NOTES ON CORAL REEFS, WITH SPECIAL REFERENCE TO THE FUNAFUTI BORINGS.

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It may be premised that the object of this paper is, not to announce any new discovery, but merely to give a brief summary of what is known of the history of coral reefs, with notices of the chief theories that have been advanced in connection with the subject.

The coral polyps belonging to the family of the Astræidæ, the chief reef-builders, flourish only in the warmer waters of the ocean within the tropics. Their range extends from about 20deg. south to 20deg. north of the Equator; but, under the influence of the Gulf Stream, they are found as far north as the Bermudas. The action of the carbonic acid derived from these minute organisms upon the lime always present in sea water enables them to secrete the carbonate of lime which forms the stony framework popularly known a "coral," and this is all that remains after the death of successive generations of reef-builders working upwards within their appointed range.

Coral reefs are classed under three heads, fringing reefs, barrier reefs, and atolls. The fringing reef lies close to the land in flat beds traversed in all directions by shallow channels and pools, and with larger breaks opposite the mouths of rivers. Building upwards from the sea bottom, where the depth is not too great, the coral polyps die on reaching the surface, and the growth of the reef is then confined to its seaward face. Barrier reefs lie at a distance from land in lines more or less parallel with the nearest coast, and generally rising from great depths on the seaward side. The atoll is a partially-closed ring of coral formation with no land in the centre, the typical coral island, though, as at Funafuti, the ring often consists of numerous detached islands.

Darwin's theory may be briefly stated. A careful and widely extended study of the life and work of the reef-building coral polyps had proved that their operations cannot be carried on at a greater depth than about 25 fathoms, and that when the formation gradually built up by successive generations on the stony remains of their predecessors reached the surface, all upward growth of live coral ceased. Darwin knew of numerous instances where the remains of old coral

reefs existed on land slopes at various heights above the sea level, which proved that there had been no subsidence at those particular points. But there was also in evidence the fact that countless numbers of coral reefs and islands rising from great depths, and with no land near them, were scattered over vast areas in the Indian and Pacific Oceans. The obvious conclusion was, that these must either have been built up on a corresponding number of submarine peaks and ridges conveniently situated at just the right depth below the sea level, or that the coral polyps had begun their work, ages ago, around and among the peaks and ridges of a slowly subsiding continent, building ever upwards as the land went down, until it was entirely submerged, and he unhesitatingly adopted the latter hypothesis.

(Reference to diagram.)

The Darwinian theory was first published in 1842. It was received with acclamation by scientific authorities in all parts of the world, and quite twenty years passed before any serious objections to its general acceptance began to be formulated. With the indomitable energy, quick perception, and freedom from prejudice, which were his chief characteristics, Darwin studied all the results of fresh explorations made by contemporary workers that could throw light upon the subject, but could find no ground for any material modification of his original theory. With the improvements that were made, especially in England and America, in the mechanical appliances of surveying ships, the exploration of the great depths of the ocean was greatly facilitated, and, after the famous voyage of H.M.S. *Challenger*, Dr. John Murray, one of the naturalists of the expedition, propounded a new theory which was supported by several leading scientists.

Before giving an account of this theory, it is necessary to briefly mention some of the additions to our knowledge of marine natural history since the date of the voyage of H.M.S. *Beagle*. The results of the *Challenger* Expedition, and of other previous explorations of the depths of the ocean, have shown that the floor of every sea, outside the range within which it is affected by deposits of river sediment, or by the wearing away of the coast line, is covered down to considerable depths with the shells and skeletons of myriads of marine organisms, which have lived either on the sea bottom or floating near the surface. The latter, especially in the warmer seas, are present in such vast numbers, that, though the individuals themselves are mostly very minute, their remains, accumulated during the course of long ages, form a very large proportion of the materials which have been gradually built up on the original foundation.

Among the silica-secreting denizens of the surface waters are simple animal forms such as the *Radiolaria*, and vegetable organisms belonging to the *Diatomaceæ*. Among those that secrete carbonate of lime are the *Pteropoda*, and familiar representatives of this class are *Hyalea* and *Cleodora*, specimens of which, with their beautiful translucent shells, are often collected by means of tow nets let down from passenger steamers or sailing ships. Of other forms, the *Foraminifera* comprise most of the minute animals with dense shells, such as those of the *Globigerinæ* and *Orbulinæ*.

The thin shells of the Pteropods, after the death of their tenants, sink so slowly that they are dissolved away before reaching great depths, and their remains are rarely found where the depth exceeds 1000 fathoms. The dense shells of the *Globigerinæ* sink to much greater depths before being dissolved, and are found all over the sea bottom down to about 2,500 fathoms. The remains of the surface organisms reaching greater depths are chiefly the silicious skeletons of Radiolarians and Diatoms. These are blended with the other materials slowly accumulating in the deepest parts of every ocean, forming a reddish brown sediment which has received the distinctive name of *Red Clay*.

The main point which has to be grasped, and it is not easy to realise it, is that, during past ages and up to the present day, there has been a never-ceasing downfall of the remains of these short-lived organisms, which has gradually raised the sea bottom over wide areas to a considerable altitude. The deposit thus formed is now known under the general name of *ooze*. That portion of it which is found at a depth not exceeding 1,000 fathoms has been called *Pteropod ooze*, from the large percentage of the remains of Pteropods contained in it. The same kind of formation extending from 1,000 to 2,500 fathoms is called *Globigerina ooze* for a similar reason, and this is succeeded by *Diatom* and *Radiolarian ooze* until these last are blended with the ultimate residuum—*Red Clay*—on the floor of the deepest seas. In connection with this part of the subject it may be noted that the great chalk formation, which occupies a large extent of country in the south of England, and on the continent of Europe, and which beneath London is about 700ft. thick, is practically identical with the deposits that have just been mentioned. It has been proved by microscopic examination that chalk is nothing more than what may be described in general terms as *Globigerina ooze* in a consolidated form, which had accumulated by slow oceanic sedimentation, long ages ago, on an ancient sea floor.

The conclusion arrived at by Dr. Murray of the *Challenger* Expedition was, that coral reefs and islands were gradually

built up on tops of submarine peaks or ridges already existing at a depth not exceeding 25 fathoms, or on banks which, in the course of ages, had been raised to the necessary height by the process of sedimentation that has been described. (Reference to diagram.)

In a letter quoted by Professor Judd, which was written by Darwin to Professor Agassiz in 1881, the year before his death, he remarks that he "has expressly stated that a bank at the proper depth would give rise to an atoll, which could not be distinguished from one formed during subsidence;" and he goes on to say that he "can hardly believe in the existence of as many banks (there having been no subsidence) as there are atolls in the great oceans, within a reasonable depth, on which minute oceanic organisms could have accumulated to the depth of many hundred feet." The letter concludes with the following words:—"If I am wrong, the sooner I am knocked on the head and annihilated so much the better. It still seems to me a marvellous thing that there should not have been much and long-continued subsidence in the beds of the great oceans. I wish some doubly-rich millionaire would take it into his head to have borings made in some of the Pacific and Indian atolls, and bring home cores for slicing from a depth of 500 or 600 feet."

The "millionaire" did not turn up, but Darwin's last wishes for the settlement of the question one way or another were not consigned to oblivion, and at last, in 1896, the Royal Society of London organised an expedition under the leadership of Professor Sollas, which was materially aided by the Admiralty, the Government of New South Wales, and leading scientific men in Sydney. A site was selected for boring operations in the Ellice Group, due north of Fiji, and about 8deg. south of the Equator. A lagoon encircled by a fringe of reefs and coral islands, the largest being Funafuti, forms the atoll, which is about 12 miles long and eight miles broad. From soundings taken by Captain Field, of H.M.S. *Penguin*, it appears that this atoll resembles a vast wall-like structure built on a cone-shaped elevation or mountain rising from a depth of about 2,000 fathoms, with a gradually increasing slope up to a contour line about 140 fathoms deep, the rise from this level up to near the surface being almost precipitous. The intention was to bore to a depth of at least 600 feet, so as to ascertain how far down the coral reef extended, and to determine, if possible, the nature of the foundation on which it rested. The boring was commenced in May, 1896, but was carried on under great difficulties, the tubes constantly getting choked by sand lying in irregular layers among masses of solid coral. A depth of 105 feet was reached, but eventually the work had to be abandoned.

In June, 1897, a second expedition was despatched from Sydney, under the charge of Professor David. Many improvements had been effected in the machinery and boring tools, and good progress was made in spite of the difficulties that were again encountered, such as the sudden and frequent changes from solid rock to bands of loose sand. A depth of 643 feet had been reached in solid coral limestone, when a complete breakdown in the machinery stopped the work. This second expedition had, however, proved that true coral reefs exist at a depth of about 80 fathoms below the range within which the coral polyps live and carry on their work.

But those who had taken such a lively interest in these two expeditions were not content to abandon the undertaking without an attempt to obtain further evidence. In 1898 a third expedition was sent out from Sydney, and the boring was continued until it reached a depth of 1,114 feet in "coral reef rock."

No detailed account of the results of the boring will be published until the examination of the cores sent to the Royal Society of London has been completed. The one important fact that has been established is, that submerged coral reefs exist at Funafuti at a depth of over 1100 feet, and at least 150 feet below the base of the wall-like formation of the atoll.

While writing the latter portion of these notes, I received a copy of Mrs. Edgeworth David's charming account of the expedition of 1897,* from the postscript to which, by Professor T. G. Bonney, I have extracted the substance of the results of the soundings taken during the visit of H.M.S. *Penguin*. Besides giving a graphic description of the voyage, with notices of its object, and some of its results, Mrs. David deals fully with the romantic side of life on a coral island, and the manners and customs of an isolated native community, and the book will be found excellent reading by all who are interested in such subjects.

* "Funafuti, or Three Months on a Coral Island," by Mrs. Edgeworth David.