DARWIN CHARLES

CORAL REEFS

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Coral Reefs:

Содержание

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EDITORIAL NOTE

Although in some respects more technical in their subjects and style than Darwin's "Journal," the books here reprinted will never lose their value and interest for the originality of the observations they contain. Many parts of them are admirably adapted for giving an insight into problems regarding the structure and changes of the earth's surface, and in fact they form a charming introduction to physical geology and physiography in their application to special domains. The books themselves cannot be obtained for many times the price of the present volume, and both the general reader, who desires to know more of Darwin's work, and the student of geology, who naturally wishes to know how a master mind reasoned on most important geological subjects, will be glad of the opportunity of possessing them in a convenient and cheap form.

The three introductions, which my friend Professor Judd has kindly furnished, give critical and historical information which makes this edition of special value.

G.T.B.

THE STRUCTURE AND DISTRIBUTION OF CORAL REEFS

CRITICAL INTRODUCTION

A scientific discovery is the outcome of an interesting process of evolution in the mind of its author. When we are able to detect the germs of thought in which such a discovery has originated, and to trace the successive stages of the reasoning by which the crude idea has developed into an epoch-making book, we have the materials for reconstructing an important chapter of scientific history. Such a contribution to the story of the "making of science" may be furnished in respect to Darwin's famous theory of coral-reefs, and the clearly reasoned treatise in which it was first fully set forth.

The subject of corals and coral-reefs is one concerning which much popular misconception has always prevailed. The misleading comparison of coral-rock with the combs of bees and the nests of wasps is perhaps responsible for much of this misunderstanding; one writer has indeed described a coral-reef as being "built by fishes by means of their teeth." Scarcely less misleading, however, are the references we so frequently meet with, both in prose and verse, to the "skill," "industry," and

"perseverance" of the "coral-insect" in "building" his "home." As well might we praise men for their cleverness in making their own skeletons, and laud their assiduity in filling churchyards with the same. The polyps and other organisms, whose remains accumulate to form a coral-reef, simply live and perform their natural functions, and then die, leaving behind them, in the natural course of events, the hard calcareous portions of their structures to add to the growing reef.

While the forms of coral-reefs and coral-islands are sometimes very remarkable and worthy of attentive study, there is no ground, it need scarcely be added, for the suggestion that they afford proofs of design on the part of the living builders, or that, in the words of Flinders, they constitute breastworks, defending the workshops from whence "infant colonies might be safely sent forth."

It was not till the beginning of the present century that travellers like Beechey, Chamisso, Quoy and Gaimard, Moresby, Nelson, and others, began to collect accurate details concerning the forms and structure of coral-masses, and to make such observations on the habits of reef-forming polyps, as might serve as a basis for safe reasoning concerning the origin of coral-reefs and islands. In the second volume of Lyell's "Principles of Geology," published in 1832, the final chapter gives an admirable summary of all that was then known on the subject. At that time, the ring-form of the atolls was almost universally regarded as a proof that they had grown up on submerged

volcanic craters; and Lyell gave his powerful support to that theory.

Charles Darwin was never tired of acknowledging his indebtedness to Lyell. In dedicating to his friend the second edition of his "Naturalist's Voyage Round the World," Darwin writes that he does so "with grateful pleasure, as an acknowledgment that the chief part of whatever scientific merit this journal and the other works of the author may possess, has been derived from studying the well-known and admirable 'Principles of Geology.'"

The second volume of Lyell's "Principles" appeared after Darwin had left England; but it was doubtless sent on to him without delay by his faithful friend and correspondent, Professor Henslow. It appears to have reached Darwin at a most opportune moment, while, in fact, he was studying the striking evidences of slow and long-continued, but often interrupted movement on the west coast of South America. Darwin's acute mind could not fail to detect the weakness of the then prevalent theory concerning the origin of the ring-shaped atolls – and the difficulty which he found in accepting the volcanic theory, as an explanation of the phenomena of coral-reefs, is well set forth in his book.

In an interesting fragment of autobiography, Darwin has given us a very clear account of the way in which the leading idea of the theory of coral-reefs originated in his mind; he writes, "No other work of mine was begun in so deductive a spirit as this, for the whole theory was thought out on the west coast of South

America, before I had seen a true coral-reef. I had therefore only to verify and extend my views by a careful examination of living reefs. But it should be observed that I had during the two previous years been incessantly attending to the effects on the shores of South America of the intermittent elevation of the land, together with the denudation and deposition of sediment. This necessarily led me to reflect much on the effects of subsidence, and it was easy to replace in imagination the continued deposition of sediment by the upward growth of corals. To do this was to form my theory of the formation of barrier-reefs and atolls."

On her homeward voyage, the "Beagle" visited Tahiti, Australia, and some of the coral-islands in the Indian Ocean, and Darwin had an opportunity of testing and verifying the conclusion at which he had arrived by studying the statements of other observers.

I well recollect a remarkable conversation I had with Darwin, shortly after the death of Lyell. With characteristic modesty, he told me that he never fully realised the importance of his theory of coral-reefs till he had an opportunity of discussing it with Lyell, shortly after the return of the "Beagle". Lyell, on receiving from the lips of its author a sketch of the new theory, was so overcome with delight that he danced about and threw himself into the wildest contortions, as was his manner when excessively pleased. He wrote shortly afterwards to Darwin as follows: – "I could think of nothing for days after your lesson on coral-reefs, but of the tops of submerged continents. It is all true, but do not

flatter yourself that you will be believed till you are growing bald like me, with hard work and vexation at the incredulity of the world." On May 24th, 1837, Lyell wrote to Sir John Herschel as follows: – "I am very full of Darwin's new theory of coral-islands, and have urged Whewell to make him read it at our next meeting. I must give up my volcanic crater forever, though it cost me a pang at first, for it accounted for so much." Dr. Whewell was president of the Geological Society at the time, and on May 31st, 1837, Darwin read a paper entitled "On Certain Areas of Elevation and Subsidence in the Pacific and Indian oceans, as deduced from the Study of Coral Formations," an abstract of which appeared in the second volume of the Society's proceedings.

It was about this time that Darwin, having settled himself in lodgings at Great Marlborough Street, commenced the writing of his book on "Coral-Reefs." Many delays from ill-health and the interruption of other work, caused the progress to be slow, and his journal speaks of "recommencing" the subject in February 1839, shortly after his marriage, and again in October of the same year. In July 1841, he states that he began once more "after more than thirteen month's interval," and the last proof-sheet of the book was not corrected till May 6th, 1842. Darwin writes in his autobiography, "This book, though a small one, cost me twenty months of hard work, as I had to read every work on the islands of the Pacific, and to consult many charts." The task of elaborating and writing out his books was, with Darwin, always a

very slow and laborious one; but it is clear that in accomplishing the work now under consideration, there was a long and constant struggle with the lethargy and weakness resulting from the sad condition of his health at that time.

Lyell's anticipation that the theory of coral-reefs would be slow in meeting with general acceptance was certainly not justified by the actual facts. On the contrary the new book was at once received with general assent among both geologists and zoologists, and even attracted a considerable amount of attention from the general public.

It was not long before the coral-reef theory of Darwin found an able exponent and sturdy champion in the person of the great American naturalist, Professor James D. Dana. Two years after the return of the "Beagle" to England, the ships of the United States Exploring Expedition set sail upon their four years' cruise, under the command of Captain Wilkes, and Dana was a member of the scientific staff. When, in 1839, the expedition arrived at Sydney, a newspaper paragraph was found which gave the American naturalist the first intimation of Darwin's new theory of the origin of atolls and barrier-reefs. Writing in 1872, Dana describes the effect produced on his mind by reading this passage: – "The paragraph threw a flood of light over the subject, and called forth feelings of peculiar satisfaction, and of gratefulness to Mr. Darwin, which still come up afresh whenever the subject of coral islands is mentioned. The Gambier Islands in the Paumotus, which gave him the key to the theory, I had not

seen; but on reaching the Feejees, six months later, in 1840, I found there similar facts on a still grander scale and of a more diversified character, so that I was afterward enabled to speak of his theory as established with more positiveness than he himself, in his philosophic caution, had been ready to adopt. His work on coral-reefs appeared in 1842, when my report on the subject was already in manuscript. It showed that the conclusions on other points, which we had independently reached, were for the most part the same. The principal points of difference relate to the reason for the absence of corals from some coasts, and the evidence therefrom as to changes of level, and the distribution of the oceanic regions of elevation and subsidence – topics which a wide range of travel over the Pacific brought directly and constantly to my attention."

Among the Reports of the United States Exploring Expedition, two important works from the pen of Professor Dana made their appearance; – one on "Zoophytes," which treats at length on "Corals and Coral-Animals," and the other on "Coral-Reefs and Islands." In 1872, Dana prepared a work of a more popular character in which some of the chief results of his studies are described; it bore the title of "Corals and Coral-Islands." Of this work, new and enlarged editions appeared in 1874 and 1890 in America, while two editions were published in this country in 1872 and 1875. In all these works their author, while maintaining an independent judgment on certain matters of detail, warmly defends the views of Darwin on all points essential to the theory.

Another able exponent and illustrator of the theory of coral-reefs was found in Professor J.B. Jukes, who accompanied H.M.S. "Fly", as naturalist, during the survey of the Great Barrier-Reef – in the years 1842 to 1846. Jukes, who was a man of great acuteness as well as independence of mind, concludes his account of the great Australian reefs with the following words: – "After seeing much of the Great Barrier-Reefs, and reflecting much upon them, and trying if it were possible by any means to evade the conclusions to which Mr. Darwin has come, I cannot help adding that his hypothesis is perfectly satisfactory to my mind, and rises beyond a mere hypothesis into the true theory of coral-reefs."

As the result of the clear exposition of the subject by Darwin, Lyell, Dana, and Jukes, the theory of coral-reefs had, by the middle of the present century, commanded the almost universal assent of both biologists and geologists. In 1859 Baron von Richthofen brought forward new facts in its support, by showing that the existence of the thick masses of dolomitic limestone in the Tyrol could be best accounted for if they were regarded as of coralline origin and as being formed during a period of long continued subsidence. The same views were maintained by Professor Mojsisovics in his "Dolomit-riffe von Sudtirol und Venetien," which appeared in 1879.

The first serious note of dissent to the generally accepted theory was heard in 1863, when a distinguished German naturalist, Dr. Karl Semper, declared that his study of the Pelew

Islands showed that uninterrupted subsidence could not have been going on in that region. Dr. Semper's objections were very carefully considered by Mr. Darwin, and a reply to them appeared in the second and revised edition of his "Coral-Reefs," which was published in 1874. With characteristic frankness and freedom from prejudice, Darwin admitted that the facts brought forward by Dr. Semper proved that in certain specified cases, subsidence could not have played the chief part in originating the peculiar forms of the coral-islands. But while making this admission, he firmly maintained that exceptional cases, like those described in the Pelew Islands, were not sufficient to invalidate the theory of subsidence as applied to the widely spread atolls, encircling reefs, and barrier-reefs of the Pacific and Indian Oceans. It is worthy of note that to the end of his life Darwin maintained a friendly correspondence with Semper concerning the points on which they were at issue.

After the appearance of Semper's work, Dr. J.J. Rein published an account of the Bermudas, in which he opposed the interpretation of the structure of the islands given by Nelson and other authors, and maintained that the facts observed in them are opposed to the views of Darwin. Although, so far as I am aware, Darwin had no opportunity of studying and considering these particular objections, it may be mentioned that two American geologists have since carefully re-examined the district – Professor W.N. Rice in 1884 and Professor A. Heilprin in 1889 – and they have independently arrived at the conclusion

that Dr. Rein's objections cannot be maintained.

The most serious opposition to Darwin's coral-reef theory, however, was that which developed itself after the return of H.M.S. "Challenger" from her famous voyage. Mr. John Murray, one of the staff of naturalists on board that vessel, propounded a new theory of coral-reefs, and maintained that the view that they were formed by subsidence was one that was no longer tenable; these objections have been supported by Professor Alexander Agassiz in the United States, and by Dr. A. Geikie, and Dr. H.B. Guppy in this country.

Although Mr. Darwin did not live to bring out a third edition of his "Coral-Reefs," I know from several conversations with him that he had given the most patient and thoughtful consideration to Mr. Murray's paper on the subject. He admitted to me that had he known, when he wrote his work, of the abundant deposition of the remains of calcareous organisms on the sea floor, he might have regarded this cause as sufficient in a few cases to raise the summits of submerged volcanoes or other mountains to a level at which reef-forming corals can commence to flourish. But he did not think that the admission that under certain favourable conditions, atolls might be thus formed without subsidence, necessitated an abandonment of his theory in the case of the innumerable examples of the kind which stud the Indian and Pacific Oceans.

A letter written by Darwin to Professor Alexander Agassiz in May 1881 shows exactly the attitude which careful consideration

of the subject led him to maintain towards the theory propounded by Mr. Murray: – "You will have seen," he writes, "Mr. Murray's views on the formation of atolls and barrier-reefs. Before publishing my book, I thought long over the same view, but only as far as ordinary marine organisms are concerned, for at that time little was known of the multitude of minute oceanic organisms. I rejected this view, as from the few dredgings made in the "Beagle", in the south temperate regions, I concluded that shells, the smaller corals, etc., decayed and were dissolved when not protected by the deposition of sediment, and sediment could not accumulate in the open ocean. Certainly, shells, etc., were in several cases completely rotten, and crumbled into mud between my fingers; but you will know whether this is in any degree common. I have expressly said that a bank at the proper depth would give rise to an atoll, which could not be distinguished from one formed during subsidence. I can, however, 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."

Darwin's concluding words in the same letter written within a year of his death, are a striking proof of the candour and openness of mind which he preserved so well to the end, in this as in other controversies.

"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."

It is noteworthy that the objections to Darwin's theory have for the most part proceeded from zoologists, while those who have fully appreciated the geological aspect of the question, have been the staunchest supporters of the theory of subsidence. The desirability of such boring operations in atolls has been insisted upon by several geologists, and it may be hoped that before many years have passed away, Darwin's hopes may be realised, either with or without the intervention of the "doubly rich millionaire."

Three years after the death of Darwin, the veteran Professor Dana re-entered the lists and contributed a powerful defence of the theory of subsidence in the form of a reply to an essay written by the ablest exponent of the anti-Darwinian views on this subject, Dr. A. Geikie. While pointing out that the Darwinian position had been to a great extent misunderstood by its opponents, he showed that the rival theory presented even greater difficulties than those which it professed to remove.

During the last five years, the whole question of the origin of coral-reefs and islands has been re-opened, and a controversy has arisen, into which, unfortunately, acrimonious elements have been very unnecessarily introduced. Those who desire it, will find clear and impartial statements of the varied and often

mutually destructive views put forward by different authors, in three works which have made their appearance within the last year, – "The Bermuda Islands," by Professor Angelo Heilprin; "Corals and Coral-Islands," new edition by Professor J.D. Dana; and the third edition of Darwin's "Coral-Reefs," with Notes and Appendix by Professor T.G. Bonney.

Most readers will, I think, rise from the perusal of these works with the conviction that, while on certain points of detail it is clear that, through the want of knowledge concerning the action of marine organisms in the open ocean, Darwin was betrayed into some grave errors, yet the main foundations of his argument have not been seriously impaired by the new facts observed in the deep-sea researches, or by the severe criticism to which his theory has been subjected during the last ten years. On the other hand, I think it will appear that much misapprehension has been exhibited by some of Darwin's critics, as to what his views and arguments really were; so that the reprint and wide circulation of the book in its original form is greatly to be desired, and cannot but be attended with advantage to all those who will have the fairness to acquaint themselves with Darwin's views at first hand, before attempting to reply to them.

JOHN W. JUDD.

CORAL-REEFS.
INTRODUCTION

The object of this volume is to describe from my own observation and the works of others, the principal kinds of coral-reefs, more especially those occurring in the open ocean, and to explain the origin of their peculiar forms. I do not here treat of the polypifers, which construct these vast works, except so far as relates to their distribution, and to the conditions favourable to their vigorous growth. Without any distinct intention to classify coral-reefs, most voyagers have spoken of them under the following heads: "lagoon-islands," or "atolls," "barrier" or "encircling reefs," and "fringing" or "shore-reefs." The lagoon-islands have received much the most attention; and it is not surprising, for every one must be struck with astonishment, when he first beholds one of these vast rings of coral-rock, often many leagues in diameter, here and there surmounted by a low verdant island with dazzling white shores, bathed on the outside by the foaming breakers of the ocean, and on the inside surrounding a calm expanse of water, which from reflection, is of a bright but pale green colour. The naturalist will feel this astonishment more deeply after having examined the soft and almost gelatinous bodies of these apparently insignificant creatures, and when he knows that the solid reef increases only on the outer edge, which day and night is lashed by the breakers

of an ocean never at rest. Well did Francois Pyrard de Laval, in the year 1605, exclaim, "C'est une merueille de voir chacun de ces atollons, enuironne d'un grand banc de pierre tout autour, n'y ayant point d'artifice humain." The accompanying sketch of Whitsunday island, in the South Pacific, taken from Captain Beechey's admirable "Voyage," although excellent of its kind, gives but a faint idea of the singular aspect of one of these lagoon-islands.

(PLATE: UNTITLED WOODCUT, WHITSUNDAY ATOLL.)

Whitsunday Island is of small size, and the whole circle has been converted into land, which is a comparatively rare circumstance. As the reef of a lagoon-island generally supports many separate small islands, the word "island," applied to the whole, is often the cause of confusion; hence I have invariably used in this volume the term "atoll," which is the name given to these circular groups of coral-islets by their inhabitants in the Indian Ocean, and is synonymous with "lagoon-island."

(PLATE: UNTITLED WOODCUT, REEF AT BOLABOLA ISLAND.)

Barrier-reefs, when encircling small islands, have been comparatively little noticed by voyagers; but they well deserve attention. In their structure they are little less marvellous than atolls, and they give a singular and most picturesque character to the scenery of the islands they surround. In the accompanying sketch, taken from the "Voyage of the 'Coquille'," the reef is

seen from within, from one of the high peaks of the island of Bolabola. (I have taken the liberty of simplifying the foreground, and leaving out a mountainous island in the far distance.) Here, as in Whitsunday Island, the whole of that part of the reef which is visible is converted into land. This is a circumstance of rare occurrence; more usually a snow-white line of great breakers, with here and there an islet crowned by cocoa-nut trees, separates the smooth waters of the lagoon-like channel from the waves of the open sea. The barrier-reefs of Australia and of New Caledonia, owing to their enormous dimensions, have excited much attention: in structure and form they resemble those encircling many of the smaller islands in the Pacific Ocean.

With respect to fringing, or shore-reefs, there is little in their structure which needs explanation; and their name expresses their comparatively small extension. They differ from barrier-reefs in not lying so far from the shore, and in not having within a broad channel of deep water. Reefs also occur around submerged banks of sediment and of worn-down rock; and others are scattered quite irregularly where the sea is very shallow; these in most respects are allied to those of the fringing class, but they are of comparatively little interest.

I have given a separate chapter to each of the above classes, and have described some one reef or island, on which I possessed most information, as typical; and have afterwards compared it with others of a like kind. Although this classification is useful from being obvious, and from including most of the coral-reefs

existing in the open sea, it admits of a more fundamental division into barrier and atoll-formed reefs on the one hand, where there is a great apparent difficulty with respect to the foundation on which they must first have grown; and into fringing-reefs on the other, where, owing to the nature of the slope of the adjoining land, there is no such difficulty. The two blue tints and the red colour (replaced by numbers in this edition.) on the map (Plate III.), represent this main division, as explained in the beginning of the last chapter. In the Appendix, every existing coral-reef, except some on the coast of Brazil not included in the map, is briefly described in geographical order, as far as I possessed information; and any particular spot may be found by consulting the Index.

Several theories have been advanced to explain the origin of atolls or lagoon-islands, but scarcely one to account for barrier-reefs. From the limited depths at which reef-building polypifers can flourish, taken into consideration with certain other circumstances, we are compelled to conclude, as it will be seen, that both in atolls and barrier-reefs, the foundation on which the coral was primarily attached, has subsided; and that during this downward movement, the reefs have grown upwards. This conclusion, it will be further seen, explains most satisfactorily the outline and general form of atolls and barrier-reefs, and likewise certain peculiarities in their structure. The distribution, also, of the different kinds of coral-reefs, and their position with relation to the areas of recent elevation, and to

the points subject to volcanic eruptions, fully accord with this theory of their origin. (A brief account of my views on coral formations, now published in my Journal of Researches, was read May 31st, 1837, before the Geological Society, and an abstract has appeared in the Proceedings.)

(DESCRIPTION OF THE PLATES

PLATE I. – MAP SHOWING THE RESEMBLANCE IN FORM BETWEEN BARRIER CORAL-REEFS SURROUNDING MOUNTAINOUS ISLANDS, AND ATOLLS OR LAGOON ISLANDS.)

In the several original surveys, from which the small plans on this plate have been reduced, the coral-reefs are engraved in very different styles. For the sake of uniformity, I have adopted the style used in the charts of the Chagos Archipelago, published by the East Indian Company, from the survey by Captain Moresby and Lieutenant Powell. The surface of the reef, which dries at low water, is represented by a surface with small crosses: the coral-islets on the reef are marked by small linear spaces, on which a few cocoa-nut trees, out of all proportion too large, have been introduced for the sake of clearness. The entire ANNULAR REEF, which when surrounding an open expanse of water, forms an "atoll," and when surrounding one or more high islands, forms an encircling "barrier-reef," has a nearly uniform structure. The reefs in some of the original surveys are represented merely by a single line with crosses, so that their breadth is not given; I have had such reefs engraved of the width usually attained by coral-reefs. I have not thought it worth while to introduce all those small and very numerous reefs, which occur within the lagoons of most atolls and within the lagoon-channels of most barrier-reefs,

and which stand either isolated, or are attached to the shores of the reef or land. At Peros Banhos none of the lagoon-reefs rise to the surface of the water; a few of them have been introduced, and are marked by plain dotted circles. A few of the deepest soundings are laid down within each reef; they are in fathoms, of six English feet.

Figure 1. – VANIKORO, situated in the western part of the South Pacific; taken from the survey by Captain D'Urville in the "Astrolabe;" the soundings on the southern side of the island, namely, from thirty to forty fathoms, are given from the voyage of the Chev. Dillon; the other soundings are laid down from the survey by D'Urville; height of the summit of the island is 3,032 feet. The principal small detached reefs within the lagoon-channel have in this instance been represented. The southern shore of the island is narrowly fringed by a reef: if the engraver had carried this reef entirely round both islands, this figure would have served (by leaving out in imagination the barrier-reef) as a good specimen of an abruptly-sided island, surrounded by a reef of the fringing class.

Figure 2. – HOGOLEU, or ROUG, in the Caroline Archipelago; taken from the

"Atlas of the Voyage of the 'Astrolabe,'" compiled from the surveys of

Captains Duperrey and D'Urville; the depth of the immense lagoon-like space within the reef is not known.

Figure 3. – RAIATEA, in the Society Archipelago; from the

map given in the quarto edition of "Cook's First Voyage;" it is probably not accurate.

Figure 4. – BOW, or HEYOU ATOLL (or lagoon-island), in the Low Archipelago, from the survey by Captain Beechey, R.N.; the lagoon is choked up with reefs, but the average greatest depth of about twenty fathoms, is given from the published account of the voyage.

Figure 5. – BOLABOLA, in the Society Archipelago, from the survey of Captain Duperrey in the "Coquille: " the soundings in this and the following figures have been altered from French feet to English fathoms; height of highest point of the island 4,026 feet.

Figure 6. – MAURUA, in the Society Archipelago; from the survey by Captain

Duperrey in the "Coquille: " height of land about eight hundred feet.

Figure 7. – POUYNIPETE, or SENIAVINE, in the Caroline Archipelago; from the survey by Admiral Lutke.

Figure 8. – GAMBIER ISLANDS, in the southern part of the Low Archipelago; from the survey by Captain Beechey; height of highest island, 1,246 feet; the islands are surrounded by extensive and irregular reefs; the reef on the southern side is submerged.

Figure 9. – PEROS BANHOS ATOLL (or lagoon-island), in the Chagos group in the Indian Ocean; from the survey by Captain Moresby and Lieutenant Powell; not nearly all the small submerged reefs in the lagoon are represented; the annular reef

on the southern side is submerged.

Figure 10. – KEELING, or COCOS ATOLL (or lagoon-island), in the Indian Ocean; from the survey by Captain Fitzroy; the lagoon south of the dotted line is very shallow, and is left almost bare at low water; the part north of the line is choked up with irregular reefs. The annular reef on the north-west side is broken, and blends into a shoal sandbank, on which the sea breaks.

CHAPTER I. – ATOLLS OR LAGOON-ISLANDS

SECTION 1.I. – KEELING ATOLL.

Corals on the outer margin. – Zone of Nulliporae. – Exterior reef. – Islets. —

Coral-conglomerate. – Lagoon. – Calcareous sediment. – Scari and Holuthuriae subsisting on corals. – Changes in the condition of the reefs and islets. —

Probable subsidence of the atoll. – Future state of the lagoon.

(PLATE: UNTITLED WOODCUT, VERTICAL SECTION THROUGH KEELING ATOLL.)

A. – Level of the sea at low water: where the letter A is placed, the depth is twenty-five fathoms, and the distance rather more than one hundred and fifty yards from the edge of the reef.

B. – Outer edge of that flat part of the reef, which dries at low water: the edge either consists of a convex mound, as represented, or of rugged points, like those a little farther seaward, beneath the water.

C. – A flat of coral-rock, covered at high water.

D. – A low projecting ledge of brecciated coral-rock washed by the waves at high water.

E. – A slope of loose fragments, reached by the sea only during gales: the upper part, which is from six to twelve feet high, is

clothed with vegetation. The surface of the islet gently slopes to the lagoon.

F. – Level of the lagoon at low water.

KEELING or COCOS atoll is situated in the Indian Ocean, in 12 deg 5' S., and longitude 90 deg 55' E.: a reduced chart of it was made from the survey of Captain Fitzroy and the Officers of H.M.S. "Beagle," is given in Plate I., Figure 10. The greatest width of this atoll is nine miles and a half. Its structure is in most respects characteristic of the class to which it belongs, with the exception of the shallowness of the lagoon. The accompanying woodcut represents a vertical section, supposed to be drawn at low water from the outer coast across one of the low islets (one being taken of average dimensions) to within the lagoon.

The section is true to the scale in a horizontal line, but it could not be made so in a vertical one, as the average greatest height of the land is only between six and twelve feet above high-water mark.

I will describe the section, commencing with the outer margin. I must first observe that the reef-building polypifers, not being tidal animals, require to be constantly submerged or washed by the breakers. I was assured by Mr. Liesk, a very intelligent resident on these islands, as well as by some chiefs at Tahiti (Otaheite), that an exposure to the rays of the sun for a very short time invariably causes their destruction. Hence it is possible only under the most favourable circumstances, afforded by an unusually low tide and smooth water, to reach the outer margin,

where the coral is alive. I succeeded only twice in gaining this part, and found it almost entirely composed of a living Porites, which forms great irregularly rounded masses (like those of an Astraea, but larger) from four to eight feet broad, and little less in thickness. These mounds are separated from each other by narrow crooked channels, about six feet deep, most of which intersect the line of reef at right angles. On the furthest mound, which I was able to reach by the aid of a leaping-pole, and over which the sea broke with some violence, although the day was quite calm and the tide low, the polypifers in the uppermost cells were all dead, but between three and four inches lower down on its side they were living, and formed a projecting border round the upper and dead surface. The coral being thus checked in its upward growth, extends laterally, and hence most of the masses, especially those a little further inwards, had broad flat dead summits. On the other hand I could see, during the recoil of the breakers, that a few yards further seaward, the whole convex surface of the Porites was alive; so that the point where we were standing was almost on the exact upward and shoreward limit of existence of those corals which form the outer margin of the reef. We shall presently see that there are other organic productions, fitted to bear a somewhat longer exposure to the air and sun.

Next, but much inferior in importance to the Porites, is the Millepora complanata. (This Millepora (Palmipora of Blainville), as well as the M. alcicornis, possesses the singular property of stinging the skin where it is delicate, as on the face

and arm.)

It grows in thick vertical plates, intersecting each other at various angles, and forms an exceedingly strong honeycombed mass, which generally affects a circular form, the marginal plates alone being alive. Between these plates and in the protected crevices on the reef, a multitude of branching zoophytes and other productions flourish, but the Porites and Millepora alone seem able to resist the fury of the breakers on its upper and outer edge: at the depth of a few fathoms other kinds of stony corals live. Mr. Liesk, who was intimately acquainted with every part of this reef, and likewise with that of North Keeling atoll, assured me that these corals invariably compose the outer margin. The lagoon is inhabited by quite a distinct set of corals, generally brittle and thinly branched; but a Porites, apparently of the same species with that on the outside, is found there, although it does not seem to thrive, and certainly does not attain the thousandth part in bulk of the masses opposed to the breakers.

The woodcut shows the form of the bottom off the reef: the water deepens for a space between one and two hundred yards wide, very gradually to twenty-five fathoms (A in section), beyond which the sides plunge into the unfathomable ocean at an angle of 45 deg. (The soundings from which this section is laid down were taken with great care by Captain Fitzroy himself. He used a bell-shaped lead, having a diameter of four inches, and the armings each time were cut off and brought on board for me to examine. The arming is a preparation of tallow, placed

in the concavity at the bottom of the lead. Sand, and even small fragments of rock, will adhere to it; and if the bottom be of rock it brings up an exact impression of its surface.) To the depth of ten or twelve fathoms the bottom is exceedingly rugged, and seems formed of great masses of living coral, similar to those on the margin. The arming of the lead here invariably came up quite clean, but deeply indented, and chains and anchors which were lowered, in the hopes of tearing up the coral, were broken. Many small fragments, however, of Millepora alcicornis were brought up; and on the arming from an eight-fathom cast, there was a perfect impression of an Astraea, apparently alive. I examined the rolled fragments cast on the beach during gales, in order further to ascertain what corals grew outside the reef. The fragments consisted of many kinds, of which the Porites already mentioned and a Madrepora, apparently the M. corymbosa, were the most abundant. As I searched in vain in the hollows on the reef and in the lagoon, for a living specimen of this Madrepore, I conclude that it is confined to a zone outside, and beneath the surface, where it must be very abundant. Fragments of the Millepora alcicornis and of an Astraea were also numerous; the former is found, but not in proportionate numbers, in the hollows on the reef; but the Astraea I did not see living. Hence we may infer, that these are the kinds of coral which form the rugged sloping surface (represented in the woodcut by an uneven line), round and beneath the external margin. Between twelve and twenty fathoms the arming came up an equal number of times

smoothed with sand, and indented with coral: an anchor and lead were lost at the respective depths of thirteen and sixteen fathoms. Out of twenty-five soundings taken at a greater depth than twenty fathoms, every one showed that the bottom was covered with sand; whereas, at a less depth than twelve fathoms, every sounding showed that it was exceedingly rugged, and free from all extraneous particles. Two soundings were obtained at the depth of 360 fathoms, and several between two hundred and three hundred fathoms. The sand brought up from these depths consisted of finely triturated fragments of stony zoophytes, but not, as far as I could distinguish, of a particle of any lamelliform genus: fragments of shells were rare.

At a distance of 2,200 yards from the breakers, Captain Fitzroy found no bottom with a line of 7,200 feet in length; hence the submarine slope of this coral formation is steeper than that of any volcanic cone. Off the mouth of the lagoon, and likewise off the northern point of the atoll, where the currents act violently, the inclination, owing to the accumulation of sediment, is less. As the arming of the lead from all the greater depths showed a smooth sandy bottom, I at first concluded that the whole consisted of a vast conical pile of calcareous sand, but the sudden increase of depth at some points, and the circumstance of the line having been cut, as if rubbed, when between five hundred and six hundred fathoms were out, indicate the probable existence of submarine cliffs.

On the margin of the reef, close within the line where the

upper surface of the Porites and of the Millepora is dead, three species of Nullipora flourish. One grows in thin sheets, like a lichen on old trees; the second in stony knobs, as thick as a man's finger, radiating from a common centre; and the third, which is less common, in a moss-like reticulation of thin, but perfectly rigid branches. (This last species is of a beautiful bright peach-blossom colour. Its branches are about as thick as crow-quills; they are slightly flattened and knobbed at the extremities. The extremities only are alive and brightly coloured. The two other species are of a dirty purplish-white. The second species is extremely hard; its short knob-like branches are cylindrical, and do not grow thicker at their extremities.) The three species occur either separately or mingled together; and they form by their successive growth a layer two or three feet in thickness, which in some cases is hard, but where formed of the lichen-like kind, readily yields an impression to the hammer: the surface is of a reddish colour. These Nulliporae, although able to exist above the limit of true corals, seem to require to be bathed during the greater part of each tide by breaking water, for they are not found in any abundance in the protected hollows on the back part of the reef, where they might be immersed either during the whole or an equal proportional time of each tide. It is remarkable that organic productions of such extreme simplicity, for the Nulliporae undoubtedly belong to one of the lowest classes of the vegetable kingdom, should be limited to a zone so peculiarly circumstanced. Hence the layer composed by

their growth merely fringes the reef for a space of about twenty yards in width, either under the form of separate mammillated projections, where the outer masses of coral are separate, or, more commonly, where the corals are united into a solid margin, as a continuous smooth convex mound (B in woodcut), like an artificial breakwater. Both the mound and mammillated projections stand about three feet higher than any other part of the reef, by which term I do not include the islets, formed by the accumulation of rolled fragments. We shall hereafter see that other coral reefs are protected by a similar thick growth of Nulliporae on the outer margin, the part most exposed to the breakers, and this must effectually aid in preserving it from being worn down.

The woodcut represents a section across one of the islets on the reef, but if all that part which is above the level of C were removed, the section would be that of a simple reef, as it occurs where no islet has been formed. It is this reef which essentially forms the atoll. It is a ring, enclosing the lagoon on all sides except at the northern end, where there are two open spaces, through one of which ships can enter. The reef varies in width from two hundred and fifty to five hundred yards, its surface is level, or very slightly inclined towards the lagoon, and at high tide the sea breaks entirely over it: the water at low tide thrown by the breakers on the reef, is carried by the many narrow and shoal gullies or channels on its surface, into the lagoon: a return stream sets out of the lagoon through the main entrance. The

most frequent coral in the hollows on the reef is Pocillopora verrucosa, which grows in short sinuous plates, or branches, and when alive is of a beautiful pale lake-red: a Madrepora, closely allied or identical with M. pocillifera, is also common. As soon as an islet is formed, and the waves are prevented breaking entirely over the reef, the channels and hollows in it become filled up with cemented fragments, and its surface is converted into a hard smooth floor (C of woodcut), like an artificial one of freestone. This flat surface varies in width from one hundred to two hundred, or even three hundred yards, and is strewed with a few large fragments of coral torn up during gales: it is uncovered only at low water. I could with difficulty, and only by the aid of a chisel, procure chips of rock from its surface, and therefore could not ascertain how much of it is formed by the aggregation of detritus, and how much by the outward growth of mounds of corals, similar to those now living on the margin. Nothing can be more singular than the appearance at low tide of this "flat" of naked stone, especially where it is externally bounded by the smooth convex mound of Nulliporae, appearing like a breakwater built to resist the waves, which are constantly throwing over it sheets of foaming water. The characteristic appearance of this "flat" is shown in the foregoing woodcut of Whitsunday atoll.

The islets on the reef are first formed between two hundred and three hundred yards from its outer edge, through the accumulation of a pile of fragments, thrown together by some

unusually strong gale. Their ordinary width is under a quarter of a mile, and their length varies from a few yards to several miles. Those on the south-east and windward side of the atoll, increase solely by the addition of fragments on their outer side; hence the loose blocks of coral, of which their surface is composed, as well as the shells mingled with them, almost exclusively consist of those kinds which live on the outer coast. The highest part of the islets (excepting hillocks of blown sand, some of which are thirty feet high), is close to the outer beach (E of the woodcut), and averages from six to ten feet above ordinary high-water mark. From the outer beach the surface slopes gently to the shores of the lagoon, which no doubt has been caused by the breakers the further they have rolled over the reef, having had less power to throw up fragments. The little waves of the lagoon heap up sand and fragments of thinly-branched corals on the inner side of the islets on the leeward side of the atoll; and these islets are broader than those to windward, some being even eight hundred yards in width; but the land thus added is very low. The fragments beneath the surface are cemented into a solid mass, which is exposed as a ledge (D of the woodcut), projecting some yards in front of the outer shore and from two to four feet high. This ledge is just reached by the waves at ordinary high-water: it extends in front of all the islets, and everywhere has a water-worn and scooped appearance. The fragments of coral which are occasionally cast on the "flat" are during gales of unusual violence swept together on the beach, where the waves each day at high-water tend to

remove and gradually wear them down; but the lower fragments having become firmly cemented together by the percolation of calcareous matter, resist the daily tides longer, and hence project as a ledge. The cemented mass is generally of a white colour, but in some few parts reddish from ferruginous matter; it is very hard, and is sonorous under the hammer; it is obscurely divided by seams, dipping at a small angle seaward; it consists of fragments of the corals which grow on the outer margin, some quite and others partially rounded, some small and others between two and three feet across; and of masses of previously formed conglomerate, torn up, rounded, and re-cemented; or it consists of a calcareous sandstone, entirely composed of rounded particles, generally almost blended together, of shells, corals, the spines of echini, and other such organic bodies; rocks, of this latter kind, occur on many shores, where there are no coral reefs. The structure of the coral in the conglomerate has generally been much obscured by the infiltration of spathose calcareous matter; and I collected a very interesting series, beginning with fragments of unaltered coral, and ending with others, where it was impossible to discover with the naked eye any trace of organic structure. In some specimens I was unable, even with the aid of a lens, and by wetting them, to distinguish the boundaries of the altered coral and spathose limestone. Many even of the blocks of coral lying loose on the beach, had their central parts altered and infiltrated.

The lagoon alone remains to be described; it is much shallower

than that of most atolls of considerable size. The southern part is almost filled up with banks of mud and fields of coral, both dead and alive, but there are considerable spaces, between three and four fathoms, and smaller basins, from eight to ten fathoms deep. Probably about half its area consists of sediment, and half of coral-reefs. The corals composing these reefs have a very different aspect from those on the outside; they are very numerous in kind, and most of them are thinly branched. Meandrina, however, lives in the lagoon, and great rounded masses of this coral are numerous, lying quite or almost loose on the bottom. The other commonest kinds consist of three closely allied species of true Madrepora in thin branches; of Seriatapora subulata; two species of Porites (This Porites has somewhat the habit of P. clavaria, but the branches are not knobbed at their ends. When alive it is of a yellow colour, but after having been washed in fresh water and placed to dry, a jet-black slimy substance exuded from the entire surface, so that the specimen now appears as if it had been dipped in ink.) with cylindrical branches, one of which forms circular clumps, with the exterior branches only alive; and lastly, a coral something like an Explanaria, but with stars on both surfaces, growing in thin, brittle, stony, foliaceous expansions, especially in the deeper basins of the lagoon. The reefs on which these corals grow are very irregular in form, are full of cavities, and have not a solid flat surface of dead rock, like that surrounding the lagoon; nor can they be nearly so hard, for the inhabitants made with crowbars

a channel of considerable length through these reefs, in which a schooner, built on the S.E. islet, was floated out. It is a very interesting circumstance, pointed out to us by Mr. Liesk, that this channel, although made less than ten years before our visit, was then, as we saw, almost choked up with living coral, so that fresh excavations would be absolutely necessary to allow another vessel to pass through it.

The sediment from the deepest parts in the lagoon, when wet, appeared chalky, but when dry, like very fine sand. Large soft banks of similar, but even finer grained mud, occur on the S.E. shore of the lagoon, affording a thick growth of a Fucus, on which turtle feed: this mud, although discoloured by vegetable matter, appears from its entire solution in acids to be purely calcareous. I have seen in the Museum of the Geological Society, a similar but more remarkable substance, brought by Lieutenant Nelson from the reefs of Bermuda, which, when shown to several experienced geologists, was mistaken by them for true chalk. On the outside of the reef much sediment must be formed by the action of the surf on the rolled fragments of coral; but in the calm waters of the lagoon, this can take place only in a small degree. There are, however, other and unexpected agents at work here: large shoals of two species of Scarus, one inhabiting the surf outside the reef and the other the lagoon, subsist entirely, as I was assured by Mr. Liesk, the intelligent resident before referred to, by browsing on the living polypifers. I opened several of these fish, which are very numerous and of considerable size,

and I found their intestines distended by small pieces of coral, and finely ground calcareous matter. This must daily pass from them as the finest sediment; much also must be produced by the infinitely numerous vermiform and molluscous animals, which make cavities in almost every block of coral. Dr. J. Allan, of Forres, who has enjoyed the best means of observation, informs me in a letter that the Holothuriae (a family of Radiata) subsist on living coral; and the singular structure of bone within the anterior extremity of their bodies, certainly appears well adapted for this purpose. The number of the species of Holothuria, and of the individuals which swarm on every part of these coral-reefs, is extraordinarily great; and many shiploads are annually freighted, as is well-known, for China with the trepang, which is a species of this genus. The amount of coral yearly consumed, and ground down into the finest mud, by these several creatures, and probably by many other kinds, must be immense. These facts are, however, of more importance in another point of view, as showing us that there are living checks to the growth of coral-reefs, and that the almost universal law of "consumed and be consumed," holds good even with the polypifers forming those massive bulwarks, which are able to withstand the force of the open ocean.

Considering that Keeling atoll, like other coral formations, has been entirely formed by the growth of organic beings, and the accumulation of their detritus, one is naturally led to inquire how long it has continued, and how long it is likely to continue,

in its present state. Mr. Liesk informed me that he had seen an old chart in which the present long island on the S.E. side was divided by several channels into as many islets; and he assures me that the channels can still be distinguished by the smaller size of the trees on them. On several islets, also, I observed that only young cocoa-nut trees were growing on the extremities; and that older and taller trees rose in regular succession behind them; which shows that these islets have very lately increased in length. In the upper and south-eastern part of the lagoon, I was much surprised by finding an irregular field of at least a mile square of branching corals, still upright, but entirely dead. They consisted of the species already mentioned; they were of a brown colour, and so rotten, that in trying to stand on them I sank halfway up the leg, as if through decayed brushwood. The tops of the branches were barely covered by water at the time of lowest tide. Several facts having led me to disbelieve in any elevation of the whole atoll, I was at first unable to imagine what cause could have killed so large a field of coral. Upon reflection, however, it appeared to me that the closing up of the above-mentioned channels would be a sufficient cause; for before this, a strong breeze by forcing water through them into the head of the lagoon, would tend to raise its level. But now this cannot happen, and the inhabitants observe that the tide rises to a less height, during a high S.E. wind, at the head than at the mouth of the lagoon. The corals, which, under the former condition of things, had attained the utmost possible limit of upward growth, would thus occasionally be exposed for

a short time to the sun, and be killed.

Besides the increase of dry land, indicated by the foregoing facts, the exterior solid reef appears to have grown outwards. On the western side of the atoll, the "flat" lying between the margin of the reef and the beach, is very wide; and in front of the regular beach with its conglomerate basis, there is, in most parts, a bed of sand and loose fragments with trees growing out of it, which apparently is not reached even by the spray at high water. It is evident some change has taken place since the waves formed the inner beach; that they formerly beat against it with violence was evident, from a remarkably thick and water-worn point of conglomerate at one spot, now protected by vegetation and a bank of sand; that they beat against it in the same peculiar manner in which the swell from windward now obliquely curls round the margin of the reef, was evident from the conglomerate having been worn into a point projecting from the beach in a similarly oblique manner. This retreat in the line of action of the breakers might result, either from the surface of the reef in front of the islets having been submerged at one time, and afterward having grown upwards, or from the mounds of coral on the margin having continued to grow outwards. That an outward growth of this part is in process, can hardly be doubted from the fact already mentioned of the mounds of Porites with their summits apparently lately killed, and their sides only three or four inches lower down thickened by a fresh layer of living coral. But there is a difficulty on this supposition which I must not pass

over. If the whole, or a large part of the "flat," had been formed by the outward growth of the margin, each successive margin would naturally have been coated by the Nulliporae, and so much of the surface would have been of equal height with the existing zone of living Nulliporae: this is not the case, as may be seen in the woodcut. It is, however, evident from the abraded state of the "flat," with its original inequalities filled up, that its surface has been much modified; and it is possible that the hinder portions of the zone of Nulliporae, perishing as the reef grows outwards, might be worn down by the surf. If this has not taken place, the reef can in no part have increased outwards in breadth since its formation, or at least since the Nulliporae formed the convex mound on its margin; for the zone thus formed, and which stands between two and three feet above the other parts of the reef, is nowhere much above twenty yards in width.

Thus far we have considered facts, which indicate, with more or less probability, the increase of the atoll in its different parts: there are others having an opposite tendency. On the south-east side, Lieutenant Sulivan, to whose kindness I am indebted for many interesting observations, found the conglomerate projecting on the reef nearly fifty yards in front of the beach: we may infer from what we see in all other parts of the atoll, that the conglomerate was not originally so much exposed, but formed the base of an islet, the front and upper part of which has since been swept away. The degree to which the conglomerate, round nearly the whole atoll, has been scooped, broken up, and

the fragments cast on the beach, is certainly very surprising, even on the view that it is the office of occasional gales to pile up fragments, and of the daily tides to wear them away. On the western side, also, of the atoll, where I have described a bed of sand and fragments with trees growing out of it, in front of an old beach, it struck both Lieutenant Sulivan and myself, from the manner in which the trees were being washed down, that the surf had lately recommenced an attack on this line of coast. Appearances indicating a slight encroachment of the water on the land, are plainer within the lagoon: I noticed in several places, both on its windward and leeward shores, old cocoa-nut trees falling with their roots undermined, and the rotten stumps of others on the beach, where the inhabitants assured us the cocoa-nut could not now grow. Captain Fitzroy pointed out to me, near the settlement, the foundation posts of a shed, now washed by every tide, but which the inhabitants stated, had seven years before stood above high watermark. In the calm waters of the lagoon, directly connected with a great, and therefore stable ocean, it seems very improbable that a change in the currents, sufficiently great to cause the water to eat into the land on all sides, should have taken place within a limited period. From these considerations I inferred, that probably the atoll had lately subsided to a small amount; and this inference was strengthened by the circumstance, that in 1834, two years before our visit, the island had been shaken by a severe earthquake, and by two slighter ones during the ten previous years. If, during these

subterranean disturbances, the atoll did subside, the downward movement must have been very small, as we must conclude from the fields of dead coral still lipping the surface of the lagoon, and from the breakers on the western shore not having yet regained the line of their former action. The subsidence must, also, have been preceded by a long period of rest, during which the islets extended to their present size, and the living margin of the reef grew either upwards, or as I believe outwards, to its present distance from the beach.

Whether this view be correct or not, the above facts are worthy of attention, as showing how severe a struggle is in progress on these low coral formations between the two nicely balanced powers of land and water. With respect to the future state of Keeling atoll, if left undisturbed, we can see that the islets may still extend in length; but as they cannot resist the surf until broken by rolling over a wide space, their increase in breadth must depend on the increasing breadth of the reef; and this must be limited by the steepness of the submarine flanks, which can be added to only by sediment derived from the wear and tear of the coral. From the rapid growth of the coral in the channel cut for the schooner, and from the several agents at work in producing fine sediment, it might be thought that the lagoon would necessarily become quickly filled up. Some of this sediment, however, is transported into the open sea, as appears from the soundings off the mouth of the lagoon, instead of being deposited within it. The deposition, moreover, of sediment,

checks the growth of coral-reefs, so that these two agencies cannot act together with full effect in filling it up. We know so little of the habits of the many different species of corals, which form the lagoon-reefs, that we have no more reasons for supposing that their whole surface would grow up as quickly as the coral did in the schooner-channel, than for supposing that the whole surface of a peat-moss would increase as quickly as parts are known to do in holes, where the peat has been cut away. These agencies, nevertheless, tend to fill up the lagoon; but in proportion as it becomes shallower, so must the polypifers be subject to many injurious agencies, such as impure water and loss of food. For instance, Mr. Liesk informed me, that some years before our visit unusually heavy rain killed nearly all the fish in the lagoon, and probably the same cause would likewise injure the corals. The reefs also, it must be remembered, cannot possibly rise above the level of the lowest spring-tide, so that the final conversion of the lagoon into land must be due to the accumulation of sediment; and in the midst of the clear water of the ocean, and with no surrounding high land, this process must be exceedingly slow.

SECTION 1.II. – GENERAL DESCRIPTION OF ATOLLS

General form and size of atolls, their reefs and islets. – External slope. – Zone of Nulliporae. – Conglomerate. – Depth of lagoons. – Sediment. – Reefs submerged wholly or in part. – Breaches in the reef. – Ledge-formed shores round certain lagoons. – Conversion of lagoons into land.

I will here give a sketch of the general form and structure of the many atolls and atoll-formed reefs which occur in the Pacific and Indian Oceans, comparing them with Keeling atoll. The Maldiva atolls and the Great Chagos Bank differ in so many respects, that I shall devote to them, besides occasional references, a third section of this chapter. Keeling atoll may be considered as of moderate dimensions and of regular form. Of the thirty-two islands surveyed by Captain Beechey in the Low Archipelago, the longest was found to be thirty miles, and the shortest less than a mile; but Vliegen atoll, situated in another part of the same group, appears to be sixty miles long and twenty broad. Most of the atolls in this group are of an elongated form; thus Bow Island is thirty miles in length, and on an average only six in width (See Figure 4, Plate I.), and Clermont Tonnere has nearly the same proportions. In the Marshall Archipelago (the Ralick and Radack group of Kotzebue) several of the atolls are more than thirty miles in length, and Rimsky Korsacoff is fifty-

four long, and twenty wide, at the broadest part of its irregular outline. Most of the atolls in the Maldiva Archipelago are of great size, one of them (which, however, bears a double name) measured in a medial and slightly curved line, is no less than eighty-eight geographical miles long, its greatest width being under twenty, and its least only nine and a half miles. Some atolls have spurs projecting from them; and in the Marshall group there are atolls united together by linear reefs, for instance Menchikoff Island (See Figure 3, Plate II.), which is sixty miles in length, and consists of three loops tied together. In far the greater number of cases an atoll consists of a simple elongated ring, with its outline moderately regular.

The average width of the annular wreath may be taken as about a quarter of a mile. Captain Beechey (Beechey's "Voyage to the Pacific and Beering's Straits," chapter viii.) says that in the atolls of the Low Archipelago it exceeded in no instance half a mile. The description given of the structure and proportional dimensions of the reef and islets of Keeling atoll, appears to apply perfectly to nearly all the atolls in the Pacific and Indian Oceans. The islets are first formed some way back either on the projecting points of the reef, especially if its form be angular, or on the sides of the main entrances into the lagoon – that is in both cases, on points where the breakers can act during gales of wind in somewhat different directions, so that the matter thrown up from one side may accumulate against that before thrown up from another. In Lutke's chart of the Caroline atolls, we see many

instances of the former case; and the occurrence of islets, as if placed for beacons, on the points where there is a gateway or breach through the reef, has been noticed by several authors. There are some atoll-formed reefs, rising to the surface of the sea and partly dry at low water, on which from some cause islets have never been formed; and there are others on which they have been formed, but have subsequently been worn away. In atolls of small dimensions the islets frequently become united into a single horse-shoe or ring-formed strip; but Diego Garcia, although an atoll of considerable size, being thirteen miles and a half in length, has its lagoon entirely surrounded, except at the northern end, by a belt of land, on an average a third of a mile in width. To show how small the total area of the annular reef and the land is in islands of this class, I may quote a remark from the voyage of Lutke, namely, that if the forty-three rings, or atolls, in the Caroline Archipelago, were put one within another, and over a steeple in the centre of St. Petersburg, the whole world would not cover that city and its suburbs.

The form of the bottom off Keeling atoll, which gradually slopes to about twenty fathoms at the distance of between one and two hundred yards from the edge of the reef, and then plunges at an angle of 45 deg into unfathomable depths, is exactly the same (The form of the bottom round the Marshall atolls in the Northern Pacific is probably similar: Kotzebue ("First Voyage," volume ii., page 16) says: "We had at a small distance from the reef, forty fathoms depth, which increased a little further so

much that we could find no bottom.") with that of the sections of the atolls in the Low Archipelago given by Captain Beechey. The nature, however, of the bottom seems to differ, for this officer (I must be permitted to express my obligation to Captain Beechey, for the very kind manner in which he has given me information on several points, and to own the great assistance I have derived from his excellent published work.) informs me that all the soundings, even the deepest, were on coral, but he does not know whether dead or alive. The slope round Christmas atoll (Lat. 1 deg 4' N., 157 deg 45' W.), described by Cook (Cook's "Third Voyage," volume ii., chapter 10.), is considerably less, at about half a mile from the edge of the reef, the average depth was about fourteen fathoms on a fine sandy bottom, and at a mile, only between twenty and forty fathoms. It has no doubt been owing to this gentle slope, that the strip of land surrounding its lagoon, has increased in one part to the extraordinary width of three miles; it is formed of successive ridges of broken shells and corals, like those on the beach. I know of no other instance of such width in the reef of an atoll; but Mr. F.D. Bennett informs me that the inclination of the bottom round Caroline atoll in the Pacific, is like that off Christmas Island, very gentle. Off the Maldiva and Chagos atolls, the inclination is much more abrupt; thus at Heawandoo Pholo, Lieutenant Powell (This fact is taken from a MS. account of these groups lent me by Captain Moresby. See also Captain Moresby's paper on the Maldiva atolls in the "Geographical Journal", volume v., page 401.) found fifty and

sixty fathoms close to the edge of the reef, and at 300 yards distance there was no bottom with a 300-yard line. Captain Moresby informs me, that at 100 fathoms from the mouth of the lagoon of Diego Garcia, he found no bottom with 150 fathoms; this is the more remarkable, as the slope is generally less abrupt in front of channels through a reef, owing to the accumulation of sediment. At Egmont Island, also, at 150 fathoms from the reef, soundings were struck with 150 fathoms. Lastly, at Cardoo atoll, only sixty yards from the reef, no bottom was obtained, as I am informed by Captain Moresby, with a line of 200 fathoms! The currents run with great force round these atolls, and where they are strongest, the inclination appears to be most abrupt. I am informed by the same authority, that wherever soundings were obtained off these islands, the bottom was invariably sandy: nor was there any reason to suspect the existence of submarine cliffs, as there was at Keeling Island. (Off some of the islands in the Low Archipelago the bottom appears to descend by ledges. Off Elizabeth Island, which, however, consists of raised coral, Captain Beechey (page 45, 4to edition) describes three ledges: the first had an easy slope from the beach to a distance of about fifty yards: the second extended two hundred yards with twenty-five fathoms on it, and then ended abruptly, like the first; and immediately beyond this there was no bottom with two hundred fathoms.) Here then occurs a difficulty; can sand accumulate on a slope, which, in some cases, appears to exceed fifty-five degrees? It must be observed, that I speak of slopes where soundings were

obtained, and not of such cases, as that of Cardoo, where the nature of the bottom is unknown, and where its inclination must be nearly vertical. M. Elie de Beaumont ("Memoires pour servir a une description Geolog. de France," tome iv., page 216.) has argued, and there is no higher authority on this subject, from the inclination at which snow slides down in avalanches, that a bed of sand or mud cannot be formed at a greater angle than thirty degrees. Considering the number of soundings on sand, obtained round the Maldiva and Chagos atolls, which appears to indicate a greater angle, and the extreme abruptness of the sand-banks in the West Indies, as will be mentioned in the Appendix, I must conclude that the adhesive property of wet sand counteracts its gravity, in a much greater ratio than has been allowed for by M. Elie de Beaumont. From the facility with which calcareous sand becomes agglutinated, it is not necessary to suppose that the bed of loose sand is thick.

Captain Beechey has observed, that the submarine slope is much less at the extremities of the more elongated atolls in the Low Archipelago, than at their sides; in speaking of Ducie's Island he says (Beechey's "Voyage," 4to edition, page 44.) the buttress, as it may be called, which "has the most powerful enemy (the S.W. swell) to oppose, is carried out much further, and with less abruptness than the other." In some cases, the less inclination of a certain part of the external slope, for instance of the northern extremities of the two Keeling atolls, is caused by a prevailing current which there accumulates a bed of sand. Where the water

is perfectly tranquil, as within a lagoon, the reefs generally grow up perpendicularly, and sometimes even overhang their bases; on the other hand, on the leeward side of Mauritius, where the water is generally tranquil, although not invariably so, the reef is very gently inclined. Hence it appears that the exterior angle varies much; nevertheless in the close similarity in form between the sections of Keeling atoll and of the atolls in the Low Archipelago, in the general steepness of the reefs of the Maldiva and Chagos atolls, and in the perpendicularity of those rising out of water always tranquil, we may discern the effects of uniform laws; but from the complex action of the surf and currents, on the growing powers of the coral and on the deposition of sediment, we can by no means follow out all the results.

Where islets have been formed on the reef, that part which I have sometimes called the "flat" and which is partly dry at low water, appears similar in every atoll. In the Marshall group in the North Pacific, it may be inferred from Chamisso's description, that the reef, where islets have not been formed on it, slopes gently from the external margin to the shores of the lagoon; Flinders states that the Australian barrier has a similar inclination inwards, and I have no doubt it is of general occurrence, although, according to Ehrenberg, the reefs of the Red Sea offer an exception. Chamisso observes that "the red colour of the reef (at the Marshall atolls) under the breakers is caused by a Nullipora, which covers the stone WHEREVER THE WAVES BEAT; and, under favourable circumstances, assumes a stalactical form," – a

description perfectly applicable to the margin of Keeling atoll. (Kotzebue's "First Voyage," volume iii., page 142. Near Porto Praya, in the Cape de Verde Islands, some basaltic rocks, lashed by no inconsiderable surf, were completely enveloped with a layer of Nulliporae. The entire surface over many square inches, was coloured of a peach-blossomed red; the layer, however, was of no greater thickness than paper. Another kind, in the form of projecting knobs, grew in the same situation. These Nulliporae are closely related to those described on the coral-reefs, but I believe are of different species.) Although Chamisso does not state that the masses of Nulliporae form points or a mound, higher than the flat, yet I believe that this is the case; for Kotzebue (Kotzebue, "First Voyage," volume ii., page 16. Lieutenant Nelson, in his excellent memoir in the Geological Transactions (volume ii., page 105), alludes to the rocky points mentioned by Kotzebue, and infers that they consist of Serpulae, which compose incrusting masses on the reefs of Bermudas, as they likewise do on a sandstone bar off the coast of Brazil (which I have described in "London Phil. Journal," October 1841). These masses of Serpulae hold the same position, relatively to the action of the sea, with the Nulliporae on the coral-reefs in the Indian and Pacific Oceans.), in another part, speaks of the rocks on the edge of the reef "as visible for about two feet at low water," and these rocks we may feel quite certain are not formed of true coral (Captain Moresby, in his valuable paper "on the Northern atolls of Maldivas" ("Geographical Journal", volume

v.), says that the edges of the reefs there stand above water at low spring-tides.) Whether a smooth convex mound of Nulliporae, like that which appears as if artificially constructed to protect the margin of Keeling Island, is of frequent occurrence round atolls, I know not; but we shall presently meet with it, under precisely the same form, on the outer edge of the "barrier-reefs" which encircle the Society Islands.

There appears to be scarcely a feature in the structure of Keeling reef, which is not of common, if not of universal occurrence, in other atolls. Thus Chamisso describes (Kotzebue's "First Voyage," volume iii., page 144.) a layer of coarse conglomerate, outside the islets round the Marshall atolls which "appears on its upper surface uneven and eaten away." From drawings, with appended remarks, of Diego Garcia in the Chagos group and of several of the Maldiva atolls, shown me by Captain Moresby (see also Moresby on the Northern atolls of the Maldivas, "Geographical Journal", volume v., page 400.), it is evident that their outer coasts are subject to the same round of decay and renovation as those of Keeling atoll. From the description of the atolls in the Low Archipelago, given in Captain Beechey's "Voyage," it is not apparent that any conglomerate coral-rock was there observed.

The lagoon in Keeling atoll is shallow; in the atolls of the Low Archipelago the depth varies from 20 to 38 fathoms, and in the Marshall Group, according to Chamisso, from 30 to 35; in the Caroline atolls it is only a little less. Within the Maldiva atolls

there are large spaces with 45 fathoms, and some soundings are laid down of 49 fathoms. The greater part of the bottom in most lagoons, is formed of sediment; large spaces have exactly the same depth, or the depth varies so insensibly, that it is evident that no other means, excepting aqueous deposition, could have leveled the surface so equally. In the Maldiva atolls this is very conspicuous, and likewise in some of the Caroline and Marshall Islands. In the former large spaces consist of sand and SOFT CLAY; and Kotzebue speaks of clay having been found within one of the Marshall atolls. No doubt this clay is calcareous mud, similar to that at Keeling Island, and to that at Bermuda already referred to, as undistinguishable from disintegrated chalk, and which Lieutenant Nelson says is called there pipe-clay. (I may here observe that on the coast of Brazil, where there is much coral, the soundings near the land are described by Admiral Roussin, in the "Pilote du Bresil", as siliceous sand, mingled with much finely comminuted particles of shells and coral. Further in the offing, for a space of 1,300 miles along the coast, from the Abrolhos Islands to Maranham, the bottom in many places is composed of "tuf blanc, mele ou forme de madrepores broyes." This white substance, probably, is analogous to that which occurs within the above-mentioned lagoons; it is sometimes, according to Roussin, firm, and he compares it to mortar.)

Where the waves act with unequal force on the two sides of an atoll, the islets appear to be first formed, and are generally of greater continuity on the more exposed shore. The islets, also,

which are placed to leeward, are in most parts of the Pacific liable to be occasionally swept entirely away by gales, equalling hurricanes in violence, which blow in an opposite direction to the ordinary trade-wind. The absence of the islets on the leeward side of atolls, or when present their lesser dimensions compared with those to windward, is a comparatively unimportant fact; but in several instances the reef itself on the leeward side, retaining its usual defined outline, does not rise to the surface by several fathoms. This is the case with the southern side of Peros Banhos (Plate I., Figure 9) in the Chagos group, with Mourileu atoll (Frederick Lutke's "Voyage autour du Monde," volume ii., page 291. See also his account of Namonouito, below, and the chart of Oulleay in the Atlas.) in the Caroline Archipelago, and with the barrier-reef (Plate I., Figure 8) of the Gambier Islands. I allude to the latter reef, although belonging to another class, because Captain Beechey was first led by it to observe the peculiarity in the question. At Peros Banhos the submerged part is nine miles in length, and lies at an average depth of about five fathoms; its surface is nearly level, and consists of hard stone, with a thin covering of loose sand. There is scarcely any living coral on it, even on the outer margin, as I have been particularly assured by Captain Moresby; it is, in fact, a wall of dead coral-rock, having the same width and transverse section with the reef in its ordinary state, of which it is a continuous portion. The living and perfect parts terminate abruptly, and abut on the submerged portions, in the same manner as on the sides of an

ordinary passage through the reef. The reef to leeward in other cases is nearly or quite obliterated, and one side of the lagoon is left open; for instance, at Oulleay (Caroline Archipelago), where a crescent-formed reef is fronted by an irregular bank, on which the other half of the annular reef probably once stood. At Namonouito, in the same Archipelago, both these modifications of the reef concur; it consists of a great flat bank, with from twenty to twenty-five fathoms water on it; for a length of more than forty miles on its southern side it is open and without any reef, whilst on the other sides it is bounded by a reef, in parts rising to the surface and perfectly characterised, in parts lying some fathoms submerged. In the Chagos group there are annular reefs, entirely submerged, which have the same structure as the submerged and defined portions just described. The Speaker's Bank offers an excellent example of this structure; its central expanse, which is about twenty-two fathoms deep, is twenty-four miles across; the external rim is of the usual width of annular reefs, and is well-defined; it lies between six and eight fathoms beneath the surface, and at the same depth there are scattered knolls in the lagoon. Captain Moresby believes the rim consists of dead rock, thinly covered with sand, and he is certain this is the case with the external rim of the Great Chagos Bank, which is also essentially a submerged atoll. In both these cases, as in the submerged portion of the reef at Peros Banhos, Captain Moresby feels sure that the quantity of living coral, even on the outer edge overhanging the deep-sea water, is quite

insignificant. Lastly, in several parts of the Pacific and Indian Oceans there are banks, lying at greater depths than in the cases just mentioned, of the same form and size with the neighbouring atolls, but with their atoll-like structure wholly obliterated. It appears from the survey of Freycinet, that there are banks of this kind in the Caroline Archipelago, and, as is reported, in the Low Archipelago. When we discuss the origin of the different classes of coral formations, we shall see that the submerged state of the whole of some atoll-formed reefs, and of portions of others, generally but not invariably on the leeward side, and the existence of more deeply submerged banks now possessing little or no signs of their original atoll-like structure, are probably the effects of a uniform cause, – namely, the death of the coral, during the subsidence of the area, in which the atolls or banks are situated.

There is seldom, with the exception of the Maldiva atolls, more than two or three channels, and generally only one leading into the lagoon, of sufficient depth for a ship to enter. in small atolls, there is usually not even one. Where there is deep water, for instance above twenty fathoms, in the middle of the lagoon, the channels through the reef are seldom as deep as the centre, – it may be said that the rim only of the saucer-shaped hollow forming the lagoon is notched. Mr. Lyell ("Principles of Geology," volume iii., page 289.) has observed that the growth of the coral would tend to obstruct all the channels through a reef, except those kept open by discharging the water, which during high tide and the greater part of each ebb is thrown over its

circumference. Several facts indicate that a considerable quantity of sediment is likewise discharged through these channels; and Captain Moresby informs me that he has observed, during the change of the monsoon, the sea discoloured to a distance off the entrances into the Maldiva and Chagos atolls. This, probably, would check the growth of the coral in them, far more effectually than a mere current of water. In the many small atolls without any channel, these causes have not prevented the entire ring attaining the surface. The channels, like the submerged and effaced parts of the reef, very generally though not invariably occur on the leeward side of the atoll, or on that side, according to Beechey (Beechey's "Voyage," 4to edition, volume i., page 189.), which, from running in the same direction with the prevalent wind, is not fully exposed to it. Passages between the islets on the reef, through which boats can pass at high water, must not be confounded with ship-channels, by which the annular reef itself is breached. The passages between the islets occur, of course, on the windward as well as on the leeward side; but they are more frequent and broader to leeward, owing to the lesser dimensions of the islets on that side.

At Keeling atoll the shores of the lagoon shelve gradually, where the bottom is of sediment, and irregularly or abruptly where there are coral-reefs; but this is by no means the universal structure in other atolls. Chamisso (Kotzebue's "First Voyage," volume iii., page 142.), speaking in general terms of the lagoons in the Marshall atolls, says the lead generally sinks "from a

depth of two or three fathoms to twenty or twenty-four, and you may pursue a line in which on one side of the boat you may see the bottom, and on the other the azure-blue deep water." The shores of the lagoon-like channel within the barrier-reef at Vanikoro have a similar structure. Captain Beechey has described a modification of this structure (and he believes it is not uncommon) in two atolls in the Low Archipelago, in which the shores of the lagoon descend by a few, broad, slightly inclined ledges or steps: thus at Matilda atoll (Beechey's "Voyage," 4to edition, volume i, page 160. At Whitsunday Island the bottom of the lagoon slopes gradually towards the centre, and then deepens suddenly, the edge of the bank being nearly perpendicular. This bank is formed of coral and dead shells.), the great exterior reef, the surface of which is gently inclined towards and beneath the surface of the lagoon, ends abruptly in a little cliff three fathoms deep; at its foot, a ledge forty yards wide extends, shelving gently inwards like the surface-reef, and terminated by a second little cliff five fathoms deep; beyond this, the bottom of the lagoon slopes to twenty fathoms, which is the average depth of its centre. These ledges seem to be formed of coral-rock; and Captain Beechey says that the lead often descended several fathoms through holes in them. In some atolls, all the coral reefs or knolls in the lagoon come to the surface at low water; in other cases of rarer occurrence, all lie at nearly the same depth beneath it, but most frequently they are quite irregular, – some with perpendicular, some with sloping sides, –

some rising to the surface, and others lying at all intermediate depths from the bottom upwards. I cannot, therefore, suppose that the union of such reefs could produce even one uniformly sloping ledge, and much less two or three, one beneath the other, and each terminated by an abrupt wall. At Matilda Island, which offers the best example of the step-like structure, Captain Beechey observes that the coral-knolls within the lagoon are quite irregular in their height. We shall hereafter see that the theory which accounts for the ordinary form of atolls, apparently includes this occasional peculiarity in their structure.

In the midst of a group of atolls, there sometimes occur small, flat, very low islands of coral formation, which probably once included a lagoon, since filled up with sediment and coral-reefs. Captain Beechey entertains no doubt that this has been the case with the two small islands, which alone of thirty-one surveyed by him in the Low Archipelago, did not contain lagoons. Romanzoff Island (in lat. 15 deg S.) is described by Chamisso (Kotzebue's "First Voyage," volume iii., page 221.) as formed by a dam of madreporitic rock inclosing a flat space, thinly covered with trees, into which the sea on the leeward side occasionally breaks. North Keeling atoll appears to be in a rather less forward stage of conversion into land; it consists of a horse-shoe shaped strip of land surrounding a muddy flat, one mile in its longest axis, which is covered by the sea only at high water. When describing South Keeling atoll, I endeavoured to show how slow the final process of filling up a lagoon must be; nevertheless, as all causes do tend

to produce this effect, it is very remarkable that not one instance, as I believe, is known of a moderately sized lagoon being filled up even to the low water-line at spring-tides, much less of such a one being converted into land. It is, likewise, in some degree remarkable, how few atolls, except small ones, are surrounded by a single linear strip of land, formed by the union of separate islets. We cannot suppose that the many atolls in the Pacific and Indian Oceans all have had a late origin, and yet should they remain at their present level, subjected only to the action of the sea and to the growing powers of the coral, during as many centuries as must have elapsed since any of the earlier tertiary epochs, it cannot, I think, be doubted that their lagoons and the islets on their reef, would present a totally different appearance from what they now do. This consideration leads to the suspicion that some renovating agency (namely subsidence) comes into play at intervals, and perpetuates their original structure.

(DESCRIPTION OF THE PLATES

PLATE II. – GREAT CHAGOS BANK, NEW CALEDONIA,MENCHIKOFF ATOLL, ETC.

FIGURE 1. – GREAT CHAGOS BANK, in the Indian Ocean; taken from the survey by Captain Moresby and Lieutenant Powell; the parts which are shaded, with the exception of two or three islets on the western and northern sides, do not rise to the surface, but are submerged from four to ten fathoms; the banks bounded by the dotted lines lie from fifteen to twenty fathoms beneath the surface, and are formed of sand; the central space is of mud, and from thirty to fifty fathoms deep.

FIGURE 2. – A vertical section, on the same scale, in an eastern and western line across the Great Chagos Bank, given for the sake of exhibiting more clearly its structure.

FIGURE 3. – MENCHIKOFF ATOLL (or lagoon-island), in the Marshall Archipelago, Northern Pacific Ocean; from Krusenstern's "Atlas of the Pacific;" originally surveyed by Captain Hagemeister; the depth within the lagoons is unknown.

FIGURE 4. – MAHLOS MAHDOO ATOLL, together with Horsburgh atoll, in the Maldiva Archipelago; from the survey by Captain Moresby and Lieutenant Powell; the white spaces in the middle of the separate small reefs, both on the margin and in the middle part, are meant to represent little lagoons; but it was found not possible to distinguish them clearly from the small

islets, which have been formed on these same small reefs; many of the smaller reefs could not be introduced; the nautical mark (dot over a dash) over the figures 250 and 200, between Mahlos Mahdoo and Horsburgh atoll and Powell's island, signifies that soundings were not obtained at these depths.

FIGURE 5. – NEW CALEDONIA, in the western part of the Pacific; from Krusenstern's "Atlas," compiled from several surveys; I have slightly altered the northern point of the reef, in accordance with the "Atlas of the Voyage of the 'Astrolabe'." In Krusenstern's "Atlas," the reef is represented by a single line with crosses; I have for the sake of uniformity added an interior line.

FIGURE 6. – MALDIVA ARCHIPELAGO, in the Indian Ocean; from the survey by Captain Moresby and Lieutenant Powell.)

SECTION 1.III. – ATOLLS OF THE MALDIVA ARCHIPELAGO – GREAT CHAGOS BANK

Maldiva Archipelago. – Ring-formed reefs, marginal and central. – Great depths in the lagoons of the southern atolls. – Reefs in the lagoons all rising to the surface. – Position of islets and breaches in the reefs, with respect to the prevalent winds and action of the waves. – Destruction of islets. – Connection in the position and submarine foundation of distinct atolls. – The apparent disseverment of large atolls. – The Great Chagos Bank. – Its submerged condition and extraordinary structure.

Although occasional references have been made to the Maldiva atolls, and to the banks in the Chagos group, some points of their structure deserve further consideration. My description is derived from an examination of the admirable charts lately published from the survey of Captain Moresby and Lieutenant Powell, and more especially from information which Captain Moresby has communicated to me in the kindest manner.

The Maldiva Archipelago is 470 miles in length, with an average breadth of about 50 miles. The form and dimensions of the atolls, and their singular position in a double line, may be seen, but not well, in the greatly reduced chart (Figure 6) in Plate II. The dimensions of the longest atoll in the group (called

by the double name of Milla-dou-Madou and Tilla-dou-Matte) have already been given; it is 88 miles in a medial and slightly curved line, and is less than 20 miles in its broadest part. Suadiva, also, is a noble atoll, being 44 miles across in one direction, and 34 in another, and the great included expanse of water has a depth of between 250 and 300 feet. The smaller atolls in this group differ in no respect from ordinary ones; but the larger ones are remarkable from being breached by numerous deep-water channels leading into the lagoon; for instance, there are 42 channels, through which a ship could enter the lagoon of Suadiva. In the three southern large atolls, the separate portions of reef between these channels have the ordinary structure, and are linear; but in the other atolls, especially the more northern ones, these portions are ring- formed, like miniature atolls. Other ring-formed reefs rise out of the lagoons, in the place of those irregular ones which ordinarily occur there. In the reduction of the chart of Mahlos Mahdoo (Plate II., Figure 4), it was not found easy to define the islets and the little lagoons within each reef, so that the ring-formed structure is very imperfectly shown; in the large published charts of Tilla-dou-Matte, the appearance of these rings, from standing further apart from each other, is very remarkable. The rings on the margin are generally elongated; many of them are three, and some even five miles, in diameter; those within the lagoon are usually smaller, few being more than two miles across, and the greater number rather less than one. The depth of the little lagoon within these small annular

reefs is generally from five to seven fathoms, but occasionally more; and in Ari atoll many of the central ones are twelve, and some even more than twelve fathoms deep. These rings rise abruptly from the platform or bank, on which they are placed; their outer margin is invariably bordered by living coral (Captain Moresby informs me that Millepora complanata is one of the commonest kinds on the outer margin, as it is at Keeling atoll.) within which there is a flat surface of coral rock; of this flat, sand and fragments have in many cases accumulated and been converted into islets, clothed with vegetation. I can, in fact, point out no essential difference between these little ring-formed reefs (which, however, are larger, and contain deeper lagoons than many true atolls that stand in the open sea), and the most perfectly characterised atolls, excepting that the ring-formed reefs are based on a shallow foundation, instead of on the floor of the open sea, and that instead of being scattered irregularly, they are grouped closely together on one large platform, with the marginal rings arranged in a rudely formed circle.

The perfect series which can be traced from portions of simple linear reef, to others including long linear lagoons, and from these again to oval or almost circular rings, renders it probable that the latter are merely modifications of the linear or normal state. It is conformable with this view, that the ring-formed reefs on the margin, even where most perfect and standing furthest apart, generally have their longest axes directed in the line which the reef would have held, if the atoll had been bounded by an

ordinary wall. We may also infer that the central ring-formed reefs are modifications of those irregular ones, which are found in the lagoons of all common atolls. It appears from the charts on a large scale, that the ring-like structure is contingent on the marginal channels or breaches being wide; and, consequently, on the whole interior of the atoll being freely exposed to the waters of the open sea. When the channels are narrow or few in number, although the lagoon be of great size and depth (as in Suadiva), there are no ring-formed reefs; where the channels are somewhat broader, the marginal portions of reef, and especially those close to the larger channels, are ring-formed, but the central ones are not so; where they are broadest, almost every reef throughout the atoll is more or less perfectly ring-formed. Although their presence is thus contingent on the openness of the marginal channels, the theory of their formation, as we shall hereafter see, is included in that of the parent atolls, of which they form the separate portions.

The lagoons of all the atolls in the southern part of the Archipelago are from ten to twenty fathoms deeper than those in the northern part. This is well exemplified in the case of Addoo, the southernmost atoll in the group, for although only nine miles in its longest diameter, it has a depth of thirty-nine fathoms, whereas all the other small atolls have comparatively shallow lagoons; I can assign no adequate cause for this difference in depth. In the central and deepest part of the lagoons, the bottom consists, as I am informed by Captain Moresby, of stiff clay

(probably a calcareous mud); nearer the border it consists of sand, and in the channels through the reef, of hard sand-banks, sandstone, conglomerate rubble, and a little live coral. Close outside the reef and the line joining its detached portions (where intersected by many channels), the bottom is sandy, and it slopes abruptly into unfathomable depths. In most lagoons the depth is considerably greater in the centre than in the channels; but in Tilla-dou-Matte, where the marginal ring-formed reefs stand far apart, the same depth is carried across the entire atoll, from the deep-water line on one side to that on the other. I cannot refrain from once again remarking on the singularity of these atolls, – a great sandy and generally concave disc rises abruptly from the unfathomable ocean, with its central expanse studded and its border symmetrically fringed with oval basins of coral-rock, just lipping the surface of the sea, sometimes clothed with vegetation, and each containing a little lake of clear water!

In the southern Maldiva atolls, of which there are nine large ones, all the small reefs within the lagoons come to the surface, and are dry at low water spring-tides; hence in navigating them, there is no danger from submarine banks. This circumstance is very remarkable, as within some atolls, for instance those of the neighbouring Chagos group, not a single reef comes to the surface, and in most other cases a few only do, and the rest lie at all intermediate depths from the bottom upwards. When treating of the growth of coral I shall again refer to this subject.

Although in the neighbourhood of the Maldiva Archipelago

the winds, during the monsoons, blow during nearly an equal time from opposite quarters, and although, as I am informed by Captain Moresby, the westerly winds are the strongest, yet the islets are almost all placed on the eastern side of the northern atolls, and on the south-eastern side of the southern atolls. That the formation of the islets is due to detritus thrown up from the outside, as in the ordinary manner, and not from the interior of the lagoons, may, I think be safely inferred from several considerations, which it is hardly worth while to detail. As the easterly winds are not the strongest, their action probably is aided by some prevailing swell or current.

In groups of atolls, exposed to a trade-wind, the ship-channels into the lagoons are almost invariably situated on the leeward or less exposed side of the reef, and the reef itself is sometimes either wanting there, or is submerged. A strictly analogous, but different fact, may be observed at the Maldiva atolls – namely, that where two atolls stand in front of each other, the breaches in the reef are the most numerous on their near, and therefore less exposed, sides. Thus on the near sides of Ari and the two Nillandoo atolls, which face S. Male, Phaleedoo, and Moloque atolls, there are seventy-three deep-water channels, and only twenty-five on their outer sides; on the near side of the three latter named atolls there are fifty- six openings, and only thirty-seven on their outsides. It is scarcely possible to attribute this difference to any other cause than the somewhat different action of the sea on the two sides, which would ensue from the protection afforded

by the two rows of atolls to each other. I may here remark that in most cases, the conditions favourable to the greater accumulation of fragments on the reef and to its more perfect continuity on one side of the atoll than on the other, have concurred, but this has not been the case with the Maldivas; for we have seen that the islets are placed on the eastern or south-eastern sides, whilst the breaches in the reef occur indifferently on any side, where protected by an opposite atoll. The reef being more continuous on the outer and more exposed sides of those atolls which stand near each other, accords with the fact, that the reef of the southern atolls is more continuous than that of the northern ones; for the former, as I am informed by Captain Moresby, are more constantly exposed than the northern atolls to a heavy surf.

The date of the first formation of some of the islets in this Archipelago is known to the inhabitants; on the other hand, several islets, and even some of those which are believed to be very old, are now fast wearing away. The work of destruction has, in some instances, been completed in ten years. Captain Moresby found on one water-washed reef the marks of wells and graves, which were excavated when it supported an islet. In South Nillandoo atoll, the natives say that three of the islets were formerly larger: in North Nillandoo there is one now being washed away; and in this latter atoll Lieutenant Prentice found a reef, about six hundred yards in diameter, which the natives positively affirmed was lately an island covered with cocoa-nut trees. It is now only partially dry at low water spring-tides, and

is (in Lieutenant Prentice's words) "entirely covered with live coral and madrepore." In the northern part, also, of the Maldiva Archipelago and in the Chagos group, it is known that some of the islets are disappearing. The natives attribute these effects to variations in the currents of the sea. For my own part I cannot avoid suspecting that there must be some further cause, which gives rise to such a cycle of change in the action of the currents of the great and open ocean.

Several of the atolls in this Archipelago are so related to each other in form and position, that at the first glance one is led to suspect that they have originated in the disseverment of a single one. Male consists of three perfectly characterised atolls, of which the shape and relative position are such, that a line drawn closely round all three, gives a symmetrical figure; to see this clearly, a larger chart is required than that of the Archipelago in Plate II.; the channel separating the two northern Male atolls is only little more than a mile wide, and no bottom was found in it with 100 fathoms. Powell's Island is situated at the distance of two miles and a half off the northern end of Mahlos Mahdoo (see Figure 4, Plate II.), at the exact point where the two sides of the latter, if prolonged, would meet; no bottom, however, was found in the channel with 200 fathoms; in the wider channel between Horsburgh atoll and the southern end of Mahlos Mahdoo, no bottom was found with 250 fathoms. In these and similar cases, the relation consists only in the form and position of the atolls. But in the channel between the two Nillandoo atolls, although

three miles and a quarter wide, soundings were struck at the depth of 200 fathoms; the channel between Ross and Ari atolls is four miles wide, and only 150 fathoms deep. Here then we have, besides the relation of form, a submarine connection. The fact of soundings having been obtained between two separate and perfectly characterised atolls is in itself interesting, as it has never, I believe, been effected in any of the many other groups of atolls in the Pacific and Indian seas. In continuing to trace the connection of adjoining atolls, if a hasty glance be taken at the chart (Figure 4., Plate II.) of Mahlos Mahdoo, and the line of unfathomable water be followed, no one will hesitate to consider it as one atoll. But a second look will show that it is divided by a bifurcating channel, of which the northern arm is about one mile and three-quarters in width, with an average depth of 125 fathoms, and the southern one three-quarters of a mile wide, and rather less deep. These channels resemble in the slope of their sides and general form, those which separate atolls in every respect distinct; and the northern arm is wider than that dividing two of the Male atolls. The ring-formed reefs on the sides of this bifurcating channel are elongated, so that the northern and southern portions of Mahlos Mahdoo may claim, as far as their external outline is concerned, to be considered as distinct and perfect atolls. But the intermediate portion, lying in the fork of the channel, is bordered by reefs less perfect than those which surround any other atoll in the group of equally small dimensions. Mahlos Mahdoo, therefore, is in every respect in

so intermediate a condition, that it may be considered either as a single atoll nearly dissevered into three portions, or as three atolls almost perfect and intimately connected. This is an instance of a very early stage of the apparent disseverment of an atoll, but a still earlier one in many respects is exhibited at Tilla-dou-Matte. In one part of this atoll, the ring-formed reefs stand so far apart from each other, that the inhabitants have given different names to the northern and southern halves; nearly all the rings, moreover, are so perfect and stand so separate, and the space from which they rise is so level and unlike a true lagoon, that we can easily imagine the conversion of this one great atoll, not into two or three portions, but into a whole group of miniature atolls. A perfect series such as we have here traced, impresses the mind with an idea of actual change; and it will hereafter be seen, that the theory of subsidence, with the upward growth of the coral, modified by accidents of probable occurrence, will account for the occasional disseverment of large atolls.

The Great Chagos bank alone remains to be described. In the Chagos group there are some ordinary atolls, some annular reefs rising to the surface but without any islets on them, and some atoll-formed banks, either quite submerged, or nearly so. Of the latter, the Great Chagos Bank is much the largest, and differs in its structure from the others: a plan of it is given in Plate II., Figure 1, in which, for the sake of clearness, I have had the parts under ten fathoms deep finely shaded: an east and west vertical section is given in Figure 2, in which the vertical

scale has been necessarily exaggerated. Its longest axis is ninety nautical miles, and another line drawn at right angles to the first, across the broadest part, is seventy. The central part consists of a level muddy flat, between forty and fifty fathoms deep, which is surrounded on all sides, with the exception of some breaches, by the steep edges of a set of banks, rudely arranged in a circle. These banks consist of sand, with a very little live coral; they vary in breadth from five to twelve miles, and on an average lie about sixteen fathoms beneath the surface; they are bordered by the steep edges of a third narrow and upper bank, which forms the rim to the whole. This rim is about a mile in width, and with the exception of two or three spots where islets have been formed, is submerged between five and ten fathoms. It consists of smooth hard rock, covered with a thin layer of sand, but with scarcely any live coral; it is steep on both sides, and outwards slopes abruptly into unfathomable depths. At the distance of less than half a mile from one part, no bottom was found with 190 fathoms; and off another point, at a somewhat greater distance, there was none with 210 fathoms. Small steep-sided banks or knolls, covered with luxuriantly growing coral, rise from the interior expanse to the same level with the external rim, which, as we have seen, is formed only of dead rock. It is impossible to look at the plan (Figure 1, Plate II.), although reduced to so small a scale, without at once perceiving that the Great Chagos Bank is, in the words of Captain Moresby (This officer has had the kindness to lend me an excellent MS. account of the Chagos Islands;

from this paper, from the published charts, and from verbal information communicated to me by Captain Moresby, the above account of the Great Chagos Bank is taken.), "nothing more than a half-drowned atoll." But of what great dimensions, and of how extraordinary an internal structure? We shall hereafter have to consider both the cause of its submerged condition, a state common to other banks in the group, and the origin of the singular submarine terraces, which bound the central expanse: these, I think, it can be shown, have resulted from a cause analogous to that which has produced the bifurcating channel across Mahlos Mahdoo.

CHAPTER II. – BARRIER REEFS

Closely resemble in general form and structure atoll-reefs. – Width and depth of the lagoon-channels. – Breaches through the reef in front of valleys, and generally on the leeward side. – Checks to the filling up of the lagoon-channels. – Size and constitution of the encircled islands. – Number of islands within the same reef. – Barrier-reefs of New Caledonia and Australia. – Position of the reef relative to the slope of the adjoining land. – Probable great thickness of barrier-reefs.

The term "barrier" has been generally applied to that vast reef which fronts the N.E. shore of Australia, and by most voyagers likewise to that on the western coast of New Caledonia. At one time I thought it convenient thus to restrict the term, but as these reefs are similar in structure, and in position relatively to the land, to those, which, like a wall with a deep moat within, encircle many smaller islands, I have classed them together. The reef, also, on the west coast of New Caledonia, circling round the extremities of the island, is an intermediate form between a small encircling reef and the Australian barrier, which stretches for a thousand miles in nearly a straight line.

The geographer Balbi has in effect described those barrier-reefs, which encircle moderately sized islands, by calling them atolls with high land rising from within their central expanse. The general resemblance between the reefs of the barrier and atoll

classes may be seen in the small, but accurately reduced charts on Plate I. (The authorities from which these charts have been reduced, together with some remarks on them and descriptive of the Plates, are given separately.), and this resemblance can be further shown to extend to every part of the structure. Beginning with the outside of the reef; many scattered soundings off Gambier, Oualan, and some other encircled islands, show that close to the breakers there exists a narrow shelving margin, beyond which the ocean becomes suddenly unfathomable; but off the west coast of New Caledonia, Captain Kent (Dalrymple, "Hydrog. Mem." volume iii.) found no bottom with 150 fathoms, at two ships' length from the reef; so that the slope here must be nearly as precipitous as off the Maldiva atolls.

I can give little information regarding the kinds of corals which live on the outer margin. When I visited the reef at Tahiti, although it was low water, the surf was too violent for me to see the living masses; but, according to what I heard from some intelligent native chiefs, they resemble in their rounded and branchless forms, those on the margin of Keeling atoll. The extreme verge of the reef, which was visible between the breaking waves at low water, consisted of a rounded, convex, artificial-like breakwater, entirely coated with Nulliporae, and absolutely similar to that which I have described at Keeling atoll. From what I heard when at Tahiti, and from the writings of the Revs. W. Ellis and J. Williams, I conclude that this peculiar structure is common to most of the encircled islands of the

Society Archipelago. The reef within this mound or breakwater, has an extremely irregular surface, even more so than between the islets on the reef of Keeling atoll, with which alone (as there are no islets on the reef of Tahiti) it can properly be compared. At Tahiti, the reef is very irregular in width; but round many other encircled islands, for instance, Vanikoro or Gambier Islands (Figures 1 and 8, Plate I.), it is quite as regular, and of the same average width, as in true atolls. Most barrier-reefs on the inner side slope irregularly into the lagoon-channel (as the space of deep water separating the reef from the included land may be called), but at Vanikoro the reef slopes only for a short distance, and then terminates abruptly in a submarine wall, forty feet high, – a structure absolutely similar to that described by Chamisso in the Marshall atolls.

In the Society Archipelago, Ellis (Consult, on this and other points, the "Polynesian Researches," by the Rev. W. Ellis, an admirable work, full of curious information.) states, that the reefs generally lie at the distance of from one to one and a half miles, and, occasionally, even at more than three miles, from the shore. The central mountains are generally bordered by a fringe of flat, and often marshy, alluvial land, from one to four miles in width. This fringe consists of coral-sand and detritus thrown up from the lagoon-channel, and of soil washed down from the hills; it is an encroachment on the channel, analogous to that low and inner part of the islets in many atolls which is formed by the accumulation of matter from the lagoon. At Hogoleu (Figure

2, Plate I.), in the Caroline Archipelago (See "Hydrographical Mem." and the "Atlas of the Voyage of the 'Astrolabe'," by Captain Dumont D'Urville, page 428.), the reef on the south side is no less than twenty miles; on the east side, five; and on the north side, fourteen miles from the encircled high islands.

The lagoon channels may be compared in every respect with true lagoons. In some cases they are open, with a level bottom of fine sand; in others they are choked up with reefs of delicately branched corals, which have the same general character as those within the Keeling atoll. These internal reefs either stand separately, or more commonly skirt the shores of the included high islands. The depth of the lagoon-channel round the Society Islands varies from two or three to thirty fathoms; in Cook's (See the chart in volume i. of Hawkesworth's 4to edition of "Cook's First Voyage.") chart of Ulieta, however, there is one sounding laid down of forty-eight fathoms; at Vanikoro there are several of fifty-four and one of fifty-six and a half fathoms (English), a depth which even exceeds by a little that of the interior of the great Maldiva atolls. Some barrier-reefs have very few islets on them; whilst others are surmounted by numerous ones; and those round part of Bolabola (Plate I., Figure 5) form a single linear strip. The islets first appear either on the angles of the reef, or on the sides of the breaches through it, and are generally most numerous on the windward side. The reef to leeward retaining its usual width, sometimes lies submerged several fathoms beneath the surface; I have already mentioned Gambier Island as an

instance of this structure. Submerged reefs, having a less defined outline, dead, and covered with sand, have been observed (see Appendix) off some parts of Huaheine and Tahiti. The reef is more frequently breached to leeward than to windward; thus I find in Krusenstern's "Memoir on the Pacific," that there are passages through the encircling reef on the leeward side of each of the seven Society Islands, which possess ship-harbours; but that there are openings to windward through the reef of only three of them. The breaches in the reef are seldom as deep as the interior lagoon-like channel; they generally occur in front of the main valleys, a circumstance which can be accounted for, as will be seen in the fourth chapter, without much difficulty. The breaches being situated in front of the valleys, which descend indifferently on all sides, explains their more frequent occurrence through the windward side of barrier-reefs than through the windward side of atolls, – for in atolls there is no included land to influence the position of the breaches.

It is remarkable, that the lagoon-channels round mountainous islands have not in every instance been long ago filled up with coral and sediment; but it is more easily accounted for than appears at first sight. In cases like that of Hogoleu and the Gambier Islands, where a few small peaks rise out of a great lagoon, the conditions scarcely differ from those of an atoll, and I have already shown, at some length, that the filling up of a true lagoon must be an extremely slow process. Where the channel is narrow, the agency, which on unprotected coasts is

most productive of sediment, namely the force of the breakers, is here entirely excluded, and the reef being breached in the front of the main valleys, much of the finer mud from the rivers must be transported into the open sea. As a current is formed by the water thrown over the edge of atoll-formed reefs, which carries sediment with it through the deep-water breaches, the same thing probably takes place in barrier-reefs, and this would greatly aid in preventing the lagoon-channel from being filled up. The low alluvial border, however, at the foot of the encircled mountains, shows that the work of filling up is in progress; and at Maura (Plate I., Figure 6), in the Society group, it has been almost effected, so that there remains only one harbour for small craft.

If we look at a set of charts of barrier-reefs, and leave out in imagination the encircled land, we shall find that, besides the many points already noticed of resemblance, or rather of identity in structure with atolls, there is a close general agreement in form, average dimensions, and grouping. Encircling barrier-reefs, like atolls, are generally elongated, with an irregularly rounded, though sometimes angular outline. There are atolls of all sizes, from less than two miles in diameter to sixty miles (excluding Tilla-dou-Matte, as it consists of a number of almost independent atoll-formed reefs); and there are encircling barrier-reefs from three miles and a half to forty-six miles in diameter, – Turtle Island being an instance of the former, and Hogoleu of the latter. At Tahiti the encircled island is thirty-six miles in its longest axis, whilst at Maurua it is only a little more than two

miles. It will be shown, in the last chapter in this volume, that there is the strictest resemblance in the grouping of atolls and of common islands, and consequently there must be the same resemblance in the grouping of atolls and of encircling barrier-reefs.

The islands lying within reefs of this class, are of very various heights. Tahiti is 7,000 feet (The height of Tahiti is given from Captain Beechey; Maurua from Mr. F.D. Bennett ("Geograph. Journ." volume viii., page 220); Aitutaki from measurements made on board the "Beagle"; and Manouai or Harvey Island, from an estimate by the Rev. J. Williams. The two latter islands, however, are not in some respects well characterised examples of the encircled class.); Maurua about 800; Aitutaki 360, and Manouai only 50. The geological nature of the included land varies: in most cases it is of ancient volcanic origin, owing apparently to the fact that islands of this nature are most frequent within all great seas; some, however, are of madreporitic limestone, and others of primary formation, of which latter kind New Caledonia offers the best example. The central land consists either of one island, or of several: thus, in the Society group, Eimeo stands by itself; while Taha and Raiatea (Figure 3, Plate I.), both moderately large islands of nearly equal size, are included in one reef. Within the reef of the Gambier group there are four large and some smaller islands (Figure 8, Plate I.); within that of Hogoleu (Figure 2, Plate I.) nearly a dozen small islands are scattered over the expanse of one vast lagoon.

After the details now given, it may be asserted that there is not one point of essential difference between encircling barrier-reefs and atolls: the latter enclose a simple sheet of water, the former encircle an expanse with one or more islands rising from it. I was much struck with this fact, when viewing, from the heights of Tahiti, the distant island of Eimeo standing within smooth water, and encircled by a ring of snow-white breakers. Remove the central land, and an annular reef like that of an atoll in an early stage of its formation is left; remove it from Bolabola, and there remains a circle of linear coral-islets, crowned with tall cocoa-nut trees, like one of the many atolls scattered over the Pacific and Indian Oceans.

Конец ознакомительного фрагмента.