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ORDINARY MEETING,*

THE PRESIDENT, SIR GEORGE GABRIEL STOKES, Bart., D.C.L. P.R.S., M.P., IN THE CHAIR.

The Minutes of the last Meeting were read and confirmed, and the following Elections were announced :—

MEMBERS.—The Right Hon. Lord Penzance, P.C., Godalming ; T. Cogswell, Esq., Kent ; Rev. L. W. Hayhurst, A.B., M.A., United States ; A. Norman Tate, Esq., F.I.C., F.C.S., Liverpool.

ASSOCIATES.—Faris Nimr, Esq., Cairo ; H. C. Nisbet, Esq., London ; Rev. J. C. Walker, Esq., Wymondham ; Rev. W. Andrews, M.A., Camb., Japan ; Rev. C. S. Green, Buxton ; Rev. R. R. Kane, LL.D., &c., Belfast ; Madame Z. A. Ragozin, United States.

The following paper, illustrated by diagrams, was then read by the author :—

CORAL ISLANDS AND SAVAGE MYTHS.

By H. B. GUPPY, M.B.

PART I.

I AM not aware whether much stress has ever been laid on the important bearing which the traditions of some of the Pacific Islands possess in connexion with the first emergence of coral islands above the waves. Since this subject is of interest in relation to the origin of coral reefs, I will commence my paper by gathering together a few of these legends.

The Rev. Wyatt Gill in his *Myths and Songs from the South Pacific* (pp. 72–74), refers to the legendary origin of the atolls of Manahiki (Humphrey I.) and Rakaanga (Reirson I.), two coral islands lying to the northward of the Society Group. . . . A Rarotongan fisherman, having brought news back to his island of a vast block of stone which he had discovered at the bottom of the ocean, at a great distance from his home, the three brothers Maui sailed away to the northward for a distance of between 600 and 700 miles in search of the

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* March 19, 1888.

sunken island. After finding "the great block of coral" at the bottom of the sea, they commenced to fish over it. Maui, the younger, ultimately hooked the sunken block, and up came the entire island of Manahiki. But his "mighty straining" broke the canoe and precipitated them all into the sea. His two brothers were drowned; but Maui, the younger, preserved his safety by resting one of his feet on the solid coral of the ascending island. "At length Manahiki rose high and dry above the breakers, drawn up from the ocean depths by the exertions of the now solitary Maui." On the return of the Rarotongan fisherman to his old fishing-ground, he contested the possession of the island with Maui, who, during the fight, cleft the original island into two parts by a violent stamp with his foot on the earth. Of the two parts, one retains the ancient name of Manahiki, the other is called Rakaanga; but these "twin coral islands" are now separated by a wide open channel of twenty-five miles. The legend ends with the ascent of Maui into the heavens; whilst the fisherman established himself on Manahiki, and introduced the first cocoa-nut palm by planting a cocoa-nut he had picked up on the sea. Maui, as we learn from Mr. Gill, was one of the ancient heroes of the Hervey Group. The production of these two coral atolls was his "last and greatest achievement."

An Aitutakian myth, referring to the emergence from the sea, and to the first peopling of the island of Aitutaki, one of the Hervey Group, is also given in this work (pp. 139–141). . . Two brothers, "who had long lived in utter darkness in the shades," made canoes, and started away in search of "the land of light." After three abortive expeditions they reached their destination, and, approaching a partially submerged island, they were unable to land on account of the heavy surf and the absence of any dry land. However, they contended with the ocean, and "the shallow waters vanished, leaving the island elevated far above the surrounding ocean." Here they took up their abode, and named the island Aitutaki, which means "God-led." . . . This island, as we know it at the present day, is 360 feet high; but from this elevation probably 100 feet should be subtracted to allow for the height of the trees. It is said to be of coral formation and to be surrounded by a barrier reef.

In Mariner's *Tonga* we have a similar account of the origin of the Tonga Islands, which were drawn up by the fishing-hook of the god, Tangaloa (chap. ix.). These islands are formed by elevated atolls and barrier-reefs rising up to some 200 or 300 feet.

Dr. George Turner, in his *Samoa, a Hundred Years Ago* *and Long Before* (p. 304), gives a tradition relating to the origin of Savage Island, an upraised atoll, about 100 feet high, which lies some 200 miles east of the Tonga Group. The present inhabitants trace their descent from two men, named Huanaki and Fao, who swam from Tonga. They found the island just above the surface, and washed by the ocean. They got up on it, stamped with the foot, up it rose, the waters ran off, and the dry land appeared. They stamped again, and up sprang the grass, trees, and other vegetation. Then they caused a man and a woman to grow from the *ti* plant, and from these sprang the present inhabitants.

An interesting Mangaian tradition, related by the Rev. Wyatt Gill, in his *Life in the Southern Isles* (p. 80), refers to the early condition of Mangaia, after its emergence above the waves. This island, one of the Hervey Group, is an upraised atoll rising to a height of about 300 feet. According to the native tradition, "the surface of Mangaia originally was everywhere a gentle slope to the sea, without a single depression or valley." Through the subsequent rivalry of the gods of the Wind, the Rain, and the Ocean, who endeavoured to overwhelm the island and its inhabitants in their strife, the present agreeable diversity of hill and vale was eventually produced.

It is very remarkable that all these legends relate to living and upraised atolls (Aitutaki, as I hold, probably belonging to the latter class). This circumstance seemingly points to the comparatively modern age of these coral islands; and it is to be noticed that all the stages in the formation of an upraised atoll island are here illustrated. First, we have the totally submerged or shoal-like condition, represented in the instance of Manahiki, which was brought up by Maui's fish-hook to the surface of the ocean. Then we have the living atoll as represented in the early condition of Savage Island and Aitutaki, the stage at which the native legends begin. Afterwards we have these two islands upraised by god-like heroes to their present elevation above the sea. Then follows the carving out by the denuding agencies of the smooth slopes of the uplifted atoll, in the manner described in the Mangaian tradition. Lastly, there spring up "the grass, trees, and other vegetation." From these old traditions we may at least learn that the Pacific Islanders regarded the origin of these living and upraised atolls as due to a movement of upheaval. The submerged coral shoal was raised to the surface, and formed the living atolls of Manahiki and Rakaanga. The living atoll was further upheaved and formed the upraised islands now known as Mangaia, Aitutaki, and Savage Island.

The recent peopling of these islands, as their traditions imply, is a noteworthy circumstance. Mr. Gill holds the view that not only the Hervey Group, which includes Aitutaki and Mangaia, but also that all the eastern Pacific islands have been peopled in comparatively recent times. "The colonisation of the Hervey Group," as he writes, "may not date back beyond five or six centuries."* The legends, therefore, relating to the origin of Mangaia and Aitutaki, and also of Manahiki and Rakaanga, discovered as coral shoals by the Rarotongan fisherman, would belong to a still more modern period; and the origin of these living and upraised coral islands would, according to this view, be of a very recent date. This is a conclusion, however, which we cannot accept. The evidence which we possess goes to show that certain coral atolls of the present day have remained very much in their present condition for three centuries and more, in fact as far as reliable records take us back. Though accepting the traditions of the natives of the Hervey Group, in so far as they throw light on the mode of origin of the living and upraised atolls, I cannot, on account of the evidence that follows, assign such a modern date for the origin of these islands as Mr. Gill's view of the recent peopling of the Hervey Group would seem to suggest.

Both Mr. Darwin and Professor Dana give evidence of the extremely slow rate of growth of coral reefs; but the former distrusts his evidence and advances facts apparently supporting the opposite conclusion, facts, however, which as he himself allows, afford only direct proof of the increase of the islets on the reef and not of the reef itself. I, however, agree with him that the stationary condition of a submerged coral reef or of a single large mass of coral may afford no proof whatever of the slow rate of coral growth. The fact of the coral knolls in the lagoon of Diego Garcia having remained at the same depth below the surface for a period of eighty years, and the stationary level of the Dolphin Shoal off Tahiti during a lapse of sixty-seven years,† may be otherwise explained when we know more of the causes that limit the upward growth of reef corals. Professor Dana, however, writing many years after and with more recent and more exact data at his disposal, arrived at the conclusion that a reef increases its extent with extreme slowness. But information is greatly needed in these matters; and we are scarcely in a position to form a true idea of the rate of growth of coral reefs.

Of the outward growth of coral atolls, we have abundant proof

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* *Journ. Anthrop. Inst.*, vol. iii. p. 334.

† Darwin's *Coral Reefs* (1842), pp. 69, 72.

in the concentric ridges of shells and broken corals, which, in the instances of Christmas Island and of the neighbouring guano islands, mark the successive strips of land gained from the sea. The fact that the shells lying on the bare surface of Christmas Island have not decayed is urged by Mr. Darwin as affording evidence of an increase of the reef in a period not very remote. This is true enough ; but, in connexion with this fact, we should remember that marine shells and corals, though much weathered and decayed, are still to be found among the trees in the interior of certain upraised coral islands in the Solomon Group, which were visited and described by the Spanish discoverers in 1567.

We possess no reliable evidence to show that a coral atoll is rapidly formed. On the other hand, we know that atolls have remained in their existing condition for centuries. The present Wake's Island, when it was first discovered to the north of the Marshall Islands by the Spaniards in 1567, had much the appearance that it presented to Commodore Wilkes in 1840. It was described by the Spanish narrator as a low uninhabited islet enclosing the sea, and possessing a sandy surface with some patches of bushes. Commodore Wilkes describes it as an uninhabited atoll, probably at times washed over by the sea, and bearing shrubs but no trees. Again, if we compare the Musquillo Islands of the Marshall Group, as described by their Spanish discoverers in 1567, with the same islands as described by Captain Bond in 1792, we shall observe that the condition of this large double atoll did not materially change in the interval. This atoll was apparently as thickly populated in 1567 as it is at the present day. If, again, as seems very probable, the inhabited Isle of Jesus, discovered by the Spaniards in the same year, should prove to be one of the northern atolls of the Ellice Group, then we have another example of an atoll, which, as pointed out by Mr. Woodford, has been occupied by natives of very similar habits for over 300 years. Sikyana Atoll, again, as we learn from Quiros, was inhabited in 1606 by natives possessing the characters of the present occupants.

The foregoing remarks are for the most part taken from my general work on the Solomon Islands, to which reference for further details should be made. They are sufficient, I think, to show that there are atolls which have been in the same habitable state for more than three centuries, and atolls which during the same period have remained in a barren, uninhabitable condition. The living atoll of the Pacific I am inclined to regard as possessing great antiquity. Those which, like Mangaia, Tongatabu and Savage Island, have been upheaved between 60 and 300 feet above the sea, are probably of greater age.

PART II.

THE ORIGIN OF CORAL REEFS.

THE problem of the formation of coral reefs has, perhaps, attracted more general attention than it originally merited from the fact of its having excited the interest and employed the genius of Mr. Darwin. The difficulties, however, that attend their examination have until within the last seventy years prevented any serious attempts to investigate their structure; yet it is very remarkable that the explanation of atolls proposed by Chamisso, the naturalist who accompanied Kotzebue, the Russian navigator, in his voyage to the South Sea in the years 1815–1818,* is the very one towards which all recent observations are tending. The larger and more massive species of corals, as this naturalist states, prefer the surf at the outer edge of the reef; whilst the corals in the interior are hindered in their growth by the accumulation of shell and coral débris. In this manner the outer edge of a submerged reef first approaches the surface, and a ring of land enclosing a lake is subsequently formed from the materials piled up by the waves. Thus the atoll was produced, in the opinion of Chamisso, by *the natural growth of corals and by the action of the waves.* Mr. Darwin himself supported this view of Chamisso, when he remarked that a reef growing on a detached bank would tend to assume an atoll structure. Some atolls in the West Indies had been probably formed, as he says, in this manner; but it was mainly the difficulty of assuming that there could be so many submerged coral banks in the Indian and Pacific Oceans that led him to reject the explanation of Chamisso as generally applicable to oceanic atolls. Mr. Darwin's lack of evidence led him to his theory of subsidence. The researches, however, of more recent years are leading us back to the original explanation of Chamisso, which Mr. Darwin, with our evidence before him, would have in the main accepted.

I will pass over the theory of subsidence, supported though it was by Dana, Couthouy, and Beete Jukes, because the more recent facts concerning the ocean depths and the regions of living and upraised reefs compel us to regard it as no longer necessary, and I will pass to the consideration of the views advanced since the year 1850. In 1851 Professor Louis Agassiz, in his Report to the Superintendent of the

* *Kotzebue's Voyage*, 1815–18, vol. iii. p. 331. London, 1821.

American Coast Survey, re-echoed the opinion of Chamisso in the instance of the reefs of Florida. All the modifications which these reefs presented were in his estimation "the natural consequence of the growth of reef-building corals."* In the year 1856, Professor Joseph Le Conte, after an examination some years before of the same reef-region of Florida, advanced a view, in a paper read before the American Association, which was simply Chamisso's explanation of atolls applied to barrier-reefs. Since corals, as he stated, will not grow on muddy shores or in water upon the bottom of which sediment is collected, the favourable conditions can only be found at some distance from the shore, where, "limited on one side by the muddiness and on the other by the depth of the water," a barrier-reef would ultimately be formed.†

After a long investigation of the reefs of the Pelew Islands, Professor Karl Semper published in 1863 the results of his researches.‡ Additional notes were appended to his original paper from time to time, by which his observations were brought into accordance with the results of the deep-sea explorations of the *Challenger* expedition, and with the facts brought to light by Agassiz, Pourtales, and others, in the Florida seas; and in 1881 the whole of his views on coral reefs were included in his interesting work entitled *The Natural Conditions of Existence as they affect Animal Life* (vol. xxxi. *Internat. Scient. Ser.*). This naturalist attributed the formation of the different classes of reefs to the following causes :—the strength and direction of the constant currents, the repressive influence of sand and sediment in the interior, the tidal scour, and the boring action of plants and animals. He showed that, wherever strong currents impinging on a reef run parallel with the coast, the corals grow perpendicularly, and the reef has an abrupt and perpendicular fall along the line of the current, but that, in eddies and places where the current is weak, the corals grow irregularly in all directions. The growth of an atoll, as he pointed out, is well illustrated in the growth of a large mass of porites, which while below the surface possesses a rounded summit, but when exposed at low tide becomes arrested in its upward growth and obtains a flat top. Whilst growing at its margin, where it is exposed to the tidal currents, its centre dies from the accumulation of sand; and in course of time the action of boring-molluscs, echinoderms and sponges, and the scour of

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* *Bull. Mus. Compar. Zool.*, vol. i. p. 363.

† *Amer. Journ. of Science*, 2nd series, vol. xxiii. p. 46.

‡ *Zeitschr. Wissen. Zool.*, vol. xiii. p. 563.

the waves, hollow out a basin surrounded by a margin of living coral. In this manner a miniature atoll is produced.

In 1870 Dr. Rein appeared in the field as a supporter of the view that the forms of reefs are due to the natural growth of corals. The Bermudas he regarded merely as portions of a large atoll crowning a submarine bank.*

In 1880 Mr. John Murray published his theory of the origin of coral reefs.† Though placed in direct antagonism to the accepted theory of subsidence, it was in no way a change of front, if we view it in the light of the researches made within the previous thirty years. The new view, in supplying a foundation for atolls without the aid of a sinking movement, filled up the great gap in the original explanation of Chamisso, a point of weakness, which, it will be remembered, led Mr. Darwin to his theory of subsidence. It had been previously shown by Agassiz and Pourtales, in 1871, that on the surface of the Pourtales Plateau in the Florida Seas, at a depth of from 100 to 250 fathoms, there was a great abundance of deep-sea corals and other organisms by which a modern coral limestone was being formed.‡ Mr. Murray, with all the facts of the explorations of the *Challenger* at his disposal, showed that in tropical seas submerged banks and plateaux are continually in process of formation, by the rapid accumulation of the shells, skeletons, and other hard parts of the organisms that flourish in great numbers and variety on their summits. Submarine volcanic peaks could in this manner be levelled up to the zone in which the ordinary reef-corals thrive, and ultimately the coral atoll would appear at the surface. This I hold to be the important feature of Mr. Murray's theory, and for these two reasons. It filled up the great gap in that explanation of the origin of coral reefs, which ascribed their forms to their mode of growth. It has been remarkably confirmed by more recent researches and discoveries in the Florida Seas and in the Western Pacific. The forms of reefs Mr. Murray ascribed to well-known physical causes, concerning which later observers only differ as to the importance they would attach to each particular agency. Atolls, he says, owe their form to the more abundant supply of food to the outer margins and to the removal of dead coral rock from the interior portions by currents and by the dissolving action of the carbonic acid of the sea-water. Barrier-reefs have built out from the shore on a foundation of volcanic débris, or on a talus of coral

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* *Bericht Senckenberg, Naturforsch. Gesellsch.*, 1869-70, p. 157.

† *Proc. Roy. Soc. Edin.*, 1879-80.

‡ *Illustr. Catal. Mus. Compar. Zool.*, 1871.

blocks and reef débris, and the lagoon channel is formed in the same way as the lagoon of an atoll. This is but a more precise and more scientific statement of the natural growth of reefs. Whilst Professor Semper relies more on the agencies of impinging currents, tidal scour, deposition of sediment, and the degradation of reefs by the numberless organisms that infest each block of coral, Mr. Murray depends more on the agency of solution, and on the distribution of the food-supply. Those accustomed to balance evidence will be inclined to consider that the more probable explanation of the forms of reefs will be found in the association of the several agencies included in the explanations of these two naturalists.

In November, 1882, Professor Alexander Agassiz published an important memoir on the Tortugas and the Florida reefs.* According to the American investigator, the atolls and barrier-reefs of the Florida Seas owe their form to the action of the breakers and currents, to the repressive influence of sediment, and to the habits of the corals. This opinion was the independent result of a line of investigation very similar to that which led Mr. Murray to his particular views. After alluding to the circumstance that the elder Agassiz had made no attempt to explain the substructure upon which the Florida reefs were based, this eminent naturalist proceeds to point out how the bottom is prepared and gradually raised to the levels in which reef-corals flourish by the accumulation of the solid parts of the numberless organisms that have lived and died upon it. On account of the increased supply of food brought by the Atlantic Equatorial current and by the Gulf Stream to the animals living on the sea-bottom in the Gulf of Mexico and in the Caribbean Sea, the deposits arising from the accumulations of the remains of molluscs, echinoderms, alcyonarians, deep-sea corals, crustacea, &c., have been mainly heaped up in the track of these great oceanic currents. There they have built up the great submarine plateaux, known as the Florida, Yucatan, and San Pedro Banks, on the surface of which the abundance of animal life is stated to be beyond our conception. A modern limestone, of which large portions were brought up in the dredge, is thus rapidly forming on these banks, which are in this manner being gradually raised to the level at which reef-corals flourish. In Yucatan, caverns penetrate this modern limestone, underlying the coral reefs to a depth of over 400 feet.

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* *Mem. Amer. Acad. Arts and Sciences.*

By this line of investigation, Professor Agassiz arrived at the conclusion that the coral reefs of these seas owe their form to agencies acting at and near the surface. The baneful action of sediment seemed to be amongst the more powerful of these agencies in determining the forms of reefs. The barrier-reefs are explained much in the way that Le Conte previously explained them. The corals, unable to live in the muddy waters and on the muddy surface of the Florida Bank, flourish in the clearer water of the steeper slopes beyond. Atolls owe their form to the action of the breakers and the currents, which, by driving the silt to leeward, cause the repression of the growth of coral except at the margins of the reef.

We are now in a position to regard in one comprehensive view the explanations of Semper, Murray, and Agassiz concerning the forms of reefs. Though prominence is given by each of these three naturalists to particular agencies,—Semper dwelling on the currents and the tidal scour; Murray, on solution and the distribution of the food supply; Agassiz, on the repressive influence of the sediment and the action of the breakers,—these differences arise from the circumstance of the problem being viewed and attacked from different standpoints. We cannot doubt that we have in the views of these three observers an enumeration of the principal agencies that determine the forms of coral reefs. On the outer edge of the roof we have the directing influence of currents, the increased food-supply, and the action of the breakers. In the interior of the reef there are the repressive influence of sediment, the degradation of the dead coral by numerous boring organisms, the solution of the dead coral by the carbonic acid in the sea-water, and, lastly, the tidal scour. Few of those who have been engaged for any time in the examination of coral reefs can have any doubt as to the reality of these several agencies; the only difference of opinion will be as to the relative importance they ascribe to each. These are the lines along which future observers will direct their researches. They are those, in fact, which have been followed in the more recent observations published since 1882.

In a paper on the Recent Calcareous Formations of the Solomon Islands, which was published in the transactions of the Edinburgh Royal Society for 1885, I described my discoveries amongst the upraised coral reefs of this region. Here I found, as terrestrial formations, underlying the ancient reefs, the volcanic muds, the coral muds, the pteropod and globigerina oozes, and the deep-sea clays of the *Challenger* Expedition, deposits that were originally formed in depths varying from 100 to 2,000 fathoms. In more than one upraised atoll, denudation had also exposed to view the original volcanic peak, thus corroborating in a remarkable manner the theory of Mr. Murray, that submerged volcanic peaks are levelled up to the zone of reef-corals by the accumulation upon them of organic deposits, and that these deposits are finally crowned by the atoll.

In another paper on the living Coral Reefs of this region, which was published in the Proceedings of the same society for 1886, I removed the chief objection against Mr. Murray's views, one which gave powerful support to Mr. Darwin's theory, namely, the awkward fact, as it was then believed to be, that lagoons and lagoon-channels are sometimes deeper than the zone in which reef-corals thrive. This belief was shown to be founded on a misconception of the conditions that limit the downward extension of this zone. Observers in different regions have variously estimated its depth between five and thirty and even forty fathoms. This great variation is due to differences in the local conditions, not only in different localities, but, as I found in the Solomon Islands, in the same locality. The main determining condition of the depths of reef-corals in all regions is to be found (as Professor A. Agassiz has also shown) in the injurious effect of sand and sediment rather than in the general influence of depth, the distribution of these materials being dependent on such local conditions as the angle of the submarine slope, the presence and situation of submarine declivities, the amount of sediment held in suspension, the force of the breakers, and other influences. Local conditions will usually restrict the reef-coral zone to depths less than twenty fathoms; but where there are a moderate submarine slope, clear water, and breakers of no great size, reef-corals may be found flourishing in depths of fifty and even sixty fathoms.

In the same paper I also referred to the conditions described by me as the determining causes of a barrier-reef. Where there is a rapid submarine slope,—for instance, more than 10 degrees,—the sand and gravel produced by the action of the breakers on the outer edge of the shore-reef will extend to depths far beyond those in which reef-corals thrive; but let the slope be small, say 1 or 2 degrees, the lower margin of the belt of sand and débris will then lie within the zone of reef-building corals, and in consequence a line of barrier-reef will ultimately be formed with a deep channel inside. This explanation I afterwards found to be precisely the same as that advanced by Professor Le Conte thirty years before in the instance of the Florida reefs, a view which I have previously shown to be but an adaptation of Chamisso's explanation of the growth of an atoll to the origin of barrier-reefs. A very gradual submarine slope and the presence of sediment in suspension in the shore waters are the determining causes of the lagoon-channel; the agencies of solution, diminished food-supply, organic degradation, and tidal scour, being, as I think, auxiliary causes which come into play after the reef has begun to grow at that distance from the shore where the suitable conditions for reef-growth exist.

A circumstance, hitherto not satisfactorily explained, is to be found in the usual apparent position of a barrier-reef at the margin of a submarine plateau, beyond which the slopes descend rapidly to great depths. I have employed the epithet "apparent" because I do not desire to commence my line of argument by assuming the point at issue. Let us examine for a moment the submarine profile of coasts bounded by barrier-reefs. I will first take the east end of the large island of Bougainville, in the Solomon Group, a locality with which I am personally acquainted. Its submarine profile is that of a submarine ledge, 15 miles in width, and possessing a scarcely recognisable slope represented by a total drop of about 300 feet, or at the rate of 20 feet per mile: at its edge lies a barrier-reef; and beyond, the slope descends very rapidly to the 100-fathom line at angles varying between 15 and 25 degrees. Take the barrier-reef of Tahiti, distant about a mile from the shore and with a depth of on the average 20 fathoms inside it, which gives the ledge, at the margin of which the reef lies, a gentle slope of somewhat over a degree. Beyond the reef, the submarine slope for the first 250 yards descends at an angle of 15 or 16 degrees to depths of from 30 to 40 fathoms; during the next 100 yards the slope is very steep, and sometimes exceeds 45 degrees; between 350 and 500 yards from the reef, the slope has an angle of about 30 degrees. Beyond this distance the angle of slope decreases, until at about a mile from the reef the angle is 6 degrees and the depth 590 fathoms. Such are the results of the soundings made by Mr. Murray and Lieutenant Swire off the Tahiti barrier-reef. I come now to the line of barrier-reef lying at a distance of between 20 and 30 miles off the north-west coast of Viti Levu, Fiji. The broad ledge, at the border of which the reef lies, has an average drop only of from 10 to 15 feet in the mile; it is, therefore, for all practical purposes, a level surface. Outside the reef, however, judging from the soundings hitherto made in this locality, the submarine slope descends to depths of between 300 and 400 fathoms at an angle of about 25 degrees, and the average angle from the 100-fathom line to a sounding of 1,200 fathoms is about 15 degrees.

I have taken the foregoing examples because they illustrate the various kinds of barrier-reefs surrounding large islands. The instances of New Caledonia and of Florida might have been similarly cited. I have, however, gone far enough to show that barrier-reefs have, as a general rule, the appearance of being situated at the edge of a submarine ledge or plateau. There are two different explanatious of this apparent position of barrier-reefs that readily present themselves to the mind.

The first is that of subsidence, which Mr. Darwin offers in his theory, the shore-reef by such a movement becoming a barrier-reef separated by a deep channel from the coast. In the instances before cited of the great Fiji barrier-reef and of the reef of Bougainville Island in the Solomon Group, this explanation, however, is at once negatived, because these localities are situated in regions of upheaval, where coral reefs and their foundations have been lifted in recent times to heights of several hundred feet above the sea.

The second explanation is that advanced by Mr. Murray in his new theory. By him this plateau-like appearance is attributed to the seaward growth of a barrier-reef on its own talus, whilst the lagoon-channel is being formed by the decay and solution of the coral. Though well convinced of the fact of the seaward growth of reefs, and of the important influence of solution, I scarcely consider the outward growth to be sufficiently rapid, or the effect of solution to be sufficiently great, to explain the situations of such distant barrier-reefs as those fronting the east coast of Australia and the north side of Viti Levu in Fiji. Both Darwin and Murray would associate the formation of the so-called submarine ledge, from the margin of which a barrier-reef appears to rise, with the history of the reef. The question now arises whether the position of a barrier-reef at the edge of a submarine plateau is apparent or real; or, in other words, whether there was a submarine ledge before the coral reefs began their growth.

To this question I expected no answer; but, after examining the submarine profile of the east border of Australia, from Cape York to Cape Howe, I obtained a very unexpected reply. There at once opened up before my imagination a new road towards the solution of this problem; and I think when I have pointed out this new method of investigation, which consists in comparing the profile of a coast outside the region of coral reefs with that of the continuation of the same coast where it is fronted by barrier-reefs, it will be seen that my hopes will not altogether be disappointed.

Let us consider the characters of the submarine profile of the east border of Australia from Cape Howe to Torres Straits. The northern half of this coast, from the vicinity of Sandy Cape northward to Torres Straits, lies within the region of coral reefs, limited here roughly by the tropical circle, and is fronted by the great Australian barrier-reef. The southern half, between Sandy Cape and Cape Howe, lies outside the coral-reef region and is bare of reefs; but there exists a characteristic submarine ledge stretching southward all along the coast from Sandy Cape. This ledge is well defined by the 100-fathom line; its width usually varies between 18 and 25 miles, but it attains double this breadth as we approach Sandy Cape. Its slope, represented usually by a fall of from 20 to 30 feet in a mile, has an angle of only a small fraction of a degree. Beyond this ledge, judging from the soundings off Wide Bay, Low Bluff, and Cape Byron, the average angle of descent to depths between 2,000 and 2,500 fathoms varies between 7 degrees and 14 degrees. Here, then, we have an undoubted submarine ledge on that portion of the Australian coast which lies outside the region of coral reefs, or, in other words, outside the tropical circle, the limit in this locality of the growth of reef-corals.

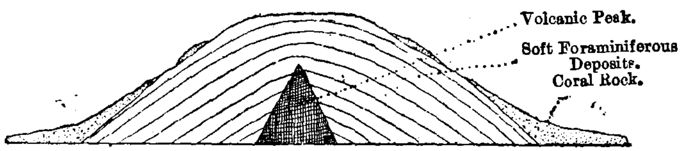
Let us now examine the submarine profile of the region fronted by barrier-reefs which extends from near Sandy Cape to Cape York. The presumption is, unless by some singular coincidence the submarine ledge terminates where the barrier-reef begins, that this ledge or plateau originally extended along the remainder of the east border of Australia northward to Torres Straits. We should naturally expect, therefore, that there would be a great difference in contour between the northern part of the ledge, which has been incrusted for unknown ages with the growing mass of the great barrier-reef, and the southern part of the ledge, which, being outside the area in which reef-corals live, is destitute of reefs; and such we find to be the case. From Sandy Cape northward to Flinders Passage, a distance of about 500 miles, the 100-fathom line extends to distances varying between 60 and 120 miles from the coast; but we have to proceed between 30 and 40 miles beyond, and to a depth of about 250 fathoms, before we can define the submarine plateau of this part of the Australian coast. The contour presents a great contrast to that of the submarine ledge south of Sandy Cape, which has a breadth of from 18 to 25 miles, and is sharply limited by the 100-fathom line. North of Flinders Passage the 100-

fathom line lies usually between 25 and 30 miles off the coast; and beyond this, there seems to be a gradual descent to deeper water, but the plateau is not sharply defined, and the submarine contour is very different from that of the ledge, bare of reefs, south of Sandy Cape.

To what conclusion do these facts tend? If we believe that the sharply-defined submarine ledge, characterising the southern half of the east coast of Australia, also exists in the northern half, but covered and concealed by the Great Barrier-reef, then the differences between the submarine profiles of the part north and the part south of Sandy Cape are mainly to be attributed to the existence of the Great Barrier-reef. Unless we can explain the reason why this ledge should end where the barrier-reef begins, the presumption arises that this submarine ledge, destitute of coral reefs for a distance of some 900 miles between Sandy Cape and Cape Howe, is extended along the remainder of the now coral-girt Australian coast. Here, then, we seem to be within a measurable distance of ascertaining the thickness and bulk of the Great Australian Barrier-reef. We assume the existence of an underlying ledge or plateau. We now require the nautical surveyor to supply us with a few lines of close soundings to the deep water in order to enable us to determine the angle of the submarine slope. After these data have been obtained, it will be possible to model the outline of the coast before the existence of the barrier-reef. I should here remark that the manner in which the Great Australian Barrier-reef has altered the submarine profile of the coast is well shown in Mr. Murray's coloured chart of the depths of the ocean, which accompanies his paper in the *Scottish Geographical Magazine* for last January.

I have now gone far enough to establish the probability, judging from the instance of the Australian Barrier-reef, that reefs of this class are in reality, and not in appearance, situated on the border of a submarine plateau or ledge. Such a position, according to the explanation of barrier-reefs, first advanced by Le Conte, and supported by myself, presents the most favourable conditions for reef-growth, the corals being limited on the outside by the depth, and on the inside by the sediment in the water. The influences of food-supply and currents act subsequently as auxiliary causes.

What, then, is the explanation of the submarine ledge? The supposition that it is a continuation of the land slope is at once negatived by the fact that the slope of the land in the reef-encircled islands of the Pacific is usually 6 degrees or 7 degrees, sometimes only 3 degrees or 4 degrees, but often as much as 10 degrees or 12 degrees, whilst the submarine ledge, when stripped of reefs and defined by the 100-fathom line, would possess a scarcely recognisable inclination, represented by a fraction of a degree. It will be found, however, when we examine the contour of such an island as Vanikoro, that the distance of the barrier-reef from the coast may vary according to the slope of the land. Thus, on the west side of this island, the average angle of the land slope is 6 degrees, and the distance of the barrier-reef about $2\frac{1}{5}$ miles. On the north side the inclination of the land is between 11 degrees and 12 degrees, and the barrier-reef is rather over a mile distant. This is just what we should expect. The more gradual the land-slope, the broader will be the submarine ledge, cut out in the course of ages by the action of the sea, and the more distant will be the barrier-reef that has grown up along its margin. This I believe to be the true explanation of the position of barrier-reefs. A submarine ledge is in the first place necessary; and, since the sediment and mud in the shallower waters on the ledge repress the growth of corals, reefs will naturally spring up towards the margin of the ledge, where the water is clearer and where the depth is within that of the reef-coral zone.



IDEAL SECTION OF AN ISLAND IN THE SOLOMON GROUP.

These ledges are sometimes of great antiquity. From the surface of the plateau inside the barrier-reef of Bougainville Island there rise up extinct volcanic cones, forming separate islands, a few hundred feet in height. Here lies also the large island of Fauro, composed of old volcanic formations. We notice the same in the instance of the great plateau inside the barrier-reef on the north side of the Fiji Group. A line of volcanic islands, varying between 700 and 1,800 feet in height, rises from the interior waters of the plateau.

It should be remarked, in conclusion, that this explanation of the situation of barrier-reefs at the margins of submarine ledges is by no means a novel one. It was suggested in 1831, by Messrs. Tyerman and Bennett, in the case of the reefs of the Society Islands.*

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* *Voyage and Travels*, vol. i. p. 215.

The PRESIDENT, Sir GEORGE GABRIEL STOKES, Bart., D.C.L., P.R.S., in the chair:—I am sure all will agree in according a vote of thanks to Dr. Guppy for his paper (applause). I will now ask those present who have made the subject their study to give the meeting the advantage of their views.

Captain W. J. L. WHARTON, R.N., F.R.S., Hydrographer to the Admiralty.—It has afforded me great pleasure to hear Dr. Guppy's most excellent paper. In it he has given us a very good abstract of the condition of affairs as regards our knowledge of coral reefs and their growth. It is rather presumptuous in me to offer an opinion, because I do not pretend to a mastery of the different branches of scientific knowledge which are requisite adequately to deal with the question of coral growth, but I have taken great interest in it, and have seen a great deal of coral reef in my time, and have formed my own ideas as to their formation. Speaking generally, I agree with Dr. Guppy, although on one point towards the end of his paper—to which I shall refer presently—I do not quite concur with him. In the early part of his paper he mentions the question of the growth of coral. A fact has recently come to my knowledge,—at least I believe it to be a fact,—and that is that at the Keeling islands, which Mr. Darwin examined, a part of the rim of the reef, which was submerged at the time the survey was made, is now above water. The depth of water over it in 1831 was eighteen feet. I have this information from a gentleman who knows the island, and who has lived there all his life,—Mr. Ross. I have written out to him to ask his opinion as to what has been the cause of this,—whether it is a growth of the coral reef itself or an upheaval; and, until we get that definite information, perhaps my observations may seem rather premature, because we cannot deduce much from what we are not quite sure of. Dr. Guppy mentioned the antiquity of coral reefs. There is one experience of my own which impressed me more than anything else with the great antiquity, not only of these reefs, but of the world in general, and that was an examination of the island of Aldabra, in the Indian Ocean. This is an upraised atoll about twenty feet high, which, from the steepness of the submarine slope outside, could never have been much larger, though it has been worn away on the outside by the action of the sea for some 150 or 200 yards, and is being slowly but surely disintegrated on the inside by the action of the mangroves which grow in the lagoon. In this small island there still exist gigantic tortoises of a species very distinct from those in other islands of the Indian Ocean. To form this distinct species must have required thousands of years, and this is a strong proof of the antiquity of coral reefs, and of the amount of time needed to wear away coral rock. On the question of barrier-reefs, especially the barrier-reef of Australia which Dr. Guppy has mentioned, I must demur to his supposition that that ledge will necessarily extend the whole length of the Australian coast. I think it would be much more extraordinary if, for a distance of over 2,000 miles, there was the same width of ledge the whole way, than that at a certain point the ledge should widen out. As Dr. Guppy truly remarks, different effects might be produced by breaker action and also by the slope of the land on which the breakers impinge, and where you get either a varying nature of the rock or a varying nature of the sea. Down on the southern part of the coast, the sea is very much heavier,—there is there a tremendous sea ; but on the other part of the coast you only get the trade wind, which blows parallel to the coast, so that one can, to a certain extent, imagine that the bank here on the southern portion of this part of coast should be wider; the ledge on the north would be narrower in consequence of the comparative smoothness of the sea, unless the rock on the coast is softer. I did not quite follow the author's argument of the growth of coral reefs in reference to his theory that the reef started on the edge and did not grow out from the land. I do not see that that would make the ledge wider above than it is farther down. There is another point; but the author is, probably, not in a position to be aware of it, because soundings have only recently been taken. He mentions that soundings are wanted. They were obtained only a few months ago, and have not been published yet, though I have had access to them. We got soundings out from the coast, showing that the slope is very gradual, and that the reef is not actually at the edge, but begins where the depth becomes about thirty fathoms. It approaches the land very closely to the north, and the reef is one narrow line, comparatively close to the shore, and the ledge is about the same width as it is down at the south of Australia.

Mr. JOHN MURRAY (of the *Challenger* Expedition).—I have listened with pleasure to this excellent paper, which suggests many questions, and, while with some of Dr. Guppy's contentions I agree, there are others with which I disagree to some extent. Perhaps one gets the best conception of what one has written when one hears it discussed by other people. The author has pointed out to-night, what he thinks a most important point, a matter which, for my part, I never thought important at all, that is, with regard to the formation of submerged reefs up to the level of the sea. That has been so amply proved that it does not appear to me to be important. It has always appeared to me that there are two fundamental things in the growth of coral reefs which must take precedence of all others, first that corals grow most abundantly and luxuriously wherever they get most food. I think that might almost apply to the human populations as well as to coral formations. Wherever there is abundance of food and other favourable conditions, coral reefs will most be found. Then, again, whenever life loses its hold of the coral structure which has been built up by the coral animals, whenever death ensues, inorganic changes commence their operations. It matters not whether this is assisted by creatures that bore into the solid structure, or whether it is due to the inorganic action of the sea. I think that by these general principles you can generally explain almost all the appearances that coral reefs present. However, there are a great many varieties and a great many differences due to locality. Temperature and the kind of food are two of the most important. For instance, you never find coral reefs except in those places where you have pure ocean currents. They are either found in mid-ocean, or off those continents or islands where the pure water is driven in upon the shores. The reason, of course, is the abundant supply of food that comes from the open ocean, driven by the trade winds. As to the question of barrier-reefs, when I read my original paper on that subject, it never occurred to me to guard what I said with respect to shallow and deep water. Whether it is that I had been accustomed to talk of deep water, I do not know; but I always considered that anything under 100 fathoms was shallow water. My view is that banks are formed at the lower limit of breaker action, but that the depth varies very greatly. Take, for instance, our own coast. Off the north end of the Butt of Lewis, where you have the whole extent of the Atlantic Ocean sweeping against the north of the Butt, you find that the sea is in motion down to 150 fathoms. The great waves that come across the Atlantic wash upon the shore, and you have moving sand and mud; but, if you go to the north-east, where there is less extent of ocean and less depth, there the depth at which sediment commences to form gets less and less. I think the author is quite right about the large extension of the bank out towards New Caledonia. For instance, we know, as I have pointed out in a recent paper, that we have a very large area of land between the coast line and 100 fathoms, very much greater than between that depth and 500 fathoms. That, in part, may be due to wave action, and in part due to the bank being sunk down, as in the case of Newfoundland. These shores may have been extended by breaker action. There are so many subjects raised, that, had I the time, I could say a great deal more.

Mr. W. H. HUDLESTON, F.R.S. &c.—Those who have spoken are very well acquainted with corals, and have been in those mighty oceans where corals grow. I am unable to speak with a similar advantage; but, at the same time, I think there are many points in Dr. Guppy's paper, which we have heard to-night, and also in his book, which I have read with very great interest, which have an important bearing on geological questions. So far as I can see, one of the great objections to the Darwinian or subsidence theory, is the very great thickness of coral which was supposed to be now forming in the Pacific and Indian Oceans. I believe that something like 2,000 feet of massive coral-rock is supposed to be the thickness in some places. In the old geological formations there is nothing of that kind to be seen. We know nothing of great thicknesses of that sort, and, according to geological calculation, the coral masses which are upon the Solomon Islands, and perhaps on others similarly situated, instead of being solid accretions of coral-rock, 1,000 or 2,000 feet in thickness, as has been hitherto supposed, are simply a veneer or facing of coral, perhaps 200 feet thick, upon the upraised oceanic muds and volcanic materials which really constitute the bulk of such islands. That seems to be very much more in accordance with what took place in former days in the various formations of the earth's crust. I am afraid that in some cases geologists have exhibited a certain amount of unwillingness in accepting these corrections. It may be that Darwin, Dana, and other high authorities have not accepted the views now propounded, and indeed they are not bound to yield to every change of theory; but so far as I can see—and I have thought so for a long time—Mr. Murray's views, subject to modification, are gaining ground slowly but surely, and those views, adopted as they have been by many practical men of great experience, and ably illustrated as they have been by Mr. Guppy in his writings, and in what he has said this evening, demand attention in the most conservative centres of scientific thought.

Captain FRANCIS PETRIE, F.G.S. (Hon. Secretary).—Some MS. communications have been received in regard to this paper.

The first is from Professor JAMES GEIKIE, F.R.S., of Edinburgh University, who writes:—

"Dear Sir,

"I regret my inability to attend the meeting of the Institute on Monday. I have read Dr. Guppy's paper with the greatest interest, and am of opinion that he has made out a very strong case indeed against the theory of coral island formation advanced by Darwin. When Mr. Murray published his antagonistic views in 1880, I felt that the whole question of the origin of reefs was opened up again, and that one could no longer accept Mr. Darwin's theory without some considerable modifications. I consider that Dr. Guppy's researches have removed many of the difficulties in the way of accepting the views advocated by Murray, Agassiz, and others; and that the famous Darwinian theory of coral reefs can no longer be said to hold the field. But, although the theory so ably supported and illustrated by Dr. Guppy seems most likely ere long to be generally accepted, it does not, I think, forbid the probability that some coral reefs may have originated in the manner suggested by Darwin."

The second is from Mr. ROBERT IRVINE, who writes:—

"I am sorry I cannot attend the Victoria Institute meeting, and that the time at my disposal is too limited to prepare any comments upon the paper, other than that I think it places the facts in connection with this interesting subject in a very clear light; and the deductions the author draws seem to me reasonable as accounting for the interesting calcareous formations known as coral reefs. I presume you have seen my letter in *Nature*, of March 15th, on this subject."

The third is from Mr. S. R. PATTISON, F.G.S., who writes:—

"Had the late Mr. Darwin possessed the advantage of considering the discoveries made, and the careful collation of facts observed by Dr. Guppy, and of perusing the able digest of previous publications on the subject which he has now put forward, I feel convinced that the great naturalist would have accepted the explanation of the phenomena now formulated, and would have given up his ingenious theory of gradual elevations and subsidences of the sea bottom. Observation has now shown, that there is simply no occasion for Mr. Darwin's or any other theory in the case. The facts should, coupled with our knowledge of the power of sea-water to dissolve carbonate of lime, explain themselves. We can see *vera causa* of the phenomena, and it would be unphilosophical to search further. This, however, does not relate to the elevatory movement from beneath, which has, in so many instances, raised the coral banks into islands, and even into cliffs and hills. This movement is not connected with the peculiar forms of atolls and reefs. I presume that the celebrated hyphothesis of Mr. Darwin, first given to the world in 1837, and often repeated since, must be considered to be abandoned."

Permit me, in conclusion, to refer to a paper "On the Tidal Currents of the Ocean," read by Mr. J. Y. Buchanan, M.A., F.R.S.E, before the Royal Society last month, in which I find some concluding remarks, which have a certain bearing upon the subject before us this evening He says :—

"These currents, in sweeping clean the rocky eminences at the bottom of the ocean, prepare a lodging place for deep-sea corals, and bring food to them when settled, thus enabling them to build up their pillar-like banks, a very fine example of which was discovered and surveyed by the *Dacia* on the 12th October, 1883. It lies in lat. 34° 57′ N., long. 13° 57′ W., and the shoalest sounding was 435 fathoms. The surface of the bank was locally very rough, and sloped gradually to the edge in about 550 fathoms, when it terminated in an actual precipice, dropping to 835 fathoms in one place. The coral on this bank was living and growing in the greatest luxuriance, and many specimens which were brought up showed that the living corals were growing on a mass of dead ones. There can, therefore, be little doubt that in this case we have a submarine bank which is in vigorous growth towards the surface, and which has been in existence long enough to have risen through a height of about 300 fathoms, or 1,800 feet. I have little doubt that, in a large number of the coral islands of the Pacific, the intermediate platform between the tropical reef-building coral and the volcanic peak, plateau, and ridge, which most probably form the foundation, is formed by these deep-sea corals, largely assisted by annelids, especially serpulæ, which secrete calcareous tubes. The tidal currents assist their growth both by bringing the animals nourishment, and by removing light débris which might choke them."

Dr. Guppy, in reply, said :—To begin at the end, that is, in reference to the remarks of Mr. Buchanan, I would say that he, to some extent, removes one of the objections against Mr. Murray's views, and that is, that it was difficult to imagine that so many volcanic peaks could be raised up to the surface of the sea or near the surface to form the foundation for the coral. Of course, in the neighbourhood of big groups of islands like the Solomon Islands, you have an immense amount of débris washed down from the reef, and that sediment is carried for 20 or 30 or 100 miles and would tend to form the reef. In the atolls in the middle of the ocean, and not in the vicinity of large groups of volcanic islands, at a distance of 500 or 1,000 miles, it is difficult to imagine how the sediment would be sufficiently raised to build these volcanic peaks up to the surface. Being some distance away from the large islands there is no débris brought down to cover the peak. In that way Mr. Buchanan's idea is that in the open sea the place of this sediment would be taken by the deep-sea corals. With regard to Captain Wharton's remarks, I must allow his correction as regards the width not being greater at the northern portion of the east coast than a little lower down, but it seems strange that this should increase and widen where the barrier-reef begins. Then, as regards the cause of the ledge widening out, this is produced by the barrier-reef gradually going on. According to Mr. Murray's idea, the reef would form on the edge of the ledge and would advance on the edge of the ledge seawards, so that the excess of this ledge over the lower part would represent the outer growth of the reef. I wanted to make a remark about the manner in which Mr. Darwin formed his original view of coral reefs. It was simply, no doubt, because he had at his disposal no evidence,—in fact, there is not a single possible explanation of the origin of coral reefs that is not in his book. His views on the subject are all objected to because he had not the evidence necessary to support them. The starting-point of Mr. Murray's view, the covering of these volcanic peaks and the lifting up of sediment, was simply objected to because there was then no evidence in regard to it. With reference to what Mr. Hudleston has said about the thickness of coral reefs, that I looked upon as the principal point of the discovery in the Solomon Islands. According to Mr. Darwin's theory, if this coral rock were formed by the sinking of the sea bottom, you would have a tremendous thickness in a certain time, 2,000 or 3,000 feet; but, if they were not caused by this sinking, but were caused by the other theory, you would only have a thickness of coral reef of not more than 200 feet, so that it is quite incompatible with any movement of the sinking of the sea bottom.

The meeting was then adjourned.

REMARKS ON THE FOREGOING PAPER.

By Mr. G. C. Bourne, M.A., F.L.S.

Dr. Guppy may fairly claim to be one of the greatest authorities on the subject of coral reefs, and I am somewhat shy of venturing to criticise his paper.

His account of Pacific myths as bearing on the origin of atolls is most interesting, but personally I am not inclined to attach much value to them as giving evidence of the upheaval of these islands. The Malays of N. Celebes, for instance, have wonderful legends relating to the formation of nearly every hill and island in or adjoining to their country, and very few of them can give any insight into the formation of those hills and islands. It must not be forgotten that an island would appear to a party of savages in a sense to rise out of the waters as they approached it, and each newly-discovered island would thus be readily described as rising out of the sea; the legendary stories would subsequently group themselves round the names of the first colonisers of the newly-discovered island.

I agree cordially with Dr. Guppy in thinking that the vast majority of atolls and barrier-reefs have remained in their present condition for upwards of three centuries. As to the extremely slow rate of coral growth, the evidence, which I have carefully considered, is very conflicting. All that can be certainly said is, that some species of coral grow far more rapidly than others, and that identical species vary very much in their rate of growth according as the conditions to which they are exposed are favourable or the reverse. Dr. Guppy, apparently quoting Mr. Darwin, says that the coral knolls of Digo Garcia have remained stationary for upwards of eighty years. This is hardly the case. I have most carefully compared the chart made by H.M.S. *Rambler* in 1885 with that made by Captain Moresby in 1837, and find that the knolls marked in the two charts rarely correspond with one another. Where they do correspond they are sometimes marked with a less depth in the later survey, sometimes with a greater. Some allowance must be made for errors of observation, but the chart of the *Rambler* shows conclusively that the reef westward of middle islet at the entrance of the lagoon has increased very largely since the original survey in 1837, as also has the reef and the number of coral patches eastern-most of the three channels leading into the lagoon. Speaking generally, the knolls, reefs, and banks within or at the mouths of the lagoon of Digo Garcia appear to have shallowed rather than to have remained stationary, but there are not a few exceptions to this statement. With much that Dr. Guppy says in the latter half of his interesting paper, I agree very heartily. In particular I am pleased to see that he admits the co-operation of several agencies, viz., currents, food supply, tidal scour, solution, and the action of breakers as necessary for the formation of an atoll or barrier-reef. It is my conviction that a true solution of the problem is only to be found when all these agencies are taken into account. Dr. Guppy's own observations are so good, and his reasoning is so convincing upon this subject, that I must refrain from criticising what I may call the individual part of his paper.

His explanation of the great barrier-reef of Australia is admirable, and there can be no doubt that fresh investigations made on other reefs will yield valuable results, which I hope will confirm his views, and enable us to formulate a general law for this class of structures.

By the Rev. WILLIAM WYATT GILL.

Dr. Guppy, in his interesting paper on "Coral Islands and Savage Myths," quotes a statement made by me several years ago before the Anthropological Society, that "the colonisation of the Hervey Group may not date back beyond five or six centuries," adding, "that the origin of these living and upraised coral islands would, according to this view, be of a very recent date. This is a conclusion, however, which we cannot accept," &c.

I still adhere to my opinion as to the modern colonisation of the Hervey Group. The grounds upon which I base this opinion may be found, not in the legend of Mani, &c., &c., given in my "Myths and Songs," but the long series of historical stories, commemorative songs, and genealogical tables given in my "Historical Sketches of Savage Life,"* published by the New Zealand Government in 1878. No critic of that volume (and there have been many in the southern hemisphere), has attempted to set aside my conclusion.

The question as to "the origin of these living and upraised coral islands" is not to be settled by traditions however interesting, but by the science of geology. I believe them to be several thousands

* W. B. Whittingham & Co., 91, Gracechurch Street, E.C.

of years old. As to the growth of coral, we need a wider basis and a longer period of observation, ere a final solution of our perplexities can be obtained. I have noted in the Pacific that the nearer we get to the equator the more numerous and extensive do these atolls become. The warmer the ocean the more active the coral zoophyte. In Torres Straits, and elsewhere, I have been astonished at the rapid growth of coral. Dr. Guppy's theory, as to the formation of the Australian barrier-reef and other reefs, appears to me to be entirely sound.

I may be permitted to add, that I have read Dr. Guppy's work on the Solomon Islands with the greatest pleasure and profit.

"PRELIMINARY NOTE" ON THE KEELING ATOLL.

By H. B. Guppy.

After Mr. Guppy had read the foregoing paper before the Institute he left England to explore the Keeling Atoll, known also as the Cocos Islands, and through the courtesy of Messrs. Macmillan, the proprietors of *Nature*, the Institute is enabled to insert his "preliminary note" to Mr. John Murray, thereon:—

During my sojourn of nearly ten weeks in these islands, I was able to make a fairly complete examination of them. Here I can only refer to some of the new features of this atoll which my investigations have disclosed, and must leave the details to be subsequently worked into a general description of the islands. Regarding myself as very fortunate in being able to examine the only atoll visited by Mr. Darwin,—the atoll, in fact, which gave rise to the theory of subsidence,—I at once set about making observations, without reference to any particular view of the origin of coral reefs. I examined all the islands and islets, more than twenty in number, making a separate description of each, and reaped the benefit of the fact that this atoll had been occupied for more than half a century by residents interested in their surroundings. The result has been to convince me that several important characters of these islands escaped the attention of Mr. Darwin, partly owing to his limited stay, partly also due to his necessarily defective information of the past changes in the atoll. The features, in fact, that escaped his notice, throw considerable light on the mode of origin of these lagoon islands, and give no support to the theory of subsidence.

In the first place, I have ascertained that Keeling Atoll consists essentially of a ring of horse-shoe or crescentic islands, inclosing a lagoon, and presenting their convexities seaward. The crescentic form is possessed in varying degrees by different islands; some of the smaller ones are perfect horse-shoe atollons, and inclose a shallow lagoonlet; others, again, exhibit only a semi-crescentic form; whilst the larger islands have been produced by the union of several islands of this shape. The whole land surface, however, is subject to continual change. The extremities of islands are often being gradually swept away or extended. Some islands are breached during heavy gales, others are joined, so that by the repetition of these changes the island, in the course of time, loses its original form. Hence it is that, although the crescent is the primitive shape of each island, this structure is partly disguised in the case of some of the larger islands by the union of several of smaller size. The Admiralty chart gives but an imperfect idea of the true shape of the islands; but, notwithstanding, its inspection will prove very instructive.

In truth, Keeling Atoll exhibits, in an incomplete manner, the features of the large compound atoll of the Maldive Group. If it was considerably larger and possessed a less protected lagoon, so that open-sea conditions prevailed in its interior, it would have all the features of a compound Maldive atoll; that is, an atoll consisting of a circle of small atolls or atollons. In its original condition, however, it was an atoll consisting of a circle of crescentic islands. Such it is essentially now, but extensive changes have often partly disguised this feature.

Before proceeding to explain the origin of the incompleted compound atoll of the Keeling Islands, it will be necessary to dwell on the exaggerated prevailing notion of an atoll. This kind of coral reef is usually described as a circular reef inclosing a deep basin or lagoon; but this description only applies to very small atolls less than a mile across. By drawing a section on a true scale of an atoll of average size, like Keeling Atoll, it will at once become apparent that such a description gives a very misleading idea of the real nature of this class of reef. A section of Keeling Atoll, drawn from the 1,000-fathom line on a true scale of an inch to the mile, and intended to illustrate a breadth of six miles, and a depth in the lagoon of 9 or 10 fathoms, would represent to the naked eye a flat-topped mountain, the depth of the so-called basin on the summit being merely represented by a slight central depression of about 1/100 of an inch. If the lagoon possessed a depth of 30 fathoms, the inclosed basin so-called would only be indicated in this section by a central depression of about 3/100 of an inch. So trifling a proportion does the depth of an atoll of ordinary size bear to the breadth, that such a reef can only be accurately described as possessing a broad level surface, with very slightly raised margin. A correct model of Keeling Atoll would at once convey a just idea of the true relative dimensions of a reef of this class. The lagoon would be there only represented by a film of water occupying a slight hollow in the level mountain-top. By thus grasping these facts, we at once perceive that by reason of our failing to view an atoll in relation to its surroundings, and through our misconceptions of its dimensions, we have been led to introduce a great cause to explain a very small effect. The slightly raised margins can be easily explained by causes dwelt upon by Murray, Agassiz, and others. No movement of the earth's crust is necessary for this purpose. The mode of growth of corals, the action of the waves, and the influence of the currents, afford agencies quite sufficient to produce the slightly raised margins of an atoll.

The development of the islands of an atoll into horse-shoe or crescentic islands, as in the instance of Keeling Atoll, or into perfect small atolls or atollons, as in the Maldive Group, is a subsequent process to be shortly explained. These small atolls and horse-shoe islands only assume their characteristic forms *after the island has been thrown up by the waves.* Such was the conclusion I arrived at concerning small atolls and crescent-shaped coral islands in the Solomon Islands (*Proc. Roy. Soc., Edinburgh,* 1885–86, p. 900); and, as just stated, I have formed the same opinion concerning the islands of Keeling Atoll. There is, in the first place, the island from which "lateral extensions grow out on either side so as to ultimately form a horse-shoe reef," which itself under favourable conditions may develop into a small atoll. In the Solomon Islands I imperfectly grasped the method by which these changes in form are effected. In Keeling Atoll I saw the process in operation, and I arrived at the conclusion that whenever a coral island stems a constant surface-current, the sand produced by the breakers on the outer edge of the reef will mostly be deposited by the current on each side of the island in the form of two literal banks or extensions, giving the island ultimately a horse-shoe form, with the convexity presented against the current. The process may be aptly compared to the formation of a V-shaped ridge of sand when a stake or some other obstacle is placed in a river bed. The stake represents the original small island thrown up by the waves. The V-shaped ridge of sand represents the arms of the horse-shoe island which are subsequently formed. The back-wash or eddy may in the river-bed join the arms of the V-shaped ridge of sand. In a similar manner a horse-shoe island may have a bank thrown up across the mouth, and thus a small atoll is formed. Such is the process, imperfectly disclosed to me in the Solomon Islands, that I found illustrated in all its stages in Keeling Atoll. In the Keeling Islands, however, it was necessary to satisfy myself of the reality of the agencies chiefly concerned in this process. For instance, I had to ascertain how and to what extent the surface-currents acted, and to discover the source of the sand. It was also necessary to observe what changes in the form and extent of the islands had occurred in the experience of the residents during the half-century of their occupation.

The westerly equatorial drift or south-east trade current, striking the south-east angle of the atoll, there divides and sweeps around the coasts, the two branches meeting and forming an eddy off the north-west island, a spot where drift timbers are often detained and stranded after having been swept around half the circumference of the atoll. Advantage of this current is taken by the proprietor of the islands, who directs his men to mark any logs of valuable timber thrown up on the weather or south-east coast, and then to launch them again outside the breakers. In this way huge logs are transported by the current to any particular island. If left alone, the logs, whether drifted around the north or south side of the atoll, arrive finally in the eddy off the north-west angle. This current finds its way into the lagoon through the several passages between the islands, its rate there varying usually from half a knot to two knots in the hour. Only rarely is there any check to the inflow of water through the passages, as, for instance, during north-west gales.

The current in these passages carries daily a large amount of sand into the lagoon. I discovered this accidentally whilst using the tow-net for catching the pelagic animals brought in by the current. The source of this sand is the weather edge of the reef on the outer side of the islands, where the breakers are unceasingly at work in keeping up the supply. After several measurements under varying conditions of current, tide, and depth, I estimated that during every day of ordinary weather at least 10 tons of sand are carried through the passages into the lagoon. During gales and cyclones this amount is greatly increased; and probably the estimate for an ordinary year would not be less than 5,000 tons. The bulk of this sand is deposited by the current near the inner mouths of the passages and on the margins of the lagoon, where it goes to extend the islands in the form of banks stretching into the lagoon. In this manner an island obtains a horse-shoe shape, just as the V-shaped ridge is formed by placing a stake in a river-bed. The first stage is represented by an island with two sand-banks extending into the lagoon, one from each extremity. The second stage is that in which the island has attained a semi-crescentic shape by the encroachment of its vegetation on the newly-formed banks. In the course of time, when the vegetation of the island has entirely occupied the banks, the third stage, that of the horse-shoe island, is reached. In some instances, there is yet a further stage, when, during a long continuance of westerly winds, another bank is thrown up across the mouth of the horse-shoe, and a small atoll with a shallow lagoonlet is produced. Thus the currents are the principal agencies in forming the horse-shoe islands of Keeling Atoll. In large atolls, where more open-sea conditions prevail in the lagoon, and especially where, as in the Maldives, there are two opposite sets of winds and surface-currents, each prevailing in its own half of the year, we should expect to find the horse-shoe island replaced by an atollon. Keeling Atoll, however, lies for eleven months out of the twelve within the region of the constant trade-wind and westerly drift current, so that the situation is only one favouring the formation of horse-shoe islands facing to the southward and eastward. The protected character of the lagoon, also, is not a condition that would assist the growth of a circular island or atollon.

Another important feature in this atoll is to be found in the existence outside the seaweed edge of the present reef of a series of submerged lines of growing corals separated from each other by sandy intervals. Unfortunately, I was not able to examine these to the extent I desired, since it can only be satisfactorily done later in the year, when the sea is sufficiently smooth to allow boats to approach the breaker edge of the reef. This feature, however, is familiar to the residents, who have supplied me with information on the subject. It would seem that all around the circumference of this atoll there is a space outside the present edge of the reef varying from 200 to 500 or 600 yards in width, where ships have anchored, and where boats in the calm season go with fishing parties. Here the submarine slope slopes gradually down to 20 or 30 fathoms; but beyond this the descent is precipitous. It is on this gradual slope that the lines of growing coral occur, separated by sandy intervals from each other. There may be two or three of these lines, the innermost covered by 4 or 5 fathoms, and the outer by from 20 to 30 fathoms.

We are thus able to perceive that the outward extension of the reef is effected, not so much by the seaward growth of the present edge of the reef, as by the formation outside it of a line of growing corals, which, when it reaches the surface reclaims, so to speak, the space inside it, which is soon filled up with sand and reef *débris*. The evidence, in fact, goes to show that a reef grows seaward rather by jumps than by a gradual outward growth. This inference is of considerable importance, since it connects all classes of reefs together in the matter of their seaward growth, the degree of inclination of the submarine slope being the chief determining factor.

Following Le Comte, I have previously shown (*Proc. Roy. Soc., Edin.*, 1885–86, p. 884) that where there is a very gradual submarine slope the deposition of sand and the presence of much sediment in the water will prevent the growth of corals in the shallow water outside the seaward edge of the reef, and that in consequence a line of living corals will spring up in the clearer and deeper waters a considerable distance beyond. The appearance of this line of coral at the surface will result in the production of a barrier-reef with a lagoon-channel inside. In a similar manner the submerged line of growing corals immediately outside the weather-edge of the reef of Keeling Atoll would form a barrier-reef, if it was removed some miles from the shore instead of being only about 100 yards distant. As it is now situated, it lies too close to the edge of the present reef to prevent the obliteration of the channel inside it after it has reached the surface. Its lagoon-channel would be very quickly filled with sand and reef-*débris*, and as a result we should merely have a permanent addition to the present reef-flat, which, when the process was complete, would be 100 yards wider. The process is the same as in the case of a barrier-reef, the difference in the result being due to the submerged line of corals being too close to the edge of the reef for the preservation of the interior channel; and this circumstance is due to the fact of the submarine slope being greater than in the case of a coast fronted by a barrier-reef. These remarks are merely intended to be suggestive. They may, perhaps, direct the attention of other observers to the examination of the outer slopes of atolls and to their mode of seaward growth. This can only be done during unusually calm weather.

I have discovered many other new features of minor interest in connexion with Keeling Atoll, to which I will refer in my full description of these islands. The island of North Keeling, lying fifteen miles to the north, is a small atoll connected with Keeling Atoll by a bank. I hope to describe it at some future time.

In conclusion, I may state that most of my observations in these islands were directed towards estimating the age of Keeling Atoll. These data have yet to be worked up, and I am fairly confident of getting a satisfactory estimate. The lagoon is rapidly filling up with sand and coral, but it is almost impossible to state in precise terms the changes since the visit of the *Beagle*, as the survey then made was little more than a sketch. The present Admiralty chart is of but little service in inquiring into past changes, for in it the original survey of the *Beagle* in 1836 has received several later additions, and there is nothing to distinguish the one from the other. For the purpose of navigation, and for the advantage of science, a complete examination of these islands should be made. The best season for surveying is during the calm weather of the months of January and February, when boats can venture close to the edge of the reef, and a satisfactory examination of the outer shores, as well as the interior of the atoll, can then be made. In collecting information from the residents, it will be necessary to remember that no records are kept in the islands; and in studying past changes the observer will have to receive what may at first sight appear to be very interesting facts with scientific caution. Some corroboration of such facts should always be looked for.