ART. XXIX.—*Petrological Notes on Rocks from the Kermadec Islands; with some Geological Evidence for the Existence of a Subtropical Pacific Continent.*

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[*Read before the Philosophical Institute of Canterbury, 6th October*, 1909.]

WHEN the scientific party visited the Kermadec Islands in the year 1907, Mr. R. B. Oliver, one of its members, made collections of the rocks occurring there, and subsequently submitted them to me for examination. Their field relations will be fully dealt with by him at a later date; but after a microscopical examination of the collection I feel justified in bringing forward at once a matter which, from what he has told me, is altogether apart from his own work, and may have a somewhat important bearing on the biological history of New Zealand. Mr. Oliver, following Mr. Cheeseman,* believes that the Kermadecs are oceanic islands; but there is some evidence that they are built up by volcanic action on the remnants of a former continent which stretched south-west from Fiji and Tonga and probably extended so as to join with northern New Zealand. The Kermadec Islands may be oceanic in a biological sense—viz., that their present fauna and flora are derived from neighbouring lands by the various processes of distribution, and are not a survival of that belonging to a continent of which they once formed part; there are facts, however, which point to a close connection with a continental area, if not recently, certainly in early Tertiary or Mesozoic times.

Mr. Cheeseman's conclusions were come to after a close study of the flora of the group. He maintained that the islands were populated by the transporting agency of birds, winds, and ocean-currents, and that they received the bulk of their plants from New Zealand, a smaller proportion from Polynesia, and that five species were endemic. The occurrence of *Aleurites moluccana,* the well-known candlenut of tropical regions, whose nuts W. H. Guppy showed could not float, is one of the special peculiarities, and would be very strongly suggestive of a continental connection for the group were it not possible that it was introduced by man. Cheeseman, however, does not mention this possibility. Apart from the flora, the existence of an indigenous rat (*Mus exulans*) on Sunday Island, and also its presence in large numbers on Macauley Island when first discovered by Lieutenant Watts, is suggestive of a land connection. The rat is widely distributed in Polynesia, and it is possible that it was introduced on Sunday Island either intentionally or unintentionally by Natives on their long sea-voyages. But Macauley Island is very inaccessible, and it is very improbable that they introduced it here. It must be remembered, however, that this rat, which is the same as the Maori *kiore,* is used as an article of food by the Natives of some islands even when other supplies are plentiful, and also it is so widely distributed in Polynesia that conclusions to be drawn from its distribution are perhaps ill founded. Man has no doubt been responsible for its introduction into many islands.

* Trans. N.Z. Institute, vol. xx, 1888.

A careful examination of the lower forms of animal life belonging to the Kermadecs will ultimately provide a definite solution to the problem; but our present knowledge is by no means satisfactory, though no doubt when all the collections made by the party are fully worked up much additional information will be available. Mr. H. Suter has furnished me with details concerning the land *Mollusca* of the group, and he concludes that the islands are the meeting-ground for forms belonging both to Polynesia and New Zealand, but that the former preponderated over the latter. The mere presence of land *Mollusca* on an island nearly five hundred miles from other land, notwithstanding the readiness with which they can be transported in the juvenile state, is certainly suggestive of a continental connection. This conclusion is strongly supported by the character of the marine *Mollusca.* The higher percentage of Polynesian forms points to a closer or more recent connection with the islands to the north than with New Zealand; and this fact is borne out by a study of the form of the sea-bottom and the depth of the sea over the area through which communication probably took place. This conclusion is apparently at variance with that arrived at by Mr. Cheeseman.

The peculiarities in distribution of plants and animals in the southern Pacific islands have suggested to several eminent naturalists the probability of the former existence of a continent in that region. They approached the subject from the biological side, without the advantage of the geological knowledge that we now possess. Alfred Russell Wallace says in his "Island Life," "It is possible, too, that there may have been an extension [of New Zealand] northward to the Kermadec Islands, and even further, to the Tonga and Fiji Islands, though this is hardly probable, or we should find more community between their productions and those of New Zealand." Wallace, however, looked to a connection with north-eastern Australia as being most probable. H. O. Forbes* had a similar idea of the existence of a continental area in this region, and included it under the vast continent in the Southern Hemisphere to which he gave the name Antarctica.

Captain Hutton held very strongly to the opinion that New Zealand was connected at one time to a Pacific continent. As early as the year 1872 he advocated the theory, and in his presidential address before the Philosophical Institute of Canterbury, 1883, published in the "New Zealand Journal of Science," 1884, and also in the "Annals and Magazine of Natural History," vol. xiii, 1884, he discussed the matter from a biological standpoint. He said then, "We must suppose that it was during the Upper Jurassic or Lower Cretaceous period that New Zealand was joined to the South Pacific continent, while during the Eocene it extended towards New Caledonia, and again in the Pliocene towards the Kermadecs." The last statement is an inference from the extension of glaciers in New Zealand, which Captain Hutton put in Pliocene times, and attributed to elevation of the land. It seems difficult, however, to account for the absence of glaciation in the North Island if that elevation extended nearly as far north as the Kermadecs; and it seems probable that elevation was only one of the causes of that glaciation.

Later on, in his "Index Faunæ Novæ-Zealandiæ," and again in the year 1905, in a letter to *Nature* (vol. lxxii, page 245), he urged the existence of a tropical and subtropical trans-Pacific continent during Cretaceous and

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* Forbes, H. O.: "Natural Science," vol. iii, 1893.

Eocene times in order to explain peculiarities in animal and plant distribution and the South American relationships of New Zealand forms. He advocated also a continental Antarctic connection in Jurassic times between New Zealand and South America, followed by a connection in the form of islands in Cretaceous times. The importance of the Kermadecs in the former land bridge was thoroughly recognised by Captain Hutton, especially as it is a kind of "half-way house" between New Zealand and the tropical areas immediately to the north-east, and he specially mentions their bearing on the migration of birds between New Zealand and the Polynesian islands. If migrations always take the line of a past or present land connection, either continuous or in the form of islands, the continental origin of the Kermadecs is rendered more probable.

He was supported by Dr. Von Ihering in a paper "On the Ancient Relations between New Zealand and South America" (Trans. N.Z. Inst., vol. xxiv, p. 431). The latter says, "The fauna of East Polynesia has such a well-pronounced Mesozoic character that the supposition of a very old Pacific continent, breaking up in pieces more and more during the Mesozoic era, may give us a very natural explanation." Von Ihering no doubt regarded the connection with America as made through an Antarctic continent, and from this land first the eastern Polynesian islands, then New Zealand, and finally Australia and New Guinea, were separated. With the exception of his disbelief in a "junction" with America in low latitude, his views accord with those of Captain Hutton.

Mr. Hedley, in his various papers* on distribution in the Pacific Islands, controverts Wallace's ideas of a direct connection between New Zealand and northern Australia, and insists on a junction once existing with New Caledonia, the New Hebrides, and New Guinea and New Zealand. The land forming this connection he called the "Melanesian platform." On it he placed Fiji, but not Tonga, Samoa, or the Kermadecs. Mr. Hedley came to this conclusion largely from a consideration of the distribution of the land *Mollusca* of the Pacific; and he regarded the molluscan fauna peopling the lands on his Melanesian platform as derived from an ancient continental fauna, and that on the other islands as a number of waifs and strays. He concluded also that the continent had no connection with America, as no sign of an American immigration can be traced in the central Pacific.

Dr. Pilsbry,† after a consideration of the character of the Polynesian snail fauna, concludes as follows: "The hypothesis of a late Palæozoic or early Mesozoic mid-Pacific continent (upon the sunken heights of which the present island-masses, volcanic or coral, have been superposed) is advanced to account for the constitution of the Pacific snail faunas, which are shown to be (1) nearly homogeneous over vast areas, (2) composed of ancient types with no admixture of the great series of modern families, and not derivable from any Tertiary or modern continental fauna or faunas in the sense that the Atlantic faunas have been derived. The *Mollusca*, land and marine, supply no evidence that the Pacific continent was ever connected with or faunally affected by the American, but emphatically deny such connection."

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* C. Hedley: "Natural Science," vol. iii, 1893; Trans. Roy. Soc. N.S.W., 1895; Proc. Linn. Soc. N.S.W., 1899.

† "Genesis of Mid-Pacific Faunas," by Henry A. Pilsbry, Sc.D., Proc. Acad. Nat. Sci. of Philadelphia, 1900.

The strongest supporter of a trans-Pacific continent is Dr. Baur, of Chicago. He deals with the matter, largely from a biological standpoint, in an extremely important paper on "The Origin of the Galapagos Islands," published in the "American Naturalist," vol. xxxi. After a thorough examination of the distribution of numerous families and genera he concludes that the Pacific islands are the remains of a former Pacific continent; that this continent existed till just before Miocene times.

It is thus very apparent that there is a strong consensus of opinion among leading zoologists that a Pacific continent once existed, the principal disagreement being in the matter of boundaries. While Hedley would restrict it to his Melanesian platform, Pilsbry and probably Von Ihering would extend it as far as Tahiti and the Marquesas, and Hutton and Baur would make it stretch as far as South America.

It is not my intention to discuss further the biological side of this question, but to collate the geological evidence afforded up to the present as to the probability of the existence of such a mass of land. The evidence as to the continental nature of each group of islands over the site of the hypothetical continent will be briefly considered.

Kermadec Islands.

Owing to their peculiar position half-way between New Zealand and Tonga, the Kermadecs possess a special importance in this matter, so that any geological evidence which they afford is of great value.

A suggested continental connection for them, based on geological evidence, was made by Professor Thomas in his paper "Notes on the Rocks of the Kermadec Islands" (Trans. N.Z. Inst., vol. xx, p. 311, 1888). In describing the specimens collected by Mr. Percy Smith he notes the occurrence of a granite, but suggests that it may have come to the islands in the ballast of some ships. Present results show that this view cannot be accepted. While the main mass of the Kermadecs is composed of volcanic rocks consisting chiefly of augite hypersthene andesites of somewhat acid character, olivine augite andesites of basic character, and acid basalts, there occur in the tuffs on the north side of Sunday Island numerous boulders of hornblende granite. These boulders also occur scattered about the island, and one specimen came from a block situated at a height of 1,600 ft. Professor Thomas's suggestion as to the "ballast" origin of these boulders is therefore untenable, and his first hypothesis of the island forming part of a continental area seems to be perfectly sound. Mr. Oliver did not find the rock in position, but from the occurrence of many fragments it is evident that plutonic rocks must be at a very shallow depth below the volcanic covering, and may even yet be discovered *in situ* in the group. When the small extent of the visible plutonic basement of volcanic islands like the Auckland Islands is considered, it is extremely likely that a mask of volcanic rocks may completely cover a granite foundation of the Kermadecs. But the existence of the fragments in such numbers undoubtedly shows its presence in close proximity. The condition seems very like that which would obtain if the Bounty Islands, which consist of a few granite islets and rocks, only a few feet above the sea, were to become the scene of volcanic activity, and were buried by fragmentary matter and flows of lava. The Bounties contain only one fresh-water alga, and a few low forms of animal life besides the birds and seals which visit them. Should such an island be built up, and become large enough to allow vegetation to flourish, then it would present most of the characters of an oceanic island. Such appears to be the probable position in the case of the Kermadecs. The great difficulty, however, is in coming to any satisfactory conclusion as to the date of their existence as land above sea-level. It is the fact of the occurrence of plutonic acidic rocks in the group that has suggested the consideration of the geological evidence for the existence of a Pacific tropical or subtropical continent, previously demanded on purely biological grounds.

LORD HOWE ISLAND.

Lord Howe Island, according to David and Etheridge,* is composed of volcanic and coral-sand rocks. The former include a series of diabasic basalts which David says are certainly pre-Tertiary, and may be Palæozoic.

NORFOLK ISLAND.

Norfolk Island is largely volcanic, but, judging from the evidence of its fauna and flora, it has undoubtedly been connected with New Zealand.

NEW CALEDONIA.

New Caledonia consists of an ancient series of mica-schists and slates with a general north-easterly strike. Limestones are interstratified with the slates. Besides this is a great series of serpentines and serpentine schists with beds of chrome and nickel, and associated with it are beds of melaphyre and tuffs overlaid by altered sedimentaries and shales with fossils identical with those of the New Zealand Trias. The Triassic zone strikes north-west and south-east parallel to the general trend of the island, and is followed by beds of coal of Jurassic age. It is probable that the serpentines are of later date than the coal-beds. The association of beds of serpentine with Triassic sedimentaries near Nelson in New Zealand, containing identical fossils, is suggestive of a common origin, though it may be a mere coincidence. These beds prove that continental conditions have existed in New Caledonia or its immediate neighbourhood for long periods of time.

NEW HEBRIDES.

Gneisses, crystalline limestones, and serpentines like those in New Caledonia are reported from some of the islands of this group. However, according to Mawson,† the New Hebrides are composed of andesitic conglomerates with overlying beds of Miocene age consisting of foraminiferous submarine tuffs and limestones. These were folded up and formed into a mountain-chain of the alpine type, with a general west-north-west trend. Associated with this were extensive faults, and volcanic eruptions along the line of faulting. Over the folded Miocene series submarine tufaceous beds were laid down, containing at times numerous *Foraminifera.* These are covered with a thin veneer of coral rock, rising in terraces to a height of over 2,000 ft. The New Hebrides are therefore of recent appearance in their present subaerial form, though biological evidence is in favour of a continuous land connection. In a footnote to his paper Mr. Mawson says, "It is none the less probable that limited outcrops [of beds older than Miocene]

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* "Lord Howe Island": Memoirs Aust. Museum, No. 2.
† Proc. Linn. Soc. N.S.W., vol. xxx, 1905.

do occur, as from the advanced metamorphism state of the pebbles of uralitic porphyry from Malekula they must date back to times preceding the folding."

The Solomon Islands, according to Guppy, contain quartzites and schists.

Fiji.

The first geological evidence of the continental origin of Fiji was supplied by Wichmann in 1883. He worked up the material collected in 1876–78 by Kleinschmidt and Gräffe from Viti Levu and other islands of the group. This included crystalline schists, granular limestone, granite, diorite, gabbro, found partially *in situ* but partially in river-deposits. Wichmann remarks, "No older massive rocks or sedimentary strata are known from the other 'volcanic' groups of islands of the Pacific Ocean (excepting Pelew, Solomon Islands, New Caledonia, Marquesas Islands). On some of them—for example, the Galapagos, or Sandwich Islands—it seems really to be made out that they have been built up by younger and recent volcanic masses. There is a possibility, and even a probability, however, that older formations served as a fundament, the examination of which is prevented by the extensive covering."* These remarks seem to apply in the case of the Kermadecs.

W. H. Guppy, in his book entitled "The Naturalist in the Pacific," discussed the question, but he approached the subject with a mind apparently made up in the contrary direction, and he denied that Fiji ever formed part of a continent. He maintained that the islands were entirely volcanic, or composed of marine tuffs now elevated above the sea. Although he found plutonic rocks in Vanua Levu, he attached no importance to the fact, and was evidently unaware of Wichmann's discoveries.

Any doubt as to the continental character of Fiji was set at rest by the work of Dr. Woolnough. He published his first paper on the subject in the Proceedings of the Linnæan Society of New South Wales in 1904, and confirmed his first results by subsequent examination of Viti Levu, publishing an account of his work in the same journal in the year 1907. On both occasions he found in the interior of Viti Levu *in situ* large developments of gneisses, schists, granite, slates, and other metamorphosed rocks of undoubtedly great age. A series of specimens sent to the present author from the northern unvisited part of the island contains large fragments of quartz (evidently derived from veins in sedimentary rock), fragments of hornblende diorite from a tuff or conglomerate, as well as trachytes, andesites, and basalts. Among the collection is a rolled fragment of nephrite which was picked up in a creek on the north of the island east of Ba. I view this specimen with a certain amount of suspicion, as it may have been brought there by man and dropped in the creek; but it nevertheless may be derived from a solid mass of the stone in position—a possibility by no means remote, seeing the development of allied rocks in the neighbouring island of New Caledonia.

Although the continental character of Fiji is certain, yet it shows evidence of a recent elevation. However, the island of Kandavu, about fifty miles south of Suva, has undoubtedly been a part of the mainland, judging from its fauna and flora, yet it is separated from the mainland of Fiji by over

* Quoted in Dr. Baur's paper, *loc. cit.*

1,000 fathoms of water—in fact, by a greater depth than separates Fiji from Tonga.

Now, this island is looked upon as an integral part of Fiji, and not populated by haphazard means. If this is the case, there has been either a local sinking of a block of the crust between Kandavu and Viti Levu, or there has been a general depression of the whole area. If Kandavu were united by land to Fiji, and severed as the result of such a general sinking, then it is highly likely that Tonga also was connected with a land bridge by a somewhat circuitous route in a southerly direction, following a submerged ridge which runs nearly to the Kermadecs, on which the water does not exceed 1,000 fathoms. Granting such an elevation, a deep, narrow gulf would extend towards the south between Fiji and Tonga. However, arguments resting purely on ocean deeps are very unreliable, as local upwarpings and downwarpings, as well as settling of earth-blocks, are known to occur of such a magnitude as would account for all the facts without any general alteration of large areas of the earth's crust; and we have the case of Krakatoa, showing how an isolated island near a coast-line may be peopled rapidly by winds, ocean-currents, and birds.

TONGA.

In 1891, in a paper on the Tonga Islands read before the Geological Society of London, Lister mentions the occurrence of fragments of garnet, tourmaline, and uralitic gabbro in tuffs of the Eua Island, toward the southern end of the group. No plutonic rocks were found *in situ*, but the occurrence of garnet and tourmaline suggests the close proximity of an area of metamorphic rocks. In his criticism of that paper, J. W. Gregory mentions the occurrence in the Marquesas Islands of granites and gneisses, and also the fact that these islands have a biological connection with both Malaysia and Chili. I cannot find any authority in the literature at my disposal for Gregory's statement, except that of Marcou, mentioned in Wallace's "Island Life."

In Jensen's paper on the geology of Samoa* reference is made to the Tonga Islands. This author concludes that they lie on a fold of the earth's crust, with a fault running parallel to them on the western side: "The islands are probably situated over continental rocks on an old shore-line"; and "that the ridge is probably a structural feature and not the effect of vulcanism." The eastern shore of the area would be determined by the Tongan trough, which lies immediately to the east of the islands.

If we consider the position of the Kermadecs with regard to Tonga, and note the similarity in situation, just to the west of profound ocean troughs in direct alignment, and note also the connecting-ridge between the two groups as revealed by soundings, then the probability of a similar origin for both groups should impress us strongly. The Kermadecs would lie on the south-westerly extension of the old Tongan shore-line, and the volcanic action in the southern group would be only a counterpart of that in the northern group—that is, it would be only a secondary phenomenon resulting from great earth-movements in the region.

SAMOA.

These islands, according to Jensen, are entirely of volcanic origin.

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* Proc. Linn. Soc. N.S.W., vol. xxxi, 1906.

TAHITI.

In 1904 Lacroix* described from Tahiti a series of plutonic rocks, embracing gabbros, monzonites of alkaline affinities, as well as true nephelene syenites; but these may be the plutonic or hypabyssal equivalents of the volcanic phonolites or nephelinites of the region.

The other islands, as far as is known, are of volcanic origin, or are composed of limestones. The occurrence of volcanic cones is not really opposed to the existence of a former continent, as they may be the unsubmerged peaks of the mountains which formerly covered its surface. However, many of the volcanoes in the area are in process of construction, and have had a submarine beginning—in fact, in some localities they have got no further, and have not yet succeeded in establishing themselves in a subaerial condition. These areas appear to be those where the crust of the earth is rising, a special case being the line of volcanic vents parallel to the general direction of the Tonga Islands, which undoubtedly show traces of recent elevation.

Thus, over a large area of the mid-Pacific region, and particularly that part where Darwin demanded a sinking land to explain the formation of coral reefs and atolls, there appears to be evidence of the former extension of continental conditions, deduced from geological considerations. The sinking crust practically implies a former continent. As the boring at Funafuti proved absolutely that the crust had been depressed relative to sea-level in that locality by at least 1,100 ft., so we may suppose that sinking has gone on in other places where there are coral islands of similar structure. The fact of a recent elevation being known in numerous cases over the same area does not dispose of the hypothesis of a general and prolonged subsidence preceding this local elevation, and indeed it draws attention to the instability of the crust in that region. If subsidence has gone on to the extent required by Darwin it would rapidly submerge any continent, and leave little trace behind except that which chance geological discoveries and a close study of the fauna and flora would reveal.

An examination of the bathymetric map of the south-western Pacific, modified by recent surveys, discloses certain well-marked submarine physical features which suggest the lines of connection with the former Pacific continent. These may be easily followed if we suppose the whole area to be raised stage by stage till it is above sea-level. Imagine, first of all, the elevation to take place till the 1,000-fathom line is exposed. We should then have a ridge extending north-west from New Zealand towards the mid-eastern coast of Queensland. Lord Howe Island would rise as a mountain on its extreme western edge, and Norfolk Island would be a similar mountain on its eastern edge. Sea would separate it completely from Australia, which coast it would approach most nearly in the neighbourhood of Rockhampton. New Caledonia would still be separated.

To the north-east the coast of New Zealand would be extended somewhat, but a long narrow ridge embracing the Kermadecs would follow the general north-eastern trend of the islands, and would approach, but not junction with, a similar ridge on which the Tonga Group would lie. A long tongue of land would stretch down from the Fiji Islands and junction with the Tongan ridge. A deep gulf would run to the south-west between Fiji and

* "Comptes Rendus," 1904.

Tonga, and a sea of triangular shape would be included between the north-east and north-west ridges. A few islands would dot the fringes of this sea.

The land connection, here established in part, would be the line of communication between New Zealand, Norfolk Island, Lord Howe Island, New Caledonia, and northern Australia on the one hand, and between the Kermadecs, Fiji, and Tonga on the other; but as yet the continental areas to the north, embracing northern Queensland, New Caledonia, and Fiji, would be separated by narrow straits. A deep sea would lie to the east of the Kermadecs and Tonga, and a similar one on the south-west of Lord Howe Island, between it and the coast of New South Wales and south-eastern Queensland.

If now we imagine the sea-bed raised another 1,000 fathoms, the north-westerly ridge would be joined on to northern Queensland, but would still be separated nearly as much as ever from the east coast of Australia. New Caledonia, the New Hebrides, Fiji, and Tonga would all be completely linked with New Zealand. Samoa would remain separate. Immediately north of New Zealand would be an inland sea rudely square in outline; south-west of New Caledonia would be a long narrow depression filled with water, running parallel to the direction of New Caledonia, and there would be a similar depression, but deeper, between it and the New Hebrides. Very deep sea, over 3,000 fathoms, would still lie east of the Kermadecs and Tonga. The land embraced at this stage probably represents roughly the extent and form of the tropical and subtropical Pacific continent, though no doubt recent warpings up and down of the earth's crust and local elevations and depressions would modify it somewhat. It will show a certain regularity in the arrangement of its physical features. The general structure will exhibit north-westerly and south-easterly trend-lines in the part to the west and north of New Zealand. The New Zealand ridge, the lines of New Caledonia, New Hebrides, Loyalty Islands, the depression and troughs between them, even certain indentations of the coast-line and valleys, would show the general orientation. This would seem to be parallel with certain lines of folding at present shown by some of the older rock-systems of New Zealand; but the identity is probably a mere coincidence, as the structural features spoken of as existing in the restored continent are in all probability of much later date.

If, however, we pass to the eastern side of the continent, the trend-lines are found to run in a north-easterly and south-westerly direction. The Tonga Group, the Kermadecs and their connections, the Kermadec trough and Tongan trough exhibit this to a remarkable degree. Their line is that of the main folding exhibited in the mountain-structure of New Zealand, and much more recent than the old north-westerly folding. At the ends of the north-easterly-running physical features there seems to be a tendency to turn north and north-west, so that the two main directions may be part and parcel of the same great crustal movement.

These, then, would be the main structural features of this restored continent, if it is possible to rely on the evidence afforded by the present form of the sea-bottom. Now, does the geological evidence afford any indication of the age of the hypothetical continent? The Kermadec Islands apparently furnish none, except that some time or other the granite rock no doubt formed a land-surface. The same remarks apply to all the eastern islands of Polynesia. Although Fiji is continental, yet its history is uncertain.

Dr. Woolnough says, "The rocks of Fiji consist of two main groups: the first of these includes continental rocks of high but undetermined geological antiquity; the second includes Tertiary to Recent formations of volcanic and sedimentary origin. Between these two is an enormous hiatus." This admits of three explanations:—

(1.) The area may have been one of prolonged and continuous subsidence since very early geological time, and the land may have been gradually decreasing in size, with an elevation of nearly 1,300 ft. since Tertiary time.

(2.) The land may have been one of continual elevation, denudation keeping pace with uplift, so that no trace is left.

(3.) A third, that land was in existence in Palæozoic and Mesozoic times, and then followed a subsidence, during which the Tertiaries were laid down, and then there was an elevation.

These three hypotheses are thus stated by Dr. Woolnough. He inclines to the first, whereas Wichmann believed in the last. Wichmann's theory apparently explains the biological facts as demanded by Hutton, Pilsbry, Hedley, Von Ihering, and Baur. It is possible that the Tertiary subsidence extended all over the south-western Pacific, and the recent elevation of Fiji has its counterpart in the recent elevation of the Kermadecs and Tonga. If this is so, the Kermadecs were cut off from Fiji in early Tertiary times, and rose at a later date, with probable periods of oscillation, either as a volcanic cone from a shallow sea or as a cone on a small area of plutonic rock which is now covered with a veneer of volcanic fragmentary material and lava-flows.

Further to the westward the presence of Triassic and Jurassic sedimentaries in New Caledonia is proof that shallow-water conditions extended over a large part of the area in Mesozoic times, with the implied presence of a land-mass in the neighbourhood of such a size that thick and extensive sediments could be derived from it.

The suggestion of a continental origin for the Kermadec Islands appears to be following the present tendency to reduce the number of oceanic islands. It is highly probable that many volcanic islands classified as oceanic will ultimately have to be looked on as built up on the remnants of a continental area. When we consider that the Galapagos Group—thought to be typically oceanic by Wallace and Darwin, although the latter had doubts about it—has been proved lately by Baur and Hemsley to be certainly of continental origin on biological grounds, the case of the Kermadecs, stated so decidedly by Cheeseman and Percy Smith, is perhaps open to revision. If their claims to be classified as continental are worthy of serious consideration (which indeed I think is the case), then they, with the volcanic Norfolk Island and Lord Howe Island, would form the northern outlier of the New Zealand continent, just as the Snares, Auckland Islands, Campbell Islands, Bounty Islands, Antipodes Islands, and Macquarie Islands form its southern outliers.

PETROLOGY OF THE KERMADEC ISLANDS.

The only previous reports on the rocks of the Kermadec Islands are those of Professor Thomas (Trans. N.Z. Inst., vol. xx, p. 311, 1888) and of the present author (Trans. N.Z. Inst., vol. xxviii, p. 625, 1896). The former reports the occurrence in the group of basalt, augite andesite, pitchstone, obsidian, as well as of a hornblende granite; and the latter mentions augite andesites and also a tachylyte. With the exception of the granite, all the rocks are volcanic. The present collection no doubt contains some of those previously described, as neither Professor Thomas nor myself has visited the group, and the exact locality and position of the specimens are somewhat doubtful. I have classified these rocks into plutonic, dyke rocks, lava-flows, and fragmentary deposits, without any regard to their age relative to each other.

Plutonic Rocks.

Hornblende granite occurs as boulders in tuff or scattered on the surface of the island. One block was found at an altitude of 1,600 ft. In the hand-specimen this is a whitish even-grained rock, with light-coloured green hornblendes of small size visible, as well as feldspar and a little quartz. The specific gravity is 2·63. Under the microscope it is found to consist of feldspar, both orthoclase and plagioclase (albite), the latter in large amount; quartz, irregularly distributed, full of liquid and gas bubbles; epidote, frequently developed along the cleavage-planes of feldspar; apatite, in grains and short needles; and also titanite, which sometimes adopts the wedge-shaped form so frequently characteristic of the mineral, and at others occurs in aggregates. Neither biotite nor muscovite is present. From the general character the rock shows a close relationship to a syenite, although containing quartz. This rock appears to be similar to that described previously by Professor Thomas.

Dyke Rocks.

These rocks are found on the summit of Meyer Island and, as intrusions, on the coast of Sunday Island.

No. 8. **Augite Andesite.**—From a dyke on Meyer Island.

In the hand-specimen this is a vesicular, dark-grey rock with prominent feldspar phenocrysts; its specific gravity is 2·56. It is an augite andesite of the most acid type of the volcanic rocks examined. This is apparently the rock described by Thomas in the "Transactions of the New Zealand Institute," vol. xx, page 313.

It is the only specimen received from the series of dykes mentioned by Percy Smith (Trans. N.Z. Inst., vol. xx, p. 339) as intersecting Meyer Island.

No. 29. **Augite Andesite.**—From a small sill or intrusion at Hutchinson Bluff, Sunday Island.

Macroscopic.—A fine-grained dark rock, slightly vesicular, containing very small phenocrysts of feldspar. Specific gravity, 2·63.

Microscopic.—The groundmass is fine-grained, contains much glass in patches, with grains of magnetite and augite, and microlites of labradorite; there are very occasional phenocrysts of labradorite and augite.

No. 30. **Augite Andesite.**—Occurs as an intrusion in tuffs on the north coast of Sunday Island.

This specimen is similar to No. 29, but is coarser in texture, and contains much magnetite in grains.

No. 40. **Andesitic Basalt.**—Occurs as a dyke in Scenery Bay, south coast of Sunday Island.

Macroscopic.—A grey rock, with prominent feldspar phenocrysts and occasional olivines and augites. Specific gravity, 2·93.

Microscopic.—The groundmass is composed of grains of augite and olivines and plagioclase laths. In some parts there is a good deal of glass, in others the rock is almost holocrystalline. The phenocrysts are of large fresh olivines, augite, basic labradorite, with grains of magnetite. The groundmass of this rock is distinctly basaltic in character, but the numerous feldspar phenocrysts give it an andesitic character. The same remark applies to other specimens.

Lava-flows.

No. 2. **Andesitic Pitchstone.**—From a boulder at base of cliffs, Fleetwood Bluff, Sunday Island.

Macroscopic.—A rock dark in colour with pitchy lustre.

Microscopic.—The groundmass consists of glass, fairly clear in some parts, crystallitic in others, perlitic, with well-marked flow structure. The phenocrysts are of sanidine, plagioclase (acid labradorite), strongly pleochroic hypersthene, and occasional augites.

No. 9. **Andesite.**—From lava-stream on Moumoukai, Sunday Island.

Macroscopic.—A dark-grey rock, vesicular with small phenocrysts of feldspar. Specific gravity, 2·44.

Microscopic.—Groundmass of feldspar laths (labradorite), augite grains, a good deal of glass in patches. The phenocrysts are of medium labradorite; no others were observed.

No. 21. **Andesite.**—From lava-stream, Denham Bay, Sunday Island.

Macroscopic.—A very dark compact rock, with very occasional small phenocrysts of feldspar showing. Specific gravity, 2·89.

Microscopic.—Groundmass composed of feldspar microlites, augite and magnetite grains, with patches of clear coloured glass. Very occasional small phenocrysts of feldspar and augite are visible.

No. 26. **Augite Olivine Andesite.**—From lava-flow, south end of Denham Bay, Sunday Island.

Macroscopic.—Dark-coloured fairly compact rock. Specific gravity, 2·80.

Microscopic.—Groundmass composed of feldspar laths and augite grains, ophitic in places, with a good deal of glass, and numerous grains of magnetite. The phenocrysts are of feldspar (basic labradorite), occasional augites, and rare olivines.

No. 34. **Olivine Andesite.**—From lava-stream west of Blue Lake, Sunday Island.

Macroscopic.—A grey rock, vesicular, with numerous feldspar phenocrysts. Specific gravity, 2·76.

Microscopic.—Groundmass consists of numerous augite feldspar microlites, simple and twinned grains of augite and olivine, and occasional patches of glass, with grains of magnetite. The phenocrysts are of basic labradorite, with numerous gas-inclusions, small phenocrysts of partly serpentinised olivines, and occasional slightly pleochroic augites. This rock resembles somewhat the olivine andesite of Banks Peninsula.

No. 36. **Basalt.**—From lava-stream, east coast of Sunday Island, overlying tuffs.

Macroscopic.—A dark-grey rock full of small vesicles. Specific gravity, 2·84.

Microscopic.—Groundmass of numerous grains of magnetite, smaller feldspar laths untwinned and twinned (labradorite), grains of olivine, and occasional patches of glass. The phenocrysts are of basic labradorite, augite crystals, and frequent grains of olivine stained with iron-oxides.

No. 37. **Basalt.**—From lava-flow behind Denham Bay, Sunday Island.

Macroscopic.—A grey rock, vesicular, with numerous phenocrysts of feldspar. Specific gravity, 2·82.

Microscopic.—Groundmass of augite grains and plagioclase microlites, showing well-marked fluxion structure. The phenocrysts are of labradorite, olivine in rounded grains, partially serpentinised with seams of limonite. Grains of magnetite are very common. A more basic rock than No. 36.

No. 38. **Andesitic Basalt.**—From lava-flow, south end of Denham Bay, Sunday Island.

Macroscopic.—Greyish rock, with prominent feldspar phenocrysts. Specific gravity, 2·86.

Microscopic.—Groundmass containing much augite, grains of olivine, feldspar laths. Subophitic in texture. The phenocrysts are of basic labradorite, irregular grains of olivine and augite. There are large grains of titaniferous magnetite in irregular forms. The feldspar phenocrysts are very numerous.

No. 39. **Andesitic Basalt.**—From lava-flow, north end of Denham Bay, Sunday Island.

Macroscopic.—Grey rock, with small phenocrysts of feldspar. Specific gravity, 2·87.

Microscopic.—Groundmass of augite grains, feldspar laths, and grains of olivine, also occasional colourless glass. The phenocrysts are of basic labradorite with numerous glass inclusions, clear grains of olivine, and small augites. Very similar to No. 38.

No. 41. **Andesitic Basalt.**—From lava-flow at sea-level, Scenery Bay, Sunday Island.

Macroscopic.—Dark-grey rock, very vesicular, with numerous feldspars showing. Specific gravity, 2·81.

Microscopic.—The groundmass is holocrystalline, of augite and magnetite grains, and feldspar microlites. There are numerous feldspar and olivine phenocrysts, the latter fresh or but slightly stained with limonite; occasional augites are present.

No. 42. **Basalt.**—From lava-flow under tuffs, Macauley Island.

Macroscopic.—Dark-grey rock, vesicular, with numerous feldspars showing. Specific gravity, 2·55.

Microscopic.—Groundmass of feldspar laths, many grains of olivine, augite, and magnetite. The phenocrysts are of basic labradorite, olivine in irregular grains, seamed with limonite and occasional augite.

No. 43. **Andesitic Pumice.**—From pumice tuffs, Macauley Island.

This is evidently the scoriaceous equivalent of the andesite lavas, as it contains numerous fragments of plagioclase feldspar and augite similar to those occurring in the lavas.

No. 46. Olivine Andesite.—Fragment from L'Espérance or French Rock.

Macroscopic.—A dark-grey vesicular rock, with small feldspar phenocrysts showing. Specific gravity, 2·68.

Microscopic.—Groundmass coarse-grained, principally of feldspar (labradorite) laths, grains of augite, and much secondary titaniferous magnetite. There are phenocrysts of labradorite, olivine, and augite, the first-named being very numerous.

Pyroclastic Rocks.

Besides the foregoing, a number of specimens of fragmentary volcanic matter were in the collection. These vary somewhat in character. Nos. 22 and 25, from Boat Cove, Sunday Island, are composed of fragments of andesitic pitchstone and ordinary andesite cemented by a calcareous base and volcanic ash. This contains numerous fragments of reef-building coral. This occurrence seems best explained by a submarine explosion, where the overlying volcanic rocks with their veneer of coral were shattered into fragments and subsequently consolidated, perhaps below sea-level. No. 32 is from a fine-grained tuff on Sunday Island, composed principally of angular fragments of feldspar and augite grains. In this were rounded bombs of blown glass, full of crystallites, and containing fragments of augite and feldspar. Nos. 5, 10, 18, 20, from the small islands north-east of Sunday Island, and Nos. 13 and 14, from Sunday Island, the latter being undoubtedly submarine, are specimens of tuff beds which show the same origin, and are andesitic in character, as they contain numerous fragments of augite and plagioclase feldspar.

The collection also contains sulphur and siliceous sinter from Curtis Island, specimens of volcanic mud from the crater on Sunday Island, and calcite incrustations from Dayrell Islet, Sunday Island.

A general conspectus of the collection shows that the islands are built up of volcanic materials which are andesitic or basaltic in origin, and that acidic rocks form no part of them. The andesites have in general a strong affinity to the basalts, and are sometimes characterized by the presence of olivine and by a groundmass which is basaltic in character; but the numerous phenocrysts of feldspar, and the small number of those of augite or olivine, demands that the rocks be classified with the andesites. Instances of intermediate varieties between andesites and basalts are very common.

The general facies of the specimens does not show any marked resemblance either to New Zealand types or to the specimens I have in my possession from Tofua and Savaii. The presence of hypersthene in some suggests a connection with the Ruapehu - Tongariro - White Island line, the rocks of which are characteristically hypersthene-bearing, as indeed are so many of the andesites of New Zealand—*e.g.*, those from the Clent Hills in the South Island, as well as those from numerous localities in the North Island (see Marshall, "Distribution of Volcanic Rocks in the North Island," Trans. N.Z. Inst., vol. xl, p. 79). The presence of olivine in the andesites is also reminiscent of the later flows from Ruapehu, but suggests much more strongly the olivine-bearing andesites of Banks Peninsula. This type, however, seems to occur in other parts of the south-central Pacific area.