infested by a *Temnocephala*, and its only occurrence on the northern crayfish is in Mexico at the southernmost point of their range. The Mexican species, according to Harrison, is a descendant from a South American form.

Matthew assumes that the southern crayfish once lived in the northern lands, and have become extinct there. According to this view, it has to be assumed that *Temnocephala* was also once widespread through Europe, Asia, and North America, and has become extinct except for the one place in Mexico. There seems no reason why *Temnocephala*, if it had lived in the north, should not have survived among the crayfish there.

Hence Metcalf [2] concludes that the improbability of the double assumptions that both Parastacids and *Temnocephala* had a wide range in the north and have been exterminated there 'seems to rule out Matthew's hypothesis completely'. 'Nearly all zoogeographers', Metcalf remarks, 'believe in a former land-connexion between South America and Australia, and a number of the more prominent students believe in large areas of land in the Pacific and especially the Southern Pacific.' This conclusion seems strongly supported by the evidence of the parasites against the alternative explanations of convergent evolution or of the northern origin of southern faunas.[3]

(iii) The Island Life of the Pacific.

The Islands of the Pacific belong to two groups. The members of the first group lie off the continents, and include various continental rocks—plutonic, metamorphic, and sedimentary. Those

[1] Note, for instance, C. Tate Regan's weighty argument from the fishes. I am not here discussing Antarctica, as it concerns mainly the Southern Ocean.

[2] Smithson. Misc. Coll. vol. lxxxi, No. 3010 (1929) p. 12.

[3] The opposite view is advocated by W. D. Matthew, 'Climate & Evolution' Ann. N. York Acad. Sci. vol. xxiv (1915) pp. 171–318; E. R. Dunn, 'The Host-Parasite Method & the Distribution of Frogs' Amer. Nat. vol. lix (1925) pp. 370–75; G. R. Noble, 'The Evolution & Dispersal of Frogs' *ibid.* pp 265–71, and 'Phylogeny of the Salientia' Bull. Amer. Mus. Nat. Hist. vol. xlvi (1922) pp. 1–87, pls. i–xxiii.

of the second group lie far out in the ocean, and consist either of volcanic materials or of reef-limestones.

The chief islands of the first group are those in the western Pacific off Australia, in the East Indies, and the festoons of islands off the coast of Asia, including the Philippines, Formosa, the Japanese chain, and Sakhalin (Saghalien). Most authorities agree that the islands east of Australia, the East Indies, and the island festoons off Eastern Asia were formerly part of the continents, and that the western margin of the Pacific lay east of Japan and the East Indies and was along the line through New Caledonia, Norfolk Island, and New Zealand. This line is extended by some authorities eastward to the Solomon Islands and the New Hebrides, with a further projection to the Fiji Islands.

The islands on and to the west of these lines doubtless received their main flora and fauna when the islands were connected to the continents on the west. The problem of the biogeography of the Pacific Islands is how those east of these lines received their inhabitants.

The best known and most significant of these islands is the Hawaiian Archipelago, which, from its volcanic composition and upbuilding, and its isolated position, represents an extreme type of oceanic conditions. A high proportion of the genera and species in its flora and fauna are peculiar to the islands, although introduced grasses and food-plants are now conspicuous. Hence the archipelago must be of considerable antiquity. As the main islands of the group are only 2100 miles from North America, as against 3400 miles from Japan, and over 4000 miles from Australia and New Zealand, their biological affinities might be expected to be American. Yet their flora includes a high proportion of Australian and Polynesian plants. According to Prof. D. H. Campbell,[1] most of the trees belong to the genera which, if not endemic, occur in Australasia or the East Indies. The commonest tree in the middle forest zone is *Metrosideros polymorpha*,[2] which is common in New Zealand and Polynesia. Acacias are abundant and of an Australian type. The Screw-Pine, *Pandanus*, is common around the Indian Ocean and the South Pacific, but does not occur in America. The chief palm of Hawaii, *Pritchardia*, is characteristic of Polynesia.

[1] 'The Derivation of the Flora of Hawaii' Ley. Stanf. Univ. Public. 1919, 34 pp.; and, for a later statement, his 'The Australasian Element in the Hawaiian Flora' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) pp. 938–46.

[2] D. H. Campbell (1919) *op. cit.* p. 15.

Many of the Composites are American, and their presence is explained by the seeds being elaborately contrived for distribution by the wind. Dr. J. H. Rock [1] points out that the abundant Lobelias are also of an American type, and that the genus does not occur in Fiji, Samoa, New Guinea, the East Indies, Juan Fernandez, and Galapagos, although a few live in the southern Polynesian islands, as at Tahiti. He favours the passage of the Lobelias from America to Hawaii by a chain of volcanic islands.

It is suggested that the seeds of some of the plants may have been carried to the islands by birds—a view which Wallace also extended to the fauna; but Prof. Campbell declares that method quite impracticable for the liverworts, on which he is an expert.

This American affinity is shared by the fungi,[2] which are predominantly eastern, as six of the rusts are known only in America, and one alone indicates a western source, as it is found in Australia and Japan.

As to the origin of the Hawaiian fauna and flora there are two conflicting opinions. According to one view, the archipelago consists of true oceanic islands, and, as remarked by R. C. L. Perkins,[3] 'the present Hawaiian fauna is derived from waifs and strays from all directions. At rare intervals from the Eocene till now chance immigrants have arrived'. The alternative view is that the archipelago is on the site of an ancient land which was either directly connected with the nearest continents or was only separated from them by a shallow sea. Campbell [4] holds that the flora supports the continental theory, and says that the Hawaiian Archipelago 'is the remnant of a once much larger land-area, which was connected more or less directly with the southern Pacific area to the south-west now occupied by Australasia and the Malayan Archipelago. . . . . The isolation of the islands probably occurred early in the Tertiary'. He recognizes in the flora some South American types, which he thought due to a connexion between South America and New Zealand through an Antarctic continent. In 1929 he (*op. cit.* p. 946) repeats his view that large land-masses in the Central Pacific once connected Hawaii with New Zealand and Australia.

[1] 'A Monographic Study of the Hawaiian Species of the Tribe Lobelioideæ' Publ. B. P. Bishop Mus. 1919, pp. 16, 25.

[2] F. L. Stevens, 'Hawaiian Fungi' B. P. Bishop Mus. Bull. 19 (1929) p. 114

[3] 'Fauna Hawaiiensis' vol. i (1913) p. lx.

[4] Ley. Stanf. Univ. Public. 1919, pp. 21–22.

This conclusion has been supported by other botanists. Prof. C. Skottsberg, Director of the Botanic Gardens at Gothenburg, considers the Hawaiian flora a remnant of a widespread 'Eu-Pacific' flora, which was developed in the Pacific:[1] and he holds that it is no less continental than that of New Zealand or Fiji.[2] He agrees with Campbell that its affinities are with New Zealand, and rejects the possibility of its introduction to Hawaii by transport oversea. He maintains that the flora of Juan Fernandez, 360 miles from the coast of Chile, is of the same type, but with a lower percentage of endemic species. He gives the following table of percentages[3]:—

	Hawaiian.	*Juan Fernandez.*
American	7·5	43
Old Pacific	32·3	39
Australian-Polynesian	29·0	13 (New Zealand & Polynesian).
Indo-Malayan	26·5	13 (Sub-Antarctic & Magellanic).
Widespread	3·3	2

That the flora of Juan Fernandez did not reach the island from the opposite coast of Chile he considers shown by the importance of two trees, the Juan Fernandez sandalwood, a species of *Santalum*, and a *Coprosoma*, of which both genera are absent from America; they are present in Hawaii and the lands of the south-western Pacific. He considers that the common element in the Hawaiian and Juan Fernandez floras was derived from an Antarctic land in the Southern Pacific, from which Hawaii received its flora by a route connected with New Zealand and Juan Fernandez *via* land connected with southern South America. The absence from Juan Fernandez of the large Indo-Malayan element in Hawaii tells against their direct connexion,[4] whereas he remarks 'I cannot see how we can do without a connexion between Hawaii and Micronesia.'

The arguments for this direct connexion are not, it is true, held by all botanists. F. P. H. Brown[5] holds that the Hawaiian flora

[1] 'Remarks on the Relative Independency of Pacific Floras' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) p. 917.

[2] *Ibid* p. 920.

[3] 'Juan Fernandez & Hawaii, a Phytogeographical Discussion' B. P. Bishop Mus. Bull. 16 (1925) p. 6.

[4] *Ibid.* p. 35.

[5] Proc. 1st Pan-Pac. Sci. Congr. (Spec. Publ. B. P. Bishop Mus. No. 7, 1921, p. 132). Brown's views are discussed and rejected by Skottsberg *op. cit.* (1925) pp. 9–20.

was introduced from Central (or Isthmian) America by ocean-currents in two consignments—one in Lower Cretaceous times, a second in the Lower Eocene—supplemented by human introductions. The resemblance to the flora of Australasia he explains by its vegetation being in the stage of that of the Mississippi Valley in the Lower Eocene.

The connexion of Hawaii with Juan Fernandez is claimed by Hans Hallier,[1] of the Royal Herbarium of Leyden, who introduces lands even more extensive than those suggested by Skottsberg. He considers that the Eu-Pacific flora developed on a large central and southern Pacific Continent which extended north-eastwards from Australia, included the East Indies and Polynesia, and was bounded by concentric mountain-chains, of which the Sandwich and Paumotu Islands mark the site. This land at one time included Southern Japan, extended north-eastwards to Revilla Gigedo off Mexico, and was united through it with the peninsula of California and with Central America; farther south this land projected south-eastwards to Easter Island, Juan Fernandez, and Sala y Gomez, and joined southern Chile. He enumerates and discusses a long series of plants which are found on both sides of the southern and tropical Pacific, and considers that their cumulative evidence proves a land-connexion of Polynesia with Chile[2].

Several authorities, therefore, claim on the evidence of plants the existence of the Pacific Continent, which has been upheld also by geologists and zoologists. The Eu-Pacific flora has its counterpart in the claim of H. H. Pilsbry[3] that the Pacific land molluscs developed upon a former Continent. Pilsbry regarded the Polynesian land-mollusca as a homogeneous fauna and as similar over vast areas of the Pacific; and, as this fauna preceded the Oriental and Australian, it could not have been introduced overseas from land on the south-west and west, and the Polynesian snails are certainly not of American origin. Hence Pilsbry infers that this fauna

[1] 'Ueber frühere Landbrücken, Pflanzen- & Völkerwanderungen zwischen Australasien & Amerika' Meded. Rijks-Herb. Leiden, No. 13 (1912) pp. 1–2.

[2] *Ibid.* pp. 2–8, from the resemblance of the Malay and Mexican looms and on philological and other grounds, he holds that the trans-Pacific land connexion lasted until the time of Man (*ibid.* pp. 12–31); but the facts which he there cites may be explained by canoe migrations.

[3] 'The Genesis of Mid-Pacific Faunas' Proc. Acad. Nat. Sci. Philad. 1899 (Nov. 1900) pp. 576, 578, 581.

could only have originated in Polynesia when it was a continental area. He considers that this continent was isolated in the middle of the Mesozoic Era, since the types that developed elsewhere in the later Mesozoic are absent. The continent, according to Pilsbry, was disrupted in stages, the northern part including Hawaii being separated first, as some of the later molluscs did not reach it. Pilsbry held that the Pacific Continent was never directly connected with America or invaded by its mollusca: and he explained the character of the flora, and the absence from the Hawaiian Islands of ancient types such as the conifers, by their supersession by the products of seeds blown overseas.[1]

A recent discussion of the evidence of the land shells by C. M. Cooke[2] supports Pilsbry's main conclusions. Cooke reasserts the continuity of the distribution of these shells through the Hawaiian Archipelago, and he concludes that the islands were once part of a continuous and ancient land. As the Tornatellinidæ, a family which has its greatest development in Hawaii, ranges from Juan Fernandez to Japan, this family tells equally in favour of those lands having been directly united, as well as the islands in the Hawaiian group.

It must be remembered that the evidence of all the groups of animals is not apparently concordant. Thus the distribution of the spiders, according to Lucien Berland, of the Natural History Museum of Paris, indicates geographical features exactly the opposite of those indicated by the land shells. 'The fauna of Hawaii,' says Berland,[3] 'is rather American'; and the Pacific spider fauna is not homogeneous. 'It seems impossible,' he therefore concludes, 'to admit that the Pacific was ever a single continent.' The spider fauna may, however, be of a later date than the land-mollusca, and its distribution may be partly due to the wafting of spiders' webs by the wind when the islands were larger and less distant than at present. The close relationships between South American and Australian spiders he attributes to their range through an Antarctic land.

The uncertainty of the evidence depends, not only on the animals, but on their interpretation. Thus, according to E. Simon,[4] the

[1] Proc. Acad. Nat. Sci. Philad. 1899 (1900) p. 581.

[2] 'The Distribution of Hawaiian Land-Snails' Proc. Pan-Pac. Sci. Congr. 1923, vol. ii (1924) pp. 1545-48.

[3] 'Distribution & Affinities of Pacific Spiders' Proc. 3rd Pan-Pac. Sci. Congr. 1926. vol. i (1929) pp. 1044–54.

[4] 'Arachnida: Fauna Hawaiiensis' vol. ii (1900) pt. 5, p. 443.

Arachnids of Hawaii are of Australian and Malaysian affinities; and he expresses this view far more positively than M. Berland states the opposite opinion.

Much of the zoological evidence supports Pilsbry's interpretation of the land shells and the Australian affinity of the Hawaiian flora. Thus, the insects have remarkable and surprising resemblances to those of New Zealand. 'There are,' says E. Meyrick,[1] 'no families of moths in Hawaii not also represented in New Zealand.' Meyrick classifies the Hawaiian Lepidoptera into four groups: the primary and oldest group is of Southern Pacific origin, and he postulates for it 'a considerable land-area (now submerged) between New Zealand and southern America'; the second group came in from Asia, when the archipelago had a great extension to the north-west; the third and largest immigration was derived almost equally from Australasia, Asia, and America. Of the latest arrivals some were introduced by Man, and the others have strong powers of flight, are of American affinity, and were probably brought in by aid of the strong north-east trade winds. According to Meyrick, therefore, the insects agree with the mollusca in indicating the existence of a former Southern Pacific continent, and the Lepidoptera give useful clues as to its northern extension and the dates of its disruption.

Budde-Lund[2] regarded the existence of an ancient Pacific continent as the only explanation of the distribution of the Isopods, the Spherilloninæ, which live in Australia, New Zealand, Polynesia, south-eastern Asia, and south-western North America.

L. Germain[3] believes in a long-established Pacific Continent lasting from the Palæozoic Era until its final dismemberment in the Pliocene or Pleistocene. He infers from the distribution of the eels that the eastern Pacific Continent was connected with Juan Fernandez and Easter Island.

The evidence of the marine fauna is also in favour of the former connexion of the Hawaiian Islands, by a coast or a series of islands, to Asia or Australia. As Hawaii is nearest to North America, the marine fauna might be expected to be predominantly American. On the contrary, C. H. Edmondson[4] concludes: 'The

[1] 'Macrolepidoptera: Fauna Hawaiiensis' vol. i (1913) pp. 124, 132–33.

[2] 'Revision of Crustacea Isopoda Terrestria' vol. ii (1904) p. 40.

[3] 'Fauna Hawaiiensis' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) pp. 973–1011.

[4] 'A Preliminary Comparison between Hawaiian & Australian Crustacea' Proc. Pan-Pac. Sci. Congr. 1923, vol. ii (1924) p. 1549.

affinity between the Hawaiian crustacean fauna and that of the west coast of North and Central America is very slight, but the relation between Hawaiian and Japanese crustacea is a close one, many species being common to the two regions.' He enumerates many species which are found both in the Hawaiian and in the Australian seas, and, although some of them are widespread, others are rare forms distributed north and south between the two areas.

This view is supported by the evidence, quoted by D. H. Campbell,[1] that the shore fishes of Hawaii, according to Principal D. S. Jordan, are South Pacific and not American; that the echinoderms, according to Prof. W. K. Fisher, present no similarity to those of western America, but are related to those of Australasia and the Indian Ocean; and that the zoophytes, according to Hurtling, agree with those of Australia by the abundance of Plumularidæ, which are sparse along Western America.

There is no need to follow the evidence regarding the other Pacific Islands. Some of them are oceanic, and are occupied only by chance stragglers; but others show a mixture of inhabitants similar to that in Hawaii: these islands must be of considerable age, and, according to some biologists, are of continental origin. A recent emphatic statement to that effect has been made by E. Meyrick[2] regarding Rapa, one of the Austral Islands (140° W., 24° S.). He concludes that Rapa must have been part of a much more extensive land, and nearly connected with Fiji and Australia when the sea-floor around was 12,000 feet higher than it is now: 'I entertain no doubt that such an elevation must have existed since the Eocene Period, because it is absolutely the only explanation possible.'

The evidence of the life of the Pacific Ocean, both on the Islands and on their shores, is, therefore, greatly in favour of the conclusion of Prof. D. H. Campbell that 'Polynesia, as a whole, may be regarded as the fragments of one or more such submerged continental masses, upon which, as they subsided, have been superimposed the volcanic islands which now exist'.[3]

[1] Ley. Stanf. Univ. Public. 1919, pp. 31–32.

[2] 'On Microlepidoptera from the Galapagos Islands & Rapa' Trans. Entomol. Soc. vol. lxxiv (1926) pp. 269–78.

[3] The Hawaiian islands are a horst with a continental foundation, with volcanoes piled on it like Etna on Sicily, according to L. Kober. 'Der Bau der Erde' 2nd ed. (1928) pp. 358–63.

5. The Pacific Islands and the Pacific Coast-Types.

(1) Composite Nature of the Pacific Basin.

If, then, the geological distribution of the Pacific seas and their biogeography are in favour of a former extensive Pacific land, some trace of it might be expected in the existing geography of the Pacific basin and the arrangement of the islands. A bathymetric map indicates the composite origin of the Pacific basin, and gives a different impression from the unity suggested by a map of the surface. The floor has not a simple trigonal form: the parts more than 2000 fathoms deep include the north-central Pacific, and a smaller elliptical area in the south. These two basins are connected west of South America, and in the Southern Ocean there are areas exceeding 2000 fathoms in depth, south of South Australia and south-west of the southern end of South America.

The areas less than 2000 fathoms deep form a marginal band off America and northern Asia, and the Polynesian Platform under the whole south-western Pacific. An eastward projection from it under south-central Polynesia towards the corresponding projection, the Patagonian Platform, from South America, nearly separates the two main Pacific basins. The relation of these two platforms suggests their former union.

(2) Evidence of Coral-Islands.

That the Polynesian Platform is a sunken land is a corollary to Darwin's theory of corali-slands. He inferred that a continent once prolonged Melanesia eastwards into the Pacific, and that its sunken mountain-chains supplied the foundations of the coral-islands.

The inconsistency of Darwin's theory with the permanence of ocean-basins led to many attempts to discredit it. But it has been, I think, fully established by the boring at Funafuti, by the physiographic proofs of subsidence, as clearly stated by Prof. W. M. Davis,[1] by the gravity observations at Jaluit, by the increasing records of early and middle Kainozoic limestones in their foundations, and by the botanical evidence of subsidence of the Marquesas Islands of from 3000 to 6000 feet.[2]

[1] 'The Coral-Reef Problem' Amer. Geogr. Soc., Spec.Publ. no. ix (1928).

[2] F. B. H. Brown, 'Botanical Evidence bearing on the Submergence of Land in the Marquesas Islands' Proc. Pan-Pac. Sci. Cong. 1923, vol. ii (1925) p. 1160.

Personally, I adhere to the view that the Pacific coral-islands afford clear evidence of a subsidence amounting to several thousands of feet, involving—with some areas of elevation—the main part of the Pacific occupied by coral-islands. The scanty palæontological evidence indicates that the sinking was mainly in the Upper Kainozoic Era.

(3) The Pacific River-Systems.

If the margins of the Pacific had always been in nearly their present position (as stated by some authorities, see p. lxxiii), they should have been worn down, and the ocean bordered by vast peneplanes traversed by great rivers entering the Pacific. On the contrary, the Pacific borders are mostly high, the coastal plains narrow, and the rivers relatively small. The only exceptions to the rule that the great rivers of the circum-Pacific lands rise near it but flow away from it are in eastern Asia, and those rivers all show clear indications of their youth.

(4) The Island Rocks.

The petrological evidence of the rocks from the Pacific Islands is scanty, and its interpretation has been much disputed. Records of plutonic rocks from many of the oceanic islands have been quoted as evidence that they have a continental basis.[1] These records relate to many widely scattered islands; they include nepheline-syenite from Tahiti; granite and gneiss from the Marquesas[2]; hornblende-granite from the Kermadecs, between New Zealand and Tahiti; granite from Maupiti (16½° S., 151° W.) and a quartz-felspar-rock from Bora-Bora (16½° S., 151¾° W.), both in the Society Islands; and crystalline schists from Yap in the Caroline Islands.

These records are additional to those from the islands between Australia, New Zealand, and Fiji, which are accepted as continental. The identifications or records from central Polynesia are dubious: they have been discussed by Prof. A. Lacroix, who rejects

[1] P. Marshall, 'Oceania' Handb. Reg. Geol. vol. vii, pt. 2 (1911) p. 30, gave a list of older or deep-seated rocks in nine widely spread islands, exclusive of the Solomon and Fiji Islands; but he has withdrawn them all in a later statement.

[2] The occurrence of gneiss and granite on the Marquesas has been widely quoted since A. Wichmann's acceptance of the unconvincing record by Marcou: A. Wichmann, 'Ein Beitrag zur Petrographie des Viti-Archipels' Beitr. Min & Petr. n.s. vol. v. (1883) p. 6.

all relating to the Society Isles and southern Polynesia. The granite of Bora-Bora is a doleritic gabbro; the peridotite and leptynite reported by Jardin from the Marquesas Prof. Lacroix identifies as basalt and trachyte respectively; the granite which he had himself identified from Taiarapu was imported. Prof. Lacroix[1] concludes that the islands of southern Polynesia contain no 'eruptive' rock, or ancient sediment, or crystalline schist.

Dr. P. Marshall extends this denial, and exempts from it only the crystalline schists of Yap, the northernmost of the Caroline Islands, which, as he remarks, is on the western edge of the oceanic area.[2]

It is doubtless true that, apart from the limestones of the coral-reef formations, almost the only rocks known from the oceanic islands are volcanic. The absence of fragments of the underlying platform is not surprising, in view of its depth. Included fragments of the subvolcanic rocks would be instructive, but are hardly to be expected. I once searched in the tuffs and lavas of Dominica and St. Lucia for ejected fragments which might reveal the nature of the foundation, and was disappointed not to find any, in view of the abundance collected in a short time in the tuffs of Monte Somma.

Included fragments appear usually to be absorbed during a comparatively short ascent in a volcanic pipe. The limestones of Vesuvius are found in the older tuffs, and not at the higher levels. The quick absorption of included material may be illustrated by the extinct volcano of Dumgoyach, in the Blane Valley north of Glasgow. It is a basaltic neck which rests on Old Red Sandstone conglomerate. The lower lavas contain the free quartz of partly digested pebbles; they are smaller, rarer, and have indefinite margins in the higher part of the hill. The absence of recognizable inclusions in lavas which have risen up a volcanic pipe from a depth of 10,000 or 20,000 feet is not surprising.

The extreme rarity of rocks other than volcanic or limestones in the Pacific Islands does not prove the absence of continental materials from their foundations. If Africa were submerged 15,000 feet, all the summits left above sea-level, except Ruwenzori, would be volcanic. Prof. Lacroix, moreover, records the presence of gabbro, the basic plutonic rock.

[1] 'La Constitution Lithologique des Iles Volcaniques de la Polynésie Australe' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) p. 737.

[2] 'The Structure of the Pacific' Proc. Pan-Pac. Sci. Congr, 1923, vol. i (1924) p. 733.

The limestones are mostly of recent age, but Miocene and Aquitanian limestones are being discovered, such as those containing *Lepidocyclina* on Mangaia, one of the Cooke Islands, and that in Jaluit,[1] the south-western member of the Marshall Isles. These foraminiferal limestones are probably remnants of sheets that have been broken up and sunk beneath the Pacific.

(5) The Plan of the Islands.

The arrangement of the islands affords some clue to their formation. J. D. Dana,[2] in an oft-quoted diagram, showed their linear arrangement in fifteen chains, of which, according to his list, nine trend between 56° and 68° W. of N., five trend between 30° and 44° W. of N., and one 50° W. of N. These island lines are the Oceanids of Suess (1909). In 1908 I had classified the islands into eight festoons and three chains.[3] The festoons are the eight arc-like series that lie off Australia, Asia, and North America. Two additional festoons may be indicated by the Pelew-Ladrone Chain and the line of rocks and islets from California to the Galapagos.

The most important islands in the central Pacific are arranged in two chains which trend from W.N.W. to E.S.E., and most of the lines there have approximately that direction. The festoons have been described by Dr. P. Marshall[4] as 'imaginary'; but they can be verified by inspection of a map of the Pacific. The linear arrangement of the islands, and of the deeps and trenches which trend at right angles to them, show that the present plan of the Pacific was determined by earth-movements on two intercepting lines:—namely, a series of ridge-folds that have been broken across by subsidence along fractures. That the main lines are due to the folding of the Pacific floor is now widely accepted, as by Mr. C. Crossland[5] and Sir G. Lenox-Conyngham.[6] These folds are not necessarily confined to the floor of the Pacific, for Sir G. Lenox-

[1] See P. Marshall, Yabe, & Aski, *op. cit.* p. 1.

[2] 'Manual of Geology' 1863, pp. 32–33; 4th ed. 1896, pp. 36–37.

[3] J. W. Gregory, 'Geography, Structural, &c.' 1908, pl. 32 & pp. 275–78. A diagram illustrating both plans was given by P. Marshall, 'Oceania' Handb. Reg. Geol. vol. vii, pt. 2 (1911) p. 3.

[4] Proc. Pan-Pac. Sci. Congr. 1923, vol. i (1924) p. 732.

[5] 'The Island of Tahiti' Geogr. Journ. vol. lxxi (1928) p. 561. A movement along intersecting fissures is adopted by L. J. Chubb in a preliminary account of the Marquesas (Abstr. Proc. Geol. Soc. 1927-28, pp. 77–78).

[6] In G. Lenox-Conyngham & F. A. Potts 'The Great Barrier-Reef: Pt. I.' Geogr. Journ. vol. lxv (1925) pp. 320–22.

Conyngham concludes that when 'the ocean-floor was thrown into undulations, the undulations may have continued under the Continent'. It is probably not a mere coincidence that the North Pacific (or Hawaiian) chain is in line with that part of the coast of South America which breaks away from the normal north-and-south trend, and projects north-westwards under the influence of an older mountain-system.[1]

The folding of the Pacific floor shows traces of the old Altaid movements by the coincidence in direction of the North Pacific Chain and the projection of Peru between Ica and Tacna; but the main folding, as stated by Prof. C. Schuchert,[2] began in the late Cretaceous, and had its chief effect during the world-wide folding of the Oligocene and Miocene. I welcome his further statement[3] that 'the entire eastern half of the Pacific bottom, and especially the Australasian region, appears to be as mobile as any of the continents of the northern hemisphere'.

(6) The Pacific Coast-Types.

The plan of the Pacific Islands, then, indicates their origin by the buckling of the floor of the ocean in broad folds, by which parts were raised and others lowered. The main folding trends W.N.W. and E.S.E., but it curves to N.W. and S.E., and adapts itself to the earlier structures as it approaches Australia and Asia. The cause of the buckling is, nevertheless, not consistent with Suess's view of the origin of the Pacific coasts. He regarded them as having a special structure in contrast to that of the Atlantic. According to Suess, the shape of the Pacific, the course of the bordering mountains, and the structure of the coastlands were determined by the same cause. With the Atlantic coast-type, on the contrary, the coast cuts across the lands regardless of their structure. I long ago pointed out the fact that large parts of the Pacific coasts do not conform to this conception, and subdivided the Pacific type into the Primary Pacific type, which agrees with Suess's definition, and the Secondary or Sub-Pacific type in which the structure of the land has no definite relation to the trend of the coast. Without this modification, as I remarked in 1913,[4]

[1] J. W. Gregory, 'Geography' 1908, and the 'Nature & Origin of Fiords' 1913, pp. 42–44.

[2] 'The Problem of Continental Fracturing & Diastrophism in Oceania' Amer. Journ. Sci. ser. 4, vol. xlii (1916) p. 42.

[3] *Ibid.* p. 105.

[4] 'Nature & Origin of Fiords' p. 41.

'very little coast can be retained under the Pacific type'; and even much that I left in the Primary Pacific type should be transferred to the other division.

(7) The Pacific and Atlantic Rock-Suites.

The view that the Pacific and Atlantic coast-types are each associated with a special type of igneous rock—those of the Atlantic being alkalic and those of the Pacific more calcic—I discussed and rejected in 1912. The distinction drawn by Prior, Harker, and Becke has been maintained, with the names Katepeirean for the Atlantic and Anapeirean (or the upbuilding) for the Pacific type by Jensen (Proc. Linn. Soc. N.S.W. vol. xxxiii, 1908, p. 188), and with the addition of a third division, the Mediterranean petrographic type, by Prof. P. Niggli.[2]

The distinction of the Atlantic lavas as chemically alkalic and the Pacific as less alkalic or calc-alkalic is generally recognized as untenable. All through the Pacific alkalic lavas have been discovered, such as the phonolites, spilites, nepheline-basalts of Western Samoa,[3] and the nephelinic rocks of Maui in the Hawaiian Isles are identified by H. S. Washington[4] as of the Atlantic suite. That the lavas of the Central Pacific islands are not of the Pacific petrographic type we also know on the high authority of Prof. A. Lacroix,[5] who says that the igneous rocks of Tahiti are 'perfectly Atlantic'. Some of the islands appear to be almost 'perfectly Ayrshire', since Mr. W. Campbell Smith[6] has identified in them kylite and crinanite as well as nepheline-tephrite,[7] which Mr. Chubb collected both on Rapa in the Austral Isles and on Maiao in the Society Isles.

[1] J. W. Gregory, 'The Structural & Petrographic Classification of Coast-Types' Scientia, vol. xi (1912) pp. 36–63.

[2] 'Der Taveyannazsandstein & die Eruptivgesteine der Jungmediterranen Kettengebirge' Schweiz. Min. Petr. Mitt. vol. ii (1923) p. 261.

[3] J. A. Thomson, 'The Geology of Western Samoa' N.Z. Journ. Sci. & Tech. vol. iv, no. 2 (1921) p. 63.

[4] 'Petrology of the Hawaiian Islands: VI. Maui' Amer. Journ. Sci. ser. 5, vol. xv (1928) pp. 216, 217.

[5] 'La Constitution Lithologique des Iles Volcaniques de la Polynésie Australe' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) pp. 734–35.

[6] W. Campbell Smith & L. J. Chubb, 'The Petrography of the Austral or Tubuai Islands (Southern Pacific)' Q. J. G. S. vol. lxxxiii (1927) pp. 322, 323, etc.

[7] *Ibid.* p. 335.

L. Kober ('Der Bau der Erde' 2nd ed. 1928, p. 70) declares

'There is no Atlantic, no Pacific, no Mediterranean magma. There is neither Sal nor Sima. There are no deep magma provinces. There are only rocks, and series of rocks, which are characteristic for certain zones of the Earth and for certain times and geological events.'

6. The Age of the Pacific in Relation to Isostasy.

All the foregoing geological and biological evidence may be said to be manifestly misleading, since the rise of the ocean-floor into land and the subsidence of a continental mass to the depth of 10,000 feet is held by some to be physically impossible. According to some authorities, the ocean-floors are composed of material so heavy that they have always lain lower than the continental areas, which consist of lighter material. The low level of the Pacific floor is attributed to an influence as inexorable as that which causes a mass of iron to sink in water, and a cork to float. If so, former land-connexions cannot be invoked to explain strange features in the distribution of animals and plants, and the Pacific islands must have been populated by such agents as ocean-currents, whirlwinds, and volcanic explosions, or by the arrival of castaways and stowaways, like Sindbad on the roc.

The possibility of any great vertical rise or fall of the Earth's crust is denied on two considerations—first, that the ocean-floor consists of rocks much heavier than that which forms the land, and, second, on inferences from their elasticity. The greater weight of the suboceanic material is one of the axioms of isostasy. Though I upheld the principles of isostasy when it was less popular than it is at present, I agree with Prof. Bailey Willis [1] in his statement that 'the isostasists have, however, pushed the mathematical theory of equilibrium to a degree of perfection that is inconsistent with the facts of geological history. There have been cycles comprising periods when mountains around a basin were high, and then other periods when they were low. The ideal equilibrium cannot have persisted during changes of such magnitude'. I have no intention of discussing isostasy to-day, and merely repeat the remark, made last year, that the extreme form of that doctrine which denies that continental rocks can sink to any great extent is opposed to an overwhelming weight of geological evidence.

[1] 'Geotectonics of the Pacific' Proc. 3rd Pan-Pac. Sci. Congr. 1926, vol. i (1929) p. 362.

Three arguments are advanced to prove that the rocks below the oceans are heavier than those below the continents. The first is that they are lower in position; but that rule does not hold on land. The material of the low plains of Cutch is not heavier than the basalts of the Deccan Plateau.

A second argument is that the suboceanic material must be basic, because the lavas of oceanic volcanoes are predominantly basic, and those of continental volcanoes predominantly acid. Comparison between the continental and the oceanic plutonic rocks is impossible, as there is no evidence as to those of the suboceanic areas. The Pacific volcanic ejectamenta are doubtless mainly basaltic, but not so universally and uniformly as was thought. Over large continental areas the volcanic rocks are also predominantly basaltic. Moreover, acid and alkalic lavas, beside being the commonest in the Atlantic islands, are represented in the Pacific by so much rhyolite and trachyte as to disprove any uniform underlying layer of basalt.

The third argument is that the suboceanic materials have been proved heavier than the subcontinental by direct measurements, such as those by V. Meinesz, who, by observations in submarines, found that gravity was in excess under the oceans, but to different amounts under the Pacific and Atlantic. His preliminary results[1] do not support the simple view of a uniform heavy suboceanic foundation. In judging the estimates of suboceanic gravity it should be remembered that the investigations by Duffield, during the voyage to Australia of the members of the British Association in 1914, gave results contradictory to those of Meinesz. According to Duffield, the oceanic anomalies are negative, and, according to Meinesz they are mainly positive. The conclusions of both authorities are based on the assumption that the ocean-surface coincides with the geoid. If, from any of the many available influences, the surface in mid-ocean is below the geoid and nearer the Earth's centre than is assumed, the difference might account for the apparent excess of gravity.

I once asked Prof. Duffield why he did not allow for the possibly lower level of the ocean-surface, and he replied that it could not be done. Geologists may be excused if they trust facts that they can observe more than calculations based on a doubtful assumption.

Elasticity and Earthquake Waves.—The second line of evidence is based on the difference of elasticity in the suboceanic

[1] 'Gravity Survey by Submarine *via* Panama & Java' Geogr. Journ. vol. lxxi (1928) pp. 144–56.

and subcontinential materials as shown by the speed of earthquake-waves. Most weight is attached to the observations by Prof. G. Angeheister[1] that earthquake-waves travel 18 to 26 per cent. faster under the Pacific than under a continent. According to E. Tams, the increase in speed on an average is only 2·5 per cent.,[2] and in some cases the speed under Asia is greater than under the Pacific.[3] Mr. R. D. Oldham,[4] on the contrary, in a paper before this Society, based a theory as to the nature of suboceanic material on the claim that the second-phase earthquake waves go more slowly under the oceans. Both Angeheister and Oldham remark that their observations require confirmation, and that caution is repeated, as regarded Angeheister's, by Dr. H. Jeffreys[5] and Commander N. H. Heck.[6]

As regards elasticity, it should not be overlooked that a layer below an ocean, say 20,000 feet below the surface, would be several hundred degrees cooler than a layer on the same plane beneath a continental plateau, and should be more rigid and denser.

The land is daily heated by the sun, whereas the ocean-floor lies in continuous contact with the almost ice-cold water of the deep sea. A difference of elasticity between a suboceanic and subcontinental layer does not prove a difference in composition.

The direct geological evidence is overwhelming, that large blocks of the Earth's crust rise and fall for vertical amounts greater than the greatest depths in the oceans. If continental blocks cannot sink, much geological evidence becomes meaningless.[7] The Kainozoic sedimentary rocks of California are estimated as 30,000

[1] 'A Study of Pacific Earthquakes' N.Z. Journ. Sci. & Techn. vol. iv (1921) pp. 219, 224. He remarks (p. 219) that the higher velocity of an earthquake-wave under the ocean may be due to an increase of rigidity or a decrease of density, and rejects the latter alternative from the geological evidence.

[2] 'Ueber die Fortpflanzungsgeschwindigkeit der Seismischen Oberflächen-Wellen längs Kontinentaler & Ozeanischer Wege' Centralb. Min. 1921, pp. 76, 82. The relative velocities are given as

$3{\cdot}897\ [\text{km. sec.}^{-1}] \pm 0{\cdot}028$ m.F. and $3{\cdot}801\ [\text{km. sec.}^{-1}] \pm 0{\cdot}029$ m.F.

[3] *Ibid.* p. 51.

[4] 'The Constitution of the Interior of the Earth . . . New Light on the Origin of the Oceans' Q. J. G. S. vol. lxiii (1907) p. 347.

[5] 'The Earth' 2nd ed. (1929) p. 115. He remarks that 'the difference, if genuine . . . .'.

[6] N. H. Heck, Proc. 3rd Pan.-Pac. Sci. Congr. 1926, vol. ii (1929) p. 1505.

[7] 'The Earth' 2nd ed. (1929) p. 305: 'vertical movements of the land-surface are to be expected.'

feet thick. Such an accumulation is only possible by the slow subsidence of the crust; and the recent date to which the movement has continued is shown by the violent Pleistocene faulting and folding along the adjacent coast. Subsidence of corresponding amounts are known in Colombia (S.A.) and in Mesopotamia, and Prof. H. de Böckh tells me that in Albania the thickness of the Pliocene and Upper Miocene west of Tirana is over 18,000 feet. The great geosynclines prove still greater subsidences, for they include sediments about 50,000 feet thick, which have accumulated in a sinking area.

In view of such facts, there is no impossibility in the heaving of the Pacific floor to an extent sufficient to cause the interchange of ocean and continent, and the interbedding of deep-sea oozes with shallow-water deposits as in Barbados.

The great deeps in the Pacific, it should be remembered, are not in the middle, but marginal, and are opposite disturbed areas.

While the Pacific deeps are due to subsidence in late geological times—the Tonga Deep is doubtless a submarine rift-valley—the island chains and festoons probably occur along uplifts of the floor. Land in the Pacific is most required by the biological evidence on lines trending approximately east and west and along the present North Pacific Chain through the Hawaiian islands, and along the South Pacific Chain through the Coral Sea east of the East Indies. Both these chains are in line with the great fold-mountain lines that trend west and east across eastern 'Asia', and through the East Indian Archipelago.

Whatever view may be held as to the internal structure of the Earth, it would appear probable that the major disturbances would have a world-wide influence. The subsidences that produced the Atlantic and Pacific Basins doubtless produced changes on the crust elsewhere. The movements that buckled a belt of the crust from Spain to China, and from Morocco to New Guinea, should have had some effect on the ocean-floor in continuation of the fold-mountain lines on land. The Pyrenees and the Atlas are probably connected under the Atlantic to the folded lines in the Antillean Region by a compressed belt; the other end should be continued eastwards from eastern Asia to the North Pacific Chain, and the fold-line from Burma to New Guinea probably extends farther into the southern Pacific in the platform beneath the coral-islands.

7. General Conclusions.

What, then, is the general conclusion from this varied evidence as to the history of the Pacific Ocean? Its formation by the escape of the moon is opposed by the facts as to its size and density. The theory of origin by horizontal drift has not been applied to the Pacific, and that process would have reduced its width by the westward drift of America. The available explanations are, either that the basin has been permanent throughout geological time, or that its range and extent have varied from time to time owing to the heaving and sagging of the crust.

Some parts of the Pacific may have been permanent, as some blocks of the crust may have remained always below sea-level, just as other blocks have apparently always been above it. But the permanence of some parts of the Pacific, regarding which there is no direct evidence, is quite a different proposition from the permanence of the ocean-basin as a whole.

The present size of the Pacific Basin is due to a resultant increase in area and depth, for, despite occasional reductions by the upheaval of the floor, subsidence has apparently been the longest and predominant process.

The Pacific has certainly been enlarged along its margins. All authorities on the geology of the East Indies agree that they are fragments of a continuous land, which lasted throughout the Palæozoic Era, and extended eastwards into the Pacific. This ancient Malaysia was continued northwards as the Cathaysia of Grabau, by which China extended far out into the ocean; Australia is generally accepted as having once continued eastwards to Fiji and New Zealand, while northern Asia extended beyond Japan to the line through the Liu Kiu and Ladrone Islands.

On the North American side the former occupation of the eastern Pacific by land—the Schuchertland of H. von Ihering—is necessary to explain the stratigraphy of western North America; Burckhardt's conglomerates in Chile, and the sudden truncation of the grain of South America in Peru, and in Ecuador near Payta, show the westward extension of the land.

On the northern side the Pacific was occupied by the land-bridge between Mongolia and the United States, south of the Bering Sea. In the southern Pacific the replacement of sea by land is affirmed by all who believe in the connexion of Australia and New Zealand with South America, either directly or by Antarctica.

A marginal reduction of the Pacific is not enough, for many botanists, zoologists, and palæontologists, from different lines of evidence, insist that the range of plants and animals, living and extinct, requires the existence of extensive lands in the Central Pacific, and probably of land-lines nearly or wholly trans-Pacific, such as the Archigalenis of H. von Ihering, which he places in the North Pacific in the Eocene, while the south-western Pacific was then occupied by the Polynesian extension of Australia. Such striking coincidences in structure as occur on the opposite sides of the Atlantic are not to be expected with the Pacific, and it may be impossible to disprove that the community of some organisms in America and Asia was not due to passage across Bering Strait; but in many cases that route is improbable, as it was not in existence at the appropriate time, or was too far north to be in a suitable zone of latitude. Many zoologists claim that the chief Pacific islands have been peopled either by inhabitants which developed in the Central Pacific, or reached the islands there by migration across land connecting them with the continent on the south-west that occupied Polynesia and was joined to Australasia. The geological evidence is fully consistent with this conclusion.

If there had been a continuous Pacific Ocean, we should expect a wide range throughout the same climatic belt of the mobile organisms. The effect of the ocean-currents must not be overlooked; but in the Pacific they tend to spread a fauna through a wide range of latitude by equalizing the temperature, as when they carry the fauna of the Southern Ocean northwards to Peru. The restrictions in the range of some of the older faunas could only be explained by the effects of the ocean-currents if the geographical conditions of the Pacific were fundamentally altered. Any changes in the oceanic circulation adequate to account for the former biogeographical range would be inconsistent with the permanence of the Pacific.

The geological evidence indicates for several periods that the Pacific area was occupied by isolated land-locked seas, which usually had their main extension east and west, and sometimes continued across Asia to Europe or across America to the Atlantic. The existence of these seas and their dividing lands is known for nearly all the Periods since the Cambrian. The lands appear to have been at times fully trans-Pacific, and to have provided routes by which animals and plants migrated between North America and Asia

and between Eastern Australasia and South America. These lands across the Central Pacific seem to have survived until the Lower Kainozoic Era; but as the higher mammals and birds characteristic of the Upper Kainozoic are distinct on opposite sides of the Pacific, the land-bridges were destroyed before those animals could use them.

Darwin's theory of coral-islands—now established by the boring at Funafuti, by gravity observations on Jaluit, the presence of mid-Kainozoic foraminiferal limestones, the drowned nature of the coasts of many of them, and the botanical evidence of their subsidence—implies the sinking of a belt across the southern Pacific during the Upper Kainozoic.

The east-and-west lands across the Pacific were renewed from time to time along different lines, and are due to the heaving of the crust and the corrugation of long bands into fold-mountain systems. The long Altaid and Alpine mountains formed by this pressure were probably continued across the Atlantic and the Pacific by at least raised belts. The ending of the Altaid line at the south-eastern corner of the main island of Japan, and of the Alpine lines in southern China and the East Indies, indicates their former extension into the Pacific. The floor of that ocean has doubtless been affected by the disturbances that crumpled strips of Eurasia into fold-mountain chains by the mutual pressure between the northern dome of the world and the protuberant tropical belt.