CORAL
REEFS

DARWIN.

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CORAL REEFS

THE

Plate 3._ SHEWING THE DISTRIBUTION OF THE DIFFERENT KINDS OF CORAL REEFS, TOGETHER WITH THE POSITION OF THE ACTIVE VOLCANOS IN THE MAP. (SEE NOTE IN LEFT HAND CORNER)

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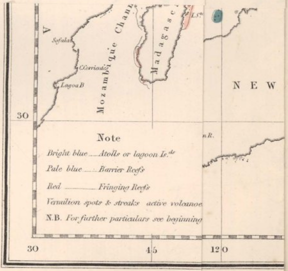
V
Sofala
C.Corrientes
Lagoa B
Mozambique Chann
Madagasc
N E W
30
Note
Bright blue......Atolls or lagoon Is.ds
Pale blue......Barrier Reefs
Red ....Fringing Reefs
Vermilion spots & streaks active volcanoe
N.B. For further particulars see beginning
30
45
120

THE

STRUCTURE AND DISTRIBUTION

OF

CORAL REEFS

BY

CHARLES DARWIN, M.A., F.R.S., F.G.S.

THIRD EDITION

WITH AN APPENDIX BY PROF. T. G. BONNEY, D.Sc., F.R.S., F.G.S.

WITH ILLUSTRATIONS

LONDON
SMITH, ELDER, & CO., 15 WATERLOO PLACE
1889

PREFACE

TO

THE THIRD EDITION.

For all that distinguishes the present from the second edition the reader has to thank Professor Bonney. He has added occasional footnotes (distinguished by square brackets), and he has given, in the form of an appendix, a careful summary of the more important memoirs published since 1874.

My own contribution is merely the fulfilment of a pleasant duty—the expression of my sincere gratitude to Professor Bonney for the ready kindness with which he undertook a difficult task, and for the care and skill with which he has completed it.

I must also be allowed the satisfaction of expressing my obligations to Captain Wharton, R.N., Hydrographer to the Admiralty, for an interesting series of notes, which are embodied by Professor Bonney in the present edition.

Francis Darwin.

Cambridge: *February* 28, 1889.

PREFACE

TO

THE SECOND EDITION.

The first edition of this book appeared in 1842, and since then only one important work on the same subject has appeared, namely, in 1872, by Professor Dana, on Corals and Coral-Reefs. In this work he justly says that I have not laid sufficient weight on the mean temperature of the sea, in determining the distribution of coral-reefs; but neither a low temperature nor the presence of mud-banks accounts, as it appears to me, for the absence of coral-reefs throughout certain areas; and we must look to some more recondite cause. Professor Dana, also, insists that volcanic action prevents the growth of coral-reefs much more effectually than I had supposed; but how the heat or poisonous exhalations from a volcano can affect the whole circumference of a large island is not clear. Nor does this fact, if fully established, falsify my generalisation that volcanos in a state of action are not found within the areas of subsidence, whilst they are often present within those of elevation; for I have not been influenced in my judgment by the absence or presence of coral-reefs round active volcanos; I have judged only by finding upraised marine remains within the areas of elevation, and by the vicinity of atolls and barrier-reefs with reference to the areas of subsidence. Professor Dana apparently supposes (p. 320) that I look at fringing-reefs as a proof of the recent elevation of the land; but I have expressly stated that such reefs, as a general rule, indicate that the land has either long remained at the same level or has been recently elevated. Nevertheless, from upraised recent remains having been found in a large number of cases on coasts which are fringed by coral-reefs, it appears that of these two alternatives recent elevation has been much more frequent than a stationary condition. Professor Dana further believes that many of the lagoon-islands in the Paumotu or Low Archipelago and elsewhere have recently been elevated to a height of a few feet, although originally formed during a period of subsidence; but I shall endeavour to show in the sixth chapter of the present edition that lagoon-islands which have long remained at a stationary level often present the false appearance of having been slightly elevated.

Although I thus demur to some of the remarks and criticisms made by this eminent naturalist, who has examined more coral formations than almost any other man, yet I do not the less admire his work.[1] It has also afforded me the highest satisfaction to find that he accepts the fundamental proposition that lagoon-islands or atolls, and barrier-reefs, have been formed during periods of subsidence.

The late Professor Jukes, in his account of the voyage of H.M.S. *Fly*, published in 1847, devoted a chapter to the Barrier-Reefs of Australia, and thus concludes: '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.'

On the other hand, a distinguished naturalist, Professor Semper, differs much from me, although he seems willing to admit that some atolls and barrier-reefs have been formed in the manner in which I suppose. I will give in the Appendix, under the head

[1] A friendly reply from Professor Dana, contesting some of the points mentioned above, will be found in Nature, Sept. 1874, p. 408.

of the Pelew Islands, which were carefully examined by him, some account of his objections, and I will here only state that his view does not differ essentially from that of Chamisso, which will hereafter be discussed. It will be seen that the evidence in favour of atolls and barrier-reefs having been formed during subsidence is of a cumulative nature; and that it is very difficult to judge with safety respecting any single lagoon-island or barrier-reef, or small group of them, even if the depth outside the reef and the slope of the encircled land are both known.

In the present edition I have added some new facts and have revised the whole book; the latter chapters having been almost re-written. The appended map of the Pacific and Indian Oceans remains in nearly the same state as before, for I have added only two red and two blue circles. I have removed an active volcano, which was formerly supposed to exist in Torres Straits. An account of a remarkable bar of sandstone off Pernambuco on the Brazilian coast has been added to the Appendix, as this bar is protected from the wear and tear of the waves by a coating of organic bodies, in the same manner as are most coral-reefs. It also resembles a coral-reef in shape or outline to a curiously deceptive degree. If I had been better situated during the last thirty years, for hearing of recent discoveries in the Pacific, and for consulting charts published in various countries, my map might have been greatly improved. But I hope that before long some one may be induced to colour a map on a large scale, on nearly the same principles as I have done, and in accordance with our advanced state of geographical knowledge; for I believe that he would thus arrive at some new and striking generalisations.

DOWN, BECKENHAM, KENT
February 1874.

PREFACE

TO

THE FIRST EDITION.

I SHALL HAVE OCCASION, in many parts of the following volume, to acknowledge the valuable information I have received from several persons; but I must more particularly express my obligations to Captain R. Moresby, I.N., who conducted the survey of the Red Sea, and of the archipelagoes of low coral-islands in the Indian Ocean. I beg, also, to be permitted to return my best thanks to Captain Beaufort, R.N., for having given me free access to the charts in the Admiralty, as well as to Captain Beecher, R.N., for most kindly aiding me in consulting them. My thanks are likewise especially due to Captain Washington, R.N., for his invariable desire to assist me in every possible manner. Having in former publications had the pleasure of acknowledging how much I owe to Captain

FitzRoy, for having permitted me to volunteer my services on board H.M.S. *Beagle*, and for his uniform kindness in giving me assistance in my researches, I can here only repeat my obligations to him. The materials for this volume were nearly ready two years ago; but owing to ill health, its publication has been delayed. The two succeeding Parts—one on the volcanic islands visited during the voyage of the *Beagle*, and the other on South America—will appear as soon as they can be prepared.

May 2, 1842.

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CHAPTER VI.

ON THE DISTRIBUTION OF CORAL-REEFS WITH REFERENCE TO THE THEORY OF THEIR FORMATION.

APPENDIX (I.)

APPENDIX (II.)

DESCRIPTION OF THE PLATES.

PLATE I. *at end of Volume.*

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 India Company, from the survey by Capt. Moresby and Lieut. Powell. The surface of the reef, which dries at low water, is represented by a stippled surface with small crosses: the coral-islets on the reef are marked by small linear unstippled 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, and has been tinted, in order to catch the eye, *of a pale blue colour*. 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.

Fig. 1.—VANIKORO, situated in the western part of the S. Pacific; taken from the survey by Capt. D'Urville in the *Astrolabe*; the scale is $\frac{1}{4}$ of an inch to a geographical mile; the soundings on the southern side of the island, namely from 30 to 40 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.

Fig. 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; scale $\frac{1}{20}$ of an inch to a mile; the depth of the immense lagoon-like space within the reef is not known.

Fig. 3.—Raiatea, in the Society Archipelago; from the map given in the quarto edition of Cook's First Voyage; it is probably not accurate; scale $\frac{1}{20}$ of an inch to a mile.

Fig. 4.—Bow, or Heyou atoll (or lagoon-island), in the Low Archipelago; from the survey by Capt. Beechey, R.N.; scale $\frac{1}{20}$ of an inch to a mile; the lagoon is choked up with reefs, but the average greatest depth of about 20 fathoms, is given from the published account of the voyage.

Fig. 5.—Bolabola, in the Society Archipelago; from the survey of Capt. Duperrey, in the *Coquille*; scale $\frac{1}{4}$ of an inch to a mile; the soundings in this and the following figure have been altered from French feet to English fathoms; height of highest point of the island 4,026 feet.

Fig. 6.—Maurua, in the Society Archipelago; from the survey by Capt. Duperrey in the *Coquille*; scale $\frac{1}{4}$ of an inch to a mile; height of land about 800 feet.

Fig. 7.—Pouynipète, or Seniavine, in the Caroline Archipelago; from the survey by Admiral Lutké; scale $\frac{1}{4}$ of an inch to a mile.

Fig. 8.—Gambier Islands, in the southern part of the Low Archipelago; from the survey by Capt. Beechey; scale $\frac{1}{4}$ of an inch to a mile; height of highest island, 1,246 feet; the islands are surrounded by extensive and irregular reefs; the reef on the southern side is submerged.

Fig. 9.—Peros Banhos atoll (or lagoon-island), in the Chagos group in the Indian Ocean; from the survey by Capt. Moresby and

Lieut. Powell; scale $\frac{1}{4}$ of an inch to a mile; not nearly all the small submerged reefs in the lagoon are represented; the annular reef on the southern side is submerged.

Fig. 10.—Keeling, or Cocos atoll (or lagoon-island), in the Indian Ocean; from the survey by Capt. FitzRoy; scale $\frac{1}{4}$ of an inch to a mile; 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 N.W. side is broken, and blends into a shoal sand-bank, on which the sea breaks.

PLATE II. *at end of Volume.*

Fig. 1.—Great Chagos Bank, in the Indian Ocean; taken from the survey by Capt. Moresby and Lieut. Powell; scale $\frac{1}{20}$ of an inch to a mile (same scale as Hogoleu, in Plate I.); 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 4 to 10 fathoms; the banks bounded by the dotted lines lie from 15 to 20 fathoms beneath the surface, and are formed of sand; the central space is of mud, and from 30 to 50 fathoms deep.

Fig. 2.—A vertical section, on the same scale, in an E. and W. line across the Great Chagos Bank, given for the sake of exhibiting more clearly its structure.

Fig. 3.—Menchicoff atoll (or lagoon-island), in the Marshall Archipelago, northern Pacific Ocean; from Krusenstern's atlas of the Pacific; originally surveyed by Capt. Hagemeister; scale $\frac{1}{20}$ of an inch to a mile; the depth within the lagoons is unknown.

Fig. 4.—Mahlos Mahdoo atoll, together with Horsburgh atoll, in the Maldiva Archipelago; from the survey by Capt. Moresby and Lieut. Powell; scale $\frac{1}{20}$ of an inch to a mile; 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 (-̇-) 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.

Fig. 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; scale $\frac{1}{60}$ of an inch to a mile.

Fig. 6.—Maldiva Archipelago, in the Indian Ocean; from the survey by Capt. Moresby and Lieut. Powell; scale $\frac{1}{60}$ of an inch to a mile.

PLATE III. *at beginning of Volume.*

The principles on which this map is coloured are explained in the beginning of Chapter VI.; and the authorities for colouring each particular spot are detailed in the Appendix. The names printed in italics in the Index refer to the Appendix.

THE

STRUCTURE AND DISTRIBUTION

OF

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, and to explain the origin of their peculiar forms. I shall not here treat of the polypifers, which construct these vast works, except as to their distribution, and 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 everyone 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 generally 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 coral-polypifers, and when he knows that the solid reef increases only on the outer edge, which day and night

No. 1.

is lashed by the breakers of an ocean never at rest. Well did François Pyrard de Laval, in the year 1605, exclaim, 'C'est une merueille de voir chacun de ces atollons, enuironné d'un grand banc de pierre tout autour, n'y ayant point d'artifice humain.' The above sketch of Whitsunday Island, in the S. Pacific, taken from Capt. Beechey's admirable Voyage, although excellent of its kind, gives but a faint idea of the singular aspect of one of these lagoon-islands. 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 coral formations by their inhabitants in the Indian Ocean, and is synonymous with 'lagoon-island.'

Barrier-reefs, when encircling small islands, have been comparatively little noticed by voyagers; but

No. 2.

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 Bolabola,[1] one of the Society Islands. 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 far from the shore, and in not having within them 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 are allied in most respects to fringing reefs, but 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

[1] I have taken the liberty of simplifying the foreground, and leaving out a mountainous island in the far distance.

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 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 to 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.[1]

[1] A brief account of my views on coral formations, now published in my Journal of Researches, was read May 31, 1837, before the Geological Society, and an abstract has appeared in the Proceedings.

CHAPTER I.

ATOLLS OR LAGOON-ISLANDS.

SECTION FIRST, KEELING ATOLL.

Corals on the outer margin—Zone of Nulliporæ—Exterior reef—Islets—Coral-conglomerate—Lagoon—Calcareous sediment—Scari and Holuthuriæ subsisting on corals—Changes in the condition of the reefs and islets—Probable subsidence of the atoll—Future state of the lagoon.

Keeling or Cocos atoll is situated in the Indian Ocean, in 12° 5′ S. and long. 90° 55′ E.: a reduced chart of it, from the survey of Capt. FitzRoy and the officers of H.M.S. Beagle, is given in Plate I. fig. 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 (No. 3) 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. But 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, an intelligent resident on these islands, as well as by some chiefs at Tahiti (Ota-

No. 3.

A—Level of the sea at low water: where the letter A is placed, the depth is 25 fathoms, and the distance rather more than 150 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.

heite), that an exposure to the rays of the sun for a very short time invariably causes their destruction.[1] Hence

[1] [This would be true of certain genera or species, but according to the observations made during the voyage of the *Challenger* (Reports xvi. pp. 23, 36), and by Mr. Guppy (Proc. R. S. Edin. xiii. p. 863), there are some which can bear exposure for a limited time, perhaps two or three hours, especially if occasionally wetted by the spray.]

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 Astræa, 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*.[1] It grows in thick vertical plates, intersecting each other at various angles, and forms an exceedingly strong honey-combed mass, which generally assumes 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 wood-cut (No. 3) shows the form of the bottom outside the reef: the water deepens very gradually for a space of between one and two hundred yards wide, to a depth of 25 fathoms (*A* in section), beyond which the sides plunge into the unfathomable ocean at an angle of 45°[2]. To the depth of ten or twelve

[1] 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.

[2] The soundings from which this section is laid down were taken with great care by Captain FitzRoy himself: he used a bell-shaped

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 Astræa, 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 Astræa were also numerous; the former is found, but not in proportionate numbers, in the hollows on the reef; but the Astræa 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 wood-cut

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.

by an uneven line) round and beneath the external margin. Between 12 and 20 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 13 and 16 fathoms. Out of twenty-five soundings taken at a greater depth than 20 fathoms, every one showed that the bottom was covered with sand; whereas at a less depth than 12 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 200 and 300 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 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 fact of the line having been cut, when between 500 and 600 fathoms were out, indicates the probable existence of submarine cliffs of rock.

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.[1] 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 Nulliporæ, 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 during either the whole or an equal proportional time of each tide. It is remarkable that organic productions of such extreme simplicity, for the Nulliporæ undoubtedly belong to one of the lowest classes of the vegetable kingdom, should be limited to a zone so peculiarly cir-

[1] 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.

cumstanced. Hence the layer composed by their growth, merely fringes the reef for a space of about 20 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 wood-cut) 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 Nulliporæ on the outer margin, the part most exposed to the breakers, and this must effectually aid in preserving it from being worn down.

The wood-cut (at p. 8) 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 the reef, as it occurs where islets have not been formed. It is this reef which essentially forms the atoll. In Keeling atoll the ring encloses 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 250 to 500 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 from breaking entirely over the reef, the channels and hollows become filled up with fragments cemented together by calcareous matter; and the surface of the reef is converted into a hard smooth floor (*C* of wood-cut), like an artificial one of freestone. This flat surface varies in width from 100 to 200, or even 300 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 Nulliporæ, 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 wood-cut of Whitsunday Atoll.

The islets on the reef are first formed between 200 and 300 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 S.E. 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 30 feet high), is close to the outer beach (*E* of the wood-cut) 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; and this slope no doubt is due to 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 800 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 wood-cut), 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 are firmly cemented together by percolated calcareous matter, and they resist the daily tides longer than the loose upper fragments; and thus a projecting ledge is formed. The cemented mass is generally of a white colour, but in some few parts reddish from ferruginous matter: it is very hard and 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 recemented: or it consists of a calcareous sandstone, entirely composed of rounded particles of shells, corals, the spines of echini, and other organic bodies generally almost blended together;—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 an 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.[1]

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, from three to 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 numerous in kind, and most of them are thinly branched. Meandrina, however, lives in the lagoon, and many great rounded masses of this coral lie loose or almost loose on the bottom. The other most common species are three closely allied species of true Madrepora with thin branches; *Seriatapora subulata*; two species of Porites[2] with cylindrical branches, one of which forms circular clumps, with only the exterior branches alive; and lastly, a coral something like an Explanaria, but with stars on both surfaces, growing in thin, brittle, stony, foliaceous

[1] [Dead coral still lying on the beach has been found to contain at least 5 per cent. of carbonate of magnesia, though only a very small quantity is present in fresh coral (usually less than 1 per cent.). In old coral-rock as much as 38·07 per cent. has been found (Dana's Corals and Coral Islands, ch. vi. § 9).]

[2] 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.

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 by the aid of crowbars made 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 Lieut. Nelson from the reefs of Bermuda, which, when shewn 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,

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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 Holuthuriæ (a family of Radiata), subsist on living coral; [1] 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 Holuthuria, and of the individuals which swarm on every part of these coral-reefs, is extraordinarily great; and many ship-loads are, as is well known, annually freighted for China with 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

[1] [Mr. Guppy, Proc. R. S. Edin. xiii. p. 894, expresses the opinion that the Holothurians do not subsist on the *living* coral, but obtain nutriment from swallowing the sand and detrital material, of which broken coral forms a large constituent.]

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 'consume 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 enquire, 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 half way 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 may have resulted, either from the surface of the reef in front of the islets having formerly been submerged, and afterwards having been raised by accumulated fragments, or from the mounds of coral on the margin having grown outwards. That an outward growth of this part is in process, can hardly be doubted from the existence 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 in 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 Nulliporæ, and so much of the surface would have been of equal height with the existing zone of living Nulliporæ: this is not the case, as may be seen in the wood-cut. 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 inner portions of the zone of Nulliporæ, 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 Nulliporæ formed the convex mound on its margin: for the zone thus formed, 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, an increase in the diameter of the atoll; but there are others having an opposite tendency. On the S.E. side, Lieut. Sulivan, to whose kindness I am indebted for many interesting observations, found the conglomerate (D, in wood-cut p. 8) projecting on the reef nearly fifty yards in front of the islets: we may infer from what we elsewhere see 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 Lieut. 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. Capt. 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 water-mark. 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 it is 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 up the lagoon. We know so little of the habits of the many different species of corals which form the lagoon-reefs, that we have no more reason 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 SECOND.

General form and size of atolls, their reefs and islets—External slope—Zone of Nulliporæ—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 Capt. 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 Fig. 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 Menchioff Island (See Fig. 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 reef may be taken at about a quarter of a mile. Capt. Beechey[1] 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 islands of Keeling atoll, appears to apply perfectly to nearly all the atolls in the Pacific and Indian

[1] Beechey's Voyage to the Pacific and Behring's Straits, chap. viii.

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 Lutké'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 Lutké, 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 would not cover that city and its suburbs.

The form of the bottom, as given by Captain Beechey in his sections of the atolls in the Low Archipelago, exactly coincides with that already described in Keeling atoll: it 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° into unfathomable depths.[1] The nature, however, of the bottom seems to differ, for this officer[2] 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° 4′ N., 157° 45′ W.), described by Cook,[3] 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.

[1] The slope of the bottom round the Marshall atolls in the Northern Pacific is probably similar: Kotzebue (First Voyage, vol. ii. p. 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.'

[2] 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.

[3] Cook's Third Voyage, vol. ii. chap. 10.

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, Lieut. Powell [1] found 50 and 60 fathoms close to the edge of the reef, and at 300 yards distance there was no bottom with a 300 yard line. Capt. 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 two hundred 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.[2] Here, then, occurs a

[1] This fact is taken from a MS. account of these groups lent me by Capt. Moresby. See also Capt. Moresby's paper on the Maldiva atolls in the Geographical Journal, vol. v. p. 401.

[2] Off some of the atolls in the Low Archipelago the bottom appears to descend by ledges. Off Elizabeth Island, which consists of raised coral-rock, Capt. Beechey (p. 45, quarto ed.) describes three ledges: the first slopes gently from the beach to a distance of about fifty yards; the second extends two hundred yards with a depth of

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. Élie de Beaumont[1] 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 appear 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. Élie 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.

Capt. 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[2] the buttress, as it may be called, which 'has the most

twenty-five fathoms, and then ends abruptly, like the first; and immediately beyond this there is no bottom with two hundred fathoms.

[1] Mémoires pour servir à une description Géolog. de France, tome iv. p. 216.

[2] Beechey's Voyage, 4to. ed. p. 44.

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 is much varied. We can, however, discern the effects of uniform laws 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; 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 called the 'flat,' and which is partly dry at low water, appears similar in every atoll. In the Marshall group in the N. 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:

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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 stalactitical form,'—a description perfectly applicable to the margin of Keeling atoll.[1] Although Chamisso does not state that the masses of Nulliporæ form points or a mound, higher than the flat, yet I believe that this is the case; for Kotzebue,[2] 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 certain are not formed of true coral.[3]

[1] Kotzebue's First Voyage, vol. iii. p. 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 Nullipora. The entire surface over many square inches, was coloured of a peach-blossom 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 Nulliporæ are closely related to those described on the coral-reefs, but I believe are of different species.

[2] Kotzebue's First Voyage, vol. ii. p. 16. Lieut. Nelson, in his excellent memoir in the Geological Transactions (vol. ii. p. 105), alludes to the rocky points mentioned by Kotzebue, and infers that they consist of Serpulæ, which compose incrusting masses on the reefs of Bermudas, as they likewise do on a sandstone-bar off the coast of Brazil, as described by me in the London Phil. Journal, Oct. 1841. I have added my description as a short supplement to the present volume. These masses of Serpulæ hold the same position, relatively to the action of the sea, with the Nulliporæ on the coral-reefs in the Indian and Pacific oceans.

[3] Capt. Moresby, in his valuable paper 'On the Northern Atolls

Whether a smooth convex mound of Nulliporæ, 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[1] 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,[2] 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

of Maldivas' (Geographical Journal, vol. v.), says that the edges of the reefs there stand above water at low spring tides.

[1] Kotzebue's First Voyage, vol. iii. p. 144.

[2] See also Moresby on the Northern Atolls of the Maldivas, Geographical Journal, vol. v. p. 400.

is only a little less. Within the Maldiva atolls there are large spaces with 45 fathoms, and some soundings are laid down at 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 levelled 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 Lieut. Nelson says is called there pipe-clay.[1]

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 length on the more exposed shore. The islets, also, which are placed

[1] 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 Brésil*, 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, mêlé ou formé de madrépores broyés.' 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. [Probably the clay is commonly similar to that mentioned by Mr. Guppy (Proc. R. S. Edin. vol. xiii. p. 879 n.) and others. See the abstract of his paper in Appendix II.]

to leeward as regards the trade-wind, are in most parts of the Pacific liable to be occasionally swept entirely away by gales, equalling hurricanes in violence, which blow in the opposite direction. The absence of islets on the leeward side of atolls, or, when present, their lesser dimensions compared with those to windward, is a comparatively unimportant fact; but it is remarkable that in several instances the reef itself, although retaining its usual defined outline, does not rise to the surface by several fathoms on the leeward side. This is the case with the southern side of Peros Banhos (Plate I. fig. 9) in the Chagos group, with Mourileu atoll[1] in the Caroline Archipelago, and with the barrier reef (Plate I. fig. 8) of the Gambier Islands, where Captain Beechey was first led to observe the peculiarity in 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

[1] Frederic Lutké's Voyage autour du Monde, vol. ii. p. 291. See also his account of Namonouïto, at pp. 97 and 105, and the chart of Oulleay in the Atlas.

the same manner as occurs where there is a 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 Namonouïto in the same Archipelago, both these modifications of the reef concur; it consists of a great flat bank, with from 20 to 25 fathoms of water on it; for a length of more than 40 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 22 fathoms deep, is 24 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 that the rim consists of dead rock thinly covered with sand, and he is certain that 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, Capt. 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 are 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 20 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. Sir C. Lyell[1] 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

[1] Principles of Geology, vol. iii. p. 289. [Vol. ii. p. 609, ed. 1872.]

high tide and the greater part of each ebb is thrown over a large portion of its circumference. Several facts indicate that a considerable quantity of sediment is likewise discharged through these channels ; and Captain Moresby has observed, during the change of the monsoon, that the sea is discoloured to some distance off the entrances into the Maldiva and Chagos atolls. This would probably check the growth of the coral in the channels, far more effectually than if they merely discharged a current of water. Where there is not any channel, as in the case of many small atolls, these causes have not prevented the entire ring attaining the surface. The channels, like the submerged and effaced parts of the reef, occur very generally, though not invariably on the leeward side of the atoll, or on that side, according to Beechey,[1] which, from extending 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.

[1] Beechey's Voyage, 4to ed. vol. i. p. 189.

Chamisso,[1] 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,[2] the great exterior reef, the surface of which is gently inclined inwards, ends abruptly in a little submarine cliff three fathoms deep; at its foot, a ledge 40 yards in width also shelves gently inwards, like the surface-reef, and terminates in a second little cliff five fathoms deep; beyond this, the bottom of the lagoon slopes to 20 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

[1] Kotzebue's First Voyage, vol. iii. p. 142.

[2] Beechey's Voyage, 4to ed. vol. i. p. 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.

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° S.) is described by Chamisso[1] 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

[1] Kotzebue's First Voyage, vol. iii. p. 221.

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 agency (namely, subsidence) comes into play at intervals, and renovates their original structure.

SECTION THIRD.

Maldiva Archipelago—Ring-formed reefs, marginal and central—Great depth in the lagoons of the southern atolls—Reefs in the lagoons all reach the surface—Position of islets, and breaches in the reefs with respect to the prevalent winds and action of the waves—Destruction of islets—Relation in position between 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 Lieut. 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, though imperfectly, in the greatly reduced chart (fig. 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 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. fig. 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 stand; their outer margins are invariably bordered by living coral,[1] within which there is a flat surface of coral rock; on this flat, sand and fragments have in many cases accumulated and been converted into islets clothed with vegetation. They are indeed larger, and contain deeper lagoons than many true atolls standing in the open sea; and I can point out no essential difference between these little ring-formed reefs and the most perfectly characterised atolls, excepting that they are based on a shallow foundation, instead of on the floor of the ocean, and that instead of being scattered irregularly, they are grouped closely together with the marginal rings arranged in a rudely-formed circle.

The perfect series which can be traced from a linear reef like that surrounding an ordinary atoll, to others which are ring-formed and much elongated but containing only a very narrow lagoon, and to others which are oval or almost circular, renders it probable that the latter are merely modifications of a linear and normal reef. The fact that the marginal annular reefs generally have their longest axes directed in the line which the exterior linear reef would have held, agrees with this view. We may also infer that the central annular 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

[1] Captain Moresby informs me that *Millepora complanata* is one of the commonest kinds on the outer margin, as it is at Keeling atoll.

ring-like structure in these central reefs 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 10 to 20 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 9 miles in its longest diameter, it has a depth of 39 fathoms, whereas all the other small atolls have comparatively shallow lagoons; I can assign no adequate cause for this difference in depth, excepting that the southern part of the Archipelago has subsided to a greater degree or at a quicker rate than the northern part; and this conclusion agrees well with the fact that, in the Chagos group, lying 280 miles still further southwards, most of the atolls are sunken and half destroyed with the dead corals. In the central and deepest part of the Maldiva 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 the bottom is sandy, and 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 singular structure of these atolls, —a great sandy and generally concave disk rises abruptly from the unfathomable ocean, with the central expanse studded and the margins 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 salt 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 the trade wind, the ship-channels into the lagoons are almost always 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 near together, the breaches in the reef are most numerous on the sides which face each other, and are therefore less exposed to the waves. Thus on the sides of Ari and the two Nillandoo atolls which face S. Māle, Phaleedoo, and Moloque atolls, there are seventy-three deep-water channels, and only twenty-five on the outer sides; on the three latter-named atolls there are fifty-six openings on the near side, and only thirty-seven on the outside. 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 mutual protection afforded by the two rows of atolls. 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 reefs of the southern atolls are more continuous than those of the northern ones, for the former, as I am informed by Captain Moresby, are more constantly exposed to a heavy surf than are the northern atolls.

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 Lieut. 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 Lieut. 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. Māle 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; but to see this, a larger chart is required than that of the Archipelago in Plate II. The channel separating the two northern Māle 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 another atoll, namely Mahlos Mahdoo (fig. 4), 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 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 a submarine connection, besides a relation in position and form. 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 (fig. 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 Mâle atolls. The ring-formed reefs on the northern and southern sides of this bifurcating channel are elongated, and so continuous that the northern and southern portions of Mahlos Mahdoo may claim to be considered as distinct atolls. But the reefs of the intermediate portion are less perfect, so that this portion hardly yet resembles a distinct atoll. Mahlos Mahdoo, therefore, is in every respect in an intermediate condition, so 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, and another 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 series such as we have here traced, impresses the mind with the idea of actual change; and it will hereafter be seen, that the theory of subsidence together with the upward growth of the coral-reefs, modified by accidents of probable occurrence, accounts for the occasional disseverment of large atolls.

The great Chagos Bank alone remains to be described.[1] In the Chagos group there are some ordi-

[1] [See Appendix II.]

nary atolls, some annular reefs rising to the surface but without any islets on them, and some atoll-formed banks either quite or nearly submerged. 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. fig. 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 fig. 2, in which the vertical scale has been necessarily exaggerated. Its longest axis is ninety nautical miles, and another line drawn across the broadest part, at right angles to the first, 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 slopes abruptly outwards 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 (fig. 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,[1] '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.

[1] 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.

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.,[1] and this resemblance can be further shown to extend to every part of their structure. Beginning with the outside of the reef; many scattered soundings off Gambier, Ualan, and some other encircled islands, show that close to the breakers there exists a narrow shelving margin, beyond which in most cases, the ocean suddenly becomes unfathomable. Off the west coast of New Caledonia, Captain Kent[2] found no bottom with 150 fathoms, at two ship's lengths 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 Nulliporæ, and absolutely similar to that which I have described at Keeling atoll. From what I heard when at Tahiti, and from the

[1] The authorities from which these charts have been reduced, together with some remarks on them, are given in a separately appended page, descriptive of the Plates.

[2] Dalrymple, Hydrog. Mem. vol. iii.

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 (figs. 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[1] 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,

[1] Consult, on this and other points, the Polynesian Researches by the Rev. W. Ellis, an admirable work, full of curious information.

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 (fig. 2, Plate I.), in the Caroline Archipelago,[1] 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 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 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[2] chart of Ulietea, however, there is one sounding laid down of 48 fathoms: at Vanikoro there are several of 54 and one of 56½ 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., fig. 5), form a single linear strip. The islets first appear either on the angles of the reef, or on the sides of the breaches

[1] See Hydrographical Mem. and the Atlas of the Voyage of the *Astrolabe*, by Capt. Dumont D'Urville, p. 428.

[2] See the chart in vol. i. of Hawkesworth's 4to ed. of Cook's First Voyage.

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, dead, covered with sand, and with a less defined outline, have been observed (see Appendix I.) off some parts of Huaheine and Tahiti. The reef is more frequently breached to leeward than to windward, although this is not so frequent as in the case of atolls. Thus I find in Krusenstern's Memoir on the Pacific, that there are passages through the encircling reef on the leeward side of the seven Society Islands, which possess ship-harbours; but that there are openings to windward through 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 generally situated in front of the valleys which descend 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 accounted for without much difficulty. 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 lagoon-channel is narrow, that agency, which on unprotected coasts is the most productive of sediment, namely the force of the breakers, is here entirely excluded; and owing to 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. The water which is thrown over the edges of atoll-formed reefs causes a current which carries sediment from the lagoon through the breaches into the sea; and the same thing probably takes place in barrier-reefs. This would greatly aid in preventing the lagoon-channels 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 Maurua (Plate I., fig. 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 see 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 reefs, like atolls, are generally elongated, and have 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, which 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 also be shown in the last chapter, that there is the strictest resemblance between the grouping of atolls and of common islands, and there is the same resemblance between atolls and encircling barrier-reefs.

The islands lying within reefs of this class, are of very various heights. Tahiti[1] is 7,000 feet; Maurua about 800; Aitutaki 360, and Manouai only 50. The geological nature of the included land also varies; in most cases it is of ancient volcanic origin, owing apparently to the fact that islands of this nature are the 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 (fig. 3, Plate I.), both

[1] The height of Tahiti is given from Captain Beechey; Maurua from Mr. F. D. Bennett (Geograph. Journ. vol. viii. p. 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.

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 (fig. 8, Plate I.); within that of Hogoleu (fig. 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 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.

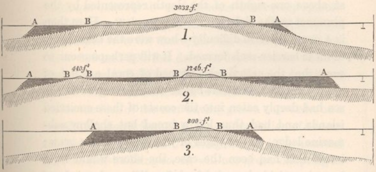
The barrier-reefs of Australia and of New Caledonia deserve a separate notice from their great dimensions. The reef on the west coast of New Caledonia (fig. 5, Plate II.) is 400 miles in length; and for a length of many leagues seldom approaches within eight miles of the shore. Near the southern end of the island, the space between the reef and the land is sixteen miles in width. The Australian barrier extends, with a few interruptions, for about eleven hundred miles; its average distance from the land is between twenty and thirty miles, but in parts from fifty to ninety. The great arm of the sea thus included, is from ten to twenty-five fathoms deep, with a sandy bottom; but towards the southern end where the reef is further from the shore, the depth gradually increases to forty, and in some parts to more than sixty fathoms. Flinders has described the surface of the reef as consisting of a hard white agglomerate of different kinds of coral, with rough projecting points. A few low islets have been formed on it. The outer edge is the highest part; it is traversed by narrow gullies, and at intervals by ship-channels. The sea close outside is in most parts profoundly deep; but to the north, near New Guinea, and to the south, the depth is much less, and here the bottom slopes gradually from the reef, as it generally does in front of the ship-channels.[1]

There is one important point in the structure of barrier-reefs which must here be considered. The accompanying diagrams represent north and south vertical sections, taken through the highest points of Vanikoro, Gambier, and Maurua islands, as well as through their encircling reefs. The scale both in the horizontal and vertical direction is the same, namely, a quarter of an inch to a nautical mile. The height and width of these islands are known; and I have attempted to represent the form of the land from the shading of the hills

[1] The foregoing details are taken chiefly from Flinders' Voyage to Terra Australis, vol. ii. p. 88; but these have been corrected by the account given by Prof. Jukes, Narrative of the Voyage of the *Fly*, vol. i. 1847, chap. xiii.

in the large published charts. It has long been remarked, even from the time of Dampier, that a considerable degree of relation subsists between the inclination of that part of the land which is beneath water and that above it: hence the dotted line in the three sections is probably a moderately accurate representation of the actual submarine prolongation of the land. If we now look at the outer edge of the reef

No. 4.



1—Vanikoro, from the Atlas of the Voyage of the *Astrolabe*, by D. D'Urville.

2—Gambier Island, from Beechey.

3—Maurua, from the Atlas of the Voyage of the *Coquille*, by Duperrey.

The horizontal line is the level of the sea, from which on the right hand a plummet descends, representing a depth of 200 fathoms, or 1,200 feet. The vertical shading shows the section of the land, and the horizontal shading that of the encircling barrier-reef; from the smallness of the scale, the lagoon-channel could not be represented.

A A—Outer edge of the coral-reefs, where the sea breaks.

B B—The shore of the encircled islands.

(A A), and bear in mind that the plummet on the right hand represents a depth of 1,200 feet, we must conclude that the vertical thickness of these barrier coral-reefs is very great.

I must observe, that if the sections had been taken in any other direction across these islands, or across other encircled islands,[1] the result would have been the same. In the succeeding chapter it will be shown that reef-building polypifers cannot flourish at great depths,—for instance, it is highly improbable that they could exist at above one-eighth of the depth represented by the plummet on the right hand of the woodcut. Here then is a great *apparent* difficulty—how were the basal parts of these barrier-reefs formed. It will perhaps occur to some that the actual reefs formed of coral are not of great thickness, but that before their first growth the sea had deeply eaten into the coasts of these encircled islands, and had thus left a broad but shallow submarine ledge, on the edges of which the corals grew; but if this had been the case, the shore would have been invariably bounded by lofty cliffs, and not have sloped down to the lagoon-channel, as it does in many instances. On this view,[2] moreover, the cause of the reef springing up at such a great distance from

[1] An East and West section across the Island of Bolabola and its barrier-reefs is given in the fifth chapter, for the sake of illustrating another point. The scale is ·57 of an inch to a mile; it is taken from the Atlas of the Voyage of the *Coquille*, by Duperrey. The depth of the lagoon-channel is exaggerated.

[2] The Rev. D. Tyerman and Mr. Bennett (Journal of Voyage and Travels, vol. i. p. 215) have briefly suggested this explanation of the origin of the encircling reefs of the Society Islands.

the land, leaving a deep and broad moat within, remains altogether unexplained. A supposition of the same nature and appearing at first more probable, is, that the reefs have risen from banks of sediment, which had accumulated round the shore previously to the growth of the coral; but the extension of a bank to the same distance round an unbroken coast, and in front of deep arms of the sea (as in Raiatea, see Plate II., fig. 3), which penetrate nearly to the heart of some encircled islands, is exceedingly improbable. And why, again, should the reef, in some cases steep on both sides like a wall, spring up at a distance of two, three, or more miles from the shore, leaving a channel often between 200 and 300 feet deep—a depth which, we have good reason to believe, is too great for the growth of coral? The existence, also, of this same channel precludes the idea of the reef having grown outwards, on a foundation slowly formed by the accumulation of its own detritus and sediment. Nor, again, can it be asserted that the reef-building corals will not grow, excepting at a great distance from the land; for, as we shall soon see, there is a whole class of reefs which take their name from growing (especially where the sea is deep) closely attached to the shore. At New Caledonia (see Plate II., fig. 5), the reefs which run in front of the west coast are prolonged in the same line for 150 miles beyond the northern extremity of the island, and this shows that some explanation, quite different from any one of those just suggested is requisite. If the island had been originally prolonged to this distance, and if the northern end had been worn away until it was a little beneath the level of the sea, why should the coral-reefs have become attached, not on the central crest, but in the same line with the reefs which still front the existing shores? We shall hereafter see, that there is one, and I believe only one solution of this difficulty.

One other supposition to account for the position of encircling reefs remains, but it is almost too preposterous to be mentioned;—namely, that they rest on enormous submarine craters surrounding the included islands. When the size, height, and form of the islands in the Society group are considered, together with the fact that all are thus encircled, such a notion will be rejected by everyone. New Caledonia, moreover, besides its size, is composed of primitive formations, as are some of the Comoro Islands;[1] and Aitutaki consists of calcareous rock. We must, therefore, reject the several explanations, and conclude that the vertical thickness of barrier-reefs, from their outer edges to the foundation on which they rest (from A A in the sections No. 4 to the dotted lines), is really great: but this presents no real difficulty, as I hope to show hereafter when the upward growth of coral-reefs, during the slow subsidence of their foundation, is discussed.

[1] I have been informed that this is the case by Dr. Allan of Forres, who has visited this group.

CHAPTER III.

FRINGING OR SHORE REEFS.

Reefs of Mauritius—Shallow channel within the reef—Its slow filling up—Currents of water formed within it—Upraised reefs—Narrow fringing-reefs in deep seas—Reefs on the coast of E. Africa and of Brazil—Fringing-reefs in very shallow seas, round banks of sediment, and on worn-down islands—Fringing-reefs affected by currents of the sea—Coral coating bottom of the sea, but not forming reefs.

FRINGING-REEFS, or, as they have been called by some voyagers, shore-reefs, whether skirting an island or part of a continent, at first appear to differ little from barrier-reefs, except that they are generally of less breadth. As far as the superficies of the actual reef is concerned, this is the case; but the absence of an interior deep-water channel, and the close relation in their horizontal extension with the probable slope of the adjoining land beneath the sea, present essential points of difference.

The reefs which fringe the island of Mauritius offer a good example of this class. They extend round its whole circumference, with the exception of two or three parts[1] where the coast is almost precipitous, and

[1] This fact is stated on the authority of the Officier du Roi, in his extremely interesting 'Voyage à l'Isle de France,' undertaken in 1768. According to Captain Carmichael (Hooker's Bot. Misc., vol. ii. p. 316), on one part of the coast there is a space of sixteen miles without a reef.

where, if as is probable the bottom of the sea has a similar inclination, the coral would have no foundation on which to become attached. A similar fact may sometimes be observed even in reefs of the barrier class, which follow much less closely the outline of the adjoining land; as, for instance, on the S.E. and precipitous side of Tahiti, where the encircling reef is interrupted. On the western side of the Mauritius, which was the only part I visited, the reef generally lies at the distance of about half a mile from the shore; but in some parts it is distant from one to two, and even three miles. Even in this last case, as the coast-land is gently inclined from the foot of the mountains to the sea-beach, and as the soundings outside the reef indicate an equally gentle slope beneath the water, there is no reason for supposing that the basis of the reef, formed by the prolongation of the strata of the island, lies at a greater depth than that at which the polypifers could begin constructing the reef. Some allowance, however, must be made for the outward extension of a foundation formed of sand and detritus, from the wear of the corals; and this would give to the reef a somewhat greater vertical thickness than would otherwise be possible.

The outer edge of the reef on the western or leeward side of the island, is tolerably well defined, and is a little higher than any other part. It chiefly consists of large strongly branched corals of the genus Madrepora, which also form a sloping bed some way out to sea: the kinds of coral growing in this part will be described in the ensuing chapter. Between the outer margin and the beach, there is a flat space with a sandy bottom and a few tufts of living coral; in some parts it is so shallow, that people, by avoiding the deeper holes and gullies, can wade across it at low water; in other parts it is deeper, seldom, however, exceeding ten or twelve feet, so that it offers a safe coasting channel for boats. On the eastern and windward side of the island which is exposed to a heavy surf, the reef was described to me as having a hard smooth surface, very slightly inclined inwards, just covered at low-water, and traversed by gullies; it appears to be quite similar in structure to the reefs of the barrier and atoll classes.

The reef of Mauritius, in front of every river and streamlet, is breached by a straight passage: at Grand Port, however, there is a channel like that within a barrier-reef: it extends parallel to the shore for four miles, and has an average depth of ten or twelve fathoms; its presence may probably be accounted for by two rivers which enter at each end of the channel, and bend towards each other. The fact of reefs of the fringing class being always breached in front of streams, even of those which are dry during the greater part of the year, will be explained, when the conditions unfavourable to the growth of coral are considered. Low coral-islets, like those on barrier-reefs and atolls, are seldom formed on reefs of this class, apparently owing in some cases to their narrowness, and in others to the gentle slope of the reef outside not yielding many fragments to the breakers. On the windward side, however, of the Mauritius, two or three small islets have been formed.

It appears, as will be shown in the ensuing chapter, that the action of the surf is favourable to the vigorous growth of the stronger corals, and that sand or sediment, if agitated by the waves, is injurious to them. Hence it is probable that a reef on a shelving shore, like that of Mauritius, would at first grow up, not attached to the actual beach, but at some little distance from it; and the corals on the outer margin would be the most vigorous. A shallow channel would thus be formed within the reef; and this channel could be filled up only very slowly with sediment, for the breakers cannot act on the shores of the island, and they do not often tear up and cast inside fragments from the outer edge of the reef, whilst every streamlet carries away its mud in a straight line through breaches in the reef. But a beach of sand and of fragments of the smaller kinds of coral seems, in the case of Mauritius, to be slowly encroaching on the shallow channel. On many shelving and sandy coasts, the breakers tend to form a bar of sand a little way from the beach, with a slight increase of depth within it—for instance, Captain Grey[1] states that the west coast of Australia, in lat. 24°, is fronted by a sand bar about 200 yards in width, on which there is only two feet of water; but within it the depth increases to two fathoms. Similar bars,

[1] Captain Grey's Journal of Two Expeditions, vol. i. p. 369.

more or less perfect, occur on other coasts. In these cases I suspect that the shallow channel, (which no doubt during storms is occasionally obliterated,) is scooped out by the flowing away of the water thrown beyond the line on which the waves break with the greatest force. At Pernambuco the bar of hard sandstone, before alluded to, has the same external form and height as a coral reef, and extends nearly parallel to the coast; within this bar currents, apparently caused by the water thrown over it during the greater part of each tide, run strongly, and are wearing away its inner wall. From these facts it can hardly be doubted that within most fringing reefs, especially within those lying some distance from the land, a return stream must carry away the water thrown over the outer edge; and the current thus produced would tend to prevent the channel being filled up with sediment, and might even deepen it under certain circumstances. To this latter belief I am led, by finding that channels are almost universally present within the fringing reefs of those islands which have undergone recent elevatory movements; and this could hardly have been the case if the conversion of the very shallow channel into land had not been counteracted to a certain extent.

A fringing-reef, if elevated in a perfect condition above the level of the sea, would present the singular appearance of a broad dry moat bounded by a low wall or mound. The author[1] of an interesting pedestrian

[1] Voyage à l'Isle de France, par un Officier du Roi, Part i. pp. 192, 200.

tour round the Mauritius seems to have met with a structure of this kind : he says, 'J'observai que là, où la mer étale indépendamment des rescifs du large, il y a à terre *une espèce d'effoncement*, ou chemin couvert naturel. On y pourrait mettre du canon,' &c. In another place he adds, 'Avant de passer le Cap, on remarque un gros banc de corail élevé de plus de quinze pieds: c'est une espèce de rescif, que la mer a abandonné: il régne au pied une longue flaque d'eau, dont on pourrait faire un bassin pour de petits vaisseaux.' But the margin of the reef, although the highest and most perfect part, from being most exposed to the surf, would generally during a slow rise of the land be either partially or entirely worn down to that level at which corals could renew their growth on its upper edge. On some parts of the coast-land of Mauritius there are little hillocks of coral-rock, which are either the last remnants of a continuous reef, or of low islands formed on it. I observed two such hillocks between Tamarin Bay and the Great Black River; they were nearly 20 feet high, about 200 yards from the present beach, and about 30 feet above its level. They rose abruptly from a smooth surface, strewn with worn fragments of coral. They consisted in their lower part of hard calcareous sandstone, and in their upper of great blocks of several species of Astræa and Madrepora, loosely aggregated; they were divided into irregular beds, dipping seaward, in one hillock at an angle of 8°, and in the other at 18°. The upraised reefs round this island have been much less worn and modified by the action of the sea than in most other cases.

Many islands[1] are fringed by reefs quite similar to those of Mauritius: but on coasts where the sea deepens very suddenly, the reefs are much narrower, and their limited extension seems evidently to depend on the high inclination of the submarine slope;—a relation which, as we have seen, does not exist in reefs of the barrier class. The fringing-reefs on steep coasts are frequently not more than from 50 to 100 yards in width: they have a nearly smooth, hard surface, scarcely uncovered at low-water, and without any interior shoal channel like that within those fringing-reefs which lie at a greater distance from the land. The fragments torn up during gales from the outer margin are thrown over the reef on the shores of the island. I may give as instances, Wateeo, where the reef is described by Cook as being 100 yards wide; and Mauti and Elizabeth[2] Islands, where it is only 50 yards in width: the sea round these islands is very deep.

Fringing-reefs, like barrier-reefs, surround islands

[1] I may give Cuba, as another instance; Mr. Taylor (Loudon's Mag. of Nat. Hist., vol. ix. p. 449) has described a reef several miles in length between Gibara and Vjaro, which extends parallel to the shore at the distance of between half and the third part of a mile, and encloses a space of shallow water, with a sandy bottom and tufts of coral. Outside the edge of the reef, which is formed of great branching corals, the depth is six and seven fathoms. This coast has been upheaved at no very distant geological period.

[2] Mauti is described by Lord Byron in the Voyage of H.M.S. *Blonde*, and Elizabeth Island by Captain Beechey.

and front the shores of continents. In the charts of the eastern coast of Africa, by Captain Owen, many extensive fringing-reefs are laid down;—thus, for a space of nearly 40 miles, from lat. 1° 5′ to 1° 45′ S., a reef fringes the shore at an average distance of rather more than one mile, and therefore at a greater distance than is usual in reefs of this class; but as the coast-land is not high, and as the bottom shoals very gradually, (the depth being only from 8 to 14 fathoms at a mile and a-half outside the reef), its extension thus far from the land offers no difficulty. The external margin of this reef is described as formed of projecting points; and within it there is a channel from six to twelve feet deep, with patches of living coral. At Mukdeesha (lat. 2° 1′ N.) 'the port is formed,' it is said,[1] 'by a long reef extending eastward four or five miles, within which there is a narrow channel, with ten to twelve feet of water at low spring tides:' it lies at the distance of a quarter of a mile from the shore. Again, in the plan of Mombas (lat. 4° S.) a reef extends for thirty-six miles, at the distance of from half a mile to one mile and a-quarter from the shore; within it, there is a channel navigable 'for canoes and small craft,' between six and fifteen feet deep: outside the reef the depth is about 30 fathoms at the distance of nearly half a mile. Part of this reef is very symmetrical, and has a uniform breadth of 200 yards.

[1] Owen's Africa, vol. i. p. 357; from which work the foregoing facts are likewise taken.

The coast of Brazil is in many parts fringed by reefs. Of these, some are not of coral formation; for instance, those near Bahia and in front of Pernambuco; but a few miles south of this latter city, the reef follows[1] every turn of the shore so closely, that I can hardly doubt it is of coral. It runs at the distance of three-quarters of a mile from the land, and within it the depth is from ten to fifteen feet. I was assured by an intelligent pilot, that at Ports Frances and Maceio, the outer part of the reef consists of living coral, and the inner of a white stone full of large irregular cavities communicating with the sea.[2] The bottom of the sea off the coast of Brazil shoals gradually to between thirty and forty fathoms, at the distance of between nine and ten leagues from the land.

From the description now given, we may conclude that the dimensions and structure of fringing-reefs depend entirely on the greater or less inclination of the submarine slope, conjoined with the fact, that reef-building polypifers can exist only at limited depths. It follows from this, that where the sea is very shallow, as in the Persian Gulf and in parts of the East Indian Archipelago, the reefs lose their fringing character,

[1] Baron Roussin's Pilote du Brésil, and the accompanying hydrographical memoir. See also the supplement to this volume on a Bar of Sandstone off Pernambuco.

[2] [Rathbun (Amer. Nat., xiii. 539–551) describes a reef on the Brazilian coast. The lower part of the reef consists of true corals, the upper of nullipores and annelid tubes. The reef has a loose structure near the surface, compact below. The coral fragments covering the channel within the reef 'form beds of considerable thickness in places, often more or less consolidated.']

and appear as separate and irregularly scattered patches often of considerable area. As the conditions are less favourable in several respects on the inner side of these patches, the growth of the coral is more vigorous on the outside; thus causing the reefs to be generally higher and more perfect in their marginal than in their central parts. Hence these reefs sometimes assume (and this circumstance ought not to be overlooked) the appearance of atolls; but as they are based on a shallow foundation, and as their central expanse is much less deep and their form less defined, this resemblance is easily seen to be merely superficial. On the other hand, when, in a deep sea, banks of sediment have accumulated round islands or submerged rocks, and they become fringed with reefs, they are distinguished with difficulty from encircling barrier-reefs or atolls. In the West Indies there are reefs, which I should probably have arranged under these two classes, if the existence of large and level banks, lying a little beneath the surface and ready to serve as the basis for the attachment of coral, had not been present; the formation of such banks through the accumulation of sediment being sufficiently evident. Fringing-reefs sometimes coat, and thus protect the foundations of islands, which have been worn down by the surf to the level of the sea. According to Ehrenberg, this has been extensively the case with the islands in the Red Sea, which formerly ranged parallel to the shores of the mainland, with deep water within them: hence the reefs now coating their bases, are situated relatively to the land like barrier-reefs, although not belonging to that class;—but there are, as I believe, in the Red Sea some true barrier-reefs. The reefs of this sea and of the West Indies will be described in the Appendix. In some cases, fringing-reefs appear to be considerably modified in outline by the course of the prevailing currents; Dr. J. Allan informs me that on the east coast of Madagascar, almost every headland and low point of sand has a coral-reef extending from it in a S.W. and N.E. line, parallel to the currents on that shore. I should think the influence of the currents chiefly consisted in causing an extension, in a certain direction, of a proper foundation for the attachment of the coral. Round many intertropical islands, for instance the Abrolhos on the coast of Brazil surveyed by Captain FitzRoy, and, as I am informed by Mr. Cuming, round the Philippines, the bottom of the sea is entirely coated by irregular masses of coral, which although often of large size, do not reach the surface and form proper reefs. This must be owing either to insufficient growth, or to the absence of those kinds of corals which can withstand the breaking of the waves.

The three classes, atoll-formed, barrier, and fringing reefs, together with the modifications just described of the latter, include all the most remarkable coral-formations anywhere existing. At the commencement of the last chapter in the volume, where I detail the principles on which the map (Plate III.) is coloured, the exceptional cases will be enumerated.

CHAPTER IV.

ON THE GROWTH OF CORAL-REEFS.

In this chapter I will give all the facts, which I have collected, relating to the distribution of coral-reefs,—to the conditions favourable to their increase,—to the rate of their growth,—and to the depth at which they are formed.

These subjects have an important bearing on the theory of the origin of the different classes of coral-reefs.

Section I.

On the Distribution of Coral-Reefs, and on the Conditions favourable to their Increase.

With regard to the limits of latitude over which coral-reefs extend, I have nothing new to add. The Bermuda Islands in 32° 15′ N., is the point furthest removed from the equator in which they appear to exist; and their extension here so far northward no doubt is due to the warmth of the Gulf Stream. In the Pacific, the Loo Choo islands, in lat. 27° N., have reefs on their shores, and there is an atoll in 28° 30′, situated N.W.

of the Sandwich Archipelago. In the Red Sea there are coral-reefs in lat. 30°. In the Southern Hemisphere coral-reefs do not extend so far from the equatorial sea. In the Southern Pacific there are only a few reefs beyond the line of the tropic, but Houtmans Abrolhos, on the western shores of Australia, in lat. 29° S., are of coral-formation.

The proximity of volcanic land, owing to the lime generally evolved from it, has been thought to be favourable to the increase of coral-reefs. There is, however, no foundation for this view; for nowhere are coral-reefs more extensive than on the shores of New Caledonia and of north-eastern Australia, which consist of primary formations; and the Maldiva, Chagos, Marshall, Gilbert, and Low Archipelagoes, the largest groups of atolls in the world, are formed exclusively of coral.

The entire absence of coral-reefs in certain large areas within the tropical seas, is a remarkable fact. Thus no coral-reefs were observed during the surveying voyages of the *Beagle* on the west coast of South America south of the equator, or round the Galapagos Islands. It appears, also, that there are none[1] on this coast north of the equator; Mr. Lloyd, who surveyed the isthmus of Panama, remarked to me, that although he had seen corals living in the Bay of Panama, yet he had never observed any reefs formed by them. I at first attributed this absence of reefs on the coasts of Peru and

[1] I have been informed that this is the case, by Lieut. Ryder, R.N., and others who have had ample opportunities for observation.

of the Galapagos Islands,[1] to the coldness of the currents from the south, but the Gulf of Panama is one of the hottest pelagic districts in the world.[2] In the central parts of the Pacific there are islands entirely free from reefs; and in some of these cases this appears to be due to recent volcanic action: but the existence of reefs, though scantily developed, and according to Dana, confined to one part of Hawaii (one of the Sandwich Islands), shows that recent volcanic action does not absolutely prevent their growth.[3]

[1] The mean temperature of the surface sea, from observations made by the direction of Captain FitzRoy on the shores of the Galapagos Islands, between the 16th of September and the 20th of October, 1835, was 68° Fahr. The lowest temperature observed was 58°·5 at the S.W. end of Albemarle Island; and on the west coast of this island, it was several times 62° and 63°. The mean temperature of the sea in the Low Archipelago of atolls, and near Tahiti, from similar observations made on board the *Beagle*, was (although further from the equator) 77°·5, the lowest any day being 76°·5. Therefore we have here a difference of 9°·5 in mean temperature, and 18° in extremes; a difference doubtless quite sufficient to affect the distribution of organic beings in the two areas.

[2] Humboldt's Personal Narrative, vol. vii. p. 434.

[3] [Mr. S. J. Whitmee (Nature, August 12, 1875, p. 291) states that in Savaii (Samoan group), one of four examples of islands which Professor Dana brings forward as instances indicating that recent volcanic action has prevented the formation of extensive coral-reefs, the cause is more probably the depth of water on the coast. Moreover, parts of Savaii differ in change of level from the rest of the island, and it is in these (the upheaved regions) that coral-reefs are almost wanting. He also says that after examining 'a good many intertropical islands of the Pacific belonging to the three orders—(1) Volcanic islands with fringing coral-reefs, such as Samoa, the New Hebrides, &c.; (2) Atolls, such as the Low Archipelago, Ellice, Gilbert Islands, &c.; (3) Upraised coral-islands, such as Niuê or Savage Island, part of the Friendly, the Loyalty Islands, &c.'—he has been the more firmly convinced, the further he has gone, of the correctness of Mr. Darwin's theory. Mr. R. Webb (Nature, *id.* p. 475) disputes

In the last chapter I stated that the bottom of the sea round some islands is thickly coated with living corals, which nevertheless do not form reefs, either from insufficient growth, or from the species not being adapted to contend with the breaking waves.

I have been assured by several navigators that there are no coral-reefs on the west coast of Africa,[1] or round the islands in the Gulf of Guinea. This perhaps may be attributed to the sediment brought down by the many rivers debouching on that coast, and to the extensive mud-banks which line great part of it. But the islands of St. Helena, Ascension, the Cape Verdes, St. Paul's, and Fernando Noronha, are, also, entirely destitute of reefs, although they lie far out at sea, are composed of the same ancient volcanic rocks, and have the same general form with those islands in the Pacific, the shores of which are surrounded by gigantic walls of coral-rock. With the exception of Bermuda, there is not a single coral-reef in the central expanse of the Atlantic ocean. It will, perhaps, be suggested that the quantity of carbonate of lime in different parts of the sea may regulate the presence of reefs. But this cannot be the case, for at Ascension, the waves, charged to excess, precipitate a thick layer of calcareous matter

Mr. Whitmee's statement as to the upheaval of the above-mentioned part of Savaii. (From materials collected by Mr. Darwin.)]

[1] It might be concluded, from a paper by Captain Owen (Geograph. Journ., vol. ii. p. 89), that the reefs off Cape St. Anne and the Sherboro' Islands were of coral, although the author states that they are not purely coralline. But I have been assured by Lieut. Holland, R.N., that these reefs are not of coral, or at least that they do not at all resemble those in the West Indies.

on the tidal rocks; and at St. Jago in the Cape Verdes, carbonate of lime not only is abundant on the shores, but it forms the chief part of some upraised post-tertiary strata. The apparently capricious distribution, therefore, of coral-reefs, cannot be fully explained by any of the above obvious causes; but, as the study of the terrestrial and better-known half of the world, must convince everyone that no station capable of supporting life is lost,—nay more, that there is a struggle for each station between different organisms, —we may conclude that in those parts of the inter-tropical sea in which there are no coral-reefs, there are other organic beings, supplying the place of the reef-building polypifers. It has been shown in the chapter on Keeling atoll that there are some species of large fish, and the whole tribe of Holothuriæ,[1] which prey on the tenderer parts of the corals. On the other hand, the polypifers in their turn must prey on other organic beings; and they would suffer by the diminution of their prey through any cause. The relations, therefore, which determine the formation of reefs on any shore, by the vigorous growth of the efficient kinds of coral, must be very complex, and with our imperfect knowledge inexplicable. From these considerations, we may infer that changes in the condition of the sea, not obvious to our senses, might destroy all the coral-reefs in one area, and cause them to appear in another: thus, the Pacific or Indian ocean might become as barren of coral-reefs as now is the Atlantic, without

[1] [See Appendix ii.]

our being able to assign any adequate cause for such a change.[1]

It has been a question with some naturalists, which part of a reef is most favourable to the growth of coral. The great mounds of living Porites and of Millepora round Keeling atoll occur exclusively on the extreme verge of the reef, which is washed by a constant succession of breakers; and living coral nowhere else forms solid masses. At the Marshall islands the larger kinds of corals (chiefly a species of Astræa, a genus closely allied to Porites), 'which form rocks measuring several fathoms in thickness,' prefer, according to Chamisso,[2] the most violent surf. I have stated that the outer margin of the Maldiva atolls consists of living corals, (some of which, if not all, are of the same species with those at Keeling atoll), and here the surf is so tremendous, that even large ships have been thrown, by a single heave of the sea, high and dry on the reef, all on board thus escaping with their lives.

Ehrenberg[3] remarks, that in the Red Sea the

[1] I have left the foregoing paragraphs nearly as they stood in the first edition; but, as stated in the Preface to the present work, Dana has shown that I have undervalued the importance of the mean temperature of the sea during the coldest season of the year, on the distribution of coral-reefs, as well as perhaps the injurious effects of recent volcanic action. But I cannot see that the absence of coral-reefs round certain islands in the Atlantic, for instance Ascension St. Paul's Rock, and Fernando Noronha, or from the shores of the Gulf of Panama, is explicable through any known cause.

[2] Kotzebue's First Voyage (Eng. Transl.), vol. iii. pp. 142, 143, 331.

[3] Ehrenberg, Ueber die Natur und Bildung der Corallen Bänke im rothen Meere, p. 49.

strongest corals live on the outer reefs, and appear to love the surf; he adds, that the more branched kinds abound a little way within, but that these in still more protected places become smaller. Many other facts having a similar tendency might be adduced.[1] It has, however, been doubted by MM. Quoy and Gaimard, whether any kind of coral can even withstand, much less flourish in, the breakers of an open sea;[2] they affirm that the saxigenous lithophytes flourish only where the water is tranquil, and the heat intense. This statement has passed from one geological work to another; nevertheless, the protection of the whole reef is undoubtedly due to those kinds of coral, which cannot even exist in the situations thought by these naturalists to be most favourable to them. For should the outer and living margin perish, of any one of the many low coral-islands, round which a line of great breakers is incessantly foaming, the whole, it is scarcely possible to doubt, would be washed away and destroyed in less than half a century. But the vital energies of the corals conquer the mechanical power of the waves; and the large fragments of reef torn up by every storm, are replaced by the slow but steady growth of the innumerable polypifers which form the living zone on its outer edge.

[1] In the West Indies, as I am informed by Captain Bird Allen, R.N., it is the common belief of those who are best acquainted with the reefs, that the coral flourishes most where freely exposed to the swell of the open sea.

[2] Annales des Sciences Naturelles, tom. vi. pp. 276, 278.—'Là où les ondes sont agitées, les Lytophytes ne peuvent travailler, parce qu'elles détruiraient leurs fragiles édifices,' &c.

From these facts, it is certain, that the strongest and most massive corals flourish where most exposed. The less perfect state of the reef of most atolls on the leeward and less exposed side, compared with its state to windward; and the analogous case of the greater number of breaches on the near sides of those atolls in the Maldiva Archipelago which afford some protection to each other, are obviously explained by this circumstance. If the question had been, under what conditions the greater number of species of coral, not regarding their bulk and strength, were developed, I should answer,—probably in the situations described by MM. Quoy and Gaimard, where the water is tranquil and the heat intense. The total number of species of coral in the circumtropical seas must be very great; in the Red Sea alone, 120 kinds, according to Ehrenberg,[1] have been observed.

The same author has observed that the recoil of the sea from a steep shore is injurious to the growth of coral, although waves breaking over a bank are not so. Ehrenberg also states that where there is much sediment, placed so as to be liable to be moved by the waves, there is little or no coral; and a collection of living specimens placed by him on a sandy shore died in the course of a few days.[2] An experiment, however, will presently be related in which some large masses of living coral increased rapidly in size, after having been secured by stakes on a sandbank. That loose sediment should be injurious to

[1] Ehrenberg Ueber die Natur, &c. &c., p. 46. [2] Ibid. p. 49.

the living polypifers, appears at first sight probable; and in sounding off Keeling atoll and Mauritius, the arming of the lead invariably came up clean, where the coral was growing vigorously. A strange belief, which, according to Captain Owen,[1] is general amongst the inhabitants of the Maldiva atolls, namely, that corals have roots, and therefore grow up again if merely broken down to the surface, but if rooted out, are permanently destroyed,—I am inclined to believe arises from the fact that loose sand injures the polypifers. For it is probable that sand would accumulate in the hollows formed by tearing out the corals, but not on the broken and projecting stumps; and therefore, in the former case, the fresh growth of the coral would be prevented. By this means the inhabitants keep their harbours clear; and thus the French governor of St. Mary's, in Madagascar, 'cleared out and made a beautiful little port at that place.'

In the last chapter I remarked, that fringing-reefs are almost universally breached where streams enter the sea.[2] Most authors have attributed this fact to the injurious effects of the fresh water, even where

[1] Captain Owen on the Geography of the Maldiva Islands, Geograph. Journal, vol. ii. p. 88.

[2] Lieut. Wellstead and others have remarked that this is the case in the Red Sea: Dr. Rüppell (Reise, in Abyss. Band. i. s. 142) says that there are pear-shaped harbours in the upraised coral-coast, into which periodical streams enter. From this circumstance, I presume, we must infer that, before the upheaval of the strata now forming the coast-land, fresh water and sediment entered the sea at these points; and the coral being thus prevented growing, the pear-shaped harbours were produced.

it enters the sea only in small quantity and during a part of the year. No doubt brackish water would prevent or retard the growth of coral; but I believe that the mud and sand, which is deposited, even by small rivulets when flooded, is a much more efficient check. The reef on each side of the channel leading into Port Louis at Mauritius, ends abruptly in a wall, at the foot of which I sounded, and found a bed of thick mud. This steepness of the sides appears to be a general character in such breaches: Cook,[1] speaking of one at Raiatea, says, 'like all the rest, it is very steep on both sides.' Now, if it were the fresh water mingling with the salt, which prevented the growth of coral, the reef certainly would not terminate abruptly; but as the polypifers nearest the impure stream would grow less vigorously than those farther off, so would the reef gradually thin away. On the other hand, the sediment brought down from the land would only prevent the growth of the coral in the line of its deposition, but would not check it on the side, so that the reefs might increase till they overhung the bed of the channel. The breaches are much fewer in number, and front only the larger valleys in reefs of the encircling barrier class. They probably are kept open in the same manner as those into the lagoon of an atoll, namely, by the force of the currents and the drifting outwards of fine sediment. Their position in front of valleys, although often separated from the land by deep-water lagoon-channels, which it might

[1] Cook's First Voyage, vol. ii. p. 271. (Hawkesworth's edit.)

be thought would entirely remove the injurious effects both of the fresh water and the sediment, will receive a simple explanation when we discuss the origin of barrier-reefs.

In the vegetable kingdom every different station has its peculiar group of plants, and similar relations appear to prevail with corals. We have already described the great difference between the corals within the lagoon of an atoll and those on its outer margin. The corals, also, on the margin of Keeling Island occurred in zones: thus the Porites and *Millepora complanata* grow to a large size, only where they are washed by a heavy sea, and are killed by a short exposure to the air; whereas, three species of Nullipora also live amidst the breakers, but are able to survive uncovered for a part of each tide: at greater depths, a strong Madrepora and *Millepora alcicornis* are the commonest kinds; the former appearing to be confined to this part: beneath the zone of massive corals, minute encrusting corallines and other organic bodies live. If we compare the external margin of the reef at Keeling atoll with that on the leeward side of Mauritius, which are very differently circumstanced, we shall find a corresponding difference in the appearance of the corals. At the latter place, the genus Madrepora is preponderant over every other kind; and beneath the zone of massive corals there are large beds of Seriatopora. There is also a marked difference, according to Captain Moresby,[1]

[1] Captain Moresby on the Northern Maldiva Atolls. Geograph. Journ., vol. v. p. 401.

between the great branching corals of the Red Sea and those on the reefs of the Maldiva atolls.

These facts, which in themselves are deserving of notice, bear, perhaps, not very remotely on a remarkable circumstance which has been pointed out to me by Captain Moresby, namely, that with very few exceptions, none of the coral-knolls within the lagoons of Peros Banhos, Diego Garcia, and the Great Chagos Bank (all situated in the Chagos group), rise to the surface of the water; whereas, with equally few exceptions, all those within Solomon and Egmont atolls in the same group, and likewise those within the large southern Maldiva atolls, reach the surface. I make these statements, after having examined the charts of each atoll. In the lagoon of Peros Banhos, which is nearly twenty miles across, there is only one single reef which rises to the surface: in Diego Garcia there are seven, but several of these lie close to the margin of the lagoon, and need scarcely have been reckoned: in the Great Chagos Bank there is not one. On the other hand, in the lagoons of some of the great southern Maldiva atolls, although thickly studded with reefs, every one without exception rises to the surface; and on an average there are less than two submerged reefs in each atoll: in the northern atolls, however, the submerged lagoon-reefs are not quite so rare. The submerged reefs in the Chagos atolls generally have from one to seven fathoms water on them, but some have from seven to ten. Most of them are small with very steep sides;[1] at Peros Banhos they rise from

[1] Some of these statements were not communicated to me verb-

a depth of about thirty fathoms, and some of them in the Great Chagos Bank from above forty fathoms: they are covered, Captain Moresby informs me, with living and healthy coral two and three feet high, consisting of several species. Why then have not these lagoon-reefs reached the surface, like the innumerable ones in the atolls above named? If we attempt to assign any difference in their external conditions, as the cause of this diversity, we are at once baffled: the lagoon of Diego Garcia is not deep, and is almost wholly surrounded by its reef; Peros Banhos is very deep, much larger, with many wide passages communicating with the open sea. On the other hand, of those atolls in which all, or nearly all the lagoon-reefs have reached the surface, some are small, others large, some shallow, others deep, some well enclosed, and others open.

Captain Moresby informs me that he has seen a French chart of Diego Garcia made eighty years before his survey, and apparently very accurate; and from it he infers, that during this interval there has not been the smallest change in the depth on any of the knolls within the lagoon. It is, also, known that during the last fifty-one years, the eastern channel into the lagoon has neither become narrower, nor decreased in depth; and as there are numerous small knolls of living coral within it, some change might have been anticipated. Moreover, as the whole reef round the lagoon of this atoll has been converted into land—an unparalleled case, I believe, in

ally by Captain Moresby, but are taken from the MS. account, before alluded to, of the Chagos Group.

an atoll of such large size,—and as the strip of land is for considerable spaces more than half a mile wide—also a very unusual circumstance,—we have the best possible evidence that Diego Garcia has remained at its present level for a very long period. With this fact, and with the knowledge that no sensible change has taken place during eighty years in the coral knolls, and considering that every single reef has reached the surface in other atolls, which do not present the smallest appearance of being older than Diego Garcia and Peros Banhos, and which are placed under the same external conditions with them, one is led to conclude that these submerged reefs, although covered with luxuriant coral, have no tendency to grow upwards, and that they would remain at their present levels for an indefinite period.

From the number of these knolls, from their position, size, and form,—many of them being only one or two hundred yards across, with a rounded outline and precipitous sides,—it is indisputable that they have been formed by the growth of coral; and this makes the case much more remarkable. In Peros Banhos and in the Great Chagos bank, some of these almost columnar masses are 200 feet high, and their summits lie only from two to eight fathoms beneath the surface; therefore, a little greater proportional amount of growth would cause them to attain the surface, like those numerous knolls which rise from an equally great depth within the Maldiva atolls. We can hardly suppose that time has been wanting for the upward growth of the coral; as in Diego Garcia, the broad annular strip of land, formed by the continued accumulation of detritus, shows how long this atoll has remained at its present level. We must look to some other cause than the rate of growth; and I suspect it will be found in the reefs being formed of different species of corals, adapted to live at different depths.

The Great Chagos bank is situated in the centre of the Chagos group, and the Pitt and Speaker banks at its two extreme points. These banks resemble atolls, except in their external rim being about eight fathoms submerged, and in being formed of dead rock, with very little living coral on it: a portion nine miles long of the annular reef of Peros Banhos atoll is in the same condition. These facts, as will hereafter be shown, render it probable that the whole group at some former period subsided seven or eight fathoms; and that the coral perished on the outer margins of those atolls which are now submerged, but that it continued alive and grew up to the surface on the others now perfect. If all these atolls did formerly subside, and if from the suddenness of the movement or from any other cause, those species of corals which are best adapted to live at a certain depth, once got possession of the knolls, supplanting their former occupants, they would have little or no power to grow upwards. To illustrate this, I may observe that if the corals of the upper zone on the outer edge of Keeling atoll were to perish, it is improbable that those of the lower zone would grow to the surface, and thus become exposed to conditions for which they do not appear to be adapted. The conjecture that the corals on the submerged knolls within the Chagos atolls have analogous habits with those of the lower zone outside Keeling atoll, receives some support from a remark by Captain Moresby, namely, that they have a different appearance from those on the reefs in the Maldiva atolls, which, as we have seen, all rise to the surface: he compares the kind of difference to that of the vegetation under different climates. I have entered at considerable length into this case, although unable to throw much light on it, in order to show that coral-reefs situated in different places or at different depths, whether forming the ring of an atoll or the knolls within a lagoon, need not all be supposed to have an equal tendency to upward growth. The inference, therefore, that one reef could not grow to the surface within a given time, because another, not known to be covered with the same species of corals, and not known to be placed under exactly the same conditions, has not within the same time reached the surface, is unsound.

SECTION II.

On the Rate of Growth of Coral-reefs.

THE remark made at the close of the last section, naturally leads to this division of our subject, which has not, I think, hitherto been considered under a right point of view. Ehrenberg[1] has stated that in the Red Sea, the corals only coat other rocks in a

[1] Ehrenberg, as before cited, pp. 39, 46, and 50.

layer from one to two feet in thickness, or at most to a fathom and a-half; and he disbelieves that, in any case, they form by their own proper growth great masses, stratum over stratum. A nearly similar observation has been made by MM. Quoy and Gaimard,[1] with respect to the thickness of some upraised beds of coral, which they examined at Timor and some other places. Ehrenberg[2] saw certain large massive corals in the Red Sea, which he imagines to be of such vast antiquity, that they might have been beheld by Pharaoh; and according to Sir C. Lyell[3] there are certain corals at Bermuda, which are known by tradition to have been living for centuries.[4] To show how slowly coral-reefs grow upwards, Captain Beechey[5] has adduced the case of the Dolphin Reef off Tahiti, which has remained at the same depth beneath the surface, namely, about two fathoms and a-half, for a period of sixty-seven years. There are reefs in the Red Sea, which certainly do not appear[6] to have in-

[1] Annales des Sciences Nat., tom. vi. p. 28.

[2] Ehrenberg, ut sup. p. 42.

[3] Lyell's Principles of Geology, book iii. ch. xviii.

[4] Since the preceding pages (of the first edit.) have been printed off, I have received from Sir C. Lyell an interesting pamphlet, entitled Remarks upon Coral-Formations, &c., by J. Couthouy, Boston, United States, 1842. A statement (p. 6) is here given on the authority of the Rev. J. Williams, corroborating the above remarks on the antiquity of certain individual corals, namely, that at Upolu, one of the Navigator islands, 'particular clumps of coral are known to the fishermen by name, derived from either some particular configuration or tradition attached to them, and handed down from time immemorial.'

[5] Beechey's Voyage to the Pacific, ch. viii.

[6] Ehrenberg, ut sup. p. 43.

creased in dimensions during the last half century, and from the comparison of old charts with recent surveys, probably not during the last two hundred years. These, and other similar facts, have so strongly impressed many with the belief of the extreme slowness of the growth of corals, that they have even doubted the possibility of islands in the great oceans having been formed by their agency. Others again, who have not been overwhelmed by this difficulty, have admitted that it would require thousands, and tens of thousands of years, to form a mass even of inconsiderable thickness: but the subject has not, I believe, been viewed in the proper light.

That masses of considerable thickness have been formed by the growth of coral, may be inferred with certainty from the following facts. In the deep lagoons of Peros Banhos and of the Great Chagos bank, there are, as already described, small steep-sided knolls covered with living coral. There are similar knolls in the southern Maldiva atolls, some of which, as Captain Moresby assures me, are less than a hundred yards in diameter, and rise to the surface from a depth of between 250 and 300 feet. Considering their number, form, and position, it would be preposterous to suppose that they are based on pinnacles of rock, or on isolated cones of sediment. As no kind of living coral grows above the height of a few feet, we are compelled to suppose that these knolls have been formed by the successive growth and death of many individuals,—first one being broken off or killed by some accident, and then another, and one set of species being replaced by another set with different habits, as the reef rose nearer the surface, or as other changes supervened. The spaces between the corals would become filled up with fragments and sand, and such matter would probably soon be consolidated, for we learn from Lieut. Nelson's[1] observations at Bermuda that a process of this kind takes place beneath water, without the aid of evaporation. In reefs, also, of the barrier class, we may feel sure, as I have shown, that masses of great thickness have been formed by the growth of coral. In the case of Vanikoro, judging only from the depth of the moat between the land and the reef, the wall of coral-rock must be at least 300 feet in vertical thickness.

So again some of the upraised islands in the Pacific show what thick masses of coral-rock have been formed. Dana[2] states that Metia, in the Paumotu or Low Archipelago, consists of white solid limestone with some disseminated corals; and this island once existed as an atoll, though now surrounded by cliffs 250 feet in height. The cliffs round Elizabeth Island in the same archipelago are 80 feet high, and are composed, according to Beechey, of homogeneous coral-rock. Mangaia in the Hervey Group, and Rurutu, appear both to have once existed as encircled islands,

[1] Geological Transactions, vol. v. p. 113.
[2] Corals and Coral Islands, 1872, p. 193. See also Mr. Couthouy's pamphlet above referred to.

and their barrier-reefs are now in parts 300 feet above the level of the sea.[1]

Some attempts have been made, with but little success, to ascertain by boring the thickness of coral formations. At Bow Island, in the Low Archipelago, Sir E. Belcher[2] bored to a depth of 45 feet, and below the first 20 found only coral-sand. During Wilke's Expedition,[3] in a boring of 21 feet in depth on one of the islands in the same archipelago, coral-sand was passed through for the first 10 or 11 feet, and then solid reef rock. On one of the Maldiva atolls in the Indian Ocean, Captain Moresby bored to a depth of 26 feet, when his auger broke. He gave me the matter brought up, and it was perfectly white like finely triturated coral-rock.

In my description of Keeling atoll, I have advanced some facts showing that the reef has probably grown outwards; and I found, just within the outer margin, the great mounds of Porites and of Millepora, with their summits lately killed, and their sides subsequently thickened by the growth of the coral: a layer, also, of Nullipora had already coated the dead surface. As the external slope of the reef is the same round the whole of this and many other atolls, the angle of inclination must result from an adaptation

[1] Dana, Corals and Coral Islands, p. 336. Also Forster's Voyage round the World with Cook, vol. ii. pp. 163, 167. Williams's Narrative of Missionary Enterprise, pp. 30, 48, and 249.

[2] Voyage Round the World, vol. i. 1843, p. 369.

[3] Narrative U.S. Exploring Expedition, vol. iv. p. 268. Dana, Corals and Coral Islands, p. 184.

between the growing powers of the coral and the force of the breakers, and their action on the loose sediment. The reef, therefore, could not increase outwards without a nearly equal addition to every part of the slope, so that the original inclination might be preserved, and this would require a large amount of sediment, all derived from the wear of corals and shells, to be added to the lower part. Moreover, at Keeling atoll and probably in many other cases, the different kinds of coral would have to encroach on each other; thus the Nulliporæ cannot increase outwards without encroaching on the Porites and *Millepora complanata*, as is now taking place; nor these latter without encroaching on the strongly branched Madrepora, the *Millepora alcicornis*, and some Astræas; nor these again without a foundation being formed for them within the requisite depth, by the accumulation of sediment. How slow, then, must be the ordinary lateral or outward growth of such reefs! But off Christmas atoll, where the sea is much more shallow than is usual, we have good reason to believe that, within a period not very remote, the reef has increased considerably in width. The land has the extraordinary breadth of three miles; it consists of parallel ridges of shells and broken corals, which furnish 'an incontestable proof,' as observed by Cook,[1] 'that the island has been produced by accessions from the sea, and is in a state of increase.' The land is fronted by a coral-reef, and from the manner in which

[1] Cook's Third Voyage, book iii. ch. x.

islets are known to be formed, we may feel confident that the reef was not three miles wide when the first, or most inward ridge, was thrown up; and, therefore, we must conclude that the reef has grown outwards during the accumulation of the successive ridges. Here then, a wall of coral-rock of very considerable breadth has been formed by the outward growth of the living margin, within a period, during which ridges of shells and corals, lying on the bare surface, have not decayed. There can be little doubt, from the account given by Captain Beechey, that Matilda atoll in the Low Archipelago has been converted in the space of thirty-four years, from being, as described by the crew of a wrecked whaling vessel, a 'reef of rocks,' into a lagoon-island fourteen miles in length, with 'one of its sides covered nearly the whole way with high trees.'[1] The islets, also, on Keeling atoll, it has been shown, have increased in length, and since the construction of an old chart, several of them have become united into one long islet: but in this case, and in that of Matilda atoll, we have no proof that the foundation of the islets, namely the reef, has increased in breadth, although it must be allowed that this is probable.

I think, therefore, in regard to the possible rate of *outward* growth of coral-reefs, but little importance need be attached to the fact that certain reefs in the Red Sea have not increased during a long interval of time, or to other similar cases, such as that of Ouluthy

[1] Beechey's Voyage to the Pacific, ch. vii and viii.

atoll in the Caroline group, where every islet, described a hundred years before by Cantova, was found in the same state by Lutké.[1] For it cannot be shown that, in these cases, the conditions were favourable to the vigorous and unopposed growth of the corals living in the different zones of depth, and that a proper basis for the extension of the reef was present. These conditions must depend on many contingencies, and a basis within the requisite depth can rarely be present in the deep oceans where coral formations most abound.

Nor do I think, when we consider the rate of the *upward* growth of reefs under favourable circumstances, that we should be influenced by the fact that certain submerged reefs, such as those off Tahiti or those within Diego Garcia, are not now nearer the surface than they were many years ago. For it has been shown that all the reefs have grown to the surface in some of the Chagos atolls, but that in neighbouring atolls which appear to be of equal antiquity and to be exposed to the same external conditions, every reef remains submerged; we are, therefore, almost driven to attribute this to a difference, not in the rate of growth, but in the habits of the corals in the two cases.

In an old-standing reef, the corals, which greatly differ in kind on different parts of it, are probably

[1] F. Lutké's Voyage autour du Monde. In the group Elato, however, it appears that what is now the islet Falipi, is called in Cantova's Chart, the Banc de Falipi. It is not stated whether this has been caused by the growth of coral, or by the accumulation of sand.

all adapted to the stations they occupy, and hold their places, like other organic beings, by a struggle one with another and with external nature; hence we may infer that their growth would be slow except under peculiarly favourable circumstances. Almost the only natural condition, allowing a quick upward growth of the whole surface of a reef, would be a slow subsidence of the area in which it stood;—if, for instance, Keeling atoll were to subside two or three feet, can we doubt that the projecting margin of live coral, about half an inch in thickness, which surrounds the dead upper surfaces of the mounds of Porites, would in this case form a concentric layer over them, and the reef thus increase upwards, instead of, as at present, outwards? The Nulliporæ are now encroaching on the Porites and Millepora, but in this case might we not confidently expect that the latter would, in their turn, encroach on the Nulliporæ? After a subsidence of this kind, the sea would gain on the islets, and the great fields of dead but upright corals in the lagoon would be covered by a sheet of clear water; and might we not then expect that these reefs would rise to the surface, as they anciently did when the lagoon was less confined by islets, and as they did within a period of ten years in the schooner-channel cut by the inhabitants. In one of the Maldiva atolls, a reef, which within a very few years existed as an islet bearing cocoa-nut trees, was found by Lieut. Prentice '*entirely covered with live coral and Madrepore*.' The natives believe that the islet was washed away by a change in the currents, but if, instead of this, it had quietly subsided, surely every part of the island which offered a solid foundation, would in a like manner have become coated with living coral.

Through steps such as these, any thickness of rock composed of a singular intermixture of various kinds of corals, shells, and calcareous sediment, might be formed; but without subsidence, the thickness would necessarily be determined by the depth at which the reef-building polypifers can exist. If it be asked, at what rate in years I suppose a reef of coral favourably circumstanced could grow up from a given depth; I must answer that we have no precise evidence on this head. It will, however, be hereafter shown that in certain large areas where subsidence has probably been long in progress, the growth of the corals has been sufficient to keep the reefs up to the surface; and this is a much more important standard of comparison than any cycle of years.

It may, however, be inferred from the following facts, that the rate under favourable circumstances would be far from slow. Dr. Allan of Forres has given, in his MS. Thesis deposited in the library of the Edinburgh University, the following account of some experiments, which he tried during his travels in the years 1830 to 1832 on the east coast of Madagascar. 'To ascertain the rise and progress of the coral family, and fix the number of species met with at Foul Point (lat. 17° 40′), twenty species of coral were taken off the reef and planted apart on a sand-bank *three feet deep at low water.* Each portion weighed ten pounds, and was kept in its place by stakes. Similar quantities were placed in a clump and secured as the rest. This was done in December 1830. In July following, each detached mass was nearly level with the sea at low water, quite immovable, and several feet long, stretching, like the parent reef, in the line of the coast-current from north to south. The masses accumulated in a clump were found equally increased, but some of the species in such unequal ratios as to be growing over each other.' [1] The loss of Dr. Allan's magnificent collection by shipwreck, unfortunately prevents its being known to what genera these corals belonged; but from the numbers experimented on, it is certain that all the more conspicuous kinds must have been included. Dr. Allan informs me, in a letter, that he believes it was a Madrepora which grew most vigorously. One may be permitted to suspect that the level of the sea might possibly have been somewhat different at the two stated periods; nevertheless, it is quite evident that the growth of the ten-pound masses, during the six or seven months at the end of which they were found to be immovably fixed [2] and several feet in length, must have been very great. The fact of the

[1] I owe the above extract to the kindness of Dr. Malcolmson.

[2] It is stated by Mr. De la Beche (Geological Manual, p. 143), on the authority of Mr. Lloyd, who surveyed the Isthmus of Panama, that some specimens of Polypifers, placed by him in a sheltered pool of water, were found in the course of a few days firmly fixed by the secretion of a stony matter, to the bottom.

different kinds of coral, when placed in one clump, having increased in extremely unequal ratios, is very interesting, as it shows the manner in which a reef, supporting many species of coral, would probably be affected by a change in the external conditions favouring one kind more than another. The growth of the masses of coral in N. and S. lines parallel to the prevailing currents, whether due to the drifting of sediment or to the simple movement of the water, is, also, an interesting circumstance.

Lieut. Wellstead, I.N., informed me that in the Persian Gulf a ship had her copper bottom encrusted in the course of twenty months with a layer of coral *two feet* in thickness, which it required great force to remove when the vessel was docked: it was not ascertained to what order this coral belonged.[1]

[1] Mr. Stutchbury (West of England Journal, No. I. p. 50) has described a specimen of Agaricia, 'weighing 2 lbs. 9 oz., which surrounds a species of oyster, whose age could not be more than two years, and yet is completely enveloped by this dense coral.' I presume that the oyster was living when the specimen was procured; otherwise the fact tells nothing. Mr. Stutchbury also mentions an anchor, which had become entirely encrusted with coral in fifty years; other cases, however, are recorded of anchors having long remained amidst coral-reefs without having become coated. The anchor of the *Beagle*, in 1832, after having been down exactly one month at Rio de Janeiro, was so thickly coated by two species of Tubularia, that large spaces of the iron were entirely concealed; the tufts of this horny zoophyte were between two and three inches in length. Spallanzani states (Travels, Eng. Translat. vol. iv. p. 313) that in the Mediterranean, the red coral of commerce is usually dredged every ten years, during which time it grows to a height of one foot. It grows, however, at different rates in different places. It has been erroneously attempted to compute the rate of growth of a reef, from the fact mentioned by Captain Beechey of the *Chama*

This fact in some degree corroborates the result of Dr. Allan's experiments. The case of the schooner-channel, choked up with coral in an interval of less than ten years, in the lagoon of Keeling atoll, should be here borne in mind. We may also infer, from the trouble which the inhabitants of the Maldiva atolls take to root out, as they express it, the coral-knolls from their harbours, that their growth can hardly be very slow. I may add, that M. Duchassaing broke off all the Madrepores growing on a marked place in a bay at Guadaloupe; and in the course of two months he found there a greater number of corals than before.[1]

From the facts given in this section, it may be concluded, first, that considerable thicknesses of rock have certainly been formed within the present geological era by the growth of corals and the accumulation of their detritus; and, secondly, that the increase of individual corals and of reefs, both outwards or horizontally, and upwards or vertically, under conditions favourable to such increase, is not slow, when referred either to the standard of the average

gigas being embedded in coral rock. But it should be remembered, that some species of this genus invariably live, both whilst young and old, in cavities, which the animal has the power of enlarging with its growth. I saw many of these shells thus embedded in the outer 'flat' of Keeling atoll, which is composed of dead rock; and therefore the cavities in this case had no relation whatever to the growth of coral. M. Lesson, also, speaking of this shell (Partie Zoolog., Voyage de la *Coquille*), has remarked, 'que constamment ses valves étaient engagées complètement dans la masse des Madrépores.'

[1] L'Institut, 1846, p. 111.

oscillations of level in the earth's crust, or to the more precise but less important one of a cycle of years.[1]

SECTION III.

On the Depths at which Reef-building Corals live.

I HAVE already described in detail the nature of the bottom of the sea immediately surrounding Keeling atoll; and I will here describe with almost equal care, the soundings off the fringing-reefs of Mauritius. I sounded with the wide bell-shaped lead which Captain FitzRoy used at Keeling Island. My examination of the bottom was confined to a few miles of coast (between Port Louis and Tomb Bay) on the leeward side of the island. The edge of the reef is formed of great shapeless masses of branching Madrepores, which chiefly consist of two species,—apparently *M. corymbosa* and *pocillifera*,—mingled with a few other kinds of coral. These masses are separated from each other by the most irregular gullies and cavities,

[1] [See Dana, Corals and Coral Islands, ch. i. sec. iv. for additional facts relating to rate of growth of corals. Le Conte (Amer. Jour. Sci. Ser. 3, vol. x. pp. 34–6) estimates that a *Madrepora* (*cervicornis* ?) in shoal water at the Tortugas grew upwards at the rate of 3½ inches per annum. Duncan (Proc. Roy. Soc. xxvi. 133) estimates in the case of *Lophohelia prolifera* and *Desmophyllum eristagalli* growing in deep water to the north-west of Spain (522 to 550 fathoms) an increase upwards at the rate of 0·29 inches per annum. The result of later researches indicates considerable variation in the rate of growth, depending probably on species, locality, &c., and confirms the general conclusions of this paragraph.]

into which the lead sinks many feet. Outside this irregular border of Madrepores, the water deepens gradually to 20 fathoms, which depth generally is found at the distance of from half to three-quarters of a mile from the reef. A little further out the depth is 30 fathoms, and thence the bank slopes rapidly into the depths of the ocean. This inclination is very gentle compared with that outside Keeling and other atolls, but compared with most coasts it is steep. The water was so clear outside the reef, that I could distinguish every object forming the rugged bottom. In this part, and to a depth of 8 fathoms, I sounded repeatedly, and at each cast pounded the bottom with the broad lead; nevertheless the arming invariably came up perfectly clean, but deeply indented. From 8 to 15 fathoms a little calcareous sand was occasionally brought up, but more frequently the arming was simply indented. In all this space the two Madrepores above mentioned, and two species of Astræa with rather large stars, seemed the commonest kinds; and it must be noticed that twice at the depth of 15 fathoms, the arming was marked with a clean impression of an Astræa. Besides these lithophytes, some fragments of the *Millepora alcicornis* which occurs in the same relative position at Keeling Island, were brought up; and in the deeper parts there were large beds of a Seriatopora, different from *S. subulata*, but closely allied to it. On the beach within the reef, the rolled fragments consisted chiefly of the corals just mentioned, and of a massive Porites like that at Keeling atoll, of a Meandrina, *Pocillopora verrucosa*, and of numerous fragments of Nullipora. From 15 to 20 fathoms the bottom was, with few exceptions, either formed of sand, or thickly covered with Seriatopora: this delicate coral seems to form at these depths extensive beds unmingled with any other kind. At 20 fathoms, one sounding brought up a fragment of Madrepora, apparently *M. pocillifera*, and I believe it to be the same species as that which mainly forms the upper margin of the reef; if so, it grows in depths varying from 0 to 20 fathoms. Between 20 and 23 fathoms I obtained several soundings, and they all showed a sandy bottom, with one exception at 30 fathoms, when the arming came up scooped out as if by the margin of a large Caryophyllia. Beyond 33 fathoms I sounded only once; and from 86 fathoms, at the distance of one mile and a third from the edge of the reef, the arming brought up calcareous sand with a pebble of volcanic rock. The circumstance of the arming having invariably come up quite clean when sounding within a certain number of fathoms off the reefs of Mauritius and Keeling atoll (8 fathoms in the former case, and 12 in the latter), and of its having always come up (with one exception) smoothed and covered with sand when the depth exceeded 20 fathoms, probably indicates a criterion, by which the limits of the vigorous growth of coral might in all cases be readily ascertained. I do not, however, suppose that if a vast number of soundings were obtained round these islands, the limit above assigned would be found never to vary, but I conceive the facts are sufficient to show that the exceptions would be few. The circumstance of a *gradual* change, in the two cases, from a field of clean coral to a smooth sandy bottom, is far more important in indicating the depth at which the larger kinds of coral flourish, than almost any number of separate observations on the depth at which certain species have been dredged up. For we can understand the gradation only as a prolonged struggle against unfavourable conditions. If a person were to find the soil clothed with turf on the banks of a stream of water, but on going to some distance on one side of it he observed the blades of grass growing thinner and thinner with intervening patches of sand, until he entered a desert of sand, he would safely conclude, especially if changes of the same kind were noticed in other places, that the presence of the water was absolutely necessary to the formation of a thick bed of turf: so may we conclude, with the same feeling of certainty, that thick beds of coral are formed only at small depths beneath the surface of the sea.

I have endeavoured to collect every fact which might either invalidate or corroborate this conclusion. Captain Moresby, whose opportunities for observation during his survey of the Maldiva and Chagos Archipelagoes were unrivalled, informs me, that the upper part or zone of the steep-sided reefs on the inner and outer coasts of the atolls in both groups, invariably consisted of coral, and the lower parts of sand. At

7 or 8 fathoms depth, the bottom is formed, as could be seen through the clear water, of great living masses of coral, which at about 10 fathoms generally stand some way apart from each other, with patches of white sand between them, and at a little greater depth these patches become united into a smooth steep slope without any coral. Captain Moresby, also, informs me in support of the above statement, that he only found decayed coral on the Padua Bank (northern part of the Laccadive group), which has an average depth of 25 to 35 fathoms; but that on some other banks in the same group, with a depth of only 10 or 12 fathoms (for instance, the Tillacapeni bank) the coral was living.

Professor Dana likewise states that during the various and extensive surveys in the Pacific Ocean, made during the United States exploring expedition, no evidence was found of corals growing beyond the depth of 20 fathoms.[1] I may here add that Sir E. Belcher, though he does not state to what depth living corals extended, says that many soundings were taken off Bow atoll, at depths ranging from 50 to 960 fathoms, and that the bottom always consisted of coral sand.[2]

With regard to the coral-reefs in the Red Sea, Ehrenberg has the following passage. 'The living corals do not descend there into great depths. On the edges of islets and near reefs, where the depth was small, very many lived; but we found no more even at

[1] Corals and Coral Islands, 1872, p. 116.
[2] Voyage Round the World, 1843, p. 379, vol. i.

six fathoms. The pearl-fishers at Yemen and Massaua asserted that there was no coral near the pearl-banks at nine fathoms depth, but only sand. We were not able to institute any more special researches.'[1] I am, however, assured both by Captain Moresby and Lieut. Wellstead, that in the more northern parts of the Red Sea, there are extensive beds of living coral at a depth of 25 fathoms, in which the anchors of their vessels were frequently entangled. Captain Moresby attributes the less depth at which the corals are able to live in the places mentioned by Ehrenberg, to the greater quantity of sediment there; the situations, where they were flourishing at the depth of 25 fathoms, were protected and the water was extraordinarily limpid. On the leeward side of Mauritius, where I found the coral growing at a somewhat greater depth than at Keeling atoll, the sea, owing apparently to its tranquil state, was likewise very clear. Within the lagoons of some of the Marshall atolls, where the water can be but little agitated, there are, according to Kotzebue, living beds of coral in 25 fathoms. From these several facts, and considering the manner in which the beds of clean coral off Mauritius, Keeling Island, the Maldiva and Chagos atolls, graduated into a sandy slope, it appears very probable that the depth at which reef-building polypifers can exist, is partly determined by the extent of inclined surface which the currents of the sea and the recoiling waves have the power to keep free from sediment.

[1] Ehrenberg, Ueber die Natur, &c. p. 50.

MM. Quoy and Gaimard [1] believe that the growth of coral is confined within very limited depths; and they state that they never found any fragment of an Astræa (the genus they consider most efficient in forming reefs) at a depth above 25 or 30 feet. But we have seen that in several places the bottom of the sea is paved with massive corals at more than twice this depth; and at 15 fathoms (or thrice this depth) off the reefs of Mauritius the arming was marked with the distinct impression of a living Astræa. *Millepora alcicornis* lives in from 0 to 12 fathoms, and the genera Madrepora and Seriatopora from 0 to 20 fathoms. Captain Moresby has given me a specimen of *Sideropora scabra* (Porites of Lamarck) brought up alive from 17 fathoms. Mr. Couthouy [2] states that on the Bahama banks he dredged up considerable masses of Meandrina from 16 fathoms, and has seen this coral growing in 20 fathoms.

Captain Beechey informs me that branches of pink and yellow coral were frequently brought up from between 20 and 25 fathoms off the Low atolls; and Lieut. Stokes, writing to me from the N.W. coast of Australia, says that a strongly branched coral was procured there from 30 fathoms: unfortunately it is not known to what genera these corals belong.

Although the limit of depth, at which each particular kind of coral ceases to exist, is thus far from being accurately known: yet when we bear in mind the

[1] Annales des Sci. Nat. tom. vi.
[2] Remarks on Coral Formations, p. 12.

manner in which the clumps of coral gradually became infrequent at about the same depth, and wholly disappeared at a greater depth than 20 fathoms on the slope round Keeling atoll, off the reefs in the Pacific (according to Dana), on the leeward side of the Mauritius, and at rather less depth both within and without the atolls of the Maldiva and Chagos Archipelagoes; and when we know that the reefs round these islands do not differ from other coral formations in their form and structure, we may, I think, conclude that in ordinary cases reef-building polypifers do not flourish at greater depths than between 20 and 30 fathoms, and rarely at above 15 fathoms.[1]

It has been argued [2]—that reefs may possibly rise from very great depths through the means of small corals first making a platform for the growth of the stronger kinds. This, however, is an arbitrary supposition: it is not always remembered, that in such cases there is an antagonistic power at work, namely, the decay of organic bodies when not protected by a covering of sediment or by their own rapid growth. We have, moreover, no right to calculate on unlimited time for

[1] [The general conclusions of this paragraph do not appear to have been disturbed by recent researches, though Mr. Guppy (Proc. Roy. Soc. Edin. xiii. p. 857, see Appendix II.) argues in favour of the possibility of reefs occasionally beginning to grow at depths of at least 50 fathoms; and in the Reports of the *Challenger* Expedition (Report on the Reef-building Corals, p. 35) cases of species which build reefs, living at a depth of 40 fathoms, and in two instances even at 70 fathoms, are recorded. Still even here it is admitted that 'the zone of most active growth is from 1 to 20 fathoms.']

[2] Journal of the Royal Geograph. Soc. 1831, p. 218.

the accumulation of small organic bodies into great masses.[1] Every fact in geology proclaims that neither the dry land nor the bed of the sea retains the same level for indefinite periods. As well might it be imagined that the British seas would in time become choked up with beds of oysters, or that the numerous small corallines off the inhospitable shores of Tierra del Fuego would in time form a solid and extensive coral-reef.[2]

[1] [This remark has, by anticipation, a direct bearing on an important part of Mr. Murray's hypothesis. See Appendix II.]

[2] I will here record the few facts which I have been able to collect as to the depths, both within and without the tropics, inhabited by

NAME OF ZOOPHYTE.	Depth in fathoms.	COUNTRY AND S. LATITUDE.	AUTHORITY.
Sertularia	40	Cape Horn 66°	[Where none is given the observation is my own.]
Cellaria	ditto	ditto	
„ A minute scarlet encrusting species, found living	190	Keeling At. 12°	
„ An allied, small stony sub-generic form	48	S. Cruz Riv. 50°	
A coral allied to Vincularia, with eight rows of cells	40	Cape Horn	
Tubulipora, near to T. patina	ditto	ditto	
Do. do.	94	East Chiloe 43°	
Cellepora, several species and allied sub-generic forms	40	Cape Horn	
Ditto	40 and 57	Chonos Arch. 45°	
Ditto	48	S. Cruz 50°	
Eschara	30	Tierra del Fuego 53°	
Ditto	48	S. Cruz R. 50°	
Retepora	40	Cape Horn	
Ditto	100	C. Good Hope 34°	Quoy and Gaimard, Ann. Scien. Nat., t. vi. p. 284.

NAME OF ZOOPHYTE.	Depth in fathoms.	COUNTRY AND S. LATITUDE.	AUTHORITY.
Millepora, a strong coral with cylindrical branches, of a pink colour, about two inches high, resembling in the form of its orifices M. aspera of Lamarck	94 and 30	E. Chiloe 43° Tierra del Fuego 53°	
Coralium	120	Barbary 33° N.	Peyssonel, in paper read to Royal Society May, 1752.
Antipathes	16	Chonos 45°	
Gorgonia (or an allied form)	160	Abrolhos, on the coast of Brazil, 18°	Capt. Beechey informed me of this fact in a letter.

those corals and corallines which we have no reason to suppose ever materially aid in the construction of a reef. Mr. Stokes also showed me a Caryophyllia which was dredged up alive by Captain King from a depth of 80 fathoms off Juan Fernandez, in lat. 33° S. Ellis (Nat. Hist. of Coralline, p. 96) states that Ombellularia was procured in lat. 79° N. *sticking* to a *line* from the depth of 236 fathoms; hence this coral either must have been floating loose, or was entangled in a stray line at the bottom. Off Keeling atoll a compound Ascidia (Sigillina) was brought up from 39 fathoms, and a piece of sponge, apparently living, from 70, and a fragment of Nullipora, also apparently living, from 92 fathoms. At a greater depth than 90 fathoms the bottom was thickly strewed with joints of a Halimeda and small fragments of other Nulliporæ, but all dead. Captain B. Allen, R.N., informs me that in the survey of the West Indies it was noticed, that between the depth of 10 and 200 fathoms, the sounding-lead very generally came up coated with the dead joints of a Halimeda, of which he showed me specimens. Off Pernambuco, in Brazil, in about 12 fathoms, the bottom was covered with fragments, dead and alive, of a dull red Nullipora, and I infer from Roussin's chart, that a bottom of this kind extends over a wide area. On the beach, within the coral-reefs of Mauritius, vast quantities of fragments of Nulliporæ were piled up. From these facts, it appears that these simply organised bodies, belonging to the vegetable kingdom, are amongst the most abundant productions of the sea. [Of late years corals, commonly solitary, have been found at much greater depths than those mentioned in this note; for instance, *Caryophyllia*, down to at least 1,000 fathoms (The Depths of the Sea, pp. 28, 431). True corals referable to the Madreporaria are not very abundant in deep water. According to Mr. Moseley's report, about ten genera reach a depth of 1,000 fathoms; four genera are found at 1,500 fathoms; and a single species extends practically through all depths, ranging from 30 to 2,900 fathoms. *Challenger* Reports, vol. ii. (Zoology), 'On Corals,' pp. 132, 133. See also Reports, vol. xvi., 'On Reef-Corals,' p. 35.

CHAPTER V.

THEORY OF THE FORMATION OF THE DIFFERENT CLASSES OF CORAL-REEFS.

The atolls of the larger archipelagoes not formed on submerged craters, or on banks of sediment—Immense areas interspersed with atolls—Their subsidence—The effects of storms and earthquakes on atolls—Recent changes in their state—The origin of barrier-reefs and of atolls—Their relative forms—The step-formed ledges and walls round the shores of some lagoons—The ring-formed reefs of the Maldiva atolls—The submerged condition of parts or of the whole of some annular reefs—The disseverment of large atolls—The union of atolls by linear reefs—The great Chagos Bank—Objections considered arising from the area and amount of subsidence required by the theory—The probable composition of the lower parts of atolls.

The naturalists who have visited the Pacific, seem to have had their attention riveted by the lagoon-islands or atolls,—those singular rings of coral-land which rise abruptly out of the unfathomable ocean,—and have passed over, almost unnoticed, the scarcely less wonderful encircling barrier-reefs. The theory most generally received on the formation of atolls, is that they are based on submarine craters: but where can we find a crater of the shape of Bow atoll, which is five times as long as it is broad (Plate I., fig. 4); or like that of Menchicoff Island (Plate II., fig. 3), with its three loops, together sixty miles in length; or like Rimsky Korsacoff, narrow, crooked, and fifty-four miles long; or like the northern Maldiva atolls, made up of numerous ring-formed reefs, placed on the margin of a disk,—one of which disks is eighty-eight miles in length, and only from ten to twenty in breadth? A further difficulty on this theory of the origin of atolls arises from the necessary assumption of so large a number of immense craters crowded together beneath the sea. But, as we shall presently see, a greater difficulty is involved, namely, that all these craters must lie within nearly the same level beneath the sea. Nevertheless, if the rim of a crater afforded a basis at the proper depth, I am far from denying that a reef like a perfectly characterized atoll might not be formed on it. Some such, perhaps, now exist; but it is incredible that the greater number could have thus originated.

An earlier and better theory was proposed by Chamisso:[1] he supposes that as the more massive kinds of corals prefer the surf, the outer portions of a reef will first reach the surface and consequently form a ring.[2] I remarked in the third chapter that a reef, growing on a detached bank, would tend to assume an atoll-like structure; if, therefore, corals were to grow up from a bank some fathoms submerged in a deep sea, having steep sides and a level surface, a reef not to be dis-

[1] Kotzebue's First Voyage, vol. iii. p. 331.

[2] [By anticipation, some of the objections which have been raised of late years (see Appendix II.) are considered in this section.]

tinguished from an atoll might be formed; and I believe some such exist in the West Indies. But on this view it must be assumed, that in every case the basis consists of a flat bank; for if it were conically formed like a mountainous mass, we can see no reason why the corals should spring up from the flanks instead of from the central and highest parts. As the lagoons of atolls are sometimes even more than 40 fathoms deep, it must, also, be assumed on this view, that at a depth at which the waves do not break, the coral grows more vigorously on the edges of a bank than on its central part: and this is an assumption without any evidence.[1] If we consider, moreover, the number of the atolls in the midst of the Pacific and Indian Oceans, this assumption of so many submerged banks is in itself very improbable.

No theory worthy of notice has been advanced to account for those barrier-reefs which encircle islands of moderate dimensions. The great reef which fronts the coast of Australia has been supposed, but without any evidence, to rest on the edge of a submarine precipice parallel to the shore. The origin of the third class, or of fringing-reefs, presents, I believe, scarcely any difficulty, and arises simply from the polypifers growing in moderate depths, and not flourishing close to gently shelving beaches where the water is often turbid.

[1] [The more vigorous growth of the coral on the outward part of a reef is, however, asserted and advocated by Mr. Murray as producing the atoll form. See Appendix II.]

What cause, then, has given to atolls and barrier-reefs their characteristic forms? Let us see whether an important deduction does not follow from the following facts,—first, that reef-building corals only flourish at a very limited depth,—and secondly, that throughout areas of vast dimensions, none of the coral-reefs and coral-islets rise to a greater height above the level of the sea than that attained by matter thrown up by the waves and winds. I do not make this latter statement vaguely; I have carefully sought for descriptions of every island in the inter-tropical seas; and my task has been in some degree facilitated by a map of the Pacific, corrected in 1834 by MM. D'Urville and Lottin, in which the low islands are distinguished from the high ones (even from those much less than a hundred feet in height) by being written without a capital letter.[1] I have also ascertained, chiefly from the writings of Cook, Kotzebue, Bellingshausen, Duperrey, Beechey, and Lutké regarding the Pacific; and from Moresby[2] with respect to the Indian Ocean, that in the following cases the term 'low island' strictly means land of the height com-

[1] I have detected a few errors in this map, respecting the heights of some of the islands, which will be noticed in the Appendix, where I treat of coral-formations in geographical order. To the Appendix, also, I must refer for a more particular account of the data on which the following statements are grounded.

[2] See also Captain Owen's and Lieut. Wood's papers in the Geographical Journal on the Maldiva and Laccadive Archipelagoes. These officers particularly refer to the lowness of the islets; but I chiefly ground my assertion respecting these two groups, and the Chagos group, from information communicated to me by Captain Moresby.

monly attained by matter thrown up by the winds and the waves of an open sea. If we draw a line joining the external atolls of that part of the Low Archipelago in which the islands are numerous—the plan always adopted—the figure will be a pointed ellipse (reaching from Hood to Lazaref Island), of which the longer axis is 840 geographical miles, and the shorter 420 miles: in this space,[1] none of the innumerable islets, united into great rings, rise above the stated level. The Gilbert group is very narrow, and 300 miles in length. In a prolonged line from this group, at the distance of 240 miles, is the Marshall Archipelago, the figure of which is an irregular square, one end being broader than the other; its length is 520 miles with an average width of 240: these two groups together are 1,040 miles in length, and all their islets are low. Between the southern end of the Gilbert and the northern end of Low Archipelago, the ocean is thinly strewed with islands, all of which, as far as I have been able to ascertain, are low: so that from nearly the southern end of the Low Archipelago, to the northern end of the Marshall Archipelago there is a narrow band of ocean more than 4,000 miles in length, containing a

[1] Metia or Aurora Island has been upraised; but it lies N.E. of Tahiti, and in the map appended to this volume is close without the line bounding the space here referred to. I shall have occasion hereafter to make some remarks on the supposed slight elevation (of about three feet) of the atolls of the Low Archipelago, subsequently to their original formation. [Other cases of upheaval have since been recorded. See Appendix II.]

vast number of islands, all of which are low. In the western part of the Caroline Archipelago, there is a space of 480 miles in length, and about 100 in breadth, thinly interspersed with low islands. Lastly, in the Indian Ocean, the archipelago of the Maldivas is 470 miles in length, and 60 in breadth; that of the Laccadives is 150 by 100 miles: as there is a low island between these two groups, they may be considered as one group of a thousand miles in length. To this may be added the Chagos group of low islands, situated 280 miles distant, in a line prolonged from the southern extremity of the Maldivas. This group, including the submerged banks, is 170 miles in length and 80 in breadth. So striking is the uniformity in direction of these three archipelagoes, all the islands of which are low, that Captain Moresby, in one of his papers, speaks of them as parts of one great chain nearly 1,500 miles long. I am, then, fully justified in repeating that immense spaces, both in the Pacific and Indian Oceans, are interspersed with islands, of which none rise above the height to which the waves and winds in an open sea can heap up matter.

On what foundations, then, have these reefs and islets of coral been constructed? A foundation must originally have been present beneath each atoll, at that limited depth which is indispensable for the first growth of the reef-building polypifers. A conjecture will perhaps be hazarded, that the requisite bases may have been afforded by the accumulation of great banks of sediment, which did not quite reach the surface owing to the action of superficial currents, aided possibly by the undulatory movement of the sea. This appears actually to have been the case in some parts of the West Indian sea. But in the form and disposition of the groups of atolls, there is nothing to countenance this notion; and the assumption that a number of immense piles of sediment have been heaped on the floor of the great Pacific and Indian Oceans in their central parts, far remote from land, where the dark blue colour of the limpid water bespeaks its purity, cannot for one moment be admitted.[1]

The many widely scattered atolls must, therefore, rest on rocky bases. But we cannot believe that a broad mountain summit lies buried at the depth of a few fathoms beneath every atoll, and nevertheless that throughout the immense areas above-named, not one point of rock projects above the level of the sea. For we may judge of mountains beneath the sea by those on the land; and where can we find a single chain, much less several such chains, many hundred

[1] [This accumulation, it will be observed, is an integral part of Mr. Murray's hypothesis. See Appendix II. for a sketch of the arguments by which it is supported. Perhaps I may be permitted to add that, in my opinion, the perusal of the observations of Mr. Murray, Mr. Guppy, and others would probably have led Mr. Darwin to modify slightly some of the clauses in these pages, and allow a more important *rôle* to the accumulation of organisms, other than corals, on submarine banks. I do not, however, anticipate that they would have seriously modified his general conclusions, or led him to regard modes of formation, which these authors consider to be normal, as other than exceptional.—T. G. B.]

miles in length and of considerable breadth, with broad summits attaining the same height, from within 120 to 180 feet? Even if it be assumed without any evidence that the reef-building corals can flourish at a depth of 100 fathoms, yet the weight of the above argument is but little diminished; for it is almost equally improbable, that as many submarine mountains, as there are low islands in the several great and widely-separated areas above-specified, should all rise within 600 feet of the surface of the sea and not one above it, as that they should be of the same height within the smaller limit of one or two hundred feet. So highly improbable is this supposition, that we are compelled to believe, that the rocky foundations of the many atolls did never at any one period all lie submerged within the depth of a few fathoms beneath the surface, but that they were brought into the requisite position or level, some at one period and some at another, through movements in the earth's crust. But this could not have been effected by elevation; for the belief that points so numerous and so widely-separated were successively uplifted to a certain level, but that not one point was raised above that level, is quite as improbable as the former supposition, and indeed differs little from it. It will probably occur to those who have read Ehrenberg's account of the reefs of the Red Sea, that many points in these great areas may have been elevated, but that as soon as raised, the protuberant parts were cut off by the destroying action of the waves: a moment's reflection, however, on the basin-like form of the atolls, will show that this is impossible; for the upheaval and subsequent abrasion of an island would leave a flat disk, which might become coated with coral, but not a deeply concave surface; moreover, we should expect to see, at least in some parts, the rock of the foundation brought to the surface. If, then, the foundations of the many atolls were not uplifted into the requisite position, they must of necessity have subsided into it; and this at once solves every difficulty,[1] for we may safely infer from the facts given in the last chapter, that during a gradual subsidence the corals would be favourably circumstanced for building up their solid frameworks and reaching the surface, as island after island slowly disappeared. Thus areas of immense extent in the central and most profound

[1] The additional difficulty on the crater hypothesis before alluded to, will now be evident; for on this view the volcanic action must be supposed to have formed within the areas specified a vast number of craters, all rising within a few fathoms of the surface, and not one above it. The supposition that the craters were at different times upraised above the surface, and were there abraded by the surf and subsequently coated by corals, is subjected to nearly the same objections with those given at the top of the page; but I consider it superfluous to detail all the arguments opposed to such a notion. Chamisso's theory, from assuming the existence of so many banks, all lying at the proper depth beneath the water, is also vitally defective. The same observation applies to an hypothesis of Lieut. Nelson's (Geolog. Trans. vol. v. p. 122), who supposes that the ring-formed structure is caused by a greater number of germs of corals becoming attached to the declivity, than to the central plateau of a submarine bank; it likewise applies to the notion formerly entertained (Forster's Observ. p. 151), that lagoon-islands owe their peculiar form to the instinctive tendencies of the polypifers. According to this latter view, the corals on the outer margin of the reef instinctively oppose themselves to the surf in order to afford protection to corals living in the lagoon which belong to other genera and to other families!

parts of the great oceans might become interspersed with coral-islets, none of which would rise to a greater height than that attained by detritus heaped up by the sea, and nevertheless they might all have been formed by corals, which absolutely require for their growth a solid foundation within a few fathoms of the surface.

It would be out of place here to do more than allude to the many facts, showing that the supposition of a gradual subsidence over large areas is by no means improbable. We have the clearest proof that a movement of this kind is possible, in the upright trees buried under strata many thousand feet in thickness; we have also every reason for believing that there are now large areas gradually sinking, in the same manner as others are rising. And when we consider how many parts of the surface of the globe have been elevated within recent geological periods, we must admit that there have been subsidences on a corresponding scale, for otherwise the whole globe would have swollen. It is very remarkable that Sir C. Lyell,[1] even in the first edition of his Principles of Geology, inferred that the amount of subsidence in the Pacific must have exceeded that of elevation, from the area of land being very small relatively to the agents there tending to form it, namely, the growth of coral and volcanic action. But, although subsidence may explain a phenomenon otherwise inexplicable, it may be asked, are there any direct proofs of a subsiding movement in these areas? This,

[1] Principles of Geology, sixth edition, vol. iii. p. 386. [Ch. xlix. vol. ii. p. 604, eleventh edition.]

however, can hardly be expected, for it must ever be most difficult, excepting in countries long civilized, to detect a movement the tendency of which is to conceal the part affected. In barbarous and semi-civilized nations how long might not a slow movement, even of elevation such as that now affecting Scandinavia, have escaped attention !

Mr. Williams[1] insists strongly that the traditions of the natives, which he has taken much pains in collecting, do not indicate the appearance of any new islands: but on the theory of a gradual subsidence, all that would be apparent would be, the water sometimes encroaching slowly on the land, and the land again recovering by the accumulation of detritus its former extent, and perhaps sometimes the conversion of an atoll with coral islets on it, into a bare or into a sunken annular reef. Such changes would naturally take place at the periods when the sea rose above its usual limits during a gale of more than ordinary strength ; and the effects of the two causes would be hardly distinguishable. In Kotzebue's Voyage there are accounts of islands, both in the Caroline and Marshall Archipelagoes, which have been partly washed away during hurricanes ; and Kadu, the native who was on board one of the Russian vessels, said 'he saw the sea at Radack rise to the feet of the cocoa-nut trees ; but it was conjured in time.'[2] A storm lately entirely swept away two of the Caroline Islands and converted them into shoals ; it also partly destroyed

[1] Williams's Narrative of Missionary Enterprise, p. 31.
[2] Kotzebue's First Voyage, vol. iii. p. 168.

two other islands.[1] According to a tradition which was communicated to Captain FitzRoy, it is believed in the Low Archipelago that the arrival of the first ship caused a great inundation which destroyed many lives. Mr. Stutchbury relates that in 1825, the western side of Chain Atoll in the same group, was completely devastated by a hurricane, and not less than 300 lives lost: 'in this instance it was evident, even to the natives, that the hurricane alone was not sufficient to account for the violent agitation of the ocean.'[2] That considerable changes have taken place recently in some of the atolls in the Low Archipelago, appears certain from the case of Matilda Island given in the last chapter. With respect to Whitsunday and Gloucester Islands in this same group, we must either attribute great inaccuracy to their discoverer, the famous circumnavigator Wallis, or believe that they have undergone a considerable change in the period of fifty-nine years between his voyage and that of Captain Beechey. Whitsunday Island is described by Wallis as 'about four miles long, and three wide,' now it is only one mile and a-half long. The appearance of Gloucester Island, in Captain Beechey's words,[3] 'has been accurately described by its discoverer, but its present form and extent differ materially.' Blenheim reef in the Chagos group, consists of a water-washed annular reef thirteen miles in circumference, surrounding a lagoon ten fathoms deep; on its sur-

[1] M. Desmoulins in Comptes Rendus, 1840, p. 837.

[2] West of England Journal, No. 1, p. 35.

[3] Beechey's Voyage to the Pacific, chap. vii., and Wallis's Voyage in the *Dolphin*, chap. iv.

face there are a few worn patches of conglomerate coral-rock of about the size of hovels; and these Captain Moresby considers as being, without doubt, the last remnants of islets; so that here an atoll has been converted into an atoll-formed reef. The inhabitants of the Maldiva Archipelago, as long ago as 1605, declared, 'that the high tides and violent currents were always diminishing the number of the islands:'[1] and I have already shown, on the authority of Captain Moresby, that the work of destruction is still in progress; but that on the other hand the first formation of some islets is known to the present inhabitants. In such cases, it would be exceedingly difficult to detect a gradual subsidence of the foundation on which these mutable structures rest.

Some of the archipelagoes of low coral-islands are subject to earthquakes: Captain Moresby informs me that they are frequent, though not very strong, in the Chagos group, which occupies a central position in the Indian Ocean, and is far from any land not of coral formation. One of the islands in this group was formerly covered by a bed of mould, which disappeared after an earthquake, and was believed by the residents to have been washed by the rain into the underlying fractured rock: the island was thus rendered unproductive. Chamisso[2] states that earth-

[1] See an extract from Pyrard's Voyage in Captain Owen's paper on the Maldiva Archipelago, in the Geographical Journal, vol. ii. p. 84.

[2] See Chamisso, in Kotzebue's First Voyage, vol. iii. pp. 132 and 136.

quakes are felt in the Marshall atolls, which are far from any high land, and likewise in the islands of the Caroline Archipelago. On Oulleay atoll, one of the latter, Admiral Lutké informs me that he observed several straight fissures about a foot in width, running for some hundred yards obliquely across the whole width of the reef. Fissures indicate a stretching of the earth's crust, and, therefore, probably changes in its level; but these coral-islands, which have been shaken and fissured, certainly have not been elevated, and, therefore, probably have subsided.[1] We shall hereafter see that the position of certain ancient buildings in the Caroline Archipelago clearly indicates recent subsidence. In the chapter on Keeling atoll, I have also attempted to show, by direct evidence, that the island subsided during the earthquakes lately felt there.

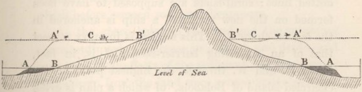
The facts then stand as follows :—there are many large spaces of ocean, without any high land, interspersed with reefs and islets formed by the growth of those kinds of coral which cannot live at great depths; and the existence of these reefs and low islets in such numbers and at such distant points, is inexplicable, excepting on the theory that their rocky bases slowly and successively sank beneath the level of the sea, whilst the corals continued to grow upwards. No positive facts are opposed to this view, and some direct evidence, as well as general considerations, render it probable. There is also evidence of

[1] [It seems to me doubtful whether the argument from the existence of fissures can be pressed.—T. G. B.]

change in form, whether or not from subsidence, on some of these coral-islands; and there is evidence of subterranean disturbances beneath them. Will then the theory, to which we have thus been led, solve the curious problem—what has given to each class of reef its peculiar form?

Let us in imagination place within a subsiding area,

No. 5.



A A—Outer edge of the reef at the level of the sea.
B B—Shores of the island.
A'A'—Outer edge of the reef, after its upward growth during a period of subsidence.
C C—The lagoon-channel between the reef and the shores of the now encircled land.
B' B'—The shores of the encircled island.

N.B.—In this, and the following woodcut, the subsidence of the land could only be represented by an apparent rise in the level of the sea.

an island surrounded by a 'fringing-reef'—that kind of which the origin alone offers no difficulty. Let the unbroken lines in the woodcut (No. 5) represent a vertical section through the land and water; and the horizontal shading a section through the reef. Now, as the island sinks down, either a few feet at a time or quite insensibly, we may infer, from what we know of the conditions favourable to the growth of coral, that the living masses bathed by the surf on the margin of the reef, will soon regain the surface. The water, however, will encroach little by little on the shore, the island becoming lower and smaller, and the space between the edge of the reef and the beach proportionally broader. A section of the reef and island in this state, after a subsidence of several hundred feet, is given by the dotted lines: coral-islets are supposed to have been formed on the new reef, and a ship is anchored in the lagoon-channel. This section is in every respect that of an encircling barrier-reef, and is, in fact, taken E. and W. through the highest point of the encircled island of Bolabola,[1] of which a plan is given in Plate I., fig. 5. The same section is more clearly shown in the following woodcut (No. 6) by the unbroken lines. The width of the reef and its slope both on the outer and inner side, will have been determined by the growing powers of the coral, under different conditions, for instance, of the force of the breakers and currents to which it has been exposed; and the lagoon-channel will be deeper or shallower, in proportion to the growth of the delicately branched corals within the reef, and to the accumulation of sediment; relatively, also, to the rate of subsi-

[1] The section has been made from the chart given in the Atlas of the Voyage of the *Coquille*. The scale is ·57 of an inch to a mile. The height of the island, according to M. Lesson, is 4,026 feet. The deepest part of the lagoon-channel is 162 feet; its depth is exaggerated in the woodcut for the sake of clearness.

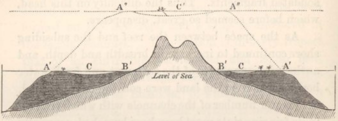
dence and the length of the intervening stationary periods.

It is evident in this section, that a line drawn perpendicularly down from the outer edge of the new reef to the foundation of solid rock, exceeds, by as many feet as there have been feet of subsidence, that small limit of depth at which the effective polypifers can live,—the corals having grown up, as the whole sank down, from a basis formed of other corals and their consolidated fragments. Thus the difficulty on this head, which before seemed so great, disappears.

As the space between the reef and the subsiding shore continued to increase in breadth and depth, and as the injurious effects of the sediment and fresh water borne down from the land were consequently lessened, the greater number of the channels with which the reef in its fringing state must have been breached, especially those which fronted the smaller streams, will have become choked up by the growth of coral: on the windward side of the reef where the coral grows most vigorously, the breaches will probably have first been closed. In barrier-reefs, therefore, the breaches kept open by draining the tidal waters of the lagoon-channel, will generally be placed on the leeward side, and they will still face the mouths of the larger streams, although removed beyond the influence of their sediment and fresh water;—and this, it has been shown, is commonly the case.

Referring to the following diagram (No. 6), in which the newly-formed barrier-reef is represented by unbroken lines, instead of by dots as in the former woodcut, let the work of subsidence go on, and the doubly-pointed hill will form two small islands included within one annular reef. Let the island continue to subside, and the coral-reef will continue growing up on its own foundation, whilst the water gains inch by inch on the land, until the last and highest pinnacle is covered, and there remains a perfect atoll. A vertical section of this

No. 6.



A′A′—Outer edges of the barrier-reef at the level of the sea. The cocoa-nut trees represent coral-islets formed on the reef.
C C—The lagoon-channel.
B′ B′—The shores of the island, generally formed of low alluvial land and of coral detritus from the lagoon-channel.
A″A″—The outer edges of the reef, now forming an atoll.
C′—The lagoon of the newly-formed atoll. According to the scale the depth of the lagoon and of the lagoon-channel is exaggerated.

atoll is shown in the woodcut by the dotted lines;—a ship is anchored in its lagoon, but islets are not supposed yet to have been formed on the reef. The depth of the lagoon and the width and slope of the reef, will depend on the different circumstances to which it has been exposed, as just stated with respect to barrier-reefs. Any further subsidence will produce no change in the atoll, except a diminution in its size, from the reef not growing vertically upwards. I may here observe, that a bank either of rock or of hardened sediment, level with the surface of the sea and fringed with living coral, would be immediately converted by subsidence into an atoll, without passing, as in the case of a reef fringing the shore of an island, through the intermediate form of a barrier-reef. As before remarked, if such a bank lay a few fathoms submerged, the simple growth of the coral, without the aid of subsidence, would produce a structure scarcely to be distinguished from a true atoll; for the corals on the outer margin, from being freely exposed to the open sea, would grow vigorously and tend to form a continuous ring, whilst the growth of the less massive kinds on the central expanse, would be checked by the sediment formed there, and by that washed inwards by the breakers; and as the space became shallower, their growth would also be checked by the impurities of the water, and probably by the small amount of food brought to them by the enfeebled currents. The subsidence of a reef based on a bank of this kind, would give depth to the central expanse or lagoon, steepness to the flanks, and through the free growth of the coral, symmetry to the whole outline; but, as we have seen, the larger groups of atolls in the Pacific and Indian Oceans cannot have been formed on banks of this nature.

If, instead of an island, as in the diagram, the shore of a continent fringed by a reef were to subside, a great barrier-reef like that on the N.E. coast of Australia, would be the necessary result; and it would be separated from the main land by a deep-water channel, broad in proportion to the amount of subsidence, and to the less or greater inclination of the bed of the sea. The effect of the continued subsidence of a barrier-reef, and its probable conversion into a chain of separate atolls, will be considered when we discuss the progressive disseverment of the larger Maldiva atolls.

We now are able to perceive that the close similarity in form, dimensions, structure, and relative position between fringing and encircling barrier-reefs, and between these latter reefs and atolls, is the necessary result of the transformation, during subsidence, of the one class into the other. On this view, the three classes of reefs ought to graduate into each other. Reefs having an intermediate character between those of the fringing and barrier classes do exist; for instance, on the S.W. coast of Madagascar, a reef extends for several miles, within which there is a broad channel from 7 to 8 fathoms deep, but the sea does not deepen abruptly outside the reef. Such cases, however, are open to doubt, for an old fringing-reef which had extended itself on a basis of its own formation, would hardly be distinguishable from a barrier-reef produced by a small amount of subsidence, and with its lagoon-channel nearly filled up with sediment during a long stationary period. Between barrier-reefs, encircling either a single lofty island or several small low ones, and atolls including a mere expanse of water, a striking series can be shown; and in proof of this, I need only refer to Plate I., which speaks more plainly to the eye, than any description to the ear. The authorities from which the figures have been copied, together with some remarks on them, are given on a separate page descriptive of the plate. At New Caledonia (Plate II., fig. 5) the barrier-reefs extend for 150 miles on each side of the submarine prolongation of the island; and at the northern extremity these reefs appear broken up and converted into a vast atoll supporting a few low coral-islets. We may imagine that we see in New Caledonia the effects of subsidence actually in progress,—the water always encroaching on the northern end of the island, towards which the mountains slope down, and the reefs steadily building up their massive fabrics in the line of their ancient growth.

We have as yet only considered barrier-reefs and atolls in their simplest form; but there remain some peculiarities in structure and some special cases, which were described in the two first chapters, to be accounted for by our theory. These consist, firstly, in the presence of an inclined ledge terminated by a wall, and sometimes succeeded by a second ledge with a wall, round the shores of certain lagoons and lagoon-channels; for this structure cannot be explained by the mere growth of the corals;—secondly, in the ring or basin-like form of the central and circumferential reefs of the northern Maldiva atolls,—thirdly, in the disseverment of some of the Maldiva atolls,—fourthly, in the existence of irregularly formed atolls, some tied together by linear reefs, and others with spurs projecting from them,—

fifthly, in the submerged condition of the whole, or of parts of certain barrier and atoll-formed reefs, and in the submerged parts being generally to leeward,—and, lastly, in the structure and origin of the Great Chagos bank.

Step-formed ledges round certain lagoons.—If we suppose an atoll to subside at an extremely slow rate, the living corals would grow up on the outer margin and on the deeper parts of the bare and hard surface of the annular reef. Detritus would soon accumulate and become agglomerated on this surface, after a time forming islets. Consequently the whole atoll before long would recover its former structure and appearance. If, however, an atoll were to subside somewhat suddenly to the depth of a few fathoms, the whole annular reef, consisting of solid rock, would constitute an excellent basis for the attachment and subsequent upward growth of a great bed of living corals. But the corals would not be able to grow up from the sandy shores of the old lagoon[1]; consequently the new annular reef would be separated from the new lagoon by an abrupt edge or wall. As the corals would grow upwards much more vigorously on the outer side, and more detritus would be accumulated there, the surface of the new annular reef would slope gently inwards. Hence the summit of the new annular reef on the inner side would probably never rise above the level of the new lagoon, and in this case would be covered with sand. If now

[1] [This would seem possible in certain cases, though obviously the position would be an unfavourable one. See Appendix II.]

a second and somewhat sudden subsidence were to occur, the same results would follow as during the previous and similar subsiding movement. Consequently the new lagoon would be surrounded by two inwardly sloping ledges, which once existed as the summits of two successive annular reefs, both terminated on the inner side by vertical walls or cliffs.[1]

The ring or basin-formed reefs of the northern Maldiva atolls.—I must first observe that small reefs within large lagoons or within broad lagoon-channels, would grow up during subsidence; and therefore such reefs would sometimes be found rising abruptly from a greater depth than that at which the efficient polypifers can flourish. We see this well exemplified in the small abruptly-sided reefs with which the deep lagoons of the Chagos and Southern Maldiva atolls are studded. With respect to the ring or basin-formed reefs of the Northern Maldiva atolls (see Plate II., fig. 4), it is evident from the perfectly continuous series which exists, that the rings on the margin, although broader than the exterior or bounding reef of an ordinary atoll, are only modified portions of such a reef; it is

[1] According to Mr. Couthouy (p. 26) the *external* slope round many atolls descends by a succession of ledges or terraces. He attempts, but I doubt whether successfully, to explain this structure somewhat in the same manner as I have attempted, with respect to the internal ledges round the lagoons of certain atolls. More facts are wanted regarding the nature both of the interior and exterior step-like ledges. Are all the ledges, or only the upper ones, covered with living coral? If they are all so covered, do the species differ on the different ledges? Do ledges occur on the inside and outside round the same atolls? &c. [Some further information on this subject has been obtained by recent investigations. See Appendix II.]

also evident that the central rings, although broader than the knolls or reefs which commonly occur within lagoons, occupy the same relative position. The ring-like structure has been shown to be contingent on the breaches into the lagoon being wide and numerous, thus causing the inner side of the marginal reef and the central reefs to be placed under nearly the same conditions with the outside of an ordinary atoll which is exposed to the open sea. Hence the margins of these reefs have been favourably circumstanced for growing outwards and increasing beyond their usual breadth; and the conditions have likewise been favourable for their growing vigorously upwards, during that subsiding movement to which by our theory the whole archipelago has been subjected; and subsidence together with the upward growth of the margin would convert the central space of each little reef into a small lagoon. This, however, could only take place with reefs which had increased in breadth sufficiently to prevent their central spaces from being almost immediately filled up with the sand and detritus driven inwards by the waves from all sides. We can thus understand how it is that few reefs less than half a mile in diameter, even in the atolls where perfect ring-formed reefs are found, include lagoons. This remark, I may add, applies to all coral-formations. The basin-formed reefs of the Maldiva Archipelago may, in fact, be briefly described as small atolls formed during subsidence over separate portions of a large and broken atoll, in the same manner as the latter was originally formed over a reef encircling one or more mountainous islands.

The disseverment of the larger Maldiva atolls.—The apparent progressive disseverment of large atolls into smaller ones in the Maldiva Archipelago, demands an explanation. The graduated series which marks, as I believe, this process, can be observed only in the northern half of the group, where the atolls have imperfect margins consisting of detached basin-formed reefs. The currents of the sea flow across these atolls with considerable force, as I am informed by Captain Moresby, and drift the sediment from side to side during the monsoons, transporting much of it seaward; yet the currents sweep with greater force round their flanks. It is historically known that these atolls have long existed in their present state; it is intelligible that they might thus remain, even during a slow subsidence, owing to the continued growth of the corals, and to the lagoon being kept at nearly its original depth by the accumulation of sediment. But during the action of such nicely balanced forces, it would be strange if the currents of the sea had never made a direct passage across some of these atolls, through the many wide breaches in their margins. As soon as this occurred the channels would be deepened by the removal of the finer sediment, and by the check to its further accumulation. The sides also of the channels would soon be worn into a slope like that on the outer coasts, from being exposed to the same force of the currents. In fact, a channel like that bifurcating one which divides Mahlos Mahdoo (Plate II., fig. 4) would almost necessarily be formed. The scattered reefs situated near the borders of the new channel, from being favourably placed for the growth of coral, would, by their extension, tend to produce fresh margins to the dissevered portions: and a tendency of this kind is evident in the elongated reefs which border the two channels intersecting Mahlos Mahdoo. Such channels would become deeper with continued subsidence, and, from the reefs on both sides not growing up perpendicularly, somewhat broader. In this case, and more especially if the channels had been originally formed of considerable breadth, the dissevered portions would soon become perfect and distinct atolls like Ari and Ross atolls (Plate II., fig. 6), or like the two Nillandoo atolls, which must be considered as distinct, although plainly related to each other in form and position, and separated only by moderately deep channels. Further subsidence would render such channels unfathomable, and the dissevered portions would then resemble Phaleedoo and Moluque atolls, or Mahlos Mahdoo and Horsburgh atolls (Plate II., fig. 4), which are related to each other only in proximity and position. Hence, on the theory of subsidence, the disseverment of large atolls which are exposed to strong currents and which have imperfect margins (for otherwise their disseverment would be scarcely possible) is far from being an improbable event; and the several stages, from a close connection to the entire isolation of some of the atolls in the Maldiva Archipelago, are readily explicable.

It is even probable that the Maldiva Archipelago originally existed as a barrier-reef of nearly the same dimensions as that of New Caledonia (Plate II. fig. 5): for if we complete in imagination the subsidence of this great island, we may infer from the broken condition of the northern portion of the reef, and from the almost entire absence of reefs on the eastern coast, that the present barrier, after repeated subsidences, would become, during its subsequent upward growth, separated into distinct portions; and these portions would tend to assume an atoll-like structure, owing to the corals growing with vigour where freely exposed to the open sea. As some large islands have subsided to a certain amount and are partly encircled by barrier-reefs, so our theory makes it probable that there should be other large islands wholly submerged; and these, as we can now see, would be surmounted, not by one enormous atoll, but by several large ones like the atolls of the Maldiva group; and these again, during long periods of subsidence, would sometimes become dissevered into smaller ones. In the Marshall and Caroline Archipelagoes, there are atolls standing close together which have an evident relationship in form; and we may suppose that either two or more encircled islands originally stood close together and afforded bases for two or more atolls, or that one large atoll has been dissevered. But from the position as well as the forms of three atolls in the Caroline Archipelago (the Namourrek and Elato groups), which are placed in an irregular circle, I am strongly inclined to believe that they owe their origin to the disseverment of a single large atoll.[1]

Irregularly-formed Atolls.—In the Marshall group, Musquillo atoll consists of two loops united by a single point; and Menchicoff atoll is formed of three loops, two of which (as may be seen in fig. 3, Plate II.) are connected by a mere ribbon-shaped reef; the three together being 60 miles in length. In the Gilbert group some of the atolls have narrow reefs like spurs, projecting from them. Linear and straight, or crescent-formed reefs with their extremities more or less cùrled inwards, may sometimes be found standing by themselves in the open ocean. All these irregular forms would naturally follow from continued subsidence, combined with the upward growth of reefs fronting one side alone of a high island, the reefs on the opposite side having perished or never having existed.

Submerged and Dead Reefs.—In the second section of the first chapter, I have shown that there sometimes exist in the neighbourhood of atolls, deeply submerged banks with level surfaces; that there are others, less deeply but yet wholly submerged, having all the characters of a perfect atoll, but consisting

[1] The same remark is, perhaps, applicable to the islands of Ollap, Fanadik, and Tamatam in the Caroline Archipelago, of which charts are given in the atlas of Duperrey's voyage; a line drawn through the linear reefs and lagoons of these three islands form a semicircle. Consult also the atlas of Lutké's voyage; and for the Marshall group that of Kotzebue; for the Gilbert group (which is referred to in the ensuing paragraph) consult the atlas of Duperrey's voyage. Most of the points here referred to may, however, be seen in Krusenstern's general Atlas of the Pacific.

merely of dead coral-rock; that there are barrier-reefs and atolls with only a portion of the reef, generally on the leeward side, submerged; and that such portions either retain their perfect outline, or appear to be more or less completely effaced, their former place being marked only by a bank, conforming in general outline with that part of the reef which remains perfect. These several cases are, I believe, intimately related, and can all be explained by the same agency of subsidence.

We see that in those parts of the ocean where coral-reefs are most abundant, one island is fringed and another neighbouring one is not fringed, and that in the same archipelago, all the reefs are more perfect in one part than in another,—for instance, in the southern compared with the northern half of the Maldiva Archipelago, and likewise on the outer as compared with the inner coasts of the double row of atolls in this same archipelago. The existence of the innumerable polypifers forming a reef depends on their finding sustenance, and we know that they are preyed on by other organic beings, and that some inorganic causes are highly injurious to their growth. Can it, therefore, be expected that the reef-building polypifers should keep alive for perpetuity in any one place, during the round of change to which earth, air, and water are subjected; and still less can this be expected during progressive subsidence, to which by our theory these reefs and islands have been liable? Should such subsidence be at any time greater than

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the rate of upward growth of the polypifers, the death of the reef must ensue, and it would have been strange had we found no evidence of this. It is, then, not at all improbable that the corals should sometimes perish either on the whole or on part of a reef. If only on a part, the dead portion, after a small amount of subsidence, would still retain its proper outline and position beneath the water. After a more prolonged subsidence, it would form, owing to the accumulation of sediment, a more or less level bank marking the limits of the former lagoon. Such dead portions of a reef would generally lie on the leeward side,[1] for the impure water and fine sediment are driven out from the lagoon over this side of the reef, where the force of the breakers is less than to windward, and where the corals are, in consequence, less vigorous and less able to resist any destroying agency. It is owing to this same cause that reefs are frequently breached to leeward by channels which serve

[1] Sir C. Lyell, in the first edition of his Principles of Geology, offered a somewhat different explanation of this structure. He supposes that there has been subsidence; but he was not aware that the submerged portions of reef were in most cases, if not in all, dead; and he attributes the difference in height in the two sides of most atolls chiefly to the greater accumulation of detritus to windward than to leeward. But as matter is accumulated only on the backward part of the reef, the front part would remain of the same height on both sides. I may here observe that in most cases (for instance at Peros Banhos, the Gambier group and the Great Chagos bank), and I suspect in all cases, the dead and submerged portions do not blend or slope into the living and perfect parts, but are separated from them by an abrupt line. In some instances small patches of living reef rise to the surface from the middle of the submerged and dead parts.

as ship-channels. If the corals perished entirely, or on the greater part of the circumference of an atoll, the result would be an atoll-shaped bank of dead rock more or less entirely submerged; and further subsidence, together with the accumulation of sediment, would obliterate its atoll-like structure, and leave only a bank with a nearly level surface.

We meet with all these cases in the Chagos group of atolls. Here within an area of 160 miles by 60, there are two atoll-formed banks of dead rock (besides another very imperfect one) entirely submerged; a third bank with merely two or three small pieces of living reef which rise to the surface; and a fourth, namely, Peros Banhos (Plate I. fig. 9), with a portion nine miles in length dead and submerged. As by our theory this area has subsided, and as there is nothing improbable in the death of the corals on portions or over the whole surface of a reef, either from changes in the state of the surrounding sea or from the subsidence being great or sudden, these Chagos banks present no difficulty. So far, indeed, are any of the above-mentioned cases of dead submerged reefs from offering any difficulty, that their occurrence might have been anticipated on our theory; and as fresh atolls are supposed to be in progressive formation by the subsidence of encircling barrier-reefs, a weighty objection might even have been raised, namely that atolls must increase indefinitely in number, unless proofs of their occasional destruction could have been adduced.

The Great Chagos Bank.[1]—I have already shown that the submerged condition of the Great Chagos bank (Plate II. fig. 1, with its section, fig. 2), and of some other banks in the Chagos group, may in all probability be attributed to the corals having perished during an unusually rapid or sudden subsidence. The external rim or upper ledge (shaded in the chart) consists of dead coral-rock thinly covered with sand; it lies at an average depth of between 5 and 8 fathoms, and perfectly resembles in form the annular reef of an atoll. The banks of the second level, the boundaries of which are marked by dotted lines in the chart, lie from about 15 to 20 fathoms beneath the surface; they are several miles in breadth, and terminate in a very steep slope round the central expanse. This central expanse consists of a level muddy flat between 30 and 40 fathoms deep. The banks of the second level appear at first sight to resemble the internal step-like ledges of dead coral-rock which border the lagoons of certain atolls, but their much greater width, and their being formed of sand, are points of essential difference. On the eastern side of the atoll some of the banks are linear and parallel, like islets in a great river, and they point directly towards a great breach on the opposite side of the atoll: these are best seen in the large published chart. I inferred from this circumstance, that strong currents sometimes set directly across this great bank; and I hear from Captain Moresby that this is the case. I observed, also, that the channels,

[1] [See Appendix II.]

or breaches through the rim, were all of the same depth as the central expanse into which they lead; whereas the channels into the other atolls of the Chagos group, and as I believe into most other large atolls, are not nearly as deep as the lagoons. For instance at Peros Banhos, the channels as well as the bottom of the lagoon for a space about a mile and a-half round its shores, are only between 10 and 20 fathoms in depth, whilst the central expanse is from 35 to 40 fathoms deep. Now, if an atoll during a gradual subsidence once became entirely submerged like the Great Chagos bank, and therefore no longer exposed to the surf, very little sediment could any longer be formed from it; consequently the channels leading into the lagoon would be no longer filled up with drifted sand and coral detritus, and would continue increasing in depth, as the whole sank down. In this case we might expect that the currents of the open sea, instead of sweeping as at first round the submarine flanks, would, as the many breaches in the reef increased, flow directly across the lagoon, thus removing the finer sediment from the channels, and preventing its further accumulation. The submerged reef would thus ultimately consist of an upper and narrow broken rim of rock, surrounded on the inner side by banks, the remnants of the sandy bed of the old lagoon, now intersected by many deep channels; these channels, with their sides worn steep by the oceanic currents, uniting in the centre and forming the central deep expanse. By such means the Great

Chagos bank—the most anomalous structure which I have met with—appears to have originated.

If this bank should continue to subside, a mere wreck of an atoll would be left; for the corals are almost everywhere dead. Pitt's bank, situated not far southward, appears to be in this actual condition: it consists of a moderately level, oblong bank of sand, lying from 10 to 20 fathoms beneath the surface, with two sides protected by a narrow ledge of rock submerged between 5 and 8 fathoms. A little to the south of this ledge, at about the same distance as the southern rim of the Great Chagos bank lies from the northern rim, there are two other small banks with from 10 to 20 fathoms on them; and not far eastward, soundings were struck on a sandy bottom with between 110 and 145 fathoms. The northern portion of Pitt's bank with its ledge-like margin, thus closely resembles any one segment of the Great Chagos bank between two of the deep-water channels, and the scattered banks southward and eastward appear to be the last wreck of the less perfect portions of one great and now ruined atoll.

I have examined with care the charts of the Indian and Pacific Oceans, and have now laid before the reader all the cases which I have met with, of reefs differing from the class to which they belong; and I think it has been shown that they are all included in our theory, modified by occasional accidents, such as might have been anticipated. We have thus seen, that in the lapse of ages encircling barrier-reefs are converted into atolls, —the term atoll being applicable as soon as the last pinnacle of encircled land sinks beneath the surface of the sea. We have seen that large atolls, during the progressive subsidence of the areas in which they stand, sometimes become dissevered into smaller ones. At other times, when the reef-building polypifers perish, atolls are converted into atoll-formed banks of dead rock; and these again, through further subsidence and the accumulation of sediment, pass into level banks with scarcely any distinguishing character. Thus may the history of an atoll be followed from its birth, through the occasional accidents of its existence, to its death and final obliteration.

Objections to our theory of the formation of Atolls and Barrier-reefs.—The vast amount of subsidence both in area and depth, necessary to have submerged every mountain, even the highest, throughout the immense spaces of ocean now interspersed with atolls, will probably strike most persons as a formidable objection to the theory. But as continents, as large as the spaces supposed to have subsided, have been raised above the level of the sea,—as whole regions are now rising, for instance, in Scandinavia and South America, —and as no reason can be assigned why subsidence should not have occurred in some parts of the earth's crust on as great a scale as elevation, this objection has little force. The remarkable point is, that a subsiding movement to such an extent and amount should have taken place within a period, during which the corals have continued to add matter to the same reefs. Another and less obvious objection to the theory may perhaps be advanced, namely, that, although atolls and barrier-reefs are supposed to have gone on subsiding for a long period, yet that their lagoons and lagoon-channels have only rarely come to exceed 40 and never 60 fathoms in depth. But if our theory is worth consideration, we already admit that the rate of subsidence has not ordinarily exceeded that of the upward growth of the massive corals which live on the margins of the reefs, so that we have only further to suppose that the rate has never exceeded that at which lagoons and lagoon-channels are filled up by the growth of the delicate corals which live there, and by the accumulation of sediment. As the filling-up process, in the case of barrier-reefs lying far from the land, and of the larger atolls, must be an extremely slow one, we are led to conclude that the subsiding movement has always been equally slow. And this conclusion accords well with what is known of the rate of recent movements of elevation.

It has, I think, been shown in this chapter, that subsidence explains both the normal structure and the less regular forms of those two great classes of reefs which have justly excited the astonishment of all the naturalists who have sailed through the Pacific and Indian Oceans. The necessity, also, that a foundation should have existed at the proper depth for the growth of the corals over certain large areas, almost compels us to accept this theory. But further to test its truth, a crowd of questions may be asked. Do the different kinds of reefs which have been produced by the same kind of movement, generally lie within the same or closely adjoining areas? How are such reefs related to each other in form and position,—for instance, do neighbouring groups of atolls, and the separate atolls in each group, bear the same relation to each other as do ordinary islands? Although coral-reefs which have just begun to re-grow, after having been killed by too rapid a subsidence, would at first belong to the fringing class, yet, as a general rule, reefs of this class indicate that the land has either long remained at a stationary level, or has been upraised. Of a stationary level it is hardly possible to find any evidence except of a negative kind; but of recent elevation, upraised marine remains afford a sure proof: it may therefore be asked, do fringed coasts often afford such evidence? Do the areas which have subsided, as shown by the presence of atolls and barrier-reefs, and the areas which have either remained stationary or have been upraised, as indicated by fringing-reefs, bear any determinate relation to each other? Is there any relation between the areas of recent subsidence or elevation, and the presence of active volcanic vents? These several questions will be considered in the following chapter.[1]

[1] I may take this opportunity of briefly considering the appearance which would probably be presented by a vertical and deep section across a coral formation (referring chiefly to an atoll) formed by the upward growth of coral during successive subsidences. This is a subject worthy of attention, as a means of comparison with ancient coral strata. The circumferential parts would consist of massive species in a vertical position, with their interstices filled up with detritus; but this would be the part most subject to subsequent denudation and removal. It is useless to speculate how large a

proportion of the exterior annular reef would consist of upright coral, and how much of fragmentary rock, for this would depend on many contingencies,—such as on the rate of subsidence occasionally allowing a fresh growth of coral to cover the whole surface, and on the breakers having force sufficient to throw fragments over this same space. The conglomerate which composes the base of the islets, would (if not removed by denudation together with the exterior reef on which it rests) be conspicuous from the size of the fragments,—the different degrees in which they have been rounded,—the presence of fragments of conglomerate torn up rounded and re-cemented,—and from the oblique stratification. The corals which lived in the lagoon-reefs at each successive level, would be preserved upright, and they would consist of many kinds, generally much branched. In this part, however, a very large proportion of the rock, and in some cases nearly all of it, would be formed of sedimentary matter, being in an excessively fine or moderately coarse state, with the particles almost blended together. The conglomerate which was formed of rounded pieces of the branched corals on the shores of the lagoon, would differ from that formed on the islets and derived from the outer coast; although both might have been accumulated very near each other. The stratification, taken as a whole, would be horizontal: but the conglomerate beds resting on the exterior reef, and the beds of sandstone on the shores of the lagoon and on the external flanks of the reef, would probably be divided (as at Keeling atoll and at Mauritius) by numerous layers dipping at considerable angles in different directions. The calcareous sandstone and coral rock would almost necessarily contain innumerable shells, echini, and the bones of fish, turtle, and perhaps of birds: possibly, also, the bones of small saurians, as these animals find their way to islands far remote from any continent. The large shells of some species of Tridacna would be found vertically imbedded in the solid rock, in the position in which they lived. We might expect, also, to find a mixture of the remains of pelagic and littoral animals in the strata formed in the lagoon, for pumice and the seeds of plants are floated from distant countries into the lagoons of many atolls; on the outer coast of Keeling atoll near the mouth of the lagoon, the shell of a pelagic Pteropodous animal was brought up on the arming of the sounding-lead. All the loose blocks of coral on Keeling atoll were burrowed by vermiform animals; and as every cavity, no doubt, ultimately becomes filled with spathose limestone, slabs of the rock would, if polished, probably exhibit the excavations of such burrowing animals. The conglomerate and fine-grained beds of coral-rock would be hard, sonorous, white, and composed of nearly pure calcareous matter; in some few parts, judging from the specimens at Keeling atoll, they would probably contain a small quantity of iron. I have seen a conglomerate now forming on the shores of the Maldiva atolls, resembling conglomerate limestone from Devonshire. Floating pumice and scoriæ, and occasionally stones transported in the roots of trees (see my Naturalist's Voyage, p. 461) appear the only sources through which foreign matter is brought to coral-formations standing in the open ocean. The area over which sediment is transported from coral-reefs must be considerable; Captain Moresby informs me that during the change of monsoons, the sea is discoloured to a considerable distance off the Maldiva and Chagos atolls. The sediment off fringing and barrier coral-reefs must be mingled with the mud which is brought down from the land, and is transported seaward through the breaches which occur in front of almost every valley. If the bed of the ocean were to be upraised and converted into land, the atolls of the larger archipelagoes would form flat-topped mountains, varying in diameter from a few to sixty miles—for the smallest atolls would probably be worn quite away; and from being horizontally stratified and of similar composition, they would, as Sir C. Lyell has remarked, falsely appear as if they had originally been united into one vast continuous mass. Such great strata of coral-rock would rarely be associated with erupted volcanic matter, for this could only take place, as may be inferred from what follows in the next chapter, when the area in which they were situated, commenced to rise, or at least ceased to subside. During the enormous period necessary to effect an elevation of the kind just alluded to, the surface would necessarily be greatly denuded; hence it is highly improbable that any fringing-reef, or even any barrier-reef, at least those encircling small islands, would be preserved to a distant period. From this same cause, the strata which were formed within the lagoons of atolls and the lagoon-channels of barrier-reefs, and which must consist in a large part of sedimentary matter, would more often be preserved to future ages, than the exterior solid reef composed of massive corals in an upright position; although it is on this exterior part that the present existence and further growth of atolls and barrier-reefs depend.

CHAPTER VI.

ON THE DISTRIBUTION OF CORAL-REEFS WITH REFERENCE TO THE THEORY OF THEIR FORMATION.

Description of the coloured map—Proximity of atolls and barrier-reefs—Relation in form and position of atolls with ordinary islands—Direct evidence of subsidence difficult to be detected—Proofs of recent elevation where fringing-reefs occur—Oscillations of level—Absence of active volcanoes in the areas of subsidence—Immensity of the areas which have been elevated and have subsided—Their relation to the present distribution of the land—Areas of subsidence elongated—Their intersection and alternation with those of elevation—Amount, and slow rate of the requisite subsidence—Recapitulation.

It will be convenient first to give a short account of the appended map of the Pacific and Indian Oceans (Plate III.); a fuller one, with the data for colouring each spot, is reserved for the Appendix, and every place there referred to may be found in the Index. A larger chart would have been desirable; but, small as the adjoined one is, it is the result of many months' labour. I have consulted, as far as I was able, every original voyage and map; and the colours were first laid down on charts on a large scale. The same blue colour, with merely a difference in the tint, is used for atolls or lagoon-islands, and for barrier-reefs;

these being in all essential respects closely related. Fringing-reefs, on the other hand, have been coloured dull red, for there is an important distinction between them and barrier-reefs and atolls with respect to the depth beneath the surface, at which, as we must believe, their foundations lie. The two distinct colours, therefore, mark two great types of structure.

The *dark blue colour* represents atolls and submerged annular reefs with deep water in their centres. I have coloured a few low and small coral-islands as if they had been atolls, although not including a lagoon; but this has been done only when it clearly appeared that they had originally contained one. When no such evidence exists they have been left uncoloured.

The *pale blue colour* represents barrier-reefs. The most obvious character of reefs of this class is the broad and deep-water moat within the reef; but this, like the lagoon of a small atoll, is liable to become filled up with detritus and with reefs of delicately-branched corals. When, therefore, a reef round the entire circumference of an island extends far into a profoundly deep sea, so that it can hardly be confounded with a fringing-reef which must rest on a foundation of rock within a small depth, it has been coloured pale blue, although it does not now include a deep-water moat. But this has been rarely done, and each case is distinctly mentioned in the Appendix.

The *red colour* represents reefs which fringe the land closely where the sea is deep, and extend to a moderate distance from it where the bottom is gently inclined; but they never include a deep-water moat or lagoon-like channel running parallel to the shore. It must, however, be remembered that fringing-reefs are frequently *breached* by deep-water channels, where mud has been deposited in front of rivers and valleys.

In all cases, a space of 30 miles in width has been coloured round or in front of the reefs of each class, in order that the colours might be made conspicuous in a map on so small a scale.

The *vermilion spots and streaks* represent volcanos now in action, or historically known to have been so. They are laid down chiefly from Von Buch's work on the Canary Islands; and my reasons for making a few alterations are given in the note below.[1]

[1] I have also made considerable use of the geological part of Berghaus' Physical Atlas. Beginning at the eastern side of the Pacific, I have added to the number of the volcanos in the southern part of the Cordillera, and have coloured Juan Fernandez according to observations collected during the voyage of the *Beagle* (Geol. Trans. vol. v. p. 601). I have added a volcano to Albemarle Island, one of the Galapagos Archipelago (see my Journal of Researches, p. 457). In the Sandwich group there are no active volcanos, except at Hawaii; but the Rev. W. Ellis informs me there are streams of lava apparently modern on Maui, having a very recent appearance, which can be traced to the craters whence they flowed. The same gentleman informs me that there is no reason to believe that any active volcano exists in the Society Archipelago; nor are there any known in the Samoa or Navigator group, although some of the streams of lava and craters there appear recent. In the Friendly group, the Rev. J. Williams says (Narrative of Missionary Enterprise, p. 29) that Toofoa and Proby Islands are active volcanos. I infer from Hamilton's Voyage in the *Pandora* (p. 95), that Proby Island is synonymous with Onouafou, but I have not ventured to

The *uncoloured parts* consist, first and chiefly, of coasts where no coral-reefs, or quite insignificant ones,

colour it. There can be no doubt respecting Toofoa; and Captain Edwards (Von Buch, p. 386) found the lava of a recent eruption at Amargura still smoking. Berghaus marks four active volcanos actually within the Friendly group; but I do not know on what authority; I may mention that Maurelle describes Latte as having a burnt-up appearance; I have marked only Toofoa and Armagura. South of the New Hebrides lies Matthews Rock, which is described as an active crater in the voyage of the *Astrolabe*. Between it and the volcano on the eastern side of New Zealand lies Brimstone Island, which from the high temperature of the water in the crater may be ranked as active (Berghaus Vorbemerk, II. Lief. S. 56). Malte Brun, vol. xii. p. 231, says that there is a volcano near Port St. Vincent, in New Caledonia: I believe this to be an error, arising from smoke seen on the *opposite* coast by Cook (2nd voyage, vol. ii. p. 23), which smoke went out at night. The Mariana Islands, especially the northern ones, contain many craters (see Freycinet's Hydrog. Descript.) which are not active. Von Buch, however, states (p. 462), on the authority of La Peyrouse, that there are no less than seven volcanos between these islands and Japan. Gemelli Careri (Churchill's Collect. vol. iv. p. 458) says there are two active volcanos in lat. 23° 30′ and in lat. 24°; but I have not coloured them. From the statements in Beechey's Voyage (p. 518, 4to edit.) I have coloured one in the northern part of the Bonin group. M. S. Julien has clearly made out from Chinese manuscripts not very ancient (Comptes Rendus, 1840, p. 832), that there are two active volcanos on the eastern side of Formosa. In the map appended to the first edition I marked an active volcano in Torres Straits, and gave my authority; but Mr. Jukes informs me that there certainly is no volcano there; a wooded island on fire having been mistaken for one. Mr. M'Clelland (Report of Committee for Investigating Coal in India, p. 39) has shown that the volcanic band which passes through Barren Island must be extended northwards. It appears by an old chart, that Cheduba was once an active volcano (see also Silliman's North American Journal, vol. xxxviii. p. 385). In Berghaus' Phys. Atlas, 1840 (No. 7 of Geological Part) a volcano on the coast of Pondicherry is said to have burst forth in 1757. Ordinaire (Hist. Nat. des Volcans, p. 218) says that there is one at the mouth of the Persian Gulf, but I have not coloured it, as he gives no particulars. A volcano in Amsterdam, or St. Paul's, in the southern part of the exist. Secondly, of coasts where the sea is extremely shallow; and the reefs in this case generally lie far from the land, and are very irregular, so that they cannot always be classed. Thirdly, reefs which appear merely to coat submerged banks of rock or of sediment; for such reefs differ in some essential respects from those which owe their whole thickness to the growth of corals. Fourthly, in the Red Sea, and within some parts of the East Indian Archipelago (if the imperfect charts of the latter can be trusted), there are many scattered reefs of small size, represented by mere dots, which rise out of deep water; and these have likewise been left uncoloured. In the Red Sea, however, some such reefs seem once to have formed parts of a continuous barrier. There exist, also, scattered in the open ocean, some linear and irregularly-formed reefs which are probably, as shown in the last chapter, remnants of atolls; but as they cannot safely be placed in this class, they have not been coloured; they are, however, few in number, and of insignificant dimensions. Lastly, some reefs have been left uncoloured from the want of sufficient information; and some because they are intermediate in character between barrier and fringing-reefs. The

Indian Ocean, has been seen (Naut. Mag. 1838, p. 842) in action. Dr. J. Allan, of Forres, informs me in a letter that, when he was at Joanna, he saw flames at night, apparently volcanic, issuing from the Chief Comoro Island, and that the Arabs assured him that they were volcanic, adding that the volcano burnt more during the wet season: I have marked this as a volcano, though with some hesitation, as the flames may have arisen from gaseous sources.

value of the map is lessened, in proportion to the number of reefs which I have thus been obliged to leave uncoloured; but their number is not very great, as will be seen by comparing the map with the statements in the Appendix. I have experienced more difficulty in colouring fringing-reefs than in colouring barrier-reefs, as the former, from their small size, have not much attracted the attention of navigators. As I have had to seek my information from all kinds of sources, I do not venture to hope that the map is free from errors. Nevertheless, I trust it will give an approximately correct view of the general distribution of the coral-reefs throughout the world, (with the exception of some fringing-reefs on the coast of Brazil, not included within the limits of the map,) and of their arrangement into the three great classes which, though necessarily ill-defined from the nature of the objects classified, have been adopted by most voyagers. I may further remark, that the dark-blue colour represents land entirely composed of coral-rock; the pale blue, land with a wide and thick border of coral-rock; and the red, land with a mere narrow fringe of coral-rock.

Looking now at the map under a theoretical point of view, the two blue tints signify that the foundations of the reefs thus coloured have largely subsided, and that the rate of subsidence has been less than the upward growth of the corals. It is also probable that in many cases the foundations are still subsiding. The red signifies that the shores thus coloured support fringing-reefs; and they have not, as a general rule, recently subsided, at least to any considerable amount, for the effects of subsidence on a small scale would hardly be distinguishable. Such shores must either have remained stationary since the period when they were first fringed; or they may have been repeatedly upraised, with new lines of reefs successively formed round them. If, however, coral-reefs became attached for the first time to a shore which was subsiding, or if a barrier-reef was destroyed and submerged with a new reef re-attached to the shore, this would necessarily belong at first to the fringing class, and would be coloured red, although the land was sinking. So it would be with a subsiding shore, if it plunged at a very high angle beneath the sea, for in this case the reef would remain closely attached to the land as it grew upwards, and would resemble in all respects a fringing-reef. This source of doubt applies especially to atolls which have been upraised (such as Metia and Elizabeth Islands), for from the steepness of their sub-marine flanks, a reef growing up during a subsequent period of subsidence round them, would still continue closely to skirt the land, and would therefore be coloured red. Well-characterised atolls or encircling reefs, where several occur together in a group, or a single barrier-reef if of large dimensions, clearly indicate a movement of subsidence. The evidence from a single atoll, or from a single encircling-reef, must be received with caution, for the former may be based upon a submerged crater or bank, and the latter on a submerged margin of sediment or of worn-down rock.

On the distribution of the different classes of reefs.—Having made the foregoing preliminary remarks, I will now consider how far the distribution of the different kinds of coral-islands and reefs corroborates our theory. A glance at the map shows that the reefs which are coloured blue and red, and which are believed to owe their origin either to widely different movements, or in the case of the red to a stationary condition, are not indiscriminately mingled together. Atolls and barrier-reefs, as may be seen by the two blue tints, generally lie near each other; and this would be the natural result of both having been produced by the same movement of subsidence. Thus, all the Society Islands are encircled by barrier-reefs; and to the N.W. and S.E. there are several scattered atolls. To the eastward lies the great Paumotu or Low Archipelago consisting entirely of atolls; and still further to the N.E., we meet with the Mendana or Marquesas Islands, which, from their abrupt and deeply indented shores, Dana [1] believes have probably subsided; though hardly any coral-reefs exist there, which might have afforded additional evidence of subsidence. In the midst of the Caroline atolls, there are three fine encircled islands. The northern point of the barrier-reef of New Caledonia apparently forms, as before remarked, a great atoll. The Australian barrier is described as including both atolls and small encircled islands. Captain King [2]

[1] Corals and Coral Islands, 1872, p. 325.
[2] Sailing Directions, appended to vol. ii. of his Surveying Voyage to Australia.

mentions many atoll-formed and encircling coral-reefs, some of which lie within the barrier, and others may be said (for instance, between lat. 16° and 13°) to form part of it. Flinders[1] has described an atoll-formed reef in lat. 10°, seven miles long and from one to three broad, resembling a boot in shape, and apparently including a deep lagoon. Eight miles westward of this, and forming part of the barrier, lie the Murray Islands, which are high and are encircled. In the Corallian sea, between the two great barrier-reefs of Australia and New Caledonia, there are many low islets and coral-reefs, some of which are annular, or like a horse-shoe. Bearing in mind the smallness of the scale of our map (the lines of latitude being 900 miles apart), we see that none of the larger groups of reefs and islands which are coloured blue, and which are supposed to have been produced by long-continued subsidence, lie near extensive lines of coast coloured red; these latter having either long remained stationary, or having been upraised with new reefs re-formed on them. Where red and blue circles do occur near each other, I am able, in several instances, to show that there have been oscillations of level; subsidence having preceded the elevation of the red spots; and elevation having preceded the subsidence of the blue spots; and in this case the juxtaposition of reefs belonging to the two great types of structure is little surprising. We find, therefore, that atolls and barrier-reefs, which both owe their origin to subsidence, lie near together and are as a general rule separated

[1] Voyage to Terra Australis, vol. ii. p. 336.

from fringing-reefs, which show that the land is stationary or rising; and all this holds good to the full extent which might have been anticipated by our theory.

As atolls have been formed during the sinking of the land by the upward growth of the reefs which primarily fringed the shores of ordinary islands; so we might expect that these rings of coral, like so many rude outline charts, would still retain traces of the general form, or at least of the general range, of the islands round which they were first modelled. That this is the case with the atolls in the Southern Pacific, as far as their range is concerned, seems highly probable, when we observe that the principal groups are directed in nearly N.W. and S.E. lines, and that nearly all the mountainous islands and shores in the S. Pacific range in this same direction; namely, N.-Eastern Australia, New Caledonia, the northern half of New Zealand, the New Hebrides, Saloman, Navigator, Society, Marquesas, and Austral Archipelagoes. In the Northern Pacific, the Caroline atolls almost abut against the N.W. line of the Marshall atolls, much in the same manner as the E. and W. line of islands extending from Ceram to New Britain abuts against New Ireland. In the Indian Ocean the Laccadive and Maldiva atolls extend nearly parallel to the western mountains of India. There is also a close resemblance between atolls and ordinary islands in the manner in which they are grouped, as well as in their shapes. Thus the outline of all the larger groups of atolls is elongated; and the atolls themselves are generally elongated in the same direction with the group. The Chagos group is less elongated than is usual, and the individual atolls in it are likewise but little elongated; this is strikingly seen by comparing them with the neighbouring Maldiva atolls. In the Marshall and Maldiva archipelagoes, the atolls are ranged in two parallel lines, like a great double mountain-chain. Some of the atolls in the larger archipelagoes stand so near to each other, and have such an evident relationship, that they compose little sub-groups; in the Caroline Archipelago, one such sub-group consists of Pouynipète, a lofty island encircled by a barrier-reef, and separated by a channel only four miles and a half in width from Andeema atoll, with a second atoll a little further removed.

On the direct evidence of the blue spaces in the map having subsided during the upward growth of the reefs thus coloured, and of the red spaces having remained stationary, or having been upraised.—With respect to subsidence, we cannot expect to obtain in semi-civilised countries proofs of a movement which tends to conceal its own evidence. But on coral-islands we see plain signs of a round of decay and renovation—on some, the last vestiges of land—its first commencement on others: we hear of storms washing away and desolating the islets to an extent which astonished the inhabitants; we know by the great fissures with which some of these islands are traversed, and by the earthquakes felt under others, that subterranean disturbances are in progress. All these appearances accord well with the belief that these islands have recently subsided; though not proving the fact. At Keeling atoll, however, I have described certain appearances, which seem directly to show that the surface subsided there during the late earthquakes. In the Caroline Archipelago, the island of Pouynipète (Plate I. fig. 7), from being encircled by a great barrier-reef, must have subsided, in accordance with our theory; and in the New South Wales Lit. Advert. Feb. 1835, there is an account of this island, (subsequently confirmed by Mr. Campbell,) in which it is said, 'At the N.E. end, at a place called Tamen, there are ruins of a town, *now only* accessible by boats, the waves *reaching to the steps of the houses*.' Hence it would appear that the island must have subsided since these houses were built. Mr. Hales also states, from information acquired during the U.S. Exploring Expedition, that certain buildings on this island are now in the water: 'what were once paths are now passages for canoes, and when the walls are broken down the water enters the enclosures.'[1] Vanikoro, according to the Chevalier Dillon, is often violently shaken by earthquakes, and there, the unusual depth of the channel between the shore and the reef, the wall-like structure on the inner side of the reef, the small quantity of low alluvial land at the foot of the mountains, and the almost entire absence of islets on the reef, all seem to show that this island has not remained long at its present level.[2] At the Society Archipelago, on the other hand,

[1] Professor Dana also concludes from these facts that the island is subsiding; see Corals and Coral Islands, 1872, p. 330.

[2] See Captain Dillon's Voyage in search of La Peyrouse. M.

where a slight tremor is only rarely felt, the shoalness of the lagoon-channels round some of the islands, the number of islets formed on the reefs of others, and the broad belt of low land at the foot of the mountains, all indicate that these islands have not undergone for a long period, any movement of subsidence, although their encircling reefs must on our theory have been originally produced through subsidence.[1]

Although Dana admits that atolls and barrier-reefs must have been originally formed by the subsidence of their foundations, he believes that a large number of atolls, situated between the Paumotu or Low group to the east and the Feejees to the west, and northward nearly as far as the equator, have recently been uplifted to the height of a very few feet.[2] Mr. Couthouy came to a similar conclusion during the same expedition with respect to many of the Paumotu atolls. These observers ground their belief chiefly from having found the great shells of the Tridacna vertically embedded in coral-rock, at a height at which they cannot now exist. Mr. Couthouy also states that he found corals standing on

Cordier, in his Report on the Voyage of the *Astrolabe* (vol. i. p. cxi.), speaking of Vanikoro, says the shores are surrounded by reefs of madrepore, '*qu'on assure être de formation tout-à-fait moderne*.'

[1] Mr. Couthouy states (Remarks, p. 44) that at Tahiti and Eimeo the space between the reef and the shore has been nearly filled up by the extension of coral-reefs of the kind which within most barrier-reefs merely fringe the land. From this circumstance, he arrives at the same conclusion as I have done, namely, that the Society Islands have remained stationary during a long period.

[2] Corals and Coral Islands, 1872, pp. 199, 345. See also Mr. Couthouy's Remarks on Coral Formations. [See Wilkes' Exploring Expedition, vol. i. chap. xv.]

the shores and in the midst of the lagoons, from 12 to 30 inches above the sea-level, with the tips of their branches dead. He also refers to masses of coral-rock which he thinks could not have been carried into their present positions and subsequently been water-worn, whilst the land stood at its present level. Nevertheless it might, I think, have been anticipated that many atolls would have presented the above appearance, if they had long remained at a stationary level. The sea, after the land had at some former period subsided a few feet, would have continued for a long time breaking over the whole reef, even after the living corals had grown up to their full height on the outer margin. The waters of the lagoon would thus have been disturbed and raised, so that shells and corals, from being bathed by the troubled waters, could have existed at a greater height than that at which they could exist after the reef had been raised by the agglutination of fragments and sand, and after islets had been formed on its surface. Even the mere outward growth of a reef, and the consequent increase of its breadth, by checking the inward rush of the breakers, would tend to lower the level in the lagoon at which corals and shells can live.

We have seen that at the Keeling Islands there are fields of rotten coral with the tips of their branches projecting above the surface of the lagoon,—the result of the tides not rising so high as formerly (as is said to be the case by the inhabitants), from the closing of the channels between the islets on the outer reef, and from the lagoon being partially choked up by the growth of the corals. Here, so far from there having been any recent elevation of the land, we have reason to believe that there has been subsidence. Messrs. Dana and Couthouy's observations relate chiefly to the Paumotu atolls, and here again some facts indicate recent subsidence rather than elevation: I refer to the manner in which Chain atoll suffered during a storm, and to Sir E. Belcher's statement,[1] that after an interval of fourteen years, a well-known islet had disappeared, and the lagoon at a particular spot had become deeper than it was before.

There are other causes of change which might, as it appears to me, easily lead to a mistaken belief in the recent elevation of low coral formations. We must remember that the outer and living margin of the reef grows up to a height determined by the constant breaking of the waves. Outside this margin there is a sloping surface also covered with living corals, but belonging to species which do not grow to the surface; and beyond this, there is a much steeper slope, consisting of coral-sand. Now after a somewhat rapid subsidence of, for instance, one or two fathoms, we may feel almost sure that the corals on the outer margin would grow up quickly to the surface and form a nearly vertical wall. This would be succeeded outside by a steeply sloping surface of living corals, which would likewise sooner or later grow up to their former level; but outside this, the much steeper slope, formed by the slow accumulation of fine detritus, would not recover for a very long

[1] Voyage Round the World, vol. i. 1843, p. 382.

time its former angle relatively to the upper bank of living corals. Now it seems highly probable that a change of any kind in the outer submarine slope of an island would influence the height to which the living corals on the margin would be constantly bathed by the surf, and to which they would consequently be able to grow. Again, it seems possible that if during one season of the year the currents of the sea and the prevalent winds coincided in direction, the waves would then reach to a higher level and the corals grow higher, than at another season when the currents and the winds did not coincide in direction. The result would be that the corals which during the one season had grown to their full height, would at the other season expose their dead summits, and give the appearance of the land having been slightly elevated. I have referred to these possibilities merely to show how difficult it must ever be to judge whether low coral formations have really been raised to a height of only two or three feet, as Dana believes to have been the case with several groups of atolls. To me it seems more probable that all the above-mentioned appearances merely indicate that the atolls in question have long remained at the same level. If, however, the conclusion arrived at by so excellent an observer as Professor Dana, should hereafter be confirmed, the question will arise, seeing how immense an area has been thus affected, whether those geologists are not right who believe that the level of the ocean is subject to secular changes from astronomical causes.

Evidence that many coasts fringed with coral-reefs and coloured red on the map, have been recently elevated.—As the areas which have slowly subsided within the period of existing corals are many and large, we might have expected that such movements would have been counterbalanced by the recent elevation of other equally large areas; and this, as we shall see, apparently holds good. Corals attached to a rising coast would necessarily form a fringing-reef; and this reef would be upraised at each successive elevation, with a new one formed on the coast at a lower level. Such reefs would differ only by their smaller breadth from those attached to a shore which had long remained stationary; for they would not have had sufficient time to form a foundation of their own detritus and grow far outwards. Fringing-reefs indicate as a general rule that the land to which they are attached has not recently subsided. But they do not tell us whether the land is rising or stationary. Nevertheless, the crust of the earth seems liable to such incessant changes of level that a long-continued stationary condition apparently is rare. We may infer that this is so from the number of cases, within the limits of our map, in which upraised corals or other organic remains have been found on the shores which are fringed with reefs, and are, therefore, coloured red. It may be mentioned as bearing on this subject, that I was much surprised on first reading a memoir on coral formations by MM. Quoy and Gaimard,[1] by finding that their de-

[1] Annales des Sciences Nat. tom. vi. p. 279, &c.

scriptions applied only to reefs of the fringing class, for I knew that they had crossed both the Pacific and Indian Oceans; but my surprise ended in satisfaction, when I discovered that all the islands which they had visited, though several in number—namely, Mauritius, Timor, New Guinea, the Mariana and Sandwich Archipelagoes —could be shown by their own statements to have been elevated within a recent geological period.

I will now enter on some details, showing how many of the islands and coasts which from being fringed with reefs are coloured red on our map, have been recently upraised.

Sandwich Islands.—Several of these islands are fringed with reefs, though Dana found very few corals at Hawaii; and almost every naturalist who has visited them has there observed upraised corals and shells, apparently identical with living species. The Rev. W. Ellis informs me that he noticed round several parts of Hawaii, beds of coral detritus, about twenty feet above the level of the sea, and where the coast is low they extend far inland. Upraised coral-rock forms a considerable part of the borders of Oahu; and at Elizabeth Island [1] it composes three strata, each about ten feet thick. Nihau, which forms the northern, as Hawaii does the southern end of the group (350 miles in length), likewise seems to consist of coral and volcanic rocks. Mr. Couthouy [2] has lately described several upraised beaches and ancient reefs with their surfaces perfectly preserved, as well as beds of recent shells and corals, at the Islands of Maui, Morokai, Oahu, and Tauai (or Kauai), all in this group. Mr. Pierce, an intelligent resident at Oahu, is convinced, from changes which have taken place within his memory during the last sixteen years, 'that the eleva-

[1] Zoology of Captain Beechey's Voyage, p. 176. See also MM. Quoy and Gaimard in Annales des Sciences Nat. tom. vi.

[2] Remarks on Coral Formations, p. 51.

tion is at present going forward at a very perceptible rate.' The natives at Kauai state that the land is there gaining rapidly on the sea; and Mr. Couthouy has no doubt, from the nature of the strata, that this is the result of elevation.

Elizabeth Island, in the southern part of the Low or Paumotu Archipelago, and Metia in the northern part, consist of upraised coral-rock, closely fringed by living reefs.[1] In cases like these, where islands have the appearance which one of the smaller surrounding atolls with a shallow lagoon would present if elevated, we are led to conclude that the elevation has taken place at an epoch not geologically remote; for it is improbable that such small and low fabrics should have resisted for an immense period all the many destroying agents of nature. When the surface of an ordinary island is strewed with marine remains, from the beach to a certain height, and not above that height, it is exceedingly improbable that these remains, although they may not have been specifically examined, should belong to any very ancient period. It is necessary to bear these remarks in mind in considering the evidence of the elevatory movements in the Pacific and Indian Oceans, as it does not often rest on specific determinations, and therefore should be received with caution. Six of the *Cook and Austral Islands* (S.W. of the Society group) are fringed; of these, five were described to me by the Rev. J. Williams, as formed of coral-rock (associated with some basalt in Mangaia), and the sixth as lofty and basaltic. Mangaia is nearly 300 feet high with a level summit; and, according to Mr. S. Wilson,[2] is an upraised reef; 'and there are in the central hollow, formerly the bed of the lagoon, many scattered patches of coral-rock, some of them raised to a height of forty feet.' These knolls of coral-rock

[1] Beechey's Voyage in the Pacific, p. 46, 4to edit. Dana, Corals and Coral Islands, p. 193. Wilkes, U.S. Exploring Expedition, vol. i. p. 337.

[2] Couthouy's Remarks, p. 34.

were evidently once reefs within the lagoon of an atoll. Mr. Martens, at Sydney, informed me that this island is surrounded by a terrace-like plain at about the height of 100 feet, which probably marks a pause in its elevation. From these facts we may infer that the Cook and Austral Islands have been upheaved at a not very remote period.

Savage Island (S.E. of the Friendly group) is according to Forster about 40 feet in height, and according to Williams about 100 feet. Forster [1] describes the plants as *already* growing out of the dead but still upright and spreading trees of coral; and the younger Forster [2] believes that an ancient lagoon is now represented by a central plain: here we cannot doubt that the elevatory forces have recently acted. The same conclusion may be extended to the islands of the *Friendly Group*, which have been well described in the second and third voyages of Cook, and recently by Dana. The surface of Tongatabou is low and level, but with parts 50 or 60 feet high; the whole consists of coral-rock, 'which yet shows the cavities and irregularities worn into it by the action of the tides.' [3] On Eoua the same appearances were noticed at an elevation of between 200 and 300 feet. Vavao, also, at the opposite or northern end of the group, consists, according to the Rev. J. Williams, of coral-rock. Tongatabou, with its northern extensive reefs, resembles either an upraised atoll with one half originally imperfect, or one unequably elevated; and Anamouka, an atoll equably elevated. This latter island contains[4] in its centre a salt-water lake, about a mile and a half in diameter, without any communication with the sea, and around it the land rises gradually like a bank: the highest part is only between twenty and thirty feet; but

[1] Observations made during Voyage Round the World, p. 147.
[2] Voyage, vol. ii. p. 163.
[3] Cook's Third Voyage (4to edit.), vol. i. p. 314.
[4] *Ibid.* vol. i. p. 235.

on this part, as well as on the rest of the land, (which, as Cook observes, rises above the height of a true lagoon-island,) coral-rock like that on the beach was found. In the *Navigator* or *Samoan Archipelago*, Mr. Couthouy[1] found on Manua many large fragments of coral at the height of eighty feet, 'on a steep hill-side, rising half a mile inland from a low sandy plain abounding in marine remains.' The fragments were embedded in a mixture of decomposed lava and sand. It is not stated whether they were accompanied by shells, or whether the corals resembled recent species; as these remains were embedded, they possibly may belong to a remote epoch; but I presume this was not the opinion of Mr. Couthouy. On the other hand, Mr. Dana says expressly in one place, that 'no satisfactory evidences of elevation were detected about these islands;' and in another place he says (p. 326) that some of the islands have probably subsided. Earthquakes are very frequent in this archipelago.

Still proceeding westward we come to the *New Hebrides*. On these islands, Mr. G. Bennett (author of Wanderings in New South Wales) informs me that he found much coral at a great altitude, which he considered of recent origin.[2] The Loyalty Islands are situated west of the New Hebrides, and not far from New Caledonia; and one of these islands has been clearly shown by the Rev. W. B. Clarke (Journal of Geolog. Soc. 1847, p. 61) to consist wholly of coral-rock, and to have been raised within a recent period by at least two distinct elevations to the height of 250 feet. The shores are now fringed by reefs. Respecting *Santa Cruz* and the *Saloman Archipelago*[3] I have no information; but at New Ireland, which forms the northern point of the

[1] Remarks on Coral Formations, p. 50.

[2] [Prof. Moseley, Notes of a Naturalist in the *Challenger*, speaks of indications of elevation to an extent of about 5 feet.]

[3] [See Mr. Guppy's description, Appendix II.]

latter chain, both Labillardière and Lesson have described large beds of an apparently very modern madreporitic rock, with the form of the corals little altered. The latter author [1] states that this formation composes a newer line of coast, modelled round an ancient one. There only remains to be described in the Pacific, that curved line of fringed islands, of which the *Marianas* form the main part. Of these Guam, Rota, Tinian, Saypan, and some islets farther north, are described by Quoy and Gaimard,[2] and Chamisso,[3] as chiefly composed of madreporitic limestone, which attains a considerable elevation, and is in several cases worn into successively rising cliffs: the two former naturalists seem to have compared the corals and shells with the existing ones, and state that they are of recent species. Peel Island, one of the Bonin or Arzobispo group, between the Marianas and Japan, has fringing-reefs; and it has clearly been upraised to a height of at least 50 feet, as shown by the ridges of corals and shells extending uniformly at this level.[4] *Fais*, which lies in the prolonged line of the Marianas, between this group and the Pellews, is fringed by reefs; it is 90 feet high, and consists entirely of madreporitic rock.[5]

In the *East Indian Archipelago*, many authors have recorded proofs of recent elevation. M. Lesson[6] states that near Port Dory, on the north coast of New Guinea, the shores are flanked, to the height of 150 feet, by madreporitic strata of a modern date. He mentions similar formations at Waigiou, Amboina, Bourou, Ceram, Sonda, and Timor: at this latter place, MM. Quoy and Gaimard[7] have

[1] Voyage de la *Coquille*, Part. Zoolog.

[2] Freycinet's Voyage autour du Monde. See also the Hydrographical Memoir, p. 215.

[3] Kotzebue's First Voyage.

[4] P. W. Graves, Journal of Geological Soc. 1855, p. 532.

[5] Lutké's Voyage, vol. ii. p. 304.

[6] Partie Zoolog. Voyage de la *Coquille*.

[7] Ann. des Scien. Nat., tom. vi. p. 281.

likewise described the primitive rocks, as coated to a considerable height with coral. Some small islets eastward of Timor are said in Kolff's Voyage [1] to resemble small coral islets upraised some feet above the sea. Dr. Malcolmson informs me that Dr. Hardie found in *Java* an extensive formation, containing an abundance of shells, of which the greater part appear to be of existing species. Dr. Jack [2] has described some upraised shells and corals, apparently recent, on Pulo Nias off *Sumatra*; and Marsden relates in his history of this great island, that the names of many promontories show that they were originally islands. On part of the west coast of *Borneo* and at the *Sooloo Islands*, the form of the land, the nature of the soil, and the water-washed rocks, present appearances [3] (although it is doubtful whether such vague evidence is worthy of mention) of having recently been covered by the sea; and the inhabitants of the Sooloo Islands believe that this has been the case. Mr. Cuming, who has lately investigated with so much success the mollusca of the *Phillippines*, found near Cabagan, in Luzon, about 50 feet above the level of the R. Cagayan and 70 miles from its mouth, a large bed of fossil shells: these, as he informs me, are certainly of the same species with those now existing on the shores of the neighbouring islands. From the accounts given by Captain

[1] Translated by Windsor Earl, chaps. vi. and vii.

[2] Geolog. Transact. 2nd series, vol. i. p. 403. On the Peninsula of Malacca, in front of Penang, 5° 30′ N., Dr. Ward collected some shells which Dr. Malcolmson informs me, although not compared with existing species, had a recent appearance. Dr. Ward describes in this neighbourhood (Trans. Asiat. Soc. vol. xviii., part 2, p. 166) a single water-worn rock, with a conglomerate of sea-shells at its base, situated six miles inland, which, according to the traditions of the natives, was once surrounded by the sea. Captain Low has also described (*ibid.* Part i. p. 131) mounds of shells lying two miles inland on this line of coast.

[3] Notices of the East Indian Arch., Singapore, 1828, p. 6, and Append. p. 43.

Basil Hall and Captain Beechey[1] of the lines of inland reefs, and walls of coral rock worn into caves, above the present reach of the waves, at the *Loo Choo* Islands, there can be little doubt that they have been upraised at no very remote period.

Dr. Davy[2] describes the northern province of *Ceylon* as being very low, and composed of a limestone with shells and corals of very recent origin; he adds, that it does not admit of a doubt that the sea has retired from this district even within the memory of man. There is also some reason for believing that the eastern shores of India, north of Ceylon, have been upraised within the recent period.[3] On the opposite side of the Gulf of Bengal, Captain Halstead everywhere found during his survey of the Burmese coast (as he informed Sir C. Lyell), proofs of recent elevation in upraised beaches and beds of shells and corals. In the Indian Ocean *Mauritius* has been recently upraised, as I have shown in the chapter on fringing-reefs. The northern extremity of *Madagascar* is described by Captain Owen[4] as formed of madreporitic rock, as likewise are the

[1] Captain B. Hall, Voyage to Loo Choo, Append. pp. xxi. and xxv. Captain Beechey's Voyage, p. 496.

[2] Travels in Ceylon, p. 13. This madreporitic formation is mentioned by M. Cordier in his report to the Institute (May 4, 1839) on the voyage of the *Chevrette*, as one of immense extent, and belonging to the latest tertiary period.

[3] Dr. Benza, in his Journey through the N. Circars (the Madras Lit. and Scient. Journal, vol. v.), has described a formation with recent freshwater and marine shells, occurring at the distance of three or four miles from the present shore. Dr. Benza, in conversation with me, attributed their position to a rise of the land. Dr. Malcolmson, however, (and there cannot be a higher authority on the geology of India,) informs me that he suspects that these beds may have been formed by the mere action of the waves and currents accumulating sediment. From analogy I should much incline to Dr. Benza's opinion.

[4] Owen's Africa, vol. ii. p. 37, for Madagascar; and for S. Africa, vol. i. pp. 412 and 426. Lieut. Boteler's narrative contains fuller

shores and outlying islands along an immense space of *Eastern Africa*, from a little north of the equator for 900 miles southward. Nothing can be more vague than the expression 'madreporitic rock;' but at the same time it is, I think, scarcely possible to look at the chart of the linear islets running in front of the coast from the equator far southward, and rising to a greater height than can be accounted for by the growth of coral, without feeling convinced that a line of fringing-reefs has been elevated at a period so recent, that no great changes have since taken place on the surface of this part of the globe. Some, also, of the higher islands of madreporitic rock on this coast, for instance Pemba, are singularly shaped, apparently showing the combined effect of the growth of coral on submerged banks, together with their subsequent upheaval. Dr. Allan informs me that he never observed any elevated organic remains on the *Seychelles*, which come under our fringed class.

The nature of the formations round the shores of the *Red Sea*, as described by several authors, proves that the whole of this large area has been elevated within a very recent tertiary epoch. A part of this space in the appended map is coloured blue, indicating the presence of barrier-reefs; on which circumstance I shall presently make some remarks. Rüppell[1] states that the tertiary formation, of which he has examined the organic remains, forms a fringe along the shores with a uniform height of from 30 to 40 feet, from the mouth of the Gulf of Suez to about lat. 26°; but that south of 26°, the beds attain only the height of from 12 to 15 feet. This, however, can hardly be quite accurate; although possibly there may be

particulars regarding the coral rock, vol. i. p. 174, and vol. ii. pp. 41 and 54. See also Ruschenberger's Voyage round the World, vol. i. p. 60.

[1] Rüppell, Reise in Abyssinien, Band i. s. 141.

a decrease in the elevation of the shores in the middle parts of the Red Sea, for Dr. Malcolmson informs me that he collected shells and corals, apparently recent, from the cliffs of Camaran Island (lat. 15° 30′ N.) at a height of between 30 and 40 feet; and Mr. Salt (Travels in Abyssinia) describes a similar formation a little southward on the opposite shore at Amphila. Moreover, near the mouth of the Gulf of Suez, although on the coast opposite to that on which Dr. Rüppell says that the modern beds attain a height of only 30 to 40 feet, Mr. Burton[1] found a deposit replete with existing species of shells, at the height of 200 feet. In an admirable series of drawings by Captain Moresby, I could see how continuously the cliff-bounded, low, tertiary plains extended with a nearly equable height, both on the eastern and western shores. The southern coast of Arabia seems to have been subjected to the same elevatory movement, for Dr. Malcolmson found at Sahar low cliffs containing shells and corals apparently of recent species.

The *Persian Gulf* abounds with coral-reefs; but as in this shallow sea it is difficult to distinguish reefs from sandbanks, I have coloured only some near the mouth. Towards the head of the gulf Mr. Ainsworth[2] says that the land is worn into terraces, and that the strata contain organic remains of existing forms.

The *West Indian Archipelago* of 'fringed islands' alone remains to be mentioned: evidence of an elevation within a late tertiary epoch of nearly the whole of this great area, may be found in the works of almost all the geologists who have visited it. I will give some of the principal references in a note.[3]

[1] Lyell's Principles of Geology, 5th edition, vol. iv. p. 25.

[2] Ainsworth's Assyria and Babylon, p. 217.

[3] These references only relate to works published before 1842, the date of the first edition of this book. On Florida and the north shores of the Gulf of Mexico, Rogers' Report to Brit. Assoc. vol. iii.

On reviewing the above details it is impossible not to be struck with the number of cases in which upraised organic remains, apparently belonging to the recent period, have been found on the shores now fringed by reefs, and which are coloured red on our map. It may, however, be thought that similar proofs of elevation could be found on the coasts coloured blue, and which we have good reason to believe have recently subsided; but such proofs cannot be found, with the few following and doubtful exceptions.

The entire area of the Red Sea appears to have been upraised within a late tertiary period; nevertheless I have been compelled, though on unsatisfactory evidence (given in the Appendix), to class the reefs in the middle part of the coast, not as fringing, but as barrier-reefs. If, however, the statements should prove accurate respecting the less height of the tertiary beds in the middle, compared with the northern and southern districts, we might well suspect that the former had subsided subsequently to a general elevation by which the whole area had previously been upraised. Several authors [1] have observed shells and corals high up on the

p. 14.—On the shores of Mexico, Humboldt, Polit. Essay on New Spain, vol. i. p. 62. (I have also some corroborative facts with respect to the shores of Mexico.)—Honduras and the Antilles, Lyell's Principles, 5th ed. vol. iv. p. 22.—Santa Cruz and Barbadoes, Prof. Hovey, Silliman's Journ. vol. xxxv. p. 74.—St. Domingo, Courrojolles Jour. de Phys. tom. liv. p. 106.—Bahamas United Service Journ. No. lxxi. pp. 218 and 224.—Jamaica, De la Beche, Geol. Man. p. 142.—Cuba, Taylor in Lond. and Edin. Phil. Mag. vol. xi. p. 17. Dr. Daubeney also at a meeting of the Geolog. Soc. orally described some very modern beds lying on the N.W. parts of Cuba. I might have added many other less important references. [See Appendix II.]

[1] Ellis, in his Polynesian Researches, was the first to call atten-

mountains of the Society Islands,—a group of islands encircled by barrier-reefs, and which, therefore, must have recently subsided. Thus at Tahiti, Mr. Stutchbury found on the summit of one of the highest mountains, between 5,000 and 7,000 feet above the level of the sea, 'a distinct and regular stratum of semi-fossil coral;' but we cannot infer from such evidence as this that the island has been elevated within the recent period; and on the other hand, several naturalists, including Mr. Dana and myself, have in vain searched near the coast for upraised shells and corals, where if present they could not have been overlooked.[1] Two of the Harvey

tion to these remains (vol. i. p. 38) and the tradition of the natives concerning them. See also Williams, Nar. of Miss. Enterprise, p. 21; also Tyerman and G. Bennett, Journ. of Voyage, vol. i. p. 213; also Mr. Couthouy's Remarks, p. 51; but his principal fact, namely, that there is a mass of upraised coral on the narrow peninsula of Tiarubu, is from hearsay evidence; also Mr. Stutchbury, West of England Journ. No. 1, p. 54. There is a passage in Von Zach, Corres. Astronom. vol. x. p. 266, inferring an uprising at Tahiti, from a footpath now used, which was formerly impassable; but I particularly enquired from several native chiefs, whether they knew of any change of this kind, and they were unanimous in giving me an answer in the negative.

[1] [Some of the mountains rise to 7,000 feet. A depth of 25 to 35 fathoms, which is the limit of the growing corals, is reached at from 100 to 150 fathoms from the edge of the reef. The slope then steepens rapidly to 160 and 180 fathoms, which depth is reached at a distance of 225 to 250 fathoms from the edge of the reef; to 100 fathoms the slope is about 45°, thence to about 200 it is about 30°, and then it eases off. From 35 to 150 fathoms sponges, alcyonarians, corals, and other invertebrates were obtained; beyond the latter, coral-sand with volcanic minerals and pelagic shells. Inside the lagoons the reefs were fringed with living corals, sloped downwards and outwards for a few feet, then plunged at once to depths of 10 and 16 fathoms. The deposit in the lagoons was in some places a coral-sand, in others a volcanic mud. There is evidence of some amount of upheaval.

Islands, namely, Aitutaki and Manouai, are formed of upraised coral rocks, and have probably been elevated within a recent period; nevertheless they are encircled by reefs extending so far from the land, that I have coloured them blue, though with much hesitation, as the space within the reef is shallow, and the encircled land is not abrupt. If these reefs really belong to the barrier class, we have here another instance of subsidence having followed elevation, both movements having been effected apparently within the recent period. There are also many cases of coral-formations, such as Elizabeth Island, Metia, Mangaia, several of the Friendly and one of the Loyalty Islands, which it can hardly be doubted once existed as atolls, and were originally formed during subsidence, but have since been elevated, and are now surrounded by fringing-reefs. We have, however, no reason to feel surprise at occasional or even frequent alternations of level of the above two kinds.

On the absence of active Volcanos in the areas of subsidence, and on their frequent presence in the areas of elevation.[1]—The absence of active volcanos throughout the great areas of subsidence on our map, as shown by the pale and dark blue tints,—namely, in the central parts of the Indian Ocean, in the China

Mr. Murray (p. 781) regards this reef as favouring his theory. Narrative of *Challenger* Voyage, p. 778.]

[1] It may be well here to state that all the reefs on the map were coloured either red or blue before the vermilion spots and streaks, showing the position of the active volcanos and volcanic chains, were added; and indeed before I knew of the existence of several of them.

Sea, in the sea between the barriers of Australia and New Caledonia, in the Caroline, Marshall, Gilbert, and Low Archipelagoes,—is a very striking fact. So is the presence of active volcanic vents and chains on or near many of the shores coloured red on our map, and which are fringed with reefs; for, as we have just seen, these fringed coasts have been recently upheaved in a large number of cases. Active volcanos likewise coincide with proofs of recent elevation on or near several other long lines of coast within the limits of our map, where there are no reefs of living corals, and which consequently are not coloured red. It must be here remarked, with regard to the proofs of both subsidence and elevation, that I do not judge by the absence or presence or nature of the coral-reefs round the volcanos themselves; for, as Dana repeatedly insists, the corals may have been there destroyed or injured by the heat or exhalations. Nor have I taken into account the presence of upraised organic remains on the flanks of the volcanos themselves. I judge from the position of the active volcanic vents in relation to neighbouring islands and coasts, situated at too great a distance for any corals growing there to be injured by the eruptions; and where, from the presence of atoll-formed or barrier-reefs, or of upraised marine remains, we have reason to believe that either subsidence or elevation has occurred within a recent period.

The following cases offer a few partial exceptions to the rule that active volcanos are situated at a distance from the areas of subsidence. The Great Comoro

Island probably contains a volcano, and it is only twenty miles distant from the barrier-reef of Mohilla. Ambil volcano, in the Phillippine Archipelago, is distant only a little more than sixty miles from the atoll-formed Appoo reef: and there are two other volcanos on the map within ninety miles of circles coloured blue. But there is not a single active volcano within several hundred miles of a group, even a small group, of atolls; and it is clear that a group of atolls, surmounting a number of islands now all sunk beneath the level of the sea, implies a much greater amount of subsidence, than does a single atoll or a single encircling barrier-reef. It is a striking fact that two volcanos are known to have been in recent action in the Friendly Archipelago; and the islands have here been formed by the recent elevation of a group of atolls. Again, extinct craters and well-preserved streams of lava occur on many of the encircled islands in the Pacific, and these by our theory have subsided at no very remote period; but although thus plainly formed of volcanic matter, they do not offer a single active volcano. In these cases the volcanos seem to have come into action or to have been extinguished, in accordance with the latest movements of elevation or subsidence.

Within the limits of our map, active volcanos occur on or near other coasts besides those which are fringed with reefs and coloured red; and some of these coasts are known to have been upraised within the recent period. Thus I have shown in my Geological Observations on S. America (1846) that the whole western shore of this great continent, for a space of between 2,000 and 3,000 miles south of the equator, has undergone an upward movement during the period of existing marine shells; and the Andes here form the grandest volcanic chain in the world. The islands on the north-western side of the Pacific, forming the second grandest volcanic chain, are very imperfectly known; but Luzon, in the Phillippines, and the Loo Choo islands, have been recently elevated; and at Kamtschatka [1] there are extensive tertiary beds of modern date. The co-existence in other parts of the world, of active volcanos with upraised beds of a modern origin, will occur to every geologist. Nevertheless, until it could be shown that volcanos were absent or inactive in subsiding areas, the conclusion that their distribution depended on the nature of the subterranean movements in progress, would have been hazardous. But now, viewing the appended map, it may, I think, be considered as almost established, that volcanos are often present in the areas which have lately risen or are still rising, and are invariably absent in those which have lately subsided or are still subsiding; and this, I think, is the most important generalisation to which the study of coral-reefs has indirectly led me.[2]

On the dimensions and relative positions of the

[1] Namely, at Sedanka, in lat. 58° N. (Von Buch's Descript. des Isles Canaries, p. 455).

[2] We may infer from this rule, that at any place where an old formation contains interstratified beds of erupted matter, the surface of the land or the bed of the sea formed, at the period of eruption, a rising, at least not a subsiding area.

subsiding areas on our map, as indicated by the presence of atolls and barrier-reefs; and of the rising or stationary areas, as known by upraised organic remains, or inferred from the presence of fringing-reefs.—The immense surfaces seen on the map, which according to our theory, or from the plain evidence of upraised remains, have undergone either a downward or upward change of level within a geologically late period, is a highly remarkable fact. The existence of continents shows that the areas which have been upraised are immense. With respect to South America we may feel sure, and with respect to the western shores of the Indian Ocean we have reason to suspect, that this rising is either now actually in progress, or has taken place quite recently. By our theory, it may safely be inferred that the areas which have lately subsided are likewise immense; or, judging from the earthquakes now occasionally felt there, and from other appearances, are still subsiding. The smallness of the scale of our map should not be overlooked; each square on it containing 810,000 square miles. If we take the space of ocean from near the southern end of the Low Archipelago to the northern end of the Marshall Archipelago,—a length of 4,500 miles, we see that, as far as known, every island, excepting Metia, is atoll-formed. The eastern and western boundaries of our map are continents, and they are rising: the central areas of the great Indian and Pacific Oceans, are mostly subsiding; between them, north of Australia, lies the most broken land on the globe, and there the rising parts are surrounded and penetrated by areas of subsidence;[1] so that the prevailing movements now in progress, seem to accord with the present state of the great terrestrial and oceanic divisions of the world.

The blue spaces on the map are nearly all elongated; such as the great north and south line of atolls in the Indian Ocean, the space between the barrier-reefs of Australia and New Caledonia, the Caroline Archipelago, &c. Whether adjoining elongated spaces, running in different directions, have subsided by one common movement, or independently of each other, we do not know. In the case of the Caroline and Marshall Archipelagoes, situated near each other, but extending in different directions, it seems probable that they have subsided independently of each other; for the McAskill Islands,[2] lying towards the eastern end of the Caroline Archipelago, are formed of upraised coral-rock; and we thus see that the above two areas of subsidence have been at one time interrupted by an area of upheaval. The curved line of elevation formed by the Mariana Islands, seems to cross a former line of subsidence prolonged from the Caroline Archipelago; for the island of Fais, apparently an upraised atoll, is situated nearly at the point of intersection of the two lines. The Sandwich Archipelago is 530 miles in length, from Hawaii to the westernmost rocky islet, but is pro-

[1] I suspect that the Arru and Timor-laut Islands present an included small area of subsidence, like that of the China Sea; but I have not ventured to colour them blue, owing to the want of sufficient information. See Appendix.

[2] Dana, Corals and Coral Islands, p. 306.

longed by numerous reefs to a point 2,000 miles distant from Hawaii. The south-eastern end of this long line is one of elevation and of volcanic activity; whereas the north-western end, judging from the structure of the reefs, though these are imperfectly known, is one of subsidence.[1] So that here we apparently have opposite movements in progress towards the two extremities of the same long line. The commonest case seems to be a tendency to alternation between the areas of subsidence and elevation, as if the sinking of one had counterbalanced the rising of another.

The existence in many parts of the world of lofty table-land, proves that large surfaces have been upraised in mass to a great height above the level of the sea; although in almost every country the highest points consist of upturned strata, or of erupted matter: and from the wide spaces over which atolls are scattered, although not one pinnacle of land now remains above the level of the sea, we may conclude that immense areas have subsided to an amount sufficient to bury not only any formerly existing lofty table-land, but even the heights formed by fractured strata and erupted matter. The effects left on the land by the later elevatory movements, namely, successively rising cliffs, successive lines of erosion, and great beds of shells and pebbles, all requiring time for their production, prove that these movements have been extremely slow. And

[1] Dana, Corals and Coral Islands, pp. 307, 355. See also my Appendix.

with respect to the whole amount of subsidence necessary to have produced the many atolls widely scattered over immense spaces, the movement, as already shown, must either have been uniform and exceedingly slow, or effected by small steps separated from each other by long intervals of time, so as to have allowed the reef-constructing polypifers to bring up their solid frameworks to the surface; and this is one of the most interesting conclusions to which we are led by the study of coral-formations. We have little means of judging whether many considerable oscillations of level have usually occurred during the elevation of large areas; but we know from clear geological evidence, such as trees still standing upright at successive levels and covered by marine strata, that this has frequently been the case; and we have seen on our map, that some of the same islands after having subsided, have been upraised; and that others after having been uplifted, have subsided. We may therefore conclude that the subterranean changes which cause some areas to rise and others to sink, have generally acted in a closely similar manner.

Recapitulation.—In the three first chapters, the principal kinds of coral-reefs were described in detail, and they were found to differ little, as far as relates to the actual surface of the reef. An atoll differs from an encircling barrier-reef only in the absence of land within its central expanse; and a barrier-reef differs from a fringing-reef only in being placed, relatively to the probable inclination of its submarine foundation, at a much greater distance from the land, and in the presence of a deep lagoon-like space within the reef. In the fourth chapter the growing powers of the reef-constructing polypifers were discussed; and it was shown that they cannot flourish beneath a very limited depth. In accordance with this limit, there is no difficulty respecting the foundation on which a fringing-reef is based; whereas, with barrier-reefs and atolls, there is the greatest difficulty on this head;—in barrier-reefs from the improbability of rock or banks of sediment having extended, in every instance, so far seaward within the required depth;—and in atolls, from the immensity of the spaces over which they are interspersed, and the apparent necessity for believing that they are all based on mountain-summits, which, although rising very near to the surface of the sea, in no one instance rise above it. To escape this latter admission, which implies the existence of submarine chains of mountains of almost exactly the same height extending over many thousand square miles, there is but one alternative; namely, the prolonged subsidence of the foundations on which the atolls first became attached, together with the upward growth of the reef-constructing corals. On this view every difficulty vanishes: fringing-reefs are thus easily converted into barrier-reefs; and barrier-reefs into atolls, as soon as the last pinnacle of land sinks beneath the surface of the sea.

The wall-like structure on the inner sides of atolls and barrier-reefs—the basin or ring-like shape of the marginal and central reefs in the Maldiva atolls—the union of some atolls as if by a ribbon—the apparent disseverment of others—the ordinary outline of groups of atolls and their forms—are all thus explained. We thus understand the occurrence in both atolls and barrier-reefs of portions, or of the whole, in a dead and submerged condition, though still retaining the outline of a living reef. The existence of breaches through barrier-reefs in front of valleys, though separated from them by wide spaces of deep water, can be similarly explained. It confirms our theory that we find the two kinds of reefs formed through subsidence generally situated near each other and at a distance from the spaces where fringing-reefs abound. On searching for other evidence of the movements assumed by the theory, we find marks of change in atolls and in barrier-reefs, and of subterranean disturbances beneath them; but from the nature of things, it is scarcely possible to find direct proofs of subsidence, although some appearances are strongly in favour of it. On the fringed coasts, however, the frequent presence of upraised marine remains belonging to a recent epoch, plainly shows that these coasts have been lately elevated.

Finally, when the two great types of structure, namely barrier-reefs and atolls on the one hand, and fringing-reefs on the other, are laid down on a map, they offer a grand and harmonious picture of the movements which the crust of the earth has undergone within a late period. We there see vast areas rising, with volcanic matter every now and then bursting forth. We see other wide spaces sinking without any volcanic outbursts; and we may feel sure that the movement has been so slow as to have allowed the corals to grow up to the surface, and so widely extended as to have buried over the broad face of the ocean every one of those mountains, above which the atolls now stand like monuments, marking the place of their burial.

APPENDIX.

APPENDIX [I.]

CONTAINING

A DETAILED DESCRIPTION OF THE REEFS AND ISLANDS IN THE COLOURED MAP, PLATE III.

In the beginning of the last chapter I stated the principles on which the map has been coloured. There only remains to be said, that it is an exact copy of one by M. C. Gressier, published by the Dépôt Général de la Marine, in 1835. The names have been altered into English, and the longitude has been reduced to that of Greenwich. The colours were first laid down on accurate charts, on a large scale. The data, on which the volcanos historically known to have been in action, have been marked with vermilion, were given in a note to the last chapter. I will commence my description on the eastern side of the map, and will describe each group of islands consecutively, proceeding westward across the Pacific and Indian Oceans, and ending with the West Indies.

The WESTERN SHORES OF AMERICA appear to be entirely without coral-reefs: south of the equator the survey of the *Beagle*, and north of it the published charts show that this is the case. Even in the Bay of *Panama*, where corals flourish, there are no true coral-reefs, as I have been informed by Mr. Lloyd. There are no coral-reefs in the *Galapagos* archipelago, as I know from personal inspection; and I believe there are none on the *Cocos*, *Revilla-gigedo*, and other neighbouring islands. *Clipperton*[1] rock, 10° N.,

[1] [Undoubtedly an atoll, according to Sir J. Belcher's chart.—Captain Wharton.]

109° W., from a drawing appended to a MS. plan in the Admiralty, does not appear to be an atoll, but Sir E. Belcher (Voyage round the World, vol. i. 1843, p. 255) speaks of it as of coral-formation, with deep water within the lagoon; left uncoloured. The eastern part of the Pacific presents an enormous area without any islands, except *Easter* and *Gomez*, which do not appear to be surrounded by reefs.

THE LOW OR PAUMOTU ARCHIPELAGO.—This group consists of about 80 atolls: it would be quite superfluous to refer to descriptions of each. In D'Urville and Lottin's chart, one island (*Wolchonsky*) is written with a capital letter, signifying, as explained in a former chapter, that it is a high island; but this must be a mistake, as the orginal chart by Bellingshausen shows that it is a true atoll. Captain Beechey says of the 32 groups which he examined (of the greater number of which I have seen beautiful MS. charts in the Admiralty), that 29 now contain lagoons, and he believes the other three orginally did so. Bellingshausen (see an account of this Russian voyage, in the Biblioth. des Voyages, 1834, p. 443) says that the 17 islands which he discovered resembled each other in structure, and he has given charts on a large scale of all of them. Kotzebue has given plans of several; Cook and Bligh mention others; a few were seen during the voyage of the *Beagle*; and notices of other atolls are scattered through several publications. The *Actæon* group in this archipelago has lately been discovered (Geograph. Journ., vol. vii. p. 454); it consists of three small and low islets, one of which has a lagoon. Another lagoon-island has been discovered (Naut. Mag. 1839, p. 770) in 22° 4′ S. and 136° 20′ W. Dana, in his work on Corals and Coral Islands, gives a full account of this archipelago. Towards the S.E. there are some islands of a different nature: *Elizabeth* Island is described by Beechey (p. 46, 4to edit.) as fringed by reefs, at the distance of between two and three hundred yards; coloured red. *Pitcairn* Island, in the immediate neighbourhood, according to the same authority, has no reefs of any kind, although numerous pieces of coral are thrown up on the beach; the sea close to its shore is very deep (see Zool. of Beechey's Voyage, p. 164); left uncoloured. *Gambier* Islands (see Plate I. fig. 8) are encircled by a barrier-reef; the greatest depth within is 38 fathoms; coloured pale blue. *Metia* or *Aurora* Island lies N.E. of Tahiti, close to the large space coloured dark blue in the map; it has been already described as an upraised atoll; as it is said by Captain Wilkes (Narrative of U.S. Exploring Expedition, vol. i. p. 337) to be surrounded by fringing-reefs, in one part 500 feet in width, it has been coloured red. But I must remind the reader of the discussion in the sixth chapter, showing that if an upraised atoll were to subside again, the reef would probably retain for a long time or for ever, its fringing character, owing to the steepness of the submarine flanks.

The Society Archipelago is separated by a narrow space from the Low Archipelago; and in their parallel direction they manifest some relation to each other. I have already described the general character of the reefs of these encircled islands. In the atlas of the *Coquille's* Voyage there is a good general chart of the group, and separate plans of some of the islands. *Tahiti*, the largest island in the group, is almost surrounded, as seen in Cook's chart, by a reef from half a mile to a mile and a half from the shore, with from 10 to 30 fathoms within it. Some considerable submerged reefs, lying parallel to the shore, with a broad and deep space within, have lately been discovered on the N.E. coast of the island, (Naut. Mag. 1836, p. 264,) where none are laid down by Cook. At *Eimeo* the reef, 'which like a ring surrounds it, is in some places one or two miles distant from the shore, in others united to the beach' (Ellis, Polynesian Researches, vol. i. p. 18, 12mo.

edit.). Cook found deep water (20 fathoms) in some of the harbours within the reef. Mr. Couthouy, however, states (Remarks, p. 45) that both at Tahiti and Eimeo, the space between the barrier-reef and the shore has been almost filled up,—'a nearly continuous fringing-reef surrounding the island, and varying from a few yards to rather more than a mile in width, the lagoons merely forming canals between this and the sea-reef,' that is the barrier-reef. *Tapamanoa* is surrounded by a reef at a considerable distance from the shore; from the island being small, it is breached, as I am informed by the Rev. W. Ellis, only by a narrow and crooked boat-channel. This is the lowest island in the group, its height probably not exceeding 500 feet. A little way north of Tahiti, the low coral islets of *Teturoa* are situated; from the description of them given me by the Rev. J. Williams (the author of the Narrative of Missionary Enterprise), I should have thought that they formed a small atoll, and likewise from the description given by the Rev. D. Tyerman and G. Bennett (Journ. of Voy. and Travels, vol. i. p. 183), who say that ten low coral islets 'are comprehended within one general reef, and separated from each other by interjacent lagoons;' but as Mr. Stutchbury (West of England Journal, vol. i. p. 54) describes it as consisting of a mere narrow ridge, I have left it uncoloured. *Maitea*, eastward of the group, is classed by Forster as a high encircled island; but from the account given by the Rev. D. Tyerman and G. Bennett (vol. i. p. 57) it appears to be an exceedingly abrupt cone rising from the sea without any reef; left uncoloured. It would be superfluous to describe the northern islands in this group, as they may be well seen in the chart accompanying the 4to. edition of Cook's Voyages, and in the atlas of the *Coquille's* Voyage. *Maurua* is the only one of the northern islands in which the water within the reef is not deep, being only 4½ fathoms; but the great width of the reef, stretching three miles and a half southward of the land (which is represented in the drawing in the atlas of the *Coquille's* Voyage as descending abruptly to the water), shows, on the principle explained in the beginning of the last chapter, that it belongs to the barrier class. I may here mention, from information communicated to me by the Rev. W. Ellis, that on the N.E. side of *Huaheine* there is a bank of sand, about a quarter of a mile wide, extending parallel to the shore, and separated from it by an extensive and deep lagoon: this bank of sand rests on coral-rock, which undoubtedly was once a living reef. North of Bolabola lies the atoll of *Toubai* (Motou-iti of the *Coquille's* atlas), which is coloured dark blue; all the islands which are surrounded by barrier-reefs are coloured pale blue: three of them are represented in figures 3, 4, and 5, in Plate I. There are three low coral-groups lying a little W. of the Society Archipelago, and almost forming part of it, namely, *Bellingshausen*, which is said by Kotzebue (Second Voyage, vol. ii. p. 255) to be a lagoon-island; *Mopeha*, which from Cook's description (Second Voyage, book iii. chap. i.) no doubt is an atoll; and the *Scilly* Islands, which are said by Wallis (Voyage, chap. ix.) to form a *group* of *low* islets and shoals, and which, therefore, probably compose an atoll: the two former have been coloured blue, but not the latter.

Mendana or Marquesas Group.—These islands are almost entirely destitute of reefs, as may be seen in Krusenstern's Atlas, making a remarkable contrast with the adjacent group of the Society Islands. Mr. F. D. Bennett has given some account of this group, in the seventh volume of the Geograph. Journ. He informs me that all the islands have the same general character, and that the water is very deep close to their shores. He visited three of them, namely, *Dominicana*, *Christiana*, and *Roapoa*, their beaches are strewed with rounded masses of coral, and although no regular reefs exist, yet the shore is in many places lined by coral rock, so that a boat grounds on this formation. Hence these islands ought perhaps to come within the class of fringed islands and be coloured red; but as I am determined to err on the cautious side, I have left them uncoloured. Dana infers (Corals and Coral Islands, p. 325), from their steepness and deeply indented outline, that they have subsided.

COOK OR HARVEY AND AUSTRAL ISLANDS.—*Palmerston* Island is minutely described as an atoll by Captain Cook during his voyage in 1774; it is coloured blue. *Aitutaki* was partially surveyed by the *Beagle* (see map accompanying Voyages of *Adventure* and *Beagle*); the land is hilly, sloping gently to the beach; the highest point is 360 feet; on the southern side, the reef projects five miles from the land: off this point the *Beagle* found no bottom with 270 fathoms: the reef is surmounted by many low coral-islets. I am informed by the Rev. J. Williams, that within the reef the water is exceedingly shallow, not being more than a few feet deep; nevertheless, from the great extension of the reef into a profoundly deep ocean, this island probably belongs, on the principle lately adverted to, to the barrier class, and I have coloured it pale blue, although with much hesitation.—*Manouai* or *Harvey* Island: the highest point is about 50 feet: the Rev. J. Williams informs me that although the reef lies far from the shore, it is less distant than at Aitutaki, but the water within the reef is rather deeper: I have likewise coloured this island pale blue, but with many doubts.—Round *Mitiaro* Island, as I am informed by Mr. Williams, the reef is attached to the shore; coloured red.—*Mauki*, or Maouti: the reef round this island (under the name of Parry Island in the Voyage of H.M.S. *Blonde*, p. 209) is described as a coral flat, only 50 yards wide, and two feet under water. This statement has been corroborated by Mr. Williams, who calls the reef attached; coloured red.—*Atiu*, or Wateeo: a moderately elevated, hilly island, like the others of the group; the reef is described in Cook's Voyage as attached to the shore, and about 100 yards wide; coloured red.—*Fenoua-iti*: Cook describes this island as very low, not more than six or seven feet in height (vol. i. book ii. chap. iii. 1777); in the chart published in the *Coquille's* atlas, a reef is engraved close to the shore: this island is not mentioned in the list given by Mr. Williams (p. 16) in the Narrative of Missionary Enterprise; nature doubtful; but as it lies so near Atiu, it has been unavoidably coloured red.—*Rarotonga*: Mr. Williams informs me that this is a lofty basaltic island, with an attached reef; coloured red.—There are three other islands, *Rourouti, Roxburgh*, and *Hull*, of which I have not been able to obtain any account, and have left them uncoloured. *Hull* Island, in the French chart, is written with small letters as being low.—*Mangaia*: height about 300 feet; 'the surrounding reef joins the shore' (Williams's Narrative, p. 18); coloured red.—*Rimetara*: Mr. Williams informs me that the reef is rather close to the shore; but, from information given me by Mr. Ellis, the reef does not appear to be quite so closely attached to it as in the foregoing cases: the island is about 300 feet high (Naut. Mag. 1839, p. 738); coloured red.—*Rurutu*: Mr. Williams and Mr. Ellis inform me that this island has an attached reef; coloured red. It is described by Cook under the name of Oheteroa: he says it is not surrounded like the neighbouring islands, by a reef; but he must mean a distant reef.—*Toubouai*: in Cook's chart (Second Voyage, vol. ii. p. 2) the reef is laid down in a part at the distance of one mile, and in another part at the distance of two miles from the shore; Mr. Ellis (Polynes. Res. vol. iii. p. 381) says the low land round the base of the island is very extensive; and this gentleman informs me that the water within the reef appears deep; coloured blue.—*Raivaivai*, or Vivitao: Mr. Williams informs me that the reef is here distant from the shore; Mr. Ellis, however, says that this is certainly not the case on one side of the island; and he believes that the water within the reef is not deep; hence I have left it uncoloured.—*Lancaster* Reef, described in Naut. Mag. 1833 (p. 693), as an extensive crescent-formed coral-reef, has not been coloured.—*Rapa*, or Oparree: from the accounts given of it by Ellis and Vancouver, there does not appear to be any reef.—*I. de Bass* is an adjoining island, of which I cannot find any account.—*Kemin* Island: Krusenstern seems hardly to know its position, and gives no further particulars.

ISLANDS BETWEEN *the Low and Gilbert Archipelagoes.*

Caroline Island (10° S., 150° W.) is described by Mr. F. D. Bennett (Geograph. Journ. vol. vii. p. 225) as containing a fine lagoon; coloured blue. Westward of Caroline Island, a small lagoon-island is described in the U.S. Exploring Expedition in lat. 10° S. and 152° 22′ W. long.; coloured blue.—*Flint* Island (11° S., 151° W.): Krusenstern believes that it is the same with *Peregrino*, which is described by Quiros (Burney's Chron. Hist. vol. ii. p. 283) as 'a cluster of small islands connected by a reef, and forming a lagoon in the middle;' coloured blue.—*Wostock* is an island a little more than half a mile in diameter, and apparently quite flat and low, discovered by Bellingshausen; it is situated a little west of Caroline Island, but it is not placed on the French charts; I have not coloured it, although I entertain little doubt, from the chart of Bellingshausen, that it originally contained a small lagoon.—*Penrhyn* Island (9° S., 158° W.): a plan in the atlas of the First Voyage of Kotzebue, shows that it is an atoll, which according to Wilkes (U.S. Exploring Expedition, vol. iv. p. 277) is nine miles in length; coloured blue.—*Starbuck*

Island (5° S., 156° W.) is described in Byron's Voyage in the *Blonde* (p. 206) as formed of a flat coral-rock, with no trees; the height not given; not coloured.—*Malden* Island[1] (4° S., 154° W.): in the same Voyage (p. 205) this island is said to be of coral formation, and no part above 40 feet high; I have not ventured to colour it, although from being of coral formation, it is probably fringed; in which case it should be red.—*Jarvis*, or *Bunker* Island (0° 20′ S., 160° W.) is described by Mr. F. D. Bennett (Geograph. Journ. vol. vii. p. 227) as a narrow, low strip of coral formation; not coloured.—*Brook* is a small, low island between the two latter; its position, and perhaps even existence is doubtful; not coloured.—*Pescado* and *Humphrey* Islands: I can find out nothing about these islands, except that the latter appears to be small and low; not coloured.—*Rearson*, or Grand Duke Alexander's (10° S., 161° W.): an atoll, of which a plan is given by Bellingshausen; blue.—*Souvoroff* Islands (13° S., 163° W.): Admiral Krusenstern, in the most obliging manner, obtained for me an account of these islands from Admiral Lazareff, who discovered them. They consist of five very low islands of coral formation, two of which are connected by a reef, with deep water close to it. They do not surround a lagoon, but are so placed that a line drawn through them includes an oval space, part of which is shallow; these islets, therefore, probably once (as is the case with some of the islands in the Caroline Archipelago) formed a single atoll[2]; but I have not coloured them.—*Danger* Island (10° S., 166° W.): described as low by Commodore Byron, and more lately surveyed by Bellingshausen; it is a small atoll with three islets on it; blue.—*Clarence* Island (9° S., 172° W.): discovered in the *Pandora* (G. Hamilton's Voyage, p. 75): it is said, 'In running along the land, we saw several canoes crossing the *lagoons*;' as

[1] [*Starbuck* and *Malden* Islands are fringed.—Captain Wharton.]

[2] [Suveroff is a complete atoll (French chart)—.Captain Wharton.]

this island is in the close vicinity of other low islands, and as it is said that the natives make reservoirs of water in old cocoa-nut trees (which shows the nature of the land), I have no doubt it is an atoll, and have coloured it blue.—*York* Island (8° S., 172° W.) is described by Commodore Byron (chap. x. of his Voyage) as an atoll; blue.—*Sydney* Island (4° S., 172° W.) is about three miles in diameter, with its interior occupied by a lagoon (Captain Tromelin, Annal. Marit. 1829, p. 297); coloured blue.—*Hull* Island is situated 60 miles to the west of Sydney Island, and is described by Wilkes (U.S. Exploring Expedition, vol. iii. p. 369) as a lagoon-island; coloured blue.—*Phœnix* Island (4° S., 171° W.) is nearly circular, low, sandy, not more than two miles in diameter, and very steep outside (Tromelin, Annal. Marit. 1829, p. 297): it may be inferred that this island originally contained a lagoon, but I have not coloured it.—*New Nantucket* (0° 15′ N., 174° W.): from the French chart it must be a low island; I can find nothing more about it, or about *Mary* Island; both uncoloured.—*Gardner* Island (5° S., 174° W.), from its position, is certainly the same as *Kemin* Island, and is described (Krusenstern, p. 435, Appen. to Mem. published 1827) as having a lagoon in its centre; coloured blue.

ISLANDS SOUTH *of the Sandwich Archipelago.*

Christmas Island (2° N., 157° W.): Captain Cook, in his Third Voyage (vol. ii. chap. x.), has given a detailed account of this atoll. The breadth of the islets on the reef is unusually great, and the sea near it does not deepen so suddenly as is generally the case. It has more lately been visited by Mr. F. D. Bennett (Geograph. Journ. vol. vii. p. 226); and he assures me that it is low and of coral formation: I particularly mention this, because it is engraved with a capital letter, signifying a high island, in D'Urville and Lottin's chart. Mr. Couthouy, also, has given some account of it (Remarks, p. 46) from the Hawaiian Spectator; he believes it has lately undergone a small elevation, but his evidence does not appear to me satisfactory; the deepest part of the lagoon is said to be only ten feet; nevertheless, I have coloured it blue.—*Fanning* Island (4° N., 158° W.), according to Captain Tromelin (Ann. Maritim. 1829, p. 283), is an atoll: his account, as observed by Krusenstern, differs from that given in Fanning's Voyage (p. 224), which, however, is far from clear; coloured blue.—*Washington* Island (4° N., 159° W.) is engraved as a low island in D'Urville's chart, but is described by Fanning (p. 226) as having a much greater elevation than Fanning Island, and hence I presume it is not an atoll; not coloured.—*Palmyra* Island (6° N., 162° W.) is an atoll divided into two parts (Krusenstern's Mem. Suppl. p. 50, also Fanning's Voyage, p. 233); blue.—*Smyth's*, or Johnston's Islands (17° N., 170° W.): Captain Smyth, R.N., has had the kindness to inform me that they consist of two very low small islands, with a dangerous reef off the east end of them; Captain Smyth does not recollect whether these islets, together with the reef, surrounded a lagoon; uncoloured.

Sandwich Archipelago.—*Hawaii*: in the chart in Freycinet's Atlas small portions of the coast are fringed by reefs; and in the accompanying Hydrog. Memoir, reefs are mentioned in several places, and the coral is said to injure the cables; but Dana saw hardly any reefs here.[1]

[1] [Prof. Dana, noticing this remark in Silliman's Amer. Jour., Dec. 1874, states the result of further enquiries on his part from the Rev. Mr. M'Coan, long a resident of Hilo:—'With respect to your enquiry whether there is any elevated coral-reef rock around the shores of Hawaii, I would reply that I think not. . . . Honolulu, on the island of Oahu, is built much of it upon the elevated coral-reef rock, and there are large areas in the district of Waiana and other portions of the Oahu shores: but there is nothing of this kind on Hawaii. You are aware that corals, even under the water, are on the weather [eastern] side

On one side of the islet of Kohaihai there is a bank of sand and coral with five feet of water on it, running parallel to the shore, and leaving a channel of about fifteen feet deep within. I have coloured this island red, but it is very much less perfectly fringed than others of the group. —*Maui*: in Freycinet's chart of the anchorage of Raheina, two or three miles of coast are seen to be fringed; and in the Hydrog. Memoir 'banks of coral along shore' are spoken of. Mr. F. D. Bennett informs me that the reefs, on an average, extend about a quarter of a mile from the beach; the land is not very steep, and outside the reefs the sea does not become suddenly deep; coloured red.—*Morotoi*, I presume, is fringed: Freycinet speaks of the breakers extending along the shore at a little distance from it. From the chart, I believe it is fringed; coloured red.—*Oahu*: Freycinet, in his Hydrog. Memoir, mentions some reefs. Mr. F. D. Bennett informs me that the shore is skirted for forty or fifty miles in length. There is even a harbour for ships formed by the reefs, but it is at the mouth of a valley; red.—*Atooi*, in La Peyrouse's charts, is represented as fringed by a reef, in the same manner as Oahu and Morotoi; and this, I am informed by Mr. Ellis, is of coral-formation on part at least of the shore; the reef does not leave a deep channel within; red.—*Oneehow*: Mr. Ellis believes that this island is also fringed by a coral-reef: considering its close proximity to the other islands, I have ventured to colour it red. I have in vain consulted the works of Cook, Vancouver, La Peyrouse, and Lisiansky for any satisfactory account of the small islands and reefs which lie scattered in a N.W. line prolonged for a great distance from the Sandwich group, and hence have left them uncoloured, with one exception; for I am indebted to Mr. F. D. Bennett for informing me of an atoll-formed reef, in lat. 28° 22′ N.,

of this island not abundant.' In the Narrative of the *Challenger* Voyage (p. 699) reefs are mentioned as occurring at Honolulu.]

long. 178° 30′ W., on which the *Gledstanes* was wrecked in 1837. It is apparently of large size, and extends in a N.W. and S.E. line: very few islets have been formed on it. The lagoon seems to be shallow; at least, the deepest part which was surveyed was only three fathoms. Mr. Couthouy (Remarks, p. 38) describes this island under the name of *Ocean* Island. Considerable doubts should be entertained regarding the nature of a reef of this kind, with a very shallow lagoon, and standing far from any other atoll, on account of the possibility of a crater or flat bank of rock lying at the proper depth beneath the surface of the water, having afforded a foundation for a ring-formed coral-reef. I have, however, thought myself compelled, from its large size and symmetrical outline, to colour it blue. Some information and references are given by Dana (Corals and Coral Islands, pp. 324, 365) with respect to the reefs and islets extending for 2,000 miles in a N.W. line from Hawaii.

Samoa or Navigator Group.—Kotzebue, in his Second Voyage, contrasts these islands with many others in the Pacific, in not having harbours for ships, formed by distant coral-reefs. The Rev. J. Williams, however, informs me that coral-reefs do occur in irregular patches on the shores; but that they do not form a continuous band as round Mangaia, and other such perfect cases of fringed islands. From the charts accompanying La Peyrouse's Voyage, it appears that the north shore of *Savaii*, *Maouna*, *Orosenga*, and *Manua* are fringed by reefs. La Peyrouse, speaking of Maouna (p. 126), says that the coral-reef surrounding its shores almost touches the beach, and is breached in front of the little coves and streams, forming passages for canoes, and probably even for boats. Further on (p. 159) he extends the same observation to all the islands which he visited.—Mr. Williams in his Narrative, speaks of a reef going round a small island attached to *Oyolava*, and returning again to it: all these islands have been coloured red.—A chart of *Rose* Island, at the extreme [east] end of the group, is given by Freycinet, from which I should have thought that it had been an atoll;[1] but according to Mr. Couthouy (Remarks, p. 43) it consists of a reef, only a league in circuit, surmounted by a very few low islets; the lagoon is very shallow, and is strewed with numerous large boulders of volcanic rock. This island, therefore, probably consists of a bank of rock, a few feet submerged, with the outer margin fringed with reefs; hence it cannot be properly classed with atolls, in which, as we have reason to believe, the foundations always lie at a depth greater than that at which the reef-constructing polypifers can live; not coloured.

Beveridge Reef, 20° S., 167° W., is described in the Naut. Mag. (May 1833, p. 442) as ten miles long in a N. and S. line, and eight wide; 'in the inside of the reef, there appears deep water;' there is a passage near the S.W. corner: this therefore seems to be a submerged atoll, and is coloured blue.

Savage Island, 19° S., 170° W., has been described by Cook and Forster. The younger Forster (vol. ii. p. 163) says it is about 40 feet high: he suspects that it contains a low plain, which formerly was the lagoon. The Rev. J. Williams gives 100 feet as its height, and he informs me that the reef fringing its shores resembles that round Mangaia; coloured red.

FRIENDLY ARCHIPELAGO.—*Pylstaart* Island: judging from the chart in Freycinet's Atlas I should have supposed that it had been regularly fringed; but as nothing is said in the Hydrog. Memoir (or in the Voyage of Tasman, the dis-

[1] [It is an atoll.—Capt. Wharton. Rose Island has a lagoon six to twelve fathoms deep and an entrance to it of four fathoms. Except two small banks, one supporting a group of trees, it is under water at high tide.—Letter from Prof. Dana to Mr. Darwin, July 21, 1874.]

coverer) about coral-reefs, I have left it uncoloured.—*Tongatabou*: in the atlas of the Voyage of the *Astrolabe*, the whole south side of the island is represented as narrowly fringed by the same reef which forms an extensive platform on the northern side. The origin of this latter reef, which might have been mistaken for a barrier-reef, has already been attempted to be explained, when giving the proofs of the recent elevation of this island.—In Cook's charts the little outlying island of *Eoaigee* is represented as fringed; coloured red.—*Eoua*: I cannot make out from Captain Cook's charts and descriptions that this island has any reef, although the bottom of the neighbouring sea seems to be covered with corals, and the island itself is formed of coral-rock. Forster, however, distinctly (Observations, p. 14) classes it with the high islands having reefs, but it certainly is not encircled by a barrier-reef; and the younger Forster (Voyage, vol. i. p. 426) says, that 'a bed of coral rocks surrounded the coast towards the landing-place.' I have therefore classed it with the fringed islands, and coloured it red. Dana also shows (Corals and Coral Islands, p. 337) that most of the islands of this group are formed of upraised coral-rock. The several islands lying N.W. of Tongatabou, namely *Anamouka*, *Komango*, *Kotou*, *Lefouga*, *Foa*, &c., are seen in Captain Cook's chart to be fringed by reefs, and several of them are connected together. From the various statements in the first volume of Cook's Third Voyage, and especially in Chapters IV. and VI., it appears that these reefs are of coral, and certainly do not belong to the barrier class; coloured red.—*Toufoa* and *Kao*, forming the western part of the group, according to Forster, have no reefs; the former is an active volcano.—*Vavao*: there is a chart of this singularly-formed island, by Espinoza: according to Mr. Williams it consists of coral-rock: the Chevalier Dillon informs me that it is not fringed; not coloured. Nor are the islands of *Latte* and

Amargura coloured, for I have not seen plans of them on a large scale, and I do not know whether they are fringed: Amargura is said (Athenæum, 1848, p. 40) to have been lately in violent eruption.

Niouha, 16° S., 174° W., or *Keppel* Island of Wallis, or *Cocos* Island: from a view and chart of this island, given in Wallis's Voyage, (4to edit.) it is evidently encircled by a reef; coloured blue. It is, however, remarkable that *Boscawen* Island, immediately adjoining, has no reef of any kind; uncoloured.

Wallis Island, 13° S., 176° W.: a chart and view of this island in Wallis's Voyage (4to edit.) shows that it is encircled.[1] A view of it in the Naut. Mag. July 1833, p. 376, shows the same fact. Nine islands, most of them high, are said in Wilkes U.S. Exploring Expedition (vol. ii. p. 157) to be enclosed within the same reef, through which, it is asserted, ships can enter; coloured blue.

Alloufatou, or *Horn* Island, *Onouafu*, or *Proby* Island,[2] and *Hunter* Islands, lie between the Navigator and Fidji groups. I can find no distinct accounts of them.

Fidji or Feejee or Viti Group.[3]—Until lately the

[1] [Wallis Island is encircled. There are eleven islands, seven of which are on the outer reef.—Note sent to Mr. Darwin by Lieut. Chas. Smith, H.M.S. *Fawn*.]

[2] ['Horn Islands, comprising Fotuna and Alofa; each has a distinct fringing-reef. Fotuna is about 2,500 feet and Alofa 1,200 feet high. I can give no information regarding the depth of water, except that there is a deep ship-channel between the islands, no soundings being obtainable with the hand-line. The channel is hardly a mile broad. Nina-fu, or Good Hope Island, which I presume to be the same as that called Onouafu in Coral Reefs, is entirely volcanic, and has no reef whatever.'—Note sent to Mr. Darwin by Lieut. Chas. Smith, H.M.S. *Fawn*.]

[3] [This group contains every description of reef.—Capt. Wharton. Makata has a central volcanic peak, according to the Narrative of *Challenger* Voyage (p. 487), and is surrounded by a barrier-reef, or one intermediate between that and a fringing-reef. The shore line suggests

best chart of the numerous islands of this group was that in the atlas of the *Astrolabe's* Voyage; but now the islands have been surveyed during the U.S. Exploring Expedition, and full information respecting them and the reefs has been given by Dana. Many of the islands are bold and mountainous, and are surrounded by reefs, lying far from the land, and outside the ocean appears very deep. The *Astrolabe* sounded with 90 fathoms in several places about a mile from the reefs, and found no bottom. It is evident that the water within many of the encircling reefs is deep: as indeed I was formerly assured was the case by Dillon. Beyond the high and encircled islands there are numerous atoll-formed reefs. Hence the whole group has been coloured blue. In the S.E. part lies *Batoa*, or *Turtle* Island of Cook (Second Voyage, vol. ii. p. 23, and chart; 4to edit.), surrounded by a coral-reef, 'which in some places extends two miles from the shore;' within the reef the water appears to be deep, and outside it is unfathomable; coloured pale blue. At the distance of a few miles, Captain Cook (*ibid.* p. 24) found a circular coral-reef, four or five leagues in circuit, with deep water within; 'in short, the bank wants only a few little islets to make it exactly like one of the half-drowned isles so often mentioned,'—namely, atolls. South of Batoa lies the high island of *Ono*, which appears in Bellingshausen's Atlas to be encircled; as do some other small islands to the south; coloured pale blue: near Ono, there is an annular reef, quite similar to the one just described in the words of Captain Cook; coloured dark blue.

subsidence, and the reef is breached opposite to the principal inlet on the land. At Ngaloa harbour, Kandava, the map of this part of the island suggests subsidence, but there are also indications of slight upheaval. There is a barrier-reef. The soundings 150 fathoms from the edge of the reef were 80 fathoms, the slope for the first 65 fathoms from the shore being 1 in 1, then 1 in 1·4, diminishing to 1 in 2 till 300 fathoms was reached.]

Rotoumah, 13° S., 179° E.—From the chart in Duperrey's Atlas, I thought that this island was encircled, but the Chevalier Dillon assures me that the reef is only a shore or fringing one; coloured red.[1]

Independence Island, 10° S., 179° E., is described by Mr. G. Bennett (United Service Journ. 1831, part ii. p. 197) as a low island of coral formation; it is small, and does not appear to contain a lagoon, although an opening through the reef is referred to. A lagoon probably once existed, and has since been filled up; left uncoloured.

Ellice Group.—*Oscar*, *Peyster*, and *Ellice* Islands are figured in Arrowsmith's Chart of the Pacific (corrected to 1832) as atolls, and are said to be very low; blue.[2]—*Nederlandisch* Island: I am greatly indebted to the kindness of Admiral Krusenstern for sending me the original documents concerning this island. From the plans given by Captains Eeg and Khremtshênko, and from the detailed account given by the former, it appears that it is a narrow coral-island, about two miles long, containing a small lagoon. The sea is very deep close to the shore, which is fronted by sharp coral-rocks. Captain Eeg compares the lagoon with that of other coral-islands; and he distinctly says, the land is 'very low.' I have therefore coloured it blue. Admiral Krusenstern (Supplément au Recueil des Mémoires Hydrographiques publiés en 1826 et 1827, &c. &c. St. Petersburg, 1835) states that its shores are 80 feet high; this probably arose from the height of the cocoa-nut trees, with which it is covered, being mistaken for land.—*Grand Cocal* is said in Krusenstern's Memoir to be low, and to be surrounded by a reef; it is small, and therefore probably

[1] ['There is an extinct volcano on the island.'—Note written in Mr. Darwin's copy of this work.]

[2] ['Mitchell Island, to the south of the Ellice group, is a very low atoll with about ten small islands on the reef. We were unable to discover any entrance to the lagoon.'—Lieut. Chas. Smith, H.M.S. *Fawn*.]

once contained a lagoon; uncoloured.[1]—*St. Augustin*: from a chart and view of it, given in the atlas of the *Coquille's* Voyage, it appears to be a small atoll, with its lagoon partly filled up; coloured blue.

Gilbert Group.—The chart of this group, given in the atlas of the *Coquille's* Voyage, shows that it is composed of ten well-characterized, but very irregularly shaped atolls. In D'Urville and Lottin's chart, *Sydenham* is written with a capital letter, signifying that it is high; but this certainly is not the case, for it is a perfectly characterized atoll, and a sketch, showing how low it is, is given in the *Coquille's* atlas. Some narrow strip-like reefs project from the southern side of *Drummond* atoll, and render it irregular. The southern island of the group is called *Chase* (in some charts, *Rotches*); of this I can find no account, but Mr. F. D. Bennett discovered (Geograph. Journ. vol. vii. p. 229) a low extensive island in nearly the same latitude, about three degrees westward of the longitude assigned to Rotches; and this probably is the same island. Mr. Bennett informs me that the man at the masthead reported an appearance of lagoon-water in the centre; and, therefore, considering its position, I have coloured it blue.—*Pitt* Island, at the extreme northern point of the group, is left uncoloured, as neither its exact position nor nature is known.—*Byron* Island, which lies a little to the eastward, does not appear to have been visited since Commodore Byron's voyage, and it was then seen only from a distance of 18 miles: it is said to be low; uncoloured.

Ocean, Pleasant, and *Atlantic* Islands all lie considerably to the west of the Gilbert group: I have been unable to find any distinct account of them. Ocean Island is written with

[1] [' Grand Cocal was searched for in vain by H.M.S. *Basilisk*, and as all the local traders deny its existence, I cannot think it exists. It has long been marked 'doubtful' on the Admiralty charts, and the description leads me to suppose the island reported to have been St. Augustin.'—Lieut. Chas. Smith, H.M.S. *Fawn*.]

small letters in the French chart, but in Krusenstern's Memoir it is said to be high.

Marshall Group.—We are well acquainted with this group from the excellent charts of the separate islands, made during the two voyages of Kotzebue: a reduced one of the whole group may be seen in Krusenstern's Atlas, and in Kotzebue's Second Voyage. The group consists (with the exception of two *little* islands which probably have had their lagoon filled up) of a double row of 23 large and well-characterized atolls, from the examination of which Chamisso drew up his well-known account of coral formations. I include in this group *Gaspar Rico*, or *Cornwallis* Island, which is described by Chamisso (Kotzebue's First Voyage, vol. iii. p. 179) 'as a low sickle-formed group, with mould only on the windward side.' Gaspard Island is considered by some geographers as a distinct island lying N.E. of the group, but it is not entered in the chart by Krusenstern; left uncoloured. In the S.W. part of this group lies *Baring* Island, of which little is known (see Krusenstern's Appendix, 1835, p. 149). I have left it uncoloured; but *Boston* Island I have coloured blue, as it is described (ibid.) as consisting of 14 small islands, which, no doubt, inclose a lagoon, as represented in a chart in the *Coquille's* atlas.—Three islands, *Aur, Kawen* and *Gaspar Rico*, are written in the French chart with capital letters; but this is an error, for from the account given by Chamisso in Kotzebue's First Voyage, they are certainly low. The nature, position, and even existence of the shoals and small islands north of the Marshall group are doubtful.

New Hebrides.—Any chart, on even a small scale, of these islands will show that their shores are almost without reefs,[1] presenting a remarkable contrast with those of New

[1] [The New Hebrides have fringing-reefs in various parts. No barrier-reefs are yet known, but the charts are still very imperfect. —Capt. Wharton.]

Caledonia on the one hand, and the Fidji group on the other. Nevertheless, I have been assured by Mr. G. Bennett, that coral grows vigorously on their shores; as, indeed, will be further shown in some of the following notices. As, therefore, these islands are not encircled, and as coral grows vigorously on their shores, we might almost conclude, without further evidence, that they are fringed, and hence I have applied the red colour with rather greater freedom than in other instances.—*Matthew's* Rock, an active volcano, some way south of the group (of which a plan is given in atlas of the *Astrolabe's* Voyage) does not appear to have reefs of any kind about it.—*Annatom*, the southernmost of the Hebrides: from a rough woodcut given in the United Service Journal (1831, part iii. p. 190), accompanying a paper by Mr. Bennett, it appears that the shore is fringed; coloured red.—*Tanna*: Forster, in his Observations (p. 22), says Tanna has on its shores coral-rock and madrepores; and the younger Forster, in his account (vol. ii. p. 269), speaking of the harbour, says the whole S.E. side consists of coral-reefs, which are overflowed at high water: part of the southern shore in Cook's chart is represented as fringed; coloured red.—*Immer* is described (United Service Journ. 1831, part iii. p. 192) by Mr. Bennett as being of moderate elevation, with cliffs appearing like sandstone; coral grows in patches on its shore, but I have not coloured it; and I mention these facts because Immer might have been thought, from Forster's classification (Observations, p. 14), to have been a low island, or even an atoll.—*Erromango* Island: Cook (Second Voyage, vol. ii. p. 45, 4to edit.) speaks of rocks everywhere *lining* the coast, and the natives offered to haul his boat over the breakers to the sandy beach: Mr. Bennett, in a letter to the editor of the Singapore Chron., alludes to the *reefs* on its shores. It may, I think, be safely inferred from these passages that the shore is fringed in parts by coral-reefs; coloured red.—*Sandwich*

Island: the east coast is said (Cook's Second Voyage, vol. ii. p. 41) to be low, and to be guarded by a chain of breakers. In the accompanying chart it is seen to be fringed by a reef; coloured red.—*Mallicollo*: Forster speaks of the reef-bounded shore: the reef is about 30 yards wide, and so shallow that a boat cannot pass over it. Forster, also, (Observat. p. 23,) says that the rocks of the sea-shore consist of madrepore. In the plan of Sandwich harbour, the headlands are represented as fringed; coloured red.—*Aurora* and *Pentecost* Islands, according to Bougainville, apparently have no reefs; nor has the large island of *S. Espiritu*, nor *Bligh* Island, nor *Banks* Islands,[1] which latter lie to the N.E. of the Hebrides. But in none of these cases have I met with any detailed account of their shores, or seen plans on a large scale; and it will be evident that a fringing-reef of only thirty, or even a few hundred yards in width is of so little importance to navigation, that it will seldom be noticed, excepting by chance; and hence I do not doubt that several of these islands, now left uncoloured, ought to be red.

Santa-Cruz Group.—*Vanikoro* (Fig. 1, Plate I.) offers a striking example of a barrier-reef: it was first described by the Chevalier Dillon, in his Voyage, and was surveyed in the *Astrolabe*; coloured pale blue.—*Tikopia* and *Fataka* Islands appear, from the descriptions of Dillon and D'Urville, to have no reefs: *Anouda* is a low, flat island, surrounded by cliffs, (*Astrolabe*, Hydrog. and Krusenstern Mem. vol. ii. p. 432); these are uncoloured.—*Toupoua* (*Otooboa* of Dillon) is stated by Captain Tromelin (Annales Marit. 1829, p. 289) to be almost entirely included in a reef, lying at the distance of two miles from the shore. There is a space of three miles without any reef, which, although indented with bays, offers no anchorage from the extreme depth of the water close to the shore. Captain Dillon also speaks

[1] [*Banks* Islands are fringed in parts.—Capt. Wharton.]

of the reefs fronting this island; coloured blue.[1]—*Santa Cruz*: I have carefully examined the works of Carteret, Dentrecasteaux, Wilson, and Tromelin, and I cannot discover any mention of reefs on its shores; left uncoloured. —*Tinakoro* is a constantly active volcano without reefs.—*Mendana* Isles (mentioned by Dillon under the name of *Mammee*, &c.) are said by Krusenstern to be low and intertwined with reefs. I do not believe they include a lagoon; I have left them uncoloured.—*Duff's* Islands compose a small group directed in a N.W. and S.E. band; they are described by Wilson (p. 296, Miss. Voy. 4to edit.) as formed by bold peaked land, with the islands surrounded by coral-reefs, extending about half a mile from the shore: at the distance of a mile from the reefs he found only seven fathoms. As I have no reason for supposing there is deep water within these reefs, I have coloured them red.—*Kennedy* Island, N.E. of Duff's: I have been unable to find any account of it.

New Caledonia.—The great barrier-reefs on the shores of this island have already been described (Fig. 5, Plate II.). They have been visited by Labillardière, Cook, and the northern point by D'Urville; this latter part so closely resembles an atoll that I have coloured it dark blue. The *Loyalty* group is situated to the east of New Caledonia; some at least of the islands are formed of upraised coral-rock, and are fringed with living reefs; see Rev. W. B. Clarke, in Journal of Geolog. Soc. 1847, p. 61; coloured red. North of this group there are some extensive low reefs (called *Astrolabe* and *Beaupré*[2]), which do not seem to be atoll-formed: these are left uncoloured.

[1] [This island has a barrier-reef, with a 4-fathom channel through it, which leads into a harbour in the island itself. There is also deep but uneven water generally inside the reef.—Lieut. Chas. Smith, H.M.S. *Fawn*.]

[2] [This is an atoll.—Capt. Wharton.]

Australian Barrier-Reef.—This great reef, which has already been described, has been coloured from the charts of Flinders and King. Jukes has given many details respecting it in the Voyage of H.M.S. *Fly* (vol. i. 1847, chap. xiii.). In the northern parts, an atoll-formed reef, lying outside the barrier, has been described by Bligh, and is coloured dark blue. In the space between Australia and New Caledonia, called by Flinders the Corallian Sea, there are numerous reefs. Of these, some are represented in Krusenstern's Atlas as having an atoll-like structure; [1] namely, *Bampton* Shoal, *Frederic*, *Vine* or Horse-shoe, and *Alert* Reefs; these have been coloured dark blue.

Louisiade.—The dangerous reefs which front and surround the western, southern, and northern coasts of this so-called peninsula and archipelago, seem evidently to belong to the barrier class. The land is lofty, with a low fringe on the coast; the reefs are distant, and the sea outside them profoundly deep. Nearly all that is known of this group is derived from the labours of Dentrecasteaux and Bougainville: the latter has represented one continuous reef 90 miles long, parallel to the shore, and in places as much as 10 miles from it; coloured pale blue. A little distance northward we have the *Laughlan* Islands, the reefs round which are engraved in the atlas of the Voyage of the *Astrolabe*, in the same manner as round the encircled islands of the Caroline Archipelago: the reef is, in parts, a mile and a half from the shore, to which it does not appear to be attached; coloured blue. At some little distance from the extremity of the Louisiade lies *Wells* Reef, described in G. Hamilton's Voyage in H.M.S. *Pandora* (p. 100): it is said, 'We found we had got embayed in a double reef, which will soon be an island.' As this statement is only intelligible on the supposition of the reef being crescent

[1] [There are many atolls in this sea.—Capt. Wharton.]

or horse-shoe formed, like so many other submerged annular reefs, I have ventured to colour it blue.

SALOMAN ARCHIPELAGO.—The chart in Krusenstern's Atlas shows that these islands are not encircled; and as coral appears, from the works of Surville, Bougainville, and Labillardière, to grow on their shores, this circumstance, as in the case of the New Hebrides, is a presumption that they are fringed. I cannot find out anything from Dentrecasteaux's Voyage, regarding the southern islands of the group, so have left them uncoloured.—*Malayta* Island, in a rough MS. chart in the Admiralty, has its northern shore fringed.—*Ysabel* Island: the N.E. part of this island, as shown in the same chart, is also fringed: Mendana (Burney, vol. i. p. 280), speaking of an islet adjoining the northern coast, says it is surrounded by reefs: the shores, also, of Port Praslin appear regularly fringed. *Choiseul* Island: parts of the shores are fringed by coral-reefs, in Bougainville's chart of Choiseul Bay.—*Bougainville* Island: according to Dentrecasteaux, the western shore abounds with coral-reefs, and the smaller islands are said to be attached to the larger ones by reefs; all the above-mentioned islands have been coloured red.—*Bouka* Islands: Captain Duperrey has kindly informed me in a letter that he passed close round the northern side of this island (of which a plan is given in his atlas of the *Coquille's* Voyage), and that it was 'garnie d'une bande de récifs à fleur d'eau adhérentes au rivage;' and he infers, from the abundance of coral on the islands north and south of Bouka, that the reef probably is of coral; coloured red.[1]

Off the north coast of the Saloman Archipelago there are several small groups which are little known: they appear to be low, and of coral formation; and some of them probably have an atoll-like structure: the Chevalier

[1] [Bouka, according to the best accounts, has a barrier-reef, but our information is still imperfect.—Capt. Wharton.]

Dillon, however, informs me this is not the case with the Baxos de *Candelaria*.[1]—*Outong Java*, according to the Spanish navigator, Maurelle, is thus characterized; but this is the only one which I have ventured to colour blue.

New Ireland.—The shores of the S.W. point of this island and some adjoining islets, are fringed by reefs, as may be seen in the atlases of the Voyages of the *Coquille* and *Astrolabe*. M. Lesson observes that the reefs are open in front of each streamlet. The *Duke of York's* Island is also fringed; but with regard to the other parts of *New Ireland*, *New Hanover*, and the small islands lying northward, I have been unable to obtain any information. I will only add that no part of New Ireland appears to be fronted by distant reefs. I have coloured red only the above specified portions.

New Britain and the Northern Shore of New Guinea.—From the charts in the Voyage of the *Astrolabe*, and from the Hydrog. Memoir, it appears that these coasts are entirely without reefs, as are the *Schouten* Islands, lying close to the northern shore of New Guinea. The western and south-western parts of New Guinea will be treated of when we come to the islands of the East Indian Archipelago.

Admiralty Group.[2]—From the accounts given by Bougainville, Maurelle, Dentrecasteaux, and the scattered

[1] [This is a perfect atoll.—Capt. Wharton.]

[2] [Narrative of *Challenger* Voyage, p. 699. Admiralty, or Bosco Islands. The main island rises to nearly 3,000 feet. The coast is low and indented with deep bays. There are many coral-reefs off the coast at varying distances, not forming a connected barier-reef. There is convenient anchorage within the reef, the soundings in the deeper part of the channel at Nares Harbour being from 25 to 34 fathoms, and very generally nearly or over 20 fathoms. Four other of the islands attain an elevation of from 600 to 800 feet; the remainder are low and are situated on coral-reefs. The coast line of the main island is a platform of coral-sand rock, and the low outlying islands are the same, but the hills are presumed to be of volcanic rock.]

notices collected by Horsburgh, it appears that some of the many islands composing it are high, with a bold outline; and others are low, small, and interlaced with reefs. All the high islands appear to be fronted by distant reefs rising abruptly from the sea, and within some of which, there is reason to believe that the water is deep. I have therefore little doubt that they belong to the barrier class. In the southern part of the group, we have *Elisabeth* Island, which is surrounded by a reef at the distance of a mile; and two miles eastward of it (Krusenstern, Append. 1835, p. 42) there is a little island containing a lagoon. Near here, also, lies *Circular* Reef (Horsburgh Direct. vol. ii. p. 796, 8th edit.), 'three or four miles in diameter, having deep water inside with an opening at the N.N.W. part: the reef on the outside is steep to.' I have from these data, coloured the group pale blue, and *Circular* Reef dark blue. —The *Anachorites*, *Echequier*, and *Hermites* consist of innumerable low islands of coral formation, which probably are atolls; but not being able to ascertain this, I have not coloured them, nor *Durour* Island, which is described by Carteret as low.

The Caroline Archipelago is now well known, chiefly from the hydrographical labours of Lutké: it contains about forty groups of atolls, and three encircled islands, two of which are engraved in Figs. 2 and 7, Plate I. Commencing with the eastern part, the encircling reef round *Ualan* appears to be only about half a mile from the shore; but as the land is low, and covered with mangroves (Voyage autour du Monde, par F. Lutké, vol. i. p. 339), its margin has not probably been ascertained. The extreme depth in one of the harbours within the reef is 33 fathoms (see charts in Atlas of *Coquille's* Voyage), and outside at half a mile distance from the reef, no bottom was obtained with 250 fathoms. The reef is surmounted by many islets, and the lagoon-like channel within is mostly shallow,

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and appears to have been much encroached on by the low land surrounding the central mountains; these facts show that time has allowed much detritus to accumulate; coloured pale blue.—*Pouynipète* or *Seniavine*. In the greater part of the circumference of this island, the reef is about one mile and three quarters from the shore; but on the north side it is five miles distant from the included high islets. The reef is broken in several places; and just within it, the depth in one place is 30 fathoms, and in another, 28, beyond which, to all appearance, there was 'un port vaste et sûr' (Lutké, vol. ii. p. 4). Coloured pale blue.—*Hogoleu* or *Roug*. This wonderful group contains at least 62 islands, and its reef is 135 miles in circuit. Of the islands, only a few, about six or eight (see Hydrog. Description, p. 428, of the Voyage of the *Astrolabe*, and the large accompanying chart taken chiefly from that given by Duperrey) are high, and the rest are all small, low, and formed on the reef. The depth of the great interior lake has not been ascertained; but Captain D'Urville appears to have entertained no doubt about the possibility of taking in a frigate. The reef lies no less than 14 miles distant from the northern coasts of the interior high islands; seven miles from their western sides, and 20 from the southern: the sea is deep outside. This island resembles on a grand scale the Gambier group in the Low Archipelago. Of the low[1] islands forming the chief part of the Caroline Archipelago, all those of larger size (as may be seen in the Atlas by Captain Lutké), and some even of the small ones of which plans are given in the Atlas of the *Coquille's* Voyage, are true atolls. There are, however, some low, small islands of coral formation, namely, *Ollap*, *Tamatam*, *Bigali*, *Satahoual*, which do not contain lagoons; but it is probable that lagoons originally existed, but have since filled up:

[1] In D'Urville and Lottin's chart, Pescrare is written with capital letters; but this evidently is an error, for it is one of the low islets on the reef of Namonouyto (see Lutké's charts), which is a regular atoll.

Lutké (vol. ii. p. 304) seems to have thought that all the low islands, with only one exception, contained lagoons. The most southern island in the group, namely, *Piguiram*, is not coloured, because I have found no account of it. *Nougouor*, or *Monte Verdison*, which was not visited by Lutké, is described and figured by Mr. Bennett (United Service Journal, Jan. 1832) as an atoll. All the before-mentioned islands have been coloured blue. It must, however, be stated that between Ualan and Pouynipète, the three McAskill Islands rise to a height of from 40 to 100 feet, and consist, according to Dana (Corals and Coral Islands, p. 306), of coral-rock; whether they are encircled or fringed by coral-reefs does not seem to be known.

Western part of the Caroline Archipelago.—*Fais* Island is 90 feet high, and is surrounded, as I have been informed by Admiral Lutké, by a narrow reef of living coral, of which the broadest part, as represented in the charts, is only 150 yards; coloured red.—*Philip* Island, I believe, is low; but Hunter, in his Historical Journal, gives no clear account of it; uncoloured. *Elivi*: from the manner in which the islets on the reefs are engraved in the Atlas of the *Astrolabe's* Voyage, I should have thought they were above the ordinary height; but Admiral Lutké assures me that this is not the case: they form a regular atoll; coloured blue. *Gouap* (*Eap* of Chamisso) is a high island with a reef (see Chart in Voyage of *Astrolabe*) in most parts more than a mile distant from the shore, and two miles in one part. Captain D'Urville thinks that there would be anchorage (Hydrog. Descript. *Astrolabe* Voyage, p. 436) for ships within the reef, if a passage could be found; coloured pale blue.—*Goulou*, from the chart in the *Astrolabe's* atlas, appears to be an atoll: D'Urville (Hydrog. Descript. p. 437) speaks of low islets on the reef; coloured dark blue.

Pelew Islands.—Krusenstern speaks of some of the islands being mountainous; the reefs are distant from the shore, and there are spaces within them, not opposite to any valley, from 10 to 15 fathoms deep. According to a MS. chart of the group by Lieut. Elmer in the Admiralty, there is a large space within the reef with deepish water: although the high land does not hold a central position with respect to the reefs, as is generally the case, I have little doubt that the reefs of the Pelew Islands ought to be ranked in the barrier class, and I have coloured them pale blue. In Lieut. Elmer's chart there is a horse-shoe-formed shoal, 13 miles N.W. of Pelew, with 15 fathoms within the reef, and some dry banks on it; coloured dark blue.—*Spanish, Martires, Sanserot, Pulo Anna* and *Mariere* Islands are not coloured, because I know nothing about them, excepting that according to Krusenstern, the second, third, and fourth mentioned, are low, placed on coral-reefs, and therefore perhaps include a lagoon; but Pulo Mariere is a little higher. Since the above remarks were written Prof. Semper has published an interesting article (Zeitschr. f. Wissensch. Zoologie, Bd. xiii. 1863, p. 558) on these islands. He states that the southern islands consist of coral-rock, upraised to the height of from 400 to 500 feet; and some of them, before their upheaval, seem to have existed as atolls. They are now merely fringed by living reefs. The northern islands are volcanic, deeply indented by bays, and are fronted by barrier-reefs. To the north there are three true atolls. Prof. Semper doubts whether the whole group has subsided, partly from the fact of the southern islands being formed of upraised coral-rock; but there seems to me no improbability in their having originally subsided, then having been upraised (probably at the time when the volcanic rocks to the north were erupted), and again having subsided. The existence of atolls and barrier-reefs in close proximity is manifestly not opposed to my views. On the other hand, the presence of reefs fringing the southern islands is opposed to my views, as such reefs generally indicate that the land has either long remained stationary, or has been upraised. It must, however, be borne in mind (as remarked in our sixth chapter) that when the land is prolonged beneath the sea in an extremely steep slope, reefs formed there during subsidence will remain closely attached to the shore, and will be undistinguishable from fringing-reefs. Now we know that the submarine flanks of most atolls are very steep; and if an atoll after upheaval and before the sea had eaten deeply into the land, and had formed a broad flat surface, were again to subside, the reefs which grew to the surface during the subsiding movement, would still closely skirt the coast. After some hesitation, I have thought myself justified in leaving these islands coloured blue.

Mariana Archipelago, or Ladrones.—*Guahan*: almost the whole of this island is fringed by reefs, which extend in most parts about a third of a mile from the land. Even where the reefs are most extensive, the water within them is shallow. In several parts there is a navigable channel for boats and canoes within the reefs. In Freycinet's Hydrog. Mem. there is an account of these reefs, and in the atlas, a map on a large scale; coloured red.—*Rota*: 'L'île est presque entièrement entourée de récifs' (p. 212, Freycinet's Hydrog. Mem.). These reefs project about a quarter of a mile from the shore; coloured red.—*Tinian*: the eastern coast is precipitous, and is without reefs; but the western side is fringed like the last island; coloured red. *Saypan*: the N.E. coast, and likewise the western shores appear to be fringed; but there is a great, irregular, horn-like reef projecting far from this side; coloured red.—*Farallon de Medinilla* appears so regularly and closely fringed in Freycinet's charts, that I have ventured to colour it red, although nothing is said about reefs in the Hydrographical Memoir. The several islands which form the northern part of the group are volcanic (with the exception perhaps of Torres, which resembles in form the madreporitic island of Medinilla), and appear to be without reefs.—*Mangs*, however, is described (by Freycinet, p. 219, Hydrog.) from some Spanish charts, as formed of small islands placed 'au milieu de nombreux récifs;' and as these reefs in the general chart of the group do not project so much as a mile; and as there is no appearance from a double line, of the existence of deep water within, I have ventured, although with much hesitation, to colour them red. Respecting *Folger* and *Marshall* Islands, which lie some way east of the Marianas, I can find out nothing, excepting that they are probably low. Krusenstern says this of Marshall Island; and Folger Island is written with small letters in D'Urville's chart; uncoloured.

Bonin or Arzobispo Group.—*Peel* Island has been examined by Captain Beechey, to whose kindness I am much indebted for giving me information regarding it: 'at Port Lloyd there is a great deal of coral; and the inner harbour is entirely formed by coral-reefs, which extend outside the port along the coast.' Captain Beechey, in another part of his letter to me, alludes to the reefs fringing the island in all directions; but at the same time it must be observed that the surf washes the volcanic rocks of the coast in the greater part of its circumference. This island has certainly been elevated at least 50 feet within the recent period (see Journal of Geolog. Soc. 1855, p. 532). I do not know whether the other islands of the archipelago are fringed; I have coloured Peel island red. —*Grampus* Island, to the eastward, does not appear (Meare's Voyage, p. 95) to have any reefs, nor does *Rosario* Island (from Lutké's chart), which lies to the westward. Respecting the few other islands in this part of the sea, namely the *Sulphur* Islands, with an active volcano, and those lying between Bonin and Japan (situated near the extreme limit in latitude at which reefs can grow), I have not been able to find any clear account.

West End of New Guinea.—*Port Dory*: from the charts in the Voyage of the *Coquille*, it would appear that the coast in this part is fringed by coral-reefs; M. Lesson, however, remarks that the corals are sickly; coloured red. —*Waigiou*: a considerable portion of the northern shore of these islands are seen in the charts (on a large scale) in Freycinet's Atlas to be fringed by coral-reefs. Forrest (p. 21, Voyage to New Guinea) alludes to the coral-reefs lining the heads of Piapis Bay; and Horsburgh (vol. ii. p. 599, 4th edit.), speaking of the islands in Dampier Strait, says, 'sharp coral-rocks line their shores;' coloured red.— In the sea north of these islands, we have *Guedes* (or *Freewill*, or *St. David's*), which from the chart given in the 4to edit. of Carteret's Voyage must be an atoll. Krusenstern says the islets are very low; coloured blue.— *Carteret's* Shoals, in 2° 53′ N., are described as circular, with stony points showing all round, with deeper water in the middle; coloured blue.—*Aiou*: the plan of this group, given in the atlas of the Voyage of the *Astrolabe*, shows that it is an atoll; and, from a chart in Forrest's Voyage, it appears there is 12 fathoms within the circular reef; coloured blue.—The S.W. coast of New Guinea appears to be low, muddy, and devoid of reefs. The *Arru*, *Timor-laut* and *Tenimber* Groups have lately been examined by Captain Kolff, the MS. translation of which, by Mr. W. Earl, I have been permitted to read, through the kindness of Captain Washington, R.N. These islands are mostly rather low, and are surrounded by distant reefs (the Ki Islands, however, are lofty, and, from Mr. Stanley's survey, appear without reefs); the sea in some parts is shallow, in others profoundly deep, as near Larrat. From the imperfection of the published charts, I have been unable to decide to which class these reefs belong. From the distance to which they extend from the land where the sea is very deep, I am strongly inclined to believe they ought to come within the barrier class, and be coloured blue; but I have been forced to leave them uncoloured.—The last-mentioned groups are connected with the east end of Ceram by a chain of small islands, of which the small groups of *Ceram-laut*, *Goram*, and *Keffing* are surrounded by very extensive reefs, projecting into deep water, which, as in the last case, I strongly suspect belong to the barrier class; but I have not coloured them. From the south side of Keffing, the reefs project five miles (Windsor Earl's Sailing Direct. for the Arafura Sea, p. 9).

CERAM.—In various charts which I have examined, several parts of the coast are represented as fringed by reefs.—*Manipa* Island, between Ceram and Bourou, in an old MS. chart in the Admiralty, is fringed by a very irregular reef, partly dry at low water, which I do not doubt is of coral formation; both islands coloured red.—*Bourou*: parts of this island appear fringed by coral-reefs, namely, the eastern coast as seen in Freycinet's chart; and *Cajeli* Bay, which is said by Horsburgh (vol. ii. p. 630) to be lined by coral-reefs, that stretch out a little way, and have only a few feet of water on them. In several charts, portions of the islands forming the AMBOINA GROUP [1] are fringed by reefs; for instance, *Noessa*, *Harenca*, and *Ucaster*, in Freycinet's charts. The above-mentioned islands have been coloured red, although the evidence is not very satisfactory.—North of Bourou the parallel line of the *Xulla* Isles extends: I have not been able to find out anything about them, excepting that Horsburgh (vol. ii. p. 543) says that the northern shore is surrounded by a reef at the distance of two or three miles; uncoloured.—*Mysol* Group: the Kanary Islands are said by Forrest (Voyage, p. 130) to be divided from each other by deep

[1] [At Amboina coral-reef rock occurs raised many hundred feet above sea level, forming a steep hill slope. Narrative of *Challenger* Voyage, vol. i. p. 580. See also Moseley, Notes by a Naturalist, p. 389.]

straits, and are lined with coral-rocks; coloured red.—*Guebe*, lying between Waigiou and Gilolo, is engraved as if fringed; and it is said by Freycinet, that all the soundings under five fathoms were on coral; coloured red.—*Gilolo*: in a chart published by Dalrymple, the numerous islands on the western, southern (*Batchian* and the *Strait of Patientia*), and eastern sides appear fringed by narrow reefs; these reefs, I suppose, are of coral, for it is said in Malte Brun (vol. xii. p. 156), 'sur les côtes (of Batchian), comme *dans la plupart* des îles de cet archipel, il y a des rocs de madrépores d'une beauté et d'une variété infinies.' Forrest, also (p. 50), says Seland, near Batchian, is a little island with reefs of coral; coloured red.—*Morty* Island (north of Gilolo): Horsburgh (vol. ii. p. 506) says the northern coast is lined by reefs, projecting one or two miles, and having no soundings close to them; I have left it uncoloured, although, as in some former cases, it ought probably to be pale blue.—*Celebes*. The western and northern coasts appear in the charts to be bold and without reefs. Near the extreme northern point, however, an islet in the Straits of *Limbe*, and part of the adjoining shore, appear to be fringed: the east side of the bay of *Manado* has deep water, and is fringed by sand and coral (*Astrol.* Voyage, Hydrog. Part, p. 453–4); this extreme point, therefore, I have coloured red. Captain Keppell, also, speaks (Expedition to Borneo, vol. i. p. 130) of the shore being in parts fringed with reefs; he found upraised coral-reefs at the height of from 80 to 100 feet above the level of the sea.—Of the islands between the northern point of Celebes and the Philippines, I have not been able to find any account, except of *Serangani*, which appears surrounded by narrow reefs; and Forrest (Voyage, p. 164) speaks of coral on its shores; I have, therefore, coloured this island red. To the eastward of this chain lie several islands; of which I cannot find any account, except of *Karkalang*, which is said by Horsburgh (vol. ii. p. 504) to be lined by a dangerous reef, projecting several miles from the northern shore; not coloured.

Islands near Timor.—The account of the following islands is taken from Captain D. Kolff's Voyage in 1825, translated by Mr. W. Earl from the Dutch.—*Lette* has 'reefs extending along shore at the distance of half a mile from the land.'—*Moa* has reefs on the S.W. part.—*Lakor* has a reef lining its shore; these islands are coloured red. —Still more eastward, *Luan*, differently from the last-mentioned islands, has an extensive reef; it is steep outside, and within there is a depth of 12 feet; from these facts it is impossible to decide to which class this island belongs.—*Kissa*, off the point of Timor, has its 'shore fronted by a reef, steep too on the outer side, over which small proahs can go at the time of high water;' coloured red.—*Timor*: most of the points, and some considerable spaces of the northern shore, are seen in Freycinet's chart to be fringed by coral-reefs; and mention is made of them in the accompanying Hydrog. Memoir; coloured red.—*Savu*, S.W. of Timor, appears in Flinders' chart to be fringed; but I have not coloured it, as I do not know that the reefs are of coral.—*Sandalwood* Island has, according to Horsburgh (vol. ii. p. 607), a reef on its southern shore, four miles distant from the land; as the neighbouring sea is deep, and generally bold, this probably is a barrier-reef, but I have not ventured to colour it.

N.W. Coast of Australia.—It appears, in Captain King's Sailing Directions (Narrative of Survey, vol. ii. pp. 325 to 369), that there are many extensive coral-reefs skirting, often at considerable distances, the N.W. shores and encompassing the small adjoining islets. Deep water in no instance is represented in the charts between these reefs and the land; and, therefore, they probably belong to the fringing class. But as they extend far into the sea, which is generally shallow, even in places where the land seems to be somewhat precipitous, I have not coloured them. Houtman's Abrolhos (lat. 28° S. on west coast) have lately been surveyed by Captain Wickham (as described in Naut. Mag. 1841, p. 511): they lie on the edge of a steeply-shelving bank, which extends about 30 miles seaward, along the whole line of coast. The two southern reefs, or islands, enclose a lagoon-like space of water, varying in depth from 5 to 15 fathoms, and in one spot with 23 fathoms. The greater part of the land has been formed on their inland sides, by the accumulation of fragments of corals; the seaward face consisting of nearly bare ledges of rock. Some of the specimens, brought home by Captain Wickham, contained fragments of marine shells, but others did not; and these closely resembled a formation at King George's Sound, principally due to the action of the wind on calcareous dust, which I have described in my work on Volcanic Islands. From the extreme irregularity of these reefs with their lagoons, and from their position on a bank, the usual depth of which is only 30 fathoms, I have not ventured to class them with atolls, and hence have left them uncoloured.—*Rowley* Shoals: these lie some way from the N.W. coast of Australia: according to Captain King (Narrative of Survey, vol. i. p. 60), they are of coral-formation. They rise abruptly from the sea, and Captain King found no bottom with 170 fathoms close to them. Three of them are crescent-shaped; a third oval reef of the same group is entirely submerged (Lyell, Principles of Geolog., book iii. chap. xviii.);[1] coloured blue.—*Scott's* Reefs, lying north of Rowley Shoals, are briefly described by Captain Wickham (Naut. Mag., 1841, p. 440) as of great size, of a circular form, and 'with smooth water within, forming probably a lagoon of great extent. There is a break on the western side, where there probably

[1] [Book iii. ch. xlix. 11th edition.]

is an entrance: the water is very deep off these reefs; coloured blue.

Proceeding westward along the great volcanic chain of the East Indian or Malay Archipelago, *Solor* Strait is represented as fringed in a chart published by Dalrymple from a Dutch MS.; as are parts of *Flores*, *Adenara*, and *Solor*. Horsburgh speaks of coral growing on these shores, and therefore I have no doubt that the reefs are of coral, and have coloured them red. We hear from Horsburgh (vol. ii. p. 602) that a coral flat bounds the shores of *Sapy* Bay. From the same authority it appears (p. 610) that reefs fringe the island of *Timor-Young*, on the N. shore of Sumbawa; and likewise (p. 600) that *Bally* town in *Lombock*, is fronted by a reef, stretching along the shore at the distance of a hundred fathoms, with channels through it for boats; these places, therefore, have been coloured red.—*Bally* Island: in a Dutch MS. chart on a large scale of Java, which was brought from that island by Dr. Horsfield, who had the kindness to show it me at the India House, its western, northern, and southern shores appear regularly fringed by a reef (see also Horsburgh, vol. ii. p. 593); and as coral is found abundantly there, I have no doubt that the reef is of coral, and therefore have coloured it red.

Java.—My information regarding the reefs of this great island is derived from the chart just mentioned. The greater part of *Madura* is represented in it as regularly fringed, and likewise portions of the coast of Java immediately south of it. Dr. Horsfield informs me that coral is very abundant near *Sourabaya*. The adjoining islets, and parts of the N. coast of Java, west of *Point Buang*, or *Japara*, are fringed by reefs, said to be of coral. *Lubeck*, or *Bavian* Islands, lying at some distance from the shore of Java, are regularly fringed by coral-reefs: *Curimon Java* appears equally so, though it is not directly said that the reefs are of coral;

there is a depth of between 30 and 40 fathoms round these islands. Parts of the shore of *Sunda* Straits, where the water is from 40 to 80 fathoms deep, and the islets near *Batavia* appear in several charts to be fringed. In the Dutch chart the southern shore, in the narrowest part of the island, is in two places fringed by reefs of coral. West of *Segorrowodee* Bay, and the extreme S.E. and E. shores are likewise fringed by coral-reefs; all the above-mentioned places coloured red.

Macassar Strait: the east coast of *Borneo* appears, in most parts, free from reefs, and where they occur, as on the coast of *Pamaroong*, the sea is very shallow; hence no part is coloured. In *Macassar* Strait itself, in about lat. 2° S., there are many small islands with coral shoals projecting far from them. There are also (old charts by Dalrymple) numerous little flats of coral, not rising to the surface of the water, and shelving suddenly from five fathoms to no bottom with 50 fathoms; they do not appear to have a lagoon-like structure. There are similar coral-shoals a little farther south; and in lat. 4° 55′ there are two, which are engraved from modern surveys, in a manner which may represent an annular reef with deep water inside: Capt. Moresby, however, who was formerly in this sea, doubts this fact, so that I have left them uncoloured: at the same time I may remark, that these two shoals make a nearer approach to the atoll-like structure than any other within the E. Indian Archipelago. Southward of these shoals there are other low islands and irregular coral-reefs; and in the space of sea, north of the great volcanic chain, from Timor to Java, we have other islands, such as the *Postillions*, *Kalatoa*, *Tokan-Bessees*, &c., which are chiefly low, and are surrounded by very irregular and distant reefs. From the imperfect charts I have seen, I have not been able to decide whether they belong to the atoll or barrier class, or whether they merely fringe submarine banks, and gently sloping land. In the Bay of *Bonin*, between the two southern arms of Celebes, there are numerous coral-reefs; but none of them seem to have an atoll-like structure. I have, therefore, not coloured any of the islands in this part of the sea; I think it, however, exceedingly probable that some of them ought to be blue. I may add that there is a harbour on the S.E. coast of *Bouton*, which, according to an old chart, is formed by a reef, parallel to the shore, with deep water within; and in the Voyage of the *Coquille*, some neighbouring islands are represented with distant reefs, but I do not know whether with deep water within. I have not thought the evidence sufficient to permit me to colour them.

Sumatra.—Commencing with the west coast and outlying islands; *Engano* Island is represented in the published chart as surrounded by a narrow reef, and Napier, in his Sailing Directions, speaks of the reef being of coral (also Horsburgh, vol. ii. p. 115); coloured red. *Rat* Island (3° 51′ S.) is surrounded by reefs of coral, partly dry at low water (Horsburgh, vol. ii. p. 96).—*Trieste* Island (4° 2′ S.): the shore is represented, in a chart which I saw at the India House, as fringed in such a manner, that I feel sure the fringe consists of coral; but as the island is so low that the sea sometimes flows quite over it (Dampier, Voyage, vol. i. p. 474) I have not coloured it.—*Pulo Dooa* (lat. 3°): it is said in an old chart that there are chasms in the reef round the island, admitting boats to the watering-place, and that the southern islet consists of a mass of sand and coral.—*Pulo Pisang*: Horsburgh (vol. ii. p. 86) says that the rocky coral-bank, which stretches about 40 yards from the shore, is steep all round: in a chart, also, which I have seen, the island is represented as regularly fringed.—*Pulo Mintao* is lined with reefs on its west side (Horsburgh, vol. ii. p. 107).—*Pulo Baniak*: the same authority (vol. ii. p. 105), speaking of a part, says it is faced with coral-rocks.—*Minguin* (3°

36′ N.); a coral reef fronts this place, and projects into the sea nearly a quarter of a mile (Notices of the Indian Archipelago, published at Singapore, p. 105).—*Pulo Brassa* (5° 46′ N.): a reef surrounds it at a cable's length (Horsburgh, vol. ii. p. 60). I have coloured all the above specified points red. I may here add, that both Horsburgh and Mr. Moor (in the Notices just alluded to) frequently speak of the numerous reefs and banks of coral on the west coast of Sumatra; but they nowhere have the structure of a barrier-reef, and Marsden (History of Sumatra) states that where the coast is flat, the fringing-reefs extend far from it. The northern and southern points, and the greater part of the east coast, are low, and faced with mud banks, and therefore without coral.

Nicobar Islands.—The chart represents the islands of this group as fringed by reefs. With regard to *Great Nicobar*, Captain Moresby informs me that it is fringed by reefs of coral, extending between 200 and 300 yards from the shore. The *Northern Nicobars* appear so regularly fringed in the published charts, that I have no doubt the reefs are of coral. This group, therefore, is coloured red.

Andaman Islands.—From an examination of the MS. chart, on a large scale, of these islands, by Captain Arch. Blair, in the Admiralty, several portions of the coast appear fringed; and as Horsburgh speaks of coral-reefs being numerous in the vicinity of these islands, I should have coloured them red, had not some expressions in a paper in the Asiatic Researches (vol. iv. p. 402) led me to doubt the existence of reefs; uncoloured.

The coast of *Malacca*, *Tanasserim*, and the coasts northward, appear in the greater part to be low and muddy: where reefs occur, as in parts of *Malacca* Straits, and near *Singapore*, they are of the fringing kind; but the water is so shoal, that I have not coloured them. In the sea, however, between Malacca and the west coast of Borneo, where there is a greater depth from 40 to 50 fathoms, I have coloured red some of the groups, which are regularly fringed. The northern *Natunas* and the *Anambas* Islands are represented in the charts on a large scale, published in the atlas of the Voyage of the *Favourite* [by La Place, 1831], as fringed by reefs of coral, with very shoal water within them. *Tumbelan* and *Bunoa* Islands (1° N.) are represented in the English charts as surrounded by a very regular fringe.—*St. Barbes* (0° 15′ N.) is said by Horsburgh (vol. ii. p. 279) to be fronted by a reef, over which boats can land only at high water.—The shore of *Borneo*, at *Tunjong Apee*, is also fronted by a reef, extending not far from the land (Horsburgh, vol. ii. p. 468). These places I have coloured red; although with some hesitation, as the water is shallow. I might perhaps have added *Pulo Leat*, in Gaspar Strait, *Lucepara* and *Carimata*; but as the sea is confined and shallow, and the reefs not very regular, I have left them uncoloured.

The water deepens very gradually from the whole west coast of *Borneo*; and I cannot make out that it has any reefs of coral. The islands, however, off the northern extremity, and near the S.W. end of *Palawan*, are fringed by very distant coral reefs: thus the reefs off *Balabac* are no less than five miles from the land; but the sea, in the whole of this district, is so shallow, that the reefs might be expected to extend very far from the land. I have not, therefore, thought myself authorized to colour them. The N.E. point of Borneo, where the water is very shoal, is connected with Magindanao by a chain of islands called the *Sooloo Archipelago*, about which I have been able to obtain very little information; *Pangootaran*, although ten miles long, entirely consists of a bed of coral-rock (Notices of E. Indian Arch. p. 58): I believe from Horsburgh that the island is low; not coloured.—*Tahow* Bank, in some old charts, appears like a submerged atoll; not coloured.

Forrest (Voyage, p. 21) states that one of the islands near Sooloo is surrounded by coral-rocks; but there is no distant reef. Near the S. end of *Basselan*, some of the islets in the chart accompanying Forrest's Voyage appear fringed with reefs; hence I have coloured, though unwillingly, parts of the Sooloo group red. The sea between Sooloo and Palawan, near the shoal coast of Borneo, is interspersed with irregular reefs and shoal patches; not coloured: but in the northern part of this sea there are two low islets, *Cagayanes* and *Cavilli*, surrounded by extensive coral-reefs; the breakers round the latter (Horsburgh, vol. ii. p. 513) extend five or six miles from a sand-bank, which forms the only dry part; these breakers are steep to outside: there appears to be an opening through the reef on one side, with four or five fathoms within: from this description, I strongly suspect that Cavilli ought to be considered an atoll; but, as I have not seen any chart of it, even on a moderately large scale, I have not coloured it. The islets off the northern end of *Palawan* are, like those off the southern end, fringed by reefs, some way distant from the shore, but the water is exceedingly shallow; uncoloured. The western shore of Palawan will be treated of under the China Sea.

Philippine Archipelago.—A chart on a large scale of *Appoo* Shoal, which lies near the S.E. coast of Mindoro, has been executed by Captain D. Ross: it appears atoll-formed, but with rather an irregular outline; its diameter is about ten miles; there are two well-defined passages leading into the lagoon; close outside and all round the reef, there is no bottom with 70 fathoms; coloured blue.—*Mindoro*: the N.W. coast is represented in several charts as fringed by a reef; and *Luban* Island is said by Horsburgh (vol. ii. p. 436) to be 'lined by a reef.'—*Luzon*: Mr. Cuming, who has lately investigated with so much success the Natural History of the Philippines, informs me that a length of about three miles of the shore northward of

Point St. Jago is fringed by a reef; as are (Horsburgh, vol. ii. p. 437) the Three Friars off Silanguin Bay. Between Point Capones and Playa Honda, the coast is 'lined by a coral-reef, stretching out nearly a mile in some places' (Horsburgh); and Mr. Cuming visited some fringing-reefs on other parts of the coast, namely, near Puebla, Iba, and Mansinglor. In the neighbourhood of Solon-solon Bay, the shore is lined (Horsburgh, vol. ii. p. 439) by coral-reefs, stretching out a great way: there are also reefs about the islets off Solamague; and as I am informed by Mr. Cuming, near St. Catalina, and a little north of it. The same gentleman informs me that there are reefs on the S.E. point of this island in front of Samar, extending from Malalabon to Bulusan. These appear to be the principal fringing-reefs on the coasts of Luzon; and they have all been coloured red. Mr. Cuming informs me that none of them have deep water within; although it appears from Horsburgh that some few extend to a considerable distance from the land. Within the Philippine Archipelago, the shores of the islands do not appear to be commonly fringed, with the exception of the S. shore of *Masbate*, and nearly the whole of *Bohol*; which are both coloured red. On the S. shore of *Magindanao*, Bunwoot Island is surrounded (according to Forrest, Voyage, p. 253) by a coral-reef, which in the chart appears one of the fringing class. With respect to the eastern coasts of the archipelago, I have not been able to obtain any account. Prof. Semper has recently published a notice (Zeitschr. f. Wissensch. Zoologie, Bd. xiii. 1863, p. 558) respecting the coral-reefs of this archipelago. It appears that some of them come under the class of barrier-reefs; but as I have not seen a chart on a large scale, and know nothing about the depth of the water outside the reefs, nor about the slope of the encircled land, I cannot judge whether they properly come under the barrier class.

Babuyan Islands.—Horsburgh says (vol. ii. p. 442) coral-reefs line the shores of the harbour in Fuga; and the charts show there are other reefs about these islands. *Camiguin* has its shore in parts lined by coral-rock (Horsburgh, p. 443); and about a mile off shore the depth is between 30 and 35 fathoms. The plan of Port San Pio Quinto shows that its shores are fringed with coral; coloured red.—Bashee Islands: Horsburgh, speaking of the southern part of the group (vol. ii. p. 445), says the shores of both islands are fortified by a reef, and through some of the gaps in it the natives can pass in their boats in fine weather; the bottom near the land is coral-rock. From the published charts, it is evident that several of these islands are regularly fringed; coloured red. The northern islands are left uncoloured, as I have been unable to find any account of them.—Formosa: the shores, especially the western one, seem composed chiefly of mud and sand, and I cannot make out that they are anywhere lined by reefs, except in a harbour (Horsburgh, vol. ii. p. 449) at the extreme northern point: hence, of course, the whole of this island is left uncoloured. The small adjoining islands are in the same case.—Patchow, or Madjiko-sima Groups: *Patchuson*: Captain Broughton says (Voyage to the N. Pacific, p. 191) that boats, with some difficulty, can pass through the coral-reefs, which extend along the coast, nearly half a mile off it. His boats were well sheltered within the reef; but it does not appear that the water is deep there. Outside the reef the depth is very irregular, varying from 5 to 50 fathoms; the form of the land is not very abrupt; coloured red.—*Taypin-san*: from the description given by the same author (p. 195) it appears that a very irregular reef extends from the southern island to the distance of several miles; but whether it encircles a space of deep water is not evident; nor, indeed, whether these outlying reefs are connected with those more immediately adjoining the land; left uncoloured. I may here add that the shore of *Kumi* (lying west of Patchow) has a narrow reef attached to it in the plan, in La Peyrouse's Atlas; but in the account of the voyage it is not stated to be of coral; uncoloured.—LOO CHOO: the greater part of the coast of this moderately hilly island is skirted by reefs, which do not extend far from the shore, and which do not leave a channel of deep water within them, as may be seen in the charts accompanying Captain B. Hall's Voyage to Loo Choo (see also remarks in Appendix, p. xxi. and xxv.) There are, however, some ports with deep water, formed by reefs, in front of the valleys, in the same manner as happens at Mauritius. Captain Beechey, in a letter to me, compares these reefs with those encircling the Society Islands; but there appears to be a marked difference between them, in the less distance at which the Loo Choo reefs lie from the land with relation to the probable submarine inclination of the land, and in the absence of an interior deep-water channel. Hence I have classed these reefs, with fringing-reefs, and coloured them red.—PESCADORES (west of Formosa): Dampier (vol. i. p. 416) has compared the appearance of these islands to the southern parts of England; they are interlaced with coral-reefs; but as the water is very shoal, and as spits of sand and gravel (Horsburgh, vol. ii. p. 450) extend far out from them, it is impossible to decide whether the reefs are of coral.

CHINA SEA.[1]—Proceeding from north to south, we first meet the *Pratas* Shoal (lat. 20° N.), which, according to Horsburgh (vol. ii. p. 335), is composed of coral, is of a circular form, and has a low islet on it. The reef is on a level with the water's edge, and when the sea runs high,

[1] [The China Sea has in it many atolls. They are of large size, though not complete, most of them having the rim submerged, with the reef awash and islands on parts. Some are wholly submerged like *Macclesfield* Bank.]

there are breakers nearly all round; 'the water within seems pretty deep in some places; although steep in most parts outside, there appear to be several parts where a ship might find anchorage outside the breakers;' coloured blue.—The *Paracells* have been accurately surveyed by Captain D. Ross, and charts on a large scale published: only a few low islets have been formed on these shoals, and this seems to be a general circumstance in the China Sea; the sea close outside these reefs is deep; several of them have a lagoon-like structure; in other cases separate islets (*Prattle*, *Robert*, *Drummond*, &c.) are so arranged round a moderately shallow space as to appear as if they had once formed one large atoll.—*Bombay* Shoal (one of the Paracells) has the form of an annular reef, and is 'apparently deep within;' it seems to have an entrance (Horsburgh, vol. ii. p. 332) on the west side; it is very steep outside.—*Discovery* Shoal, also, is of an oval form, with a lagoon-like space within, and three openings leading into it, in which there is a depth from 2 to 20 fathoms. Outside, at the distance (Horsburgh, vol. ii. p. 333) of only twenty yards from the reef, soundings could not be obtained. The Paracells are coloured blue.—*Macclesfield* Bank is a coral bank of great size, lying east of the Paracells; some parts are level, with a sandy bottom, but generally the depth is very irregular, and intersected by deep channels; not coloured. —*Scarborough* Shoal: this coral shoal is engraved with a double row of crosses, forming a circle, as if there was deep water within the reef: close outside no bottom was found with a hundred fathoms; coloured blue.— The sea off the west coast of Palawan and the northern part of Borneo is strewed with shoals: *Swallow* Shoal, according to Horsburgh (vol. ii. p. 431), 'is formed, *like most* of the shoals hereabouts, of a belt of coral-rocks, with a basin of deeper water within.'—*Half-Moon* Shoal has a similar structure; Captain D. Ross describes it as a narrow belt of coral-rock, 'with a basin of deeper water in the centre,' and deep sea close outside.—*Bombay* Shoal appears (Horsburgh, vol. ii. p. 432) 'to be a basin of smooth water surrounded by breakers.' I have coloured these three shoals blue.—The *Paraquas* Shoals are of a circular form, with deep gaps running through them; not coloured. A bank, gradually shoaling to the depth of 30 fathoms, extends to a distance of about 20 miles from the northern part of *Borneo*, and to 30 miles from the southern part of *Palawan*; near the land this bank appears tolerably free from danger, but a little further out is thickly studded with coral-reefs, which do not generally rise to the surface; some of them are very steep, whilst others have a fringe of shoal-water round them. I should have thought that these shoals had level surfaces, had it not been for a statement made by Horsburgh, 'that most of the shoals hereabouts are formed of a belt of coral:' I have not coloured them.—The coasts of *China*, *Tonquin*, and *Cochin-China*, forming the western boundary of the China Sea, appear to be without reefs: with regard to the two last-mentioned coasts, I judge from an examination of the charts on a large scale in the atlas of the Voyage of the *Favourite*.

INDIAN OCEAN.—*South Keeling* atoll has been specially described in my first chapter. Nine miles north of it lies North Keeling, a very small atoll, surveyed by the *Beagle*, the lagoon of which is dry at low water.—*Christmas* Island,[1] lying to the east, is a high island, without, as I have been

[1] [This island is described in letters to *Nature* by Captains Wharton and Maclear (vol. xxxvi. pp. 12, 413, and vol. xxxvii. p. 203; cf. also p. 222). It is 190 miles from Java, the intervening ocean attaining a depth of 2,430 fathoms. It consists of coral limestone, no other rock being visible, which rises from the sea to a height of about 1,200 feet. At the base is commonly a cliff about 30 feet high, and there are two upper tiers of cliffs: one is described as being from 200 to 300 feet high. A depth of 100 fathoms is found at one or two cables' length from the water's edge at the base of the lowest line of cliffs.]

informed, any reef.—CEYLON: a space of about 80 miles in length on the south-western and southern shores of these islands has been described by Mr. Twynam (Naut. Mag. 1836, pp. 365 and 518); and parts appear to be regularly fringed by coral-reefs, which extend from a quarter to half a mile from the shore. These reefs are in places breached, and afford safe anchorage for the small trading craft. Outside, the sea gradually deepens; there is 40 fathoms about six miles off shore: I have coloured these reefs red. In the published charts of Ceylon, reefs also appear to fringe several parts of the south-eastern shores, coloured red.—At Venloos Bay the shore is likewise fringed. North of Trincomalee there are also reefs of the same character. The sea off the northern part of Ceylon is exceedingly shallow; and therefore I have not coloured the reefs which partially fringe portions of the shores, and the adjoining islets, as well as the Indian promontory of *Madura*.

CHAGOS, MALDIVA, AND LACCADIVE ARCHIPELAGOES.[1]—These three great groups of atolls and atoll-formed banks, have been often referred to in this volume, and are now well known from the admirable surveys of Captain Moresby and Lieut. Powell. Their published charts are worthy of the most attentive examination. In the *Laccadive* group, the atoll-like structure is less evident than in the Maldivas; nevertheless the islands are all low, not exceeding the usual height of coral formations (see Lieut. Wood's account, Geograph. Journ. vol. vi. p. 29), and most of the reefs are circular; within several of them, as I am informed by Captain Moresby, there is deepish water; these, therefore, have been coloured blue. Directly north of the Laccadives, and almost forming part of the same group, there is a long, narrow, slightly-curved bank, rising out of the depths of the ocean, composed of sand shells and decayed coral, with from 23 to 30 fathoms on it. I have no doubt that it has

[1] [See Appendix II.]

had the same origin with the other atoll-like banks; but as it does not deepen towards the centre, I have not coloured it. I might have referred to other authorities regarding these three archipelagoes; but after the publication of the charts by Captain Moresby (to whose personal kindness in giving me much information I am exceedingly indebted), this would have been superfluous.

The *Sahia de Malha* Bank consists of a series of narrow banks, with from 8 to 16 fathoms on them; they are arranged in a semi-circular manner, round a space about 40 fathoms in depth, sloping to the S.E. to unfathomable depths; they are steep on both sides, but more especially on the ocean-side. Hence this bank closely resembles in structure, and I may add from Captain Moresby's information in composition, Pitt's Bank in the Chagos group; and Pitt's Bank must, from what we know about the great Chagos Bank, be considered as a sunken, half-destroyed atoll; hence coloured blue.—*Cargados Carajos* Bank: its southern portion consists of a large, curved coral-shoal, with some low islets on the eastern edge, and likewise some on the western side, between which there is a depth of about 12 fathoms: northward, a great bank extends. I cannot (probably owing to the want of perfect charts) refer this reef and bank to any class; therefore not coloured.—*Ile de Sable* is a little island, lying west of C. Carajos, only some toises in height (Voyage of the *Favourite*, vol. i. p. 130); it is surrounded by reefs; but its structure is unintelligible to me. There are some small banks north of it, of which I can find no clear account.—*Mauritius*: the reefs round this island have been described in the chapter on fringing-reefs; coloured red.—*Rodriguez*: the coral-reefs here are very extensive; in one part they project even five miles from the shore. As far as I can make out, there is no deep-water channel within them; and the sea outside does not deepen very suddenly. The outline, however, of the land appears to be (Life of Sir J. Mackintosh, vol. ii. p. 165) hilly and rugged. I am unable to decide whether these reefs belong to the barrier class, as seems probable from their great extension, or to the fringing class; uncoloured.[1]—*Bourbon*: the greater part of the shores of this island are without reefs; but Captain Carmichael (Hooker's Bot. Misc.) states that a portion, 15 miles in length, on the S.E. side, is imperfectly fringed with coral-reefs; I have not thought this sufficient evidence for colouring the island.

Seychelles.—The rocky islands of primary formation, composing this group, rise from a very extensive and tolerably level bank, having a depth of between 20 and 40 fathoms. In Captain Owen's chart, and in that in the atlas of the Voyage of the *Favourite*, it appears that the east side of *Mahé* and the adjoining islets of *St. Anne* and *Cerf*, are regularly fringed by coral-reefs. A portion of the S.E. part of *Curieuse* Island, the N. and part of the S.W. shore of *Praslin* Island, and the whole west side of *Digue* Island, appear fringed. From a MS. account of these islands by Captain F. Moresby, in the Admiralty, it appears that *Silhouette* is also fringed; he states that all these islands are formed of granite and quartz, that they rise abruptly from the sea, and that 'coral-reefs have grown round them, and project for some distance.' Dr. Allan of Forres, who visited these islands, informs me that there is no deep water between the reefs and the shore. The above specified points have been coloured red. *Amirantes* Islands: the small islands of this neighbouring group, according to the MS. account of them by Captain F. Moresby, are situated on an extensive bank; they consist of the débris of corals and shells; they are only about 20 feet in height, and are

[1] [There are fringing-reefs of a width of four and a half miles to leeward and of a few yards to windward. Outside them the water shoals gradually. The island is high and basaltic, with upraised coral in many places up to a height of about 50 feet above the sea.—Capt. Wharton. See Appendix II.]

environed by reefs, some attached to the shore, and some rather distant from it.—I have taken pains to procure plans and information regarding the several islands which lie to the S.E. and S.W. of the Seychelles; from accounts given me by Captain F. Moresby and Dr. Allan, it appears that the greater number—namely, *Platte*, *Alphonse*, *Coetivi*, *Galega*, *Providence*, *St. Pierre*, *Astova*, *Assomption*, and *Glorioso*[1]—are low, formed of sand or coral-rock, and irregularly shaped; they are situated on very extensive banks, and are in connection with great coral-reefs. Galega is said by Dr. Allan to be rather higher than the others; and St. Pierre is described by Captain F. Moresby as being cavernous throughout, and as not consisting of either limestone or granite. These islands, as well as the Amirantes, certainly are not atoll-formed, and they seem to differ from all other groups; I have not coloured them; but probably the reefs belong to the fringing class. Their formation is attributed both by Dr. Allan and Captain F. Moresby, to the action of the currents, here exceedingly violent, on banks which no doubt have had an independent geological origin. They resemble in many respects some of the islands and banks in the West Indies, which owe their origin to a similar agency, in conjunction with an elevation of the entire area. In close vicinity to the above several islands, there are three others of an apparently different nature; first, *Juan de Nova*, which appears from some plans and accounts to be an atoll, but from others this does not appear to be the case;[2] not coloured. Secondly, *Cosmoledo*: 'this group consists of a ring of coral, ten leagues in circumference, and a quarter of a mile broad in

[1] [*Platte*, *Coetivi*, and *Galega* have narrow fringing-reefs.—Capt. Wharton.]

[2] [*Juan de Nova* is an imperfect atoll. The islands on its eastern or weather side have been raised about 8 or 10 feet. The western part is submerged.—Capt. Wharton. A coral-bank, with 5 fathoms water on it stretches off the southern end.—Lieut. Chas. Smith.]

some places, inclosing a magnificent lagoon, into which there did not appear a single opening' (Horsburgh, vol. i. p. 151); coloured blue.[1] Thirdly, *Aldabra*: consists of three islets, about 25 feet in height, with red cliffs (Horsburgh, vol. i. p. 176), surrounding a very shallow basin or lagoon. The sea is profoundly deep close to the shore. Viewing this island in a chart, it would be thought to be an atoll; but the foregoing description shows that there is something different in its nature; Dr. Allan also states that it is cavernous, and that the coral-rock has a vitrified appearance. Is it an upheaved atoll, or the crater of a volcano?—uncoloured.[2]

COMORO GROUP.—*Mayotta*, according to Horsburgh (vol. i. p. 216, 4th edit.), is completely surrounded by a reef, which runs at the distance of three, four, and in some places even five miles from the land; in an old chart, published by Dalrymple, a depth in many places of 36 and 38 fathoms is laid down within the reef. In the same chart, the space of open water within the reef is in some parts even more than three miles wide: the land is bold and peaked; this island, therefore, is encircled by a well-characterized barrier-reef, and is coloured pale blue.—*Johanna*: Horsburgh says (vol. i. p. 217), this island from the N.W. to the S.W. point, is bounded by a reef, at the

[1] [The islands on the ring have been upraised about 10 feet.—Capt. Wharton.]

[2] [*Aldabra* is an upraised atoll 22 miles long; the lagoon is nearly dry at low water. The height of the rock on the encircling islands is 20 feet, and it descends on both sides to the water for that distance in a cliff, though on the lagoon side the coral is much disintegrated by the mangroves. This is the only island in the Indian Ocean where the gigantic tortoise, of a distinct species, exists.—Capt. Wharton. Horsburgh's account is misleading, as neither the red cliffs nor high forests were to be found. It is entirely composed of coral-rock with a fine growth of mangroves, inclosing an extensive but shallow lagoon. There is a narrow riband of 5 fathoms water running 3 miles into the lagoon from the N.W. corner.—Lieut. Chas. Smith.]

distance of two miles from the shore; in some parts, however, the reef must be attached, since Lieut. Boteler (Narr. vol. i. p. 161) describes a passage through it, within which there is room only for a few boats. Its height, as I am informed by Dr. Allan, is about 3,500 feet; it is very precipitous, and is composed of granite, greenstone, and quartz; coloured blue.—*Mohilla*: on the S. side of this island there is anchorage between a reef and the shore in from 30 to 45 fathoms (Horsburgh, vol. i. p. 214); it appears also encircled in Captain Owen's chart of Madagascar; coloured blue.—*Great Comoro* Island is, as I am informed by Dr. Allan, about 8,000 feet high, and apparently volcanic; [1] it is not regularly encircled; but reefs of various shapes and dimensions jut out from every headland on the W., S., and S.E. coasts, inside of which reefs there are channels, often parallel with the shore, with deep water. On the N.W. coasts the reefs appear attached to the shore. The land near the coast is in some places bold, but generally speaking it is flat; Horsburgh says (vol. i. p. 214), the water is profoundly deep close to the *shore*, from which expression I presume some parts are without reefs. From this description, I apprehend the reef belongs to the barrier class; but I have not coloured it, as most of the charts which I have seen represent the reefs round it as very much less extensive than round the other islands of the group.

Madagascar.—My information is chiefly derived from the published charts by Captain Owen, and the accounts given by him and by Lieut. Boteler. Commencing at the S.W. extremity of the island: towards the northern part of *Star* Bank (in lat. 25° S.) the coast for ten miles is fringed by a reef; coloured red. The shore immediately S. of *St.*

[1] [Great Comoro is volcanic and about 8,600 feet high. There is a little fringing-reef on the north and on the south-east side.—Lieut. Chas. Smith.]

Augustin's Bay appears fringed; but *Tullear* Harbour, directly N. of it, is formed by a narrow reef ten miles long, extending parallel to the shore, with from 4 to 10 fathoms within it. If this reef had been more extensive, it must have been classed as a barrier-reef; but as the line of coast falls inwards here, a submarine bank perhaps extends parallel to the shore, which has offered a foundation for the growth of the coral; I have left this part uncoloured. From *lat.* 22° 16′ *to* 21° 37′, the shore is fringed by coral-reefs (see Lieut. Boteler's Narrative, vol. ii. p. 106), less than a mile in width, and with shallow water within. There are outlying coral shoals in several parts of the offing, with about 10 fathoms between them and the shore, and the depth of the sea one mile and a half seaward, is only about 30 fathoms. The part above specified is engraved on a large scale; and as in the charts on rather a smaller scale the same fringe of reef extends as far as lat. 23° 15′, I have coloured the whole of this part of the coast red. The islands of *Juan de Nova* (in lat. 17° S.) appear in the charts on a large scale to be fringed, but I have not been able to ascertain whether the reefs are of coral; uncoloured. The main part of the west coast appears to be low, with outlying sand banks, which Lieut. Boteler (vol. ii. p. 106) says, 'are faced on the edge of deep water by a line of sharp-pointed coral-rocks.' Nevertheless I have not coloured this part, as I cannot make out by the charts that the coast itself is fringed. The headlands of *Narrenda* and *Passandava Bays* (14° 40′) and the islands in front of *Radama harbour* are presented in the plans as regularly fringed, and have accordingly been coloured red. With respect to the *East Coast of Madagascar*, Dr. Allan informs me, that the whole line of coast, from *Tamatave* in 18° 12′ to *C. Amber* at the extreme northern point of the island, is bordered by coral-reefs. The land is low, uneven, and gradually rises from the coast. From Captain Owen's charts, the existence of reefs, which evidently belong to the fringing class, N. of *British Sound* and near *Ngoncy*, might also have been inferred. Lieut. Boteler (vol. i. p. 155) speaks of 'the reef surrounding the island of *St. Mary's* at a small distance from the shore.' In a previous chapter I have described, from the information of Dr. Allan, the manner in which the reefs extend in N.E. lines from the headlands on this coast, thus sometimes forming rather deep channels within them: this seems caused by the currents, the reefs springing up from the submarine prolongations of the sandy headlands. The above specified portion of the coast is coloured red.[1] The remaining S.E. portions do not appear in any published chart to possess reefs of any kind; and the Rev. W. Ellis believes that there are none.

East Coast of Africa.—The northern parts appear, for a considerable space, to be without reefs. My information, I may observe, is derived from the survey by Captain Owen, together with his Narrative; and that by Lieut. Boteler. At *Mukdeesha* (2° 1′ N.) there is a coral-reef extending four or five miles along the shore (Owen's Nar. vol. i. p. 357), which in the chart lies at a distance of a quarter of a mile from the shore, and has within it from 6 to 10 feet of water: this then is a fringing-reef and is coloured red. From *Juba*, a little S. of the equator, to *Lamoo* (in 2° 20′ S.) 'the coast and islands are formed of madrepore' (Owen's Narrative, vol. i. p. 363). The chart of this part (entitled *Dundas* Islands) presents an extraordinary appearance; the coast of the mainland is quite straight, and is fronted at the average distance of two miles, by exceedingly narrow, straight islets, fringed with reefs. Within this chain of islets, there are extensive tidal flats and muddy bays, into which many rivers enter: the depth of these spaces varies from one to four fathoms—the latter

[1] [The northern end of Madagascar, of volcanic origin, has upraised coral, and is fringed with living coral.—Capt. Wharton.]

depth not being common, and about 12 feet the average. Outside the chain of islets, the sea, at the distance of a mile, varies in depth from 8 to 15 fathoms. Lieut. Boteler (Nar. vol. i. p. 369) describes the muddy bay of *Patta*, which seems to resemble other parts of the coast, as fronted by small, narrow, level islets formed of decomposing coral, the margin of which is seldom of greater height than 12 feet, overhanging the rocky surface from which the islets rise. Knowing that the islets are formed of coral, it is I think scarcely possible to view the coast, and not at once conclude that we here see a fringing-reef, which has been upraised a few feet: the unusual depth of from two to four fathoms within some of these islets, is probably due to the mud of the rivers having prevented the growth of coral near the shore. As several parts of this line of coast are undoubtedly fringed by living reefs, I have coloured it red.—*Maleenda* (3° 20′ S.): in the plan of the harbour, the south headland appears fringed; and in Owen's chart on a larger scale, the reefs are seen to extend nearly 30 miles southward; coloured red. *Mombas* (4° 5′ S.): the island which forms the harbour 'is surrounded by cliffs of madrepore, capable of being rendered almost impregnable' (Owen's Nar. vol. i. p. 412). The shore of the mainland, N. and S. of Mombas, is regularly fringed by a coral-reef at a distance from half a mile to a mile and a quarter from the land; within the reef the depth is from 9 to 15 feet; outside the reef the depth at rather less than half a mile is 30 fathoms. From the charts it appears that a space about 36 miles in length, is here fringed; coloured red.—*Pemba* (5° S.) is an island of coral formation, level, and about 200 feet in height (Owen's Nar. vol. i. p. 425); it is 35 miles long, and is separated from the mainland by a deep sea. The outer coast is represented in the charts as regularly fringed; coloured red. The mainland in front of Pemba is likewise fringed.—*Zanzibar* resembles Pemba in most respects; its southern half on the western side and the neighbouring islets are fringed; coloured red.[1] On the

[1] [The following interesting account of Zanzibar is contained in a letter from Captain Wharton, found among Mr. Darwin's papers :—

'Zanzibar seems to me to have undergone several motions of subsidence and upheaval, the latter being the latest; it appears now to have been for many years nearly stationary.

'The island at present is surrounded with a nearly perfectly flat, dead, altered coral ledge, more or less dry at low water, without doubt the result of long action of the sea on the upheaved ancient and compressed coral of which the island is principally formed. This action has worn away the sea face of the land to the level of low water for a distance, in some instances, of $1\frac{1}{2}$ miles inside the original high-water line, which now remains as a steep rim, dropping to 10 and 20 fathoms almost immediately, with (on the outside of the island) 100 fathoms within a quarter of a mile. I could see no sign of this ledge extending seaward, though there is living coral on its steep face visible a few feet below at low water, but this is not abundant, as it is on some of the detached reefs off the island.

'The present high-water line of the island at the back of this flat area is, for the major part of its perimeter, a cliff of the same old coral from 10 to 20 feet in height, undermined by the waves, and overhanging, in some places, to a marvellous extent, showing the hardness and cohesion of the material, and giving a notion of the long period of time necessary to wear it away. As a further proof of this is the fact of very few lately detached pieces being seen at the foot of the cliffs, though the blocks, when they *do* fall, must be large and not easily moved by the sea.

'In most parts of the island the tops of these low cliffs run back from the sea nearly level for a greater or less distance, showing water-worn coral wherever the surface rock is exposed, and indicating another stationary period or one of very slow upheaval. Out of this level the higher lands of the island rise.

'Zanzibar is intersected by what may be regarded as 3 lines of hills running north and south, the highest of them being 450 feet above the sea.

'I regret to add that I cannot say of what formation these hills may be; I cannot call to mind any rock beyond the coral, which crops out at considerable heights (in one instance 250 feet), but there is a good deal of hardened clay or mudstone, which generally appears main land, a little S. of Zanzibar, there are some banks parallel to the coast, which I should have thought had been

in the ravines, &c., and on the bare sides of the hills, but there may be other rock lying under this.

'The valleys, or rather flat plains, between the ranges of hills, are mostly (particularly to the south) coral, worn and roughened, undoubtedly by water. These are generally about 50 feet above the sea. Several isolated hills of coral stand on these plains, their bases being undermined and worn precisely as the present cliffs, and their flat summits present the same appearance.

'The whole thickness of the coral of Zanzibar must be very great.

'The coast of the mainland about Zanzibar is similar to the island, and, as far as I know them, Pemba, Monfia, and the coast far north and south are the same.

'The outlying and detached reefs are of two kinds, those growing up with living coral, and those of dead coral, like the island washing gradually away. Of these latter many still have level islets and rocks on them, remnants of a former upheaval; others afford a foundation to coral sand-banks that are dry high at low water, and others are perfectly smooth and covered at high water, being just awash at low tide. Of the second of these, are the reefs referred to by you at page 258 as described by Lieut. Boteler as sand-banks. That description is erroneous.

'One island, mentioned in the beginning of the century, had by Capt. Owen's time (1825) been reduced to a sand-head always visible. Now (1874) even this has entirely disappeared, and the reef on which it stood is flat and bare.

'This is the only instance in which I have been able to make any *reliable* comparison between Capt. Owen's chart and mine, as to reduction of reefs.

'As to the perhaps still more interesting question of growing coral, I have been unable to make any such, as Owen's work was so cursory and hurried that it is impossible to know whether he struck the shoalest part of a reef.

'There is, indeed, one instance that, if not isolated, might have been of use. He describes a particular shoal as being a 'knoll with deep water all round,' and in his chart, 7 fathoms is marked on it and 25 fathoms around. That patch has now only 1½ fathoms on it and 20 fathoms round.

'This, altogether, looks like upheaval of the whole bottom; but as in most instances our soundings agree remarkably well, I cannot think

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formed of coral, had it not been said (Boteler's Nar. vol. ii. p. 39) that they were composed of sand: not coloured.—*Latham's* Bank is a small island fringed by coral-reefs; but being only 10 feet high it has not been coloured.—*Monfeea* is an island of the same character as Pemba: its outer shore is fringed, and its southern extremity is connected with Keelwa Point on the main land by a chain of islands fringed by reefs; coloured red. The four last-mentioned islands resemble in many respects some of the islands in the Red Sea, which will presently be described.—*Keelwa*: in a plan of the shore, a space of 20 miles N. and S. of this place is fringed by reefs, apparently of coral; these reefs are prolonged still further southwards in Owen's general chart. In the plans of the rivers *Lindy* and *Monghow* (9° 59′ and 10° 7′ S.) the coast seems to have the same structure, coloured red.—*Querimba Islands* (from 10° 40′ to 13° S.): a chart on a large scale is given of these islands; they are low and of coral formation (Boteler's Nar. vol. ii. p. 54); and generally have extensive reefs projecting from them, which are dry at low water, and which on the outside rise abruptly from a deep sea; on the inside they are separated from the continent by a channel, or rather a succession of bays, with an average depth of 10 fathoms. The small headlands on the continent also have coral banks attached to them; and the Querimba islands and banks are placed on the line of prolongation of these headlands, and are separated from them by very shallow channels. It is evident that whatever cause, whether the

that that can be so. On the other hand, the reef is so small and the bottom so clear, that it is difficult to understand how they could have missed the shoaler water if it existed then, as it is very plain to see.

'Other reefs, with from 7 to 10 fathoms on them, seem not to have altered.

'W. J. S. WHARTON, Commander R.N.

'Mauritius: Sept. 15, 1874.]

drifting of sediment or subterranean movements, produced the headlands, likewise produced, as might have been expected, submarine prolongations to them; and these towards their outer extremities have since afforded a favourable basis for the growth of coral-reefs, and subsequently for the formation of islets. As these reefs clearly belong to the fringing class, the Querimba Islands have been coloured red.—*Monabila* (13° 32′ S.): in the plan of this harbour, the headlands outside are fringed by reefs apparently of coral; coloured red.—*Mozambique* (15° S.): the outer part of the island on which the city is built, and the neighbouring islands are fringed by coral-reefs; coloured red. From the description given in Owen's Nar. (vol. i. p. 162) the shore from *Mozambique* to *Delagoa Bay* appears to be low and sandy: many of the shoals and islets off this line of coast are of coral formation; but from their small size and lowness, it is not possible, from the charts, to know whether they are truly fringed. Hence this portion of coast is left uncoloured, as are likewise those parts more northward, of which no mention has been made in the foregoing pages, from the want of information.[1]

PERSIAN GULF.—From the charts lately published on a large scale by the East Indian Company, it appears that several parts, especially the southern shores, are fringed by coral-reefs; but as the water is very shallow, and as there are numerous sand-banks, which are difficult to distin-

[1] [The whole of the eastern coast of Africa, from the equator to Mozambique (at least) is of upraised coral, and so are the outlying islands. Fringing-reefs occur everywhere, partly formed by the action of the sea wearing back the upraised coral, and partly by living coral. In Zanzibar undoubted coralline limestone exists at 100 feet, and a limestone of origin as yet undetermined at 300 feet. —W. From Wasin to Pangani (about lat. 5° S.) there is a barrier of large coral-reefs from 2 to 5 miles off shore with a deep channel inside, sometimes as much as 20 fathoms in depth.—Lieut. Chas. Smith.—From Mr. Darwin's papers.]

guish on the chart from reefs, I have not coloured the upper part red. Towards the mouth, however, where the water is rather deeper, the islands of *Ormuz* and *Larrack*, appear so regularly fringed, that I have coloured them red. There are certainly no atolls in the Persian Gulf. The shores of *Immaum*, and of the promontory forming the southern headland of the Persian Gulf, seem to be without reefs. The whole S.W. part of *Arabia Felix*, except one or two small patches, and the shores of *Socotra* appear from the charts and the memoir of Captain Haines (Geograph. Journ. 1839, p. 125) to be without reefs. I believe there are no extensive coral-reefs on any part of the coasts of *India*, except on the low promontory of *Madura* (as already mentioned) in front of Ceylon.

Red Sea.—My information is chiefly derived from the admirable charts published by the East India Company in 1836, from personal communication with Captain Moresby, one of the surveyors, and from the excellent memoir, 'Ueber die Natur der Corallen-Bänken des Rothen Meeres,' by Ehrenberg. The plains immediately bordering the Red Sea seem to consist chiefly of a sedimentary formation of the newer tertiary period. The shore is, with the exception of a few parts, fringed by coral-reefs. The water is generally profoundly deep close to the shore; but this fact, which has attracted the attention of most voyagers, seems to have no necessary connection with the presence of reefs; for Captain Moresby particularly observed that, in lat. 24° 10′ on the eastern side, there is a piece of coast with very deep water close to it, without any reefs, but not differing in any other respect from the usual coast line. The most remarkable feature in the Red Sea is the chain of submerged banks, reefs, and islands lying some way from the shore, chiefly on the eastern side; the space within being deep enough to admit safe navigation in small vessels. The banks are generally of an oval form, and some miles in width; but some of them are very long in proportion to their width. Captain Moresby informs me that any one who had not made actual plans of them, would be apt to think that they were much more elongated than they really are. Many of them rise to the surface, but the greater number lie from 5 to 30 fathoms beneath it, with irregular soundings on them. They consist of sand and living coral; the latter in most cases, according to Captain Moresby, covering the greater part of their surface. They extend parallel to the shore, and are not unfrequently connected in their middle parts by short transverse banks with the main land. The sea is generally profoundly deep quite close to them, as it is near most parts of the coast of the main land; but this is not universally the case, for between lat. 15° and 17° the water deepens quite gradually from the banks, both on the eastern and western shores. In many parts islands rise from the banks; they are low, flat-topped, and consist of the same horizontally stratified formation with that forming the plain-like margin of the main land. Some of the smaller and lower islands consist of mere sand. Captain Moresby informs me that small masses of rock, the remnants of islands, are left on many of the banks where there is now no dry land. Ehrenberg also asserts that most of the islets, even the lowest, have a flat abraded basis, composed of the same tertiary formation as elsewhere: he believes that as soon as the surf wears down the protuberant parts of the banks to just beneath the level of the sea, the surface becomes protected from further abrasion by the growth of coral, and he thus accounts for the existence of so many banks standing on a level with the surface of this sea. It appears that most of the islands are certainly decreasing in size.

The banks and islands are curiously shaped in the parts just referred to, namely, from lat. 15° to 17°, where the sea deepens quite gradually: the *Dhalac* group, on the western coast, is surrounded by an intricate archipelago of islets and shoals; the main island is irregular in outline, and includes a bay seven miles long, by four across, in which no bottom was found with 252 feet; there is only one entrance into it, half a mile wide, and with an island in front. The submerged banks on the eastern coast, within the same latitudes, round *Farsan* Island, are, likewise, penetrated by many narrow creeks of deep water; one is twelve miles long, in the form of a hatchet, and close to its broad upper end, soundings were not struck with 360 feet; its entrance is only half a mile wide. In another creek of the same nature, but even with a more irregular outline, there was no bottom with 480 feet.[1] The island of Farsan itself, has as singular a form as any of its surrounding banks. The bottom of the sea round the Dhalac and Farsan Islands consists chiefly of sand and agglutinated fragments of coral, but, in the deep and narrow creeks, it consists of mud; the islands consist of thin, horizontally stratified, modern tertiary beds, containing but little broken coral;[2] their shores are fringed by living coral-reefs.

From the account given by Rüppell[3] of the manner in which Dhalac is rent by fissures, the opposite sides of which have been unequally elevated (in one instance to the amount of 50 feet), it seems probable that this irregular form, as well as that of Farsan, may have been partly caused by unequal elevation; but, considering the general form of the banks, and of the deep-water creeks, together with the composition of the land, I think their configura-

[1] [The islands of this group are of upraised coral, as is the foreshore of the opposite coast of Abyssinia. In many parts of the Red Sea coast the low coral cliffs give evidence of upheaval. There are, nevertheless, reefs which would be classed as barrier-reefs on both sides of the central part of the Red Sea.—Capt. Wharton.]

[2] Rüppell, Reise in Abyssinie, Band. i. s. 247.

[3] Ibid. s. 245.

tion is more probably due in great part to currents having drifted sediment over an uneven bottom. It is almost certain that their form cannot be attributed to the growth of coral. The greater number of banks on the eastern side of the Red Sea seems to have originated in nearly the same manner, whatever this may have been, as the Dhalac and Farsan archipelagoes. I judge of this from their similar configuration (in proof of which I may instance a bank on the east coast in lat. 22°) and from their similar composition. The depth, however, within the banks northward of lat. 17° is usually greater, and their outer sides shelve more abruptly (circumstances which seem to go together) than in the Dhalac and Farsan archipelagoes; but this may have been caused by a stronger action of the currents during their formation: moreover, the greater abundance of living coral on the northern banks, tends to give them steeper margins.

From this account, brief and imperfect as it is, we can see that the great chain of banks on the eastern side of the Red Sea, and on the western side of the southern portion, differ greatly from true barrier-reefs, which are wholly formed by the growth of coral. Ehrenberg also concludes (Ueber die, &c. pp. 45 and 51) that these banks owe their origin in a quite secondary manner to the growth of coral. He remarks that the islands off the coast of Norway, if worn down level with the sea, and merely coated with living coral, would present a nearly similar appearance. It seems, however, from information given me by Dr. Malcolmson and Captain Moresby, that Ehrenberg has rather under-rated the influence of corals on the formation of the tertiary deposits of the Red Sea.

The West Coast of the Red Sea between Lat. 19° *and* 22°. —Reefs exist here, which, if I had known nothing of the others in the Red Sea, I should unhesitatingly have considered as barrier-reefs. One of these reefs, in 20° 15′, is twenty miles long, less than a mile in width (but expanding at the northern end into a disk), slightly sinuous, and parallel to the main land at the distance of five miles from it, with very deep water inside, so that in one place soundings were not obtained with 205 fathoms. Some leagues further south, there is another very narrow reef, ten miles long, with other small portions of reef, north and south, almost connected with it; and within this line of reefs (as well as outside) the water is profoundly deep. There are also some small linear and sickle-formed reefs, lying a little way out at sea. All these reefs are covered, as I am informed by Captain Moresby, by living corals. Here, then, we have all the characters of reefs of the barrier class, and some of the outlying reefs partially resemble atolls. My only source of doubt arises from the narrowness and straightness of the spits of sand and rock in the Dhalac and Farsan groups; one of these spits in the former group is nearly fifteen miles long, only two broad, and is bordered on each side with deep water; so that, if worn down by the surf, and coated with living corals, it would form a reef nearly similar to those within the space under consideration. Nevertheless I cannot believe that the many small, isolated, and sickle-formed reefs, as well as others long, nearly straight, and very narrow, with the water unfathomably deep close round them, could have been formed by corals merely coating banks of sediment or the abraded surfaces of irregularly shaped islands. It seems more probable that the foundations of these reefs have subsided, and that the corals, during their upward growth, have given to them their present forms. I have, therefore, with much hesitation coloured this part blue.

The West Coast, from Lat. 22° *to* 24°.—This part of the coast (north of the space coloured blue on the map) is fronted by an irregularly shelving bank, from 10 to 30 fathoms deep; numerous little reefs, some of which have the most singular shapes, rise from this bank. Many of them may have been formed by the growth of coral on small abraded islets; but some almost atoll-formed reefs rising from deep water near a promontory in lat. 24°, are probably allied to the barrier class. I have not, however, ventured to colour this portion of coast blue.—*On the west coast, from lat.* 19° *to* 17° (south of the space coloured blue on the map), there are many low islets of small dimensions not much elongated, and rising out of great depths at a distance from the coast: these cannot be classed either with atolls, or barrier, or fringing-reefs.

Eastern Coast.—There are many small outlying coral-reefs along this whole line of coast; but as the greater number rise from banks not very deeply submerged, their origin, as we have seen, may be due simply to the growth of corals on an irregular abraded foundation. But between lat. 18° and 20° there are so many linear, elliptic and extremely small reefs, rising abruptly out of profound depths, that the same reasons which led me to colour a portion of the west coast blue, have induced me here to do the same. There are some small outlying reefs on the east coast, north of lat. 20° (the northern limit coloured blue), which rise from deep water; but as they are not numerous, and as scarcely any of them are linear, I have left them uncoloured.

In the *southern parts* of the Red Sea, considerable spaces of the main land, and some of the Dhalac islands, are skirted by reefs, which, as I am informed by Captain Moresby, are of living coral, and have all the characters of the fringing class. As there are here no outlying linear or sickle-formed reefs, rising out of unfathomable depths, I have coloured these parts of the coast red. On similar grounds I have coloured the *northern parts of the western coast* (north of lat. 24° 30′) red, and likewise the shores of the chief part of the *Gulf of Suez.*[1] In the *Gulf of Acaba*, as I am informed by Captain Moresby, there are no coral-reefs, and the water is profoundly deep.

West Indies.—My information regarding the reefs of this area is derived from various sources, and from an examination of numerous charts; especially of those lately executed during the survey under Captain Owen, R.N. I lie under particular obligation to Captain Bird Allen, R.N., one of the members of the late survey, for many personal communications on this subject. As in the case of the Red Sea, it is necessary to make some preliminary remarks on the submerged banks of the West Indies, which are in some degree connected with coral-reefs, and cause considerable doubts in their classification. That large accumulations of sediment are in progress on the West Indian shores, will be evident to any one who examines the charts of that sea, especially of the portion north of a line joining Yucutan and Florida. The area of deposition seems less intimately connected with the débouchement of the great rivers, than with the course of the sea-currents; as is evident from the vast extension of the banks from the promontories of Yucutan and Mosquito.

Besides the coast-banks, there are others of various dimensions which stand isolated; these closely resemble each other; they lie from 2 or 3 to 20 or 30 fathoms under water, and are composed of sand, sometimes firmly agglutinated, with little or no coral; their surfaces are smooth and nearly level, shelving very gradually to the amount of a few fathoms all round towards their edges, where they plunge abruptly into the unfathomable sea. This steep inclination of their sides, which is likewise characteristic of the coast-banks, is very remarkable: I may give as an

[1] [Wherever I have seen the coast of the Red Sea, it shows clear signs of upheaval in low coral cliffs. There are, nevertheless, reefs which would be classed as barrier on both sides of the central part of the Red Sea.—Capt. Wharton. For Masámarhu Island, see App. II.]

instance, the Misteriosa Bank, on the edges of which the soundings change in 250 fathoms horizontal distance, from 11 to 210 fathoms; off the northern point of Old Providence Bank, in 200 fathoms horizontal distance, the change is from 19 to 152 fathoms; off the Great Bahama Bank, in 160 fathoms horizontal distance, the inclination is in many places from 10 fathoms to no bottom with 190 fathoms. In all parts of the world, where sediment is accumulating, something of the same kind may be observed; the banks shelving very gently far out to sea, and then terminating abruptly. The form and composition of the banks in the middle parts of W. Indian sea, clearly show that their origin must be chiefly attributed to the accumulation of sediment; and the only obvious explanation of their isolated position is the presence of a nucleus, round which the currents have collected fine drift matter. Any one who will compare the bank surrounding the hilly island of Old Providence, with the banks in its neighbourhood which stand isolated, will scarcely doubt that they surround submerged mountains. We are led to the same conclusion by examining the bank called Thunder Knoll, which is separated from the Great Mosquito bank by a channel only seven miles wide, and 145 fathoms deep. There cannot be any doubt that the Mosquito bank has been formed by the accumulation of sediment round the promontory of the same name; and Thunder Knoll resembles the Mosquito bank, in the state of its surface submerged 20 fathoms, in the inclination of its sides, in composition, and in every other respect. I may observe, although the remark is here irrelevant, that geologists should be cautious in concluding that all the outlyers of any formation have once been connected together, for we here see that deposits, doubtless of exactly the same nature, may be deposited with large valley-like spaces between them.

Linear coral-reefs and small knolls project from many of the isolated, as well as from the coast banks; sometimes they are irregularly placed, as on the Mosquito bank, but more generally they form crescents on the windward side, situated some little distance within the outer edge:—thus on the Serranilla bank they form an interrupted chain which ranges between two and three miles within the windward margin: generally they occur, as on Roncador, Courtown and Anegada banks, nearer the line of deep water. Their occurrence on the windward side is conformable to the general rule, of the efficient kinds of corals flourishing best where most exposed; but I cannot explain their position some way within the line of deep water unless it be that a depth somewhat less than that close to the outer margin is most favourable to their growth. Where the corals have formed a nearly continuous rim, close to the windward edge of a bank some fathoms submerged, the reef closely resembles an atoll; and if the bank surrounds an island (as in the case of Old Providence), the reef resembles an encircling barrier-reef. I should undoubtedly have classed some of these fringed banks as imperfect atolls, or barrier-reefs, if the sedimentary nature of their foundations had not been evident from the presence of other neighbouring banks, of similar forms and of similar composition, but without the crescent-like marginal reef. In the third chapter, I remarked that some atoll-like reefs probably did exist, which had originated in the manner here supposed.

Proofs of elevation within recent tertiary periods abound, as referred to in the sixth chapter, over nearly the whole area of the West Indies. Hence it is easy to understand the origin of the low land near those coasts where sediment is now accumulating; for instance, on the northern part of Yucutan, and on the N.E. part of Mosquito. Hence, also, the origin of the great Bahama banks, which are bordered on their western and southern edges by narrow, long, singularly-shaped islands, formed of sand, shells and coral-rock, some of them being about a hundred feet in height, is easily explained by the elevation of banks fringed on their windward sides by coral-reefs. On this view, however, we must suppose either that the great Bahama sand-banks were all originally deeply submerged, and were brought up to their present level by the same elevatory action which formed the linear islands ; or that during the elevation of the banks, the superficial currents and swell of the waves wore them down, and kept them at a nearly uniform level. But this level is not quite uniform ; for in proceeding from the N.W. end of the Bahama group towards the S.E., the depth of the banks increases, and the area of land decreases, in a very gradual and remarkable manner. The view that these banks have been worn down by the currents and waves of the sea during their elevation, seems to me the most probable one. This view is also, I believe, applicable to many of the submerged banks, in widely distant parts of the West Indian sea ; for, on any other view, the elevatory forces must have acted with astonishing uniformity.

The shore of the Gulf of Mexico, for a space of many hundred miles, is formed by a chain of lagoons, from 1 to 20 miles in breadth (Columbian Navigator, p. 178, &c.), containing either fresh or salt water, and separated from the sea by linear strips of sand. The shores of southern Brazil, and of the United States from Long Island (as observed by Professor Rogers,) to Florida, have the same character. Professor Rogers, in his report to the British Association (vol. iii. p. 13), speculates on the origin of these low, sandy, linear islets ; he states that the layers of which they are composed are too homogeneous, and contain too large a proportion of shells, to permit the common supposition of their formation being simply due to matter thrown up, where it now lies, by the surf : he considers these islands as upheaved bars or shoals, which were deposited in lines where opposed currents met. It is evident that these islands and spits of sand parallel to the coast and separated from it by shallow lagoons, have no necessary connection with coral-formation.

Having now endeavoured to remove some sources of doubt in classifying the reefs of the West Indies, I will give my authorities for colouring such portions of coast as I have thought myself warranted in doing. Captain Bird Allen informs me that most of the islands on the *Bahama Banks* are fringed, especially on their windward sides, with living reefs; and hence I have coloured those, which are thus represented in Captain Owen's chart, red. The same officer informs me, that the islets along the southern part of *Florida* are similarly fringed; coloured red.—CUBA: proceeding along the northern coast, at the distance of 40 miles from the extreme S.E. point, the shores are fringed by reefs, which extend westward for a space of 160 miles, with only a few breaks. Parts of these reefs are represented in the plans of the harbours on this coast by Captain Owen; and an excellent description is given of them by Mr. Taylor (Loudon's Mag. of Nat. Hist. vol. ix. p. 449); he states that they enclose a space called the '*baxo*,' from half to three-quarters of a mile in width, with a sandy bottom, and a little coral. In most parts people can wade, at low water, to the reef; but in some parts the depth is between two and three fathoms. Close outside the reef, the depth is between six and seven fathoms: these well-characterized fringing-reefs are coloured red.—Westward of long. 77° 30′, on the northern side of Cuba, a great bank commences, which extends along the coast for nearly four degrees of longitude. In its structure, and in the '*cays*,' or low islands on its edge, there is a marked correspondence (as observed by Humboldt, Pers. Narr. vol. vii. p. 88) between it and the great Bahama and Sal Banks, which lie directly in front. Hence one is led to attribute the same origin to all these banks; namely, the accumulation of sediment, conjoined with an elevatory movement, and the growth of coral on their outer edges. The parts which are fringed by living reefs are coloured red.—Westward of these banks there is a portion of coast apparently without reefs, except in the harbours, the shores of which seem in the published plans to be fringed.—The *Colorado* Shoals (see Captain Owen's charts), and the low land at the western end of Cuba, correspond as closely in relative position and structure to the banks at the extreme point of Florida, as the banks above described on the north side of Cuba do to the Bahamas. The depth within the islets and reefs on the outer edge of the *Colorados*, is generally between two and three fathoms, increasing to 12 fathoms in the southern part, where the bank becomes nearly open, without islets or coral-reefs; the portions which are fringed are coloured red.—The southern shore of Cuba is deeply concave, and the included space is filled up with mud and sand-banks, low islands and coral-reefs. Between the mountainous *Isle of Pines* and the southern shore of Cuba, the general depth is only between two and three fathoms; and in this part, small islands, formed of fragmentary rocks and broken madrepores (Humboldt, Pers. Narr. vol. vii. pp. 51, 86 to 90, 291, 309, 320), rise abruptly, and just reach the surface of the sea. From some expressions used in the Columbian Navigator (vol. i. pt. ii. p. 94), it appears that considerable spaces along the outer coast of southern Cuba are bounded by cliffs of coral-rock, formed probably by the upheaval of coral-reefs and sand-banks. The charts represent the southern part of the Isle of Pines as fringed by reefs, which the Columb. Navig. says extend some way from the coast, but have only from 9 to 12 feet of water on them; these are coloured red.—I have not been able to procure any detailed description of the large group of banks and 'cays' further eastward on the southern side of Cuba;

within them there is a large expanse, with a muddy bottom, from 8 to 12 fathoms deep: although some parts on this line of coast are represented in the general charts of the West Indies, as fringed, I have not thought it prudent to colour them. The remaining portion of the south coast of Cuba appears to be without coral-reefs.

YUCUTAN.—The N.E. part of the promontory appears, in Captain Owen's charts, to be fringed; coloured red. The eastern coast from 20° to 18° is fringed. South of lat. 18°, there commences the most remarkable reef in the West Indies: it is about 130 miles in length, ranging in a N. and S. line, at an average distance of fifteen miles from the coast. The islets on it are all low, as I have been informed by Captain B. Allen; the water deepens suddenly on the outside of the reef, but not more abruptly than off many of the sedimentary banks: within its southern extremity (off *Honduras*) the depth is 25 fathoms; but in the more northern parts, the depth soon decreases to 10 fathoms, and within the northernmost part, for a space of 20 miles, the depth is only from one or two fathoms. In most of these respects we have the characteristics of a barrier-reef; nevertheless, from observing, first, that the channel within the reef is a continuation of a great irregular bay, which penetrates the mainland to the depth of 50 miles; and secondly, that considerable spaces of this barrier-like reef (for instance, in lat. 16° 45′ and 16° 12′) are described in the charts as formed of pure sand; and thirdly, from knowing that sediment is accumulating in many parts of the West Indies in banks parallel to the shore; I have not ventured to colour this reef as a barrier. To add to my doubts, close outside this barrier-like reef, *Turneffe*, *Lighthouse*, and *Glover* reefs are situated, and these have so completely the form of atolls, that if they had occurred in the Pacific, I should not have hesitated to colour them blue. *Turneffe Reef* seems almost entirely filled up with low mud islets; and the depth within the other two reefs is only from one to three fathoms. From this circumstance, and from their similarity in form, structure, and relative position, both to the bank called *Northern Triangles*, on which there is an islet between 70 and 80 feet in height, and to *Cozumel* Island, the level surface of which is likewise between 70 and 80 feet high, it is probable that the three foregoing banks are the worn-down bases of upheaved shoals, fringed with corals; left uncoloured.

In front of the eastern *Mosquito* coast there are, between lat. 12° and 16°, some extensive banks (already mentioned), with high islands rising from their centres, and others wholly submerged, both kinds being bordered, near their windward margins, by crescent-shaped coral-reefs. But it can hardly be doubted that these banks owe their origin, like the great bank extending from the Mosquito promontory, almost entirely to the accumulation of sediment, and not to the growth of corals; hence I have not coloured them.

Cayman Island: this island appears in the charts to be fringed; and Captain B. Allen informs me that reefs extend about a mile from the shore, and have only from 5 to 12 feet of water within them; coloured red.—*Jamaica*: judging from the charts, about 15 miles of the S.E. extremity, and about twice that length at the S.W. extremity, and some portions on the S. side near Kingston and Port Royal, are regularly fringed, and are therefore coloured red. From the plans of some harbours on the N. side, parts of the coast appear to be there fringed; but I have not coloured them.—*St. Domingo*: I have not been able to obtain sufficient information, either from plans of the harbours, or from general charts, to enable me to colour any part of the coast, except 60 miles from Port de Plata westward, which seems regularly fringed: many other parts, however, of the coast are probably fringed, especially towards the eastern end of the island.—*Puerto Rico*: considerable portions of the southern, western, and eastern coasts, and some parts of the northern coast, appear in the charts to be fringed; coloured red. Some miles in length of the southern side of the Island of *St. Thomas* is fringed; most of the *Virgin Gorda* Islands, as I am informed by Sir R. Schomburgk, are fringed; the shores of *Anegada*, as well as the bank on which it stands, are likewise fringed; these islands have been coloured red. The greater part of the southern side of *Santa Cruz* appears in the Danish survey to be fringed (see also Professor Hovey's account of this island, in Silliman's Journal, vol. xxxv. p. 74); the reefs extend along shore for a considerable space, and project rather more than a mile; the depth within the reef is three fathoms; coloured red.—The *Antilles*, as remarked by Von Buch (Descrip. Iles Canaries, p. 494), may be divided into two linear groups, the western row being volcanic, and the eastern of modern calcareous origin; my information is very defective on the whole group. Of the eastern islands, *Barbuda* and the western coasts of *Antigua* and *Mariagalante* appear to be fringed; this is also the case with *Barbadoes*, as I have been informed by a resident; these islands are coloured red. On the shores of the western Antilles, of volcanic origin, very few coral-reefs appear to exist. The island of *Martinique*, of which there are beautifully executed French charts on a very large scale, alone presents any appearance worthy of special notice. The south-western, southern, and eastern coasts, together forming about half the circumference of the island, are skirted by very irregular banks, projecting generally rather less than a mile from the shore, and lying from two to five fathoms submerged. In front of almost every valley, they are breached by narrow, crooked, steep-sided passages. The French engineers ascertained by boring, that these submerged banks consisted of madreporitic rocks, covered in many parts by thin layers of mud or sand. From this fact, and especially from the structure of the narrow breaches, these banks were probably formed by living reefs, which fringed the shores of the island, and once reached the surface. From some of these submerged banks reefs of living coral still rise abruptly, either in small detached patches, or in lines parallel to, but some way within, the margin. Besides the above banks which skirt the shores of the island, there is on the eastern side a range of linear banks, similarly constituted, 20 miles in length, extending parallel to the coast-line, and separated from it by a space between two and four miles in width, and from 5 to 15 fathoms in depth. From this range of detached banks, some linear reefs of living coral likewise rise abruptly; and if they had been of greater length (for they do not front more than a sixth part of the circumference of the island) they would necessarily from their position have been coloured as barrier-reefs; as the case stands, they are left uncoloured.

Florida.—An account of the reefs on this coast, together with references to various authorities, will be found in Professor Dana's work on Corals and Coral Islands, 1872, p. 204.[1]

The Bermuda Islands have been carefully described by Lieut. Nelson, in an excellent memoir in the Geol. Transactions (vol. v. part i. p. 103).[2] In the form of the bank or reef, on one side of which the islands stand, there is a close general resemblance to an atoll; but in the following respects there is a considerable difference,—first, in the margin of the reef not forming (as I have been informed by Mr. Chaffers, R.N.) a flat, solid surface, which is laid bare at low water; secondly, in the water gradually shoaling for nearly a mile and a half in width round the entire reef, as may be seen in Captain Hurd's chart; and thirdly, in the size, height, and extraordinary form of the islands, which present little resemblance to the long, narrow, simple

[1] [See Appendix II.]

[2] [An interesting account will also be found in Sir Wyville Thomson, Voyage of the *Challenger*, vol. i. chap. iv.]

islets, seldom exceeding half a mile in breadth, which surmount the annular reefs of almost all the atolls in the Indian and Pacific Oceans. Moreover, there are evident proofs (Nelson, ibid. p. 118) that islands similar to the existing ones formerly extended over other parts of the reef. It would, I believe, be difficult to find a true atoll with land exceeding 30 feet in height; whereas, Mr. Nelson estimates the highest point of the Bermuda Islands at 260 feet; if, however, Mr. Nelson's view, that the whole land consists of sand drifted by the winds and agglutinated together, is correct, this difference would be immaterial; but, from his own account (p. 118), there occur in one place five or six layers of red earth, interstratified with the ordinary calcareous rock, and including stones too heavy for the wind to have moved, without having at the same time utterly dispersed every grain of the accompanying drifted matter. Mr. Nelson attributes the origin of these several layers, with their embedded stones, to violent catastrophes; but further investigation has generally succeeded in explaining such phenomena by simpler means. Finally, I may remark that these islands bear a considerable resemblance in shape to Barbuda in the West Indies, and to Pemba on the eastern coast of Africa, which latter island is about 200 feet in height, and consists of coral-rock. I believe that the Bermuda Islands, from being fringed by living reefs, ought to have been coloured red; but I have left them uncoloured, on account of their general resemblance in external form to a lagoon-island or atoll. Professor Dana (Corals and Coral Islands, pp. 218, 269) ranks them in this class.[1]

[1] [The following particulars relating to Bermuda, taken from the Report of the *Challenger* Voyage, Narrative, p. 138, are of interest:—

An excavation made to form a bed for the floating dock went down to 50 feet below low-water mark. It cut through calcareous mud, loose beds (coral-sands mixed with mollusks, smaller corals and other organisms), passing into a loosely coherent freestone

Supplement on a remarkable Bar of Sandstone off Pernambuco, on the Coast of Brazil. (Originally published in the Philosophical Magazine, October 1841, p. 257.)

In entering the harbour of Pernambuco, a vessel passes close round the point of a long reef, which, viewed at high water when the waves break heavily over it, would naturally be thought to be of coral formation, but when beheld at low water might be mistaken for an artificial breakwater, erected by cyclopean workmen. At low tide it shows itself as a smooth level-topped ridge, from 30 to 60 yards in width, with even sides, and extending in a *perfectly* straight line, for several miles parallel to the shore. Off the town it includes a shallow lagoon or channel about half a mile in width, which further south decreases to scarcely more than a hundred yards. Close within the northern point, ships lie moored to old guns let into the reef. Here, on the inner side, at low water spring-tides, a section of about seven feet in height is exhibited. This consists of hard pale-coloured sandstone breaking with a smooth fracture, and formed of siliceous grains, cemented by calcareous matter. Well-rounded quartz pebbles, from the size of a bean, rarely to that of an apple, are embedded in it, together with a very few fragments of shells. Traces of

formed of the same material cemented; and then, at a depth of 45 feet, through an old peat with land vegetation, shells of *Helix bermudensis*, and bones of birds, beneath which was the ordinary hard 'base rock.'

Serpulæ are very abundant on the Bermuda reefs, and form evidently, by their mode of growth, miniature atolls from 2 to 20 feet in diameter, with little interior lagoons. It was found by soundings that on the S.E. edge of the bank the 100-fathom line was about $1\frac{1}{4}$ mile from the rocks awash. Then a slope of about 20° led down to 350 or 400 fathoms, after which it varied, from 7° to 15°, to 1,000 fathoms. The 100-fathom line on the N.E. edge was about 3 miles away; on the S.W. still further, and the submarine slopes were more gentle. The rock of the island appears to be of æolian origin, but it is not said whether this also forms the highest ground, which is 256 feet above the sea.]

stratification are obscure, but in one spot there was an included layer of stalactitic limestone, an eighth of an inch in thickness. In another place some false strata, dipping landwards at an angle of 45°, were capped by a horizontal mass. On each side of the ridge quadrangular fragments have subsided; and the whole mass is in some places fissured, apparently from the washing out of some soft underlying bed. One day, at low water, I walked a full mile along this singular, smooth, and narrow causeway, with water on both sides of me, and could see that for nearly a mile further south its form remained unaltered. In Baron Roussin's beautiful chart of Pernambuco (*Le Pilote du Brésil*) it is represented as stretching on, in an absolutely straight line, for several leagues; how far its composition remains the same, I know not; but from the accounts I received from intelligent native pilots, it seems to be replaced on some parts of the coast by true coral-reefs.

The upper surface, though it must on a large scale be called smooth, yet presents, from unequal disintegration, numerous small irregularities. The larger embedded pebbles stand out supported on short pedestals of sandstone. There are, also, many sinuous cavities, two or three inches in width and depth, and from six inches to two feet in length. The upper edges of these furrows sometimes slightly overhang their sides; and they end abruptly with a rounded outline. A furrow occasionally branches into two arms, but generally they run nearly parallel to each other, in a line transverse to the sandstone ridge. I know not how to account for their origin except through the washing to and fro of pebbles in originally slight depressions, by the waves which break daily over the bar. Opposed to this notion is the fact that some of these furrows were lined with numerous small living *Actiniæ*. The exterior surface of the bar is coated with a thin layer of calcareous matter; this, on the outer subsided masses, which can be reached only at low water, between the successively breaking waves, is so thick that I could seldom expose the sandstone by the aid of a heavy hammer. I procured, however, some fragments, which were between three and four inches in thickness, and consisted chiefly of small *Serpulæ*, including some *Balani*, with a few thin paper-like layers of a *Nullipora*. The surface alone is alive, and all within consists of the above organic bodies, filled up with dirty white calcareous matter. The layer, though not hard, is tough, and from its rounded surface resists the breakers. Along the whole external margin of the bar, I only saw one very small point of sandstone which was exposed to the surf. In the Pacific and Indian Oceans the outer and upper margin of the coral-reefs are, as we have seen, protected by a similar coating; but formed almost exclusively of several species of *Nulliporæ*. Lieut. Nelson, in his excellent memoir on the Bermudas (Geol. Trans. vol. v. part 1, p. 117), says that the reefs there are formed of similar masses of *Serpulæ*; but I suspect that they are only thus coated.

I enquired from some old pilots at Pernambuco whether there was any tradition of the bar having undergone any change during the lapse of time; but they were unanimous in answering me in the negative. It is astonishing to reflect, that although waves of turbid water, charged with sediment, are driven night and day by the ceaseless trade wind against the abrupt edges of this natural breakwater, yet that it has lasted in its present perfect state for centuries, or perhaps for thousands of years. Seeing that the surface on the inner side does gradually wear away, as shown by the pebbles on the little sandstone pedestals, this durability must be entirely due to the protection afforded by the thin coating of *Serpulæ* and other organic bodies.

This is a fine example of what apparently inefficient means may be effectual.[1]

I believe that similar bars of rock occur in front of some of the other bays and rivers on the coast of Brazil: Baron Roussin states that at Porto Seguro there is a '*quay*' similar to that of Pernambuco. Spaces of several hundred miles in length on the shores of the Gulf of Mexico, the United States, and of Southern Brazil are formed by long narrow islands and spits of sand, including extensive shallow lagoons, some of which are several leagues in width. The origin of these linear islets is rather obscure: Professor Rogers (Report to British Association, vol. iii. p. 13) gives reasons for suspecting that they have been formed by the upheaval of sand-banks, deposited where currents formerly met. The bar of sandstone at Pernambuco has probably been formed in an analogous manner. The town stands partly on a low narrow islet and partly on a long spit of sand, in front of a low shore, bounded in the distance by a semicircle of hills. By digging at low water near the town, the sand is found consolidated into sandstone, similar to that of the bar, but containing many more shells. If, then, the nucleus of a spit of sand, extending in front of the bay, had formerly become consolidated, a small change, probably of level, but perhaps merely in the currents, might have given rise, by washing away the loose sand, to a structure like that of the bar in front of Pernambuco and along the coast southward of it; but without the protection afforded by the successive growth of the above-named organic beings, its duration would have been short.

[1] [There is an interesting account of this reef, containing particulars of some borings undertaken in 1874, by Mr. J. C. Hawkshaw, in the Quarterly Journal of the Geological Society for 1879 (vol. xxxv. p. 239).]

APPENDIX II.

SUMMARY OF THE PRINCIPAL CONTRIBUTIONS TO THE HISTORY OF CORAL REEFS SINCE THE YEAR 1874.

By Professor T. G. Bonney, D.Sc., LL.D., F.R.S.

Since the publication of the last edition of Mr. Darwin's work several important researches have been undertaken, which have added largely to the stock of knowledge concerning marine physical geography in general and coral reefs in particular. Of the valuable material thus obtained Mr. Darwin would, no doubt, have availed himself had his life been spared and his health allowed. Probably additions would have been made to the text of this work, and not a few pages have been rewritten; the older and less precise information being replaced by the more ample and exact results of recent explorations. The criticism to which Mr. Darwin's theory has been subjected during the last few years, and the hypotheses which have been advanced by other workers, would, no doubt, have been discussed by him in that candid and philosophic spirit which is so evident in all his writings. This revision may be counted as one of the heavy losses which science has suffered by his death. It became, then, a question, when a new edition of this book was called for, what should be done to it. Simply to reprint the last edition, without any notice of the important contributions which have been made to the knowledge of the subject during the last few years, seemed undesirable; but any attempt to reconstruct the work seemed yet more undesirable. Mr. F. Darwin, after consultation with several of his friends (including myself, whom he had asked to aid him in preparing the new edition for the press), accordingly decided to reprint 'The Structure and Distribution of Coral Reefs' from the edition of 1874, subject only to a few press corrections, and to give any important emendations or additions in the form of notes, so arranged as to be easily distinguished from those written by the late author. As regards the extent and amount of the additional matter, we thought that, as the volume was never intended as a text-book for examination purposes, it was needless to endeavour to concentrate within its pages every result of recent work, and it would suffice to call attention to the more important points, which would almost certainly have been noticed by the author in any new edition.

Therefore, from a few papers left by Mr. Darwin, from information kindly supplied by Capt. Wharton and other friends, and from my own reading, I have added a few foot-notes to the text, and have given in this appendix a summary of the papers which appeared to me of special importance among those which have been published since 1874. No attempt has been made to compile a bibliography of the literature of 'Coral Reefs.' This was a task, as I told Mr. F. Darwin candidly at the outset, which my previous studies and present occupations would not permit me to undertake, and it was also one which, for the reason above given, seemed to me needless. I believe, however, that I have looked through most of the recent literature, and I have selected therefrom certain papers, in which, as it seemed to me, the arguments for and against Mr. Darwin's theory were stated with considerable fulness. The remainder have been passed over, either because they did not contain original information, or because they would have supplied additional details, on the one side or the other, rather than fresh arguments. In making this selection I have been influenced to some extent by the adventitious prominence which, during the last two or three years, has been given to certain valuable and interesting communications on this subject. Of the papers selected I have given a fairly full abstract, which represents, to the best of my ability, the views of their authors, whichever side they may have espoused, so that I trust the reader will be enabled to understand the present state of this difficult question, and to appreciate the reasons which have led some very competent authorities to maintain, and others to reject, the theory advanced by the late Mr. Darwin.

It is true that, as I have stated in the conclusion, the close study of the question has not materially altered the view which I entertained when I began the task, but I have done my best to make my abstract a fair statement of each writer's case. If, then, it should appear to any one that I ought to have given more prominence to this point and less to that, I may fairly plead that this has resulted from deficient apprehension, and not from conscious bias. I have placed first, arranging them chronologically, the papers which are more or less unfavourable to the distinctive feature of Mr. Darwin's theory; then those which in the main support it.

The following is a summary of Mr. Murray's[1] views: Very nearly all oceanic islands, other than coral atolls, are now known to be of volcanic origin. Hence it is probable that the foundations of the latter are volcanic rocks and not those indicative of an ancient and pre-existent land. As shown by the soundings of the 'Tuscarora' and 'Challenger,' numerous submarine elevations exist which rise from depths of 2,500 to 3,000 fathoms to within a few hundred fathoms of the surface. The upper water of the ocean (to a depth,

[1] On the Structure and Origin of Coral Reefs and Islands. By John Murray. Proc. R. S. Edin. (1880), vol. x. p. 505.

probably, of about 100 fathoms) teems with organisms, calcareous and siliceous; such as algæ, protozoa, hydrozoa, mollusca and other members of the animal kingdom : these are drifted by the currents from place to place; by these the reef-building corals are supplied with food. It has been estimated, as the result of experiment, that a mass of ocean water one mile square and 100 fathoms deep contains more than sixteen tons of carbonate of lime.[1] After death the 'skeletons' of these organisms are showered down upon the bed of the ocean. In water which exceeds some 800 or 900 fathoms in depth their remains are more or less affected by the solvent power of the carbonic acid present in the water, but at less depths they accumulate. Thus any submarine bank which rose within the above-named depth would be brought nearer to the surface, and its upper part, as the water above it shallowed, would be colonised by larger pelagic organisms; these, after death, would augment by their remains the increasing pile of material, which at last would arrive within the bathymetrical zone in which reef-building corals can live and the formation of an atoll would commence.

As already pointed out by Mr. Darwin,[2] the corals on the outer margin of a bank grow vigorously, while the diminution of food and the increase of sediment tend to check the development of those in the inner part. Thus,

[1] I estimate that this amount of carbonate of lime is equivalent to a solid layer of the same area which is approximately ·00009 of an inch thick. We may arrive at it thus: taking 2·7 as the specific gravity of carbonate of lime, we shall find the volume of sixteen tons to be about 212·4 cubic feet, or 7·8 cubic yards. This has to be spread out over 3,097,600 square yards (the number of square yards in a mile), giving the above result. Even if we make a large allowance for the fact that the carbonate of lime is not solid, but in the form of an aggregate of hollow shells, I believe ·09 of an inch is in excess rather than in defect of the truth.

[2] Page 87.

while the reef is still several fathoms below the surface, the corals in the central part are placed at a disadvantage, which becomes greater as they are left behind in the upward race by their neighbours. In a small reef, the periphery for the supply of food to the interior is relatively large; thus the lagoons in small atolls are also small and are soon filled up, while long and narrow banks have no lagoons. As the reef becomes larger the conditions become more favourable to the formation of lagoons, for (as is shown by experiment) the lagoon of such an atoll is less rich in pelagic life than the exterior water. Thus growth is checked; many species of coral die, and their calcareous 'skeletons' are exposed to the solvent action of sea-water. When the water outside becomes too deep for reef-building corals to live, the *débris* from the existing reef, aided by the accumulation of organisms, forms a talus at the foot of its submarine cliffs, and thus the reef spreads slowly outward, 'like a fairy ring,' on foundations to which its own materials have contributed. Coral-reefs which have been elevated for some distance above sea-level are frequently found to rest upon a deposit thus constituted.[1] The lagoon channels have in many cases been subsequently formed by the solvent action of sea-water, and the islets in the lagoon channel are parts of the original reef still left standing. Where the reefs rise quite up to the surface and are nearly continuous, there is little coral growth in the lagoon or its channels; where the outer reefs are much broken up the growth is relatively abundant.

'At the Admiralty Islands, on the lagoon side of the islets of the barrier-reefs, the trees were found overhanging the water, and in some cases the soil was washed away from their roots. It is a common observation in atolls that the islets on the reefs are situated close to the lagoon shore.

[1] The case of Tahiti is here described; see p. 314, where it is discussed by Prof. Dana.

These facts point out the removal of matter which is going on in the lagoons and lagoon channels.'

Elevation, not subsidence, is to be expected in a volcanic region, as there is an *à priori* reason for attributing the phenomena of coral reefs—as resting on volcanic foundations—to elevation rather than to subsidence. The former hypothesis appears to Mr. Murray to accord with all the facts indicated by the published charts of coral-reefs, and thus is considered by him preferable to the latter.

Mr. Murray's general conclusions may be briefly enunciated as follows :—

1. That foundations have been prepared for barrier-reefs and atolls by the disintegration of volcanic islands, and by the building up of submarine volcanoes, and by the deposition on their summits of organic and other sediments.

2. That the chief food of the corals consists of the abundant pelagic life of the tropical regions, and the extensive solvent action of sea-water is shown by the removal of the carbonate of lime shells of these surface organisms from the greater depths of the ocean.

3. That when coral plantations build up from submarine banks they assume an atoll form, owing to the more abundant supply of food to the outer margins and the removal of dead coral-rock from the interior portions by currents and the action of the carbonic acid dissolved in the water.

4. That barrier-reefs have built out from the shore on a foundation of volcanic *débris* or on a talus of coral blocks, coral sediment and pelagic shells, and the lagoon channel is formed in the same way as a lagoon.

5. That it is not necessary to call in subsidence to explain any of the characteristic features of barrier-reefs or atolls, and that all their features would exist alike in areas of slow elevation, of rest, or of slow subsidence.

Professor A. Agassiz [1] accepts the views of L. Agassiz, Le Conte, and E. B. Hunt, that the Florida reefs cannot be explained by subsidence, but that the southern extremity of Florida is of comparatively recent growth, consisting of concentric barrier-reefs which have been gradually converted into land by the accumulation of intervening mud-flats, and thus explains the details of the process and the manner in which the foundations of the reefs are formed.

He rejects Le Conte's explanation that the substructure of the reefs was formed by the mass of material brought by the Gulf Stream, pointing out that more recent investigations have shown that it ran across, not parallel with, the peninsula, the curve of the eastern shore of the latter being due to a counter-current along the reef running westwards. The Gulf Stream, however, has an indirect influence by reason of the abundant food which it supplies to animals living on the Bank of Florida. Across the reefs, and through the channels between the Keys, the tides set strongly, bearing the mud derived from coral and other organisms; this gradually accumulates to form the intervening mud-flats, and when swept westwards enlarges the submarine plateau in that direction. The Tortugas, the most recent cluster of Florida reefs, are at the very extremity of the slope upon which the line of these reefs has been built up. Nothing among them corresponds

[1] Agassiz, Alexander. The Tortugas and Florida Reefs. Mem. Amer. Acad. Arts and Sci., vol. xi. p. 107, 1885. In Three Cruises of the *Blake*, vol i. (Bulletin of the Museum of Comparative Zoology, Harvard College, vol. xiv., 1888), a chapter is devoted to the Florida Reefs. As, however, the line of argument and the principal facts are identical with those given above, I have not thought it necessary to give a separate analysis. A convenient and clear summary of the views of Semper, Rein, Murray, and Agassiz is given by Prof. A. Geikie in his presidential address to the Royal Physical Society of Edinburgh in 1883 (Proc. vol. viii. p. 1).

with the extensive mud-flat which extends at a depth of a few feet below the surface northward of the Keys. Where there is a larger accumulation of material than usual on the submarine plateau, so as to bring its surface within the depth at which corals can flourish, a reef begins to form; that is the history of the Tortugas. West of it, an incipient reef may be found now in process of formation, east of it all the reefs in their turn have had a like origin. Then the deposition of silt produces mud-flats, and material accumulates, till at last the channels are closed and the whole is added to the land. From Everglades to Cape Sable the work may be seen completed; on the eastern coast, and beyond the latter place to Marquesas Key, it occurs in its various stages, until at last it is shown in its beginning. The backbone, however, of the Florida peninsula is ascribed to a fold in the earth's crust in an earlier geological period. As a secondary result of this a great submarine plateau was formed directly in the track of the Gulf Stream, which has since been gradually built up by the accumulation of marine organisms of various kinds. The area within the 100-fathom line on the west coast of the great Florida plateau is extraordinarily rich in organic life; large fragments of the modern limestone were often brought up in trawl or dredge, consisting of the solid parts of the very species which now live on the top of this recent limestone. West of the western shore-line Florida now stretches out as an immense submarine plateau, forming a huge tongue, coated or veneered only by coral limestone over its very top. The eastern and western edges of Florida consist of recent limestones, predecessors of that now forming on the western and southern slopes of the Florida plateau. Very probably the part of the peninsula north of the Everglades has had in the past a like formation. Pourtales plateau is built of the same species of corals and shells as now live upon it. Of like origin are the great bank east of the Mosquito coast and the reefs on the south coast of Cuba; the Basse-Terre of Guadeloupe is the same, now slightly elevated, and the barrier-reefs on the windward side of the West India Islands rest on plateaux of similar origin. At Barbados the nucleus is a trachytic mass round which are terraces formed of mollusca and radiata, still living in the sea, which have been successively lifted.[1] The author considers that in the West India Islands many volcanic masses, which probably have never reached the surface, form the foundation of these banks of organisms.

It would seem probable that reef-building corals had little to do with building the peninsula north of Cape Florida. The author explains the Alacran reef (atoll-shaped) by a growth of corals upwards from a submarine bank, and shows that the slope is steep down to a depth of thirty fathoms, then more gradual.

He lays much stress on the importance of currents bringing food, and points out that, on the lee side of a reef, corals may be killed by the drift of sediment. 'When Darwin wrote, and when we knew little of the limestone deposits formed by the accumulation of the *débris* of molluscs, echinoderms, polyps, and the like, upon folds of the earth's crust, the basal parts of barrier-reefs were difficult of explanation. The evidence gathered by Murray, Semper, and myself, partly in districts which Darwin had already examined, and partly in regions where his theory of reef-formation never seemed to find its proper application, has in part removed this difficulty. It tends to show that we must look to many other causes than those of elevation

[1] In Three Cruises of the *Blake*, vol. i. p. 79, Prof. A. Agassiz says: 'In some instances coral reefs have unquestionably been uplifted. I have seen the elevated reefs of Cuba, of San Domingo, and other West Indian Islands, and of Barbados, which are perhaps the most striking examples of elevated reefs.'

and subsidence for a satisfactory explanation of coral-reef formation. All-important among these causes are the prevailing winds and currents, the latter charged with sediment which helps to build extensive plateaux from lower depths to levels at which corals can prosper. This explanation, tested as it has been by penetrating into the thickness of the beds underlying the coral reefs, seems a more natural one, for many of the phenomena at least, than that of the subsidence of the foundation to which the great vertical thickness of barrier-reefs has been hitherto referred. It is, however, difficult to account for the great depth of some of the lagoons—forty fathoms—on any other theory than that of subsidence' (p. 121).

The author also describes the distribution of material, living and dead, on the Tortugas, the action of the waves in pounding up dead coral, molluscs, and other organisms. Thus a great quantity of calcareous ooze is formed (aided by the material which passes through the digestive cavity of holothurians, echinoderms, &c.). This silt, by its accumulation, kills the corals, which accordingly can only flourish where well 'scoured.' The water is often chalk colour for a considerable distance from the reefs; it is sometimes, after a heavy wind, discoloured for six to ten miles from the outer reefs. This process accounts for the scarcity of fossils. He also expresses the opinion that in this region the corals do not flourish at depths over six or seven fathoms, being probably choked by the ooze.[1]

[1] In Three Cruises of the *Blake*, vol. i. p. 74, Prof. A. Agassiz states that 'all the evidence accumulated by Dana, Darwin, Ehrenberg, Quoy, and Gaimard tends to show that the limit of reef-building corals is to be found at about twenty fathoms.'

Prof. Agassiz's views in regard to Florida do not appear to have met with universal acceptance among American men of science; for instance, Mr. W. H. Dall (Geology of Florida, Amer. Journ. Sci., 3rd ser. xxxiv. p. 161, 1877) says that in the southern part of Florida he saw no coral-rock or coral-reef formation: 'The coral formation

Mr. Guppy[1] describes the Solomon Archipelago, which includes seven or eight large islands, some being from seventy to eighty miles in length, and the highest rising from 8,000 to 10,000 feet above the sea, with a great number of smaller islands and islets, some of volcanic and others of recent calcareous formations. The author found exploration to be difficult and dangerous, but believes that he saw enough to give him a fair idea of the leading types of structure among these islands. The observations recorded in the paper may be summed up in his own words:—

The islands examined indicate upheaval, in some cases to at least 1,200 feet. 'There are, in the first place, numerous small islands and islets, less than a hundred feet in height, which are composed entirely of coral limestone. Then there are islands of larger size, which are composed in bulk of partially consolidated volcanic muds, such as are at present forming around oceanic volcanic islands. Coral limestones encrust the lower slopes of these islands, and do not attain a greater thickness than 150 feet. In the next place we have islands of similar structure, but possessing in their centre some ancient volcanic peak that was once submerged. Then there are

observed by Agassiz in the region in the Keys must be of very limited scope, as it has not been identified from the mainland of Florida by any modern geologist.' Further, Prof. A. Heilprin in a paper on Explorations in Florida (Transactions Wagner Inst. Sci. Philadelphia, May 1887), noticed in the above-named volume (p. 230), says: 'No observed facts sustain the coral theory of formation propounded by Agassiz. They prove, on the contrary, that the coral tract of Florida is confined to a border region on the south and south-east, and there are no tertiary reefs whatever.' But he admits that the southern area is one of shallow sea formation, so that there has been a gradual uniform progressive elevation over the whole.

[1] H. B. Guppy. Observations on the Recent Calcareous Formations of the Solomon Group made during 1882–4. Tr. R. S. Edin. xxxii. p. 545 (1884–5).

islands in which the volcanic peak has become an eccentric nucleus, from which line after line of barrier-reef has been advanced, overlying the volcanic muds;' islands in which he did not find the coral limestone of a thickness of 100 feet. Then we have the upraised atoll, such as Santa Anna, which within the small compass of a height of 470 feet displays the several stages of its growth: 'first, the originally submerged volcanic peak, then the investing soft deposit, and over all the ring of coral limestone, that cannot far exceed 150 feet in thickness; lastly, we come to the mountainous islands formed of old volcanic rocks, such as St. Christoval, which, although over 4,000 feet in height, showed to me no calcareous envelopes at a greater height than 500 feet above the sea, the coral limestone crust being even thinner than at the smaller and more recent islands.' From these considerations the author concludes '(1) that these upraised reef masses, whether atoll, barrier-reef, or fringing-reef, were formed in a region of elevation; (2) that such upraised reefs are of moderate thickness, their virtual measurement not exceeding the limit of the depth of the reef-coral zone, *i.e.* not more than about 150 feet; (3) that these upraised reef masses in the majority of islands rest on a partially consolidated deposit which possesses the characters of the "volcanic muds" which were found during the 'Challenger' expedition to be at present forming around volcanic islands; (4) that this deposit envelopes anciently submerged volcanic peaks.'

The earlier part of the next paper [1] is occupied by a description of a reef of the Solomon group and the distribution upon it of coral life. According to Mr. Guppy's observations the large masses of corals usually flourish below the wash of the breakers, and in these regions corals generally do not

[1] H. B. Guppy. Notes on the Character and Mode of Formation of the Coral Reefs of the Solomon Islands. Proc. R. S. Edin. xiii. p. 857 (Session 1885–6).

thrive in the break of the trade-swell. 'They are only to be found in luxuriance on the slopes of the declivity that is situated in depths between five and fifteen fathoms, a declivity which may be truly termed the growing edge of the reef.' At exceptionally low tides, when there is a heavy sea, large branches are apt to be torn off from corals growing beyond the usual reach of the breakers, and these are thrown up on the upper flat of the reef. But in cases where the reefs are protected from the heavier rollers, the corals living in the wash of the breakers are more numerous and in greater variety. The same rule holds good on the lee sides of small coral islands. Here the corals are often grouped in irregular patches or masses, which sometimes rise with wall-like sides from depths of twelve or fifteen feet of water. A large part of the interior both of lagoons and of their channels, is occupied by sandy and chalky mud; but in the shallower portions, and especially in those situations which are near the breaks in the reef, corals, especially of foliaceous and branching habit, thrive in great profusion. As a rule corals are unable to sustain exposure to the air for long; from one to two hours continuously appears the maximum of endurance, and that is reached only by a few species.

Mr. Guppy considers that in this group the numerous detached submerged reefs or shoals, which lie at depths of from 4 to 10 fathoms (that is, at depths which vary with the amounts of disturbance produced by the breakers), represent the earliest conditions of coral reefs. Numerous instances of such reefs are given in this memoir: one, Lark Shoal, covered by water having a minimum depth of 7 fathoms, rises from a depth of 200 fathoms. The shoal within the 20 fathom line measures 1½ miles in one direction and 1 mile in the other. There is no sign of a central depression, the summit being comparatively level and covered by from 7 to 10 fathoms of water. This general flatness of the upper surface is not peculiar to Lark Shoal, but was observed at similar depths in the case of others. Between such submerged reefs and those marked on the surface by a reef flat, with its accompanying islet, or by a sand key, intermediate conditions were not found, and Mr. Guppy is of opinion that reefs on arriving within from 4 to 8 fathoms from the surface have reached the limit of their upward growth, and afterwards have to extend laterally. Hence he infers that detached submerged reefs are unable to raise themselves within the limit of constructive breaker-action without the assistance of a movement of elevation. Of such a movement, in this region, there are certainly proofs, and the same is the case in the Low Archipelago, the Fiji and Pelew groups.

Among the reefs which have reached the surface in the Solomon Archipelago, fringing and barrier reefs are much commoner than atolls. 'A line of barrier reef probably not much under 60 miles in length, and having innumerable islets on its surface, fronts the eastern coasts of the islands of New Georgia at a distance of from 1 to 3 miles from the shore. At St. Christoval the fringing reefs occasionally reach a mile in breadth, but usually do not exceed a quarter of a mile. The 100 fathom line lies generally about 1,200 yards from the edge of the reef flat which would give an average slope of 10°.' Upheaval is indicated by a recently elevated flat of coral rock, which is in some places 15 feet or so above high water level. North of St. Christoval are three small islands (named the Three Sisters). They commenced their growth, according to Mr. Guppy, as submerged flat-topped reefs, like those already mentioned. They were then elevated to about 70 feet above the sea, and have since assumed an atoll structure. He regards them as 'based on three submerged peaks which lie at some unknown distance below the surface.' They are enclosed within the same hundred fathom line; the submarine slope at first is gradual and then descends more rapidly; on the weather side at an angle of rather more than 20°, on the lee side usually at a smaller angle. The highest points (of coral limestone) on the southernmost island rise to about 70 feet above the sea. It has two lagoons; the deeper is about 9 fathoms, and over the bar at its mouth the water is less than a fathom deep at low water neaps.

Mr. Guppy is of opinion that this island commenced its history as two flat-topped submerged reefs, and that the atoll form has been assumed since these have been upheaved. *Santa Anna* is an upheaved atoll with shore-reefs ranging from 150 to 600 yards wide according to the steepness of the land. On the westward the shore-reefs enclose a circular lagoon 700 to 800 yards wide and 16 to 17 fathoms deep. *Ugi* island has shore-reefs of varying width, and on the east coast the shore-reef encloses a narrow lagoon a mile long and 10 fathoms or less in depth. There is also in that on the south coast a circular lagoon about 100 yards wide and 6 fathoms deep, approached by a narrow channel. *Biu* is a patch of coral reef which has been raised about 100 feet above the sea, and is still encircled by living reefs. *Rua Sura* is an atoll of elongated form about 3 miles in length. Except for three wooded islets on the south side, its circumference is either just awash at low tide or is within a fathom of the surface; but soundings in the lagoon to a depth of 37 fathoms failed to reach the bottom. The islets are at highest only 15 or 20 feet above the sea, 'cliffs of coral rock 4 or 5 feet in height' in one 'betokens recent elevation of a small amount.' *Eddystone* Island consists of 'two distinct islands (volcanic) which have become united by elevation of an intervening coral reef. On the east coast the submarine slope down to the 100 fathom line is from 30° to 35°. There is a hole in the middle of the reef on the west side, about 150 yards across and 18 fathoms deep, which Mr. Guppy thinks may mark an old crater cavity, and a smaller one in a reef on the east side, where also there is an elevated barrier reef. Within a mile or two to the south are a couple of submerged coral patches with level summits covered by from 5 to 10 fathoms of water, and in each case measuring within the latter contour line about half a mile in length. They both rise on all sides from water in which casts of 100 fathoms did not reach the bottom.

East of *Bougainville* Island, in the strait between it and *Choiseul* Island, is a submarine plateau, about 15 miles in width, extending from the former, and covered by from 30 to 50 fathoms of water. This, at its outer edge, terminates abruptly in a steep slope of from 15° to 25°, 'which is sharply delineated on the charts, by the 100 fathom line, and descends to considerable depths.' There is a hole 80 fathoms deep in its generally level surface, towards the middle of the strait, and another, not bottomed by 100 fathoms of line off *Cyprian Bridge* Island. A narrow neck rather over 2 miles wide links this plateau to a smaller one prolonging Choiseul Island. 'Broken lines of barrier reef (sometimes elevated) and elongated coral shoals, covered by 4 to 10 fathoms of water, which may be regarded as incipient barrier reefs, mark the edge of the Bougainville plateau, within a few hundred yards of the 100 fathom line.' The western extremity of Choiseul is skirted by a broken line of barrier reef, which encloses a lagoon-like channel, and supports islets on which coral rock indicates an elevation of at least a few feet; and there is an island in the lagoon which bears similar testimony, while 'the hills on the coast, composed as they are of foraminiferous and pteropod mud encrusted by coral limestones, have been antecedently upheaved.' *Oima* atoll, about 2 miles long, has been built up above a group of islets composed of hornblende-andesite, each probably indicating four separate volcanic necks. This atoll rises from depths of 40 to 50 fathoms, with a submarine slope, varying from 12° to 26°. The erosion line on the volcanic rocks indicates an upheaval of some four or five feet, prior to the coral growth. The land is bordered by extensive flats, covered by less than a fathom of water, on which the coral appears to be dead, and two basins or lagoons occur within them, about 20 fathoms deep.

Sections are given of some barrier reefs. As the result of his investigations of these, Mr. Guppy concludes that, from the edge of the reef flat for the first 70 or 80 yards, there is usually a gradual slope to a depth of from 4 to 5 fathoms. On this but little living coral is found. Beyond it, there is generally a rapid descent to a depth ranging between 12 and 18 fathoms, on the face of which the corals flourish: 'this is in fact the growing edge of the reef.' Below this descent sand and gravel, produced by the action of the breakers at the margin of the reef, collect at a depth generally of from 15 to 20 fathoms, though sometimes this occurs at greater depths. One section, that of Santa Anna Island, exhibits two submarine cliffs,—the one, after a rapid slope, occurs between the depths of 16 and 32 fathoms; the other, after reaching a depth of about 42 fathoms, gives a drop of 25 fathoms, after which, a slope at an angle of 18° or 19° descends to considerable depths; corals thrive in this case at a depth of 30 fathoms. Another section exhibits a second but less strongly marked drop at about 25 fathoms.

In an explanation of the formation of barrier reefs, which Mr. Guppy regards as produced successively while the ground is uprising, it is admitted that on this hypothesis, lagoon channels should never be deeper than the limit at which reef-building corals can grow. 'But as a matter of fact the depths inside barrier reefs as well as atolls, not unfrequently exceed' 25 fathoms—in corroboration of which statement several cases of soundings in these positions of 40, 50 and even 60 fathoms are mentioned. This difficulty Mr. Guppy overcomes by the hypothesis that the limit for the development of reef-building coral is really determined, not so much by actual depth as by the condition of the water, especially in regard to the presence or absence of suspended mud (p. 888).

Another consideration confirms Mr. Guppy in his opinion that reefs are often begun at a much greater depth than 25 fathoms. The usual foundation, so far as his observations go, is composed of partially consolidated volcanic mud or ooze, more or less foraminiferous, and generally abounding in recent shells, and is not a layer of detrital sand and gravel. But in all the soundings about the reef, which often extended down to 50 fathoms, the armings never brought up any indication of the nature of the bottom other than sand and gravel. Hence it may be presumed that such reefs—as, for example, those in the Shortland Islands—began at depths greater than 50 fathoms. But if it be urged that in this case the reefs should be more than 100 feet thick—and this amount is rarely exceeded in the Solomon Islands—he replies that, as a rule, reef corals will be confined to depths of 25 or 30 fathoms, and the beginning of a reef in deeper waters will be an exceptional thing. It must also be remembered that the rapid subaerial denudation which occurs in these regions may, in some cases, have reduced the vertical thickness of the reef.

In support of Mr. Murray's view that reefs spread by an outward growth, Mr. Guppy states that he found the corals inside the lagoons to be much larger than those which occur near the outward border of the reef, and in the barrier reefs the corals were largest near the inner edge of the flat, and diminished in size as the outer edge of the reef was approached. 'These facts are of importance, since, according to the theory of subsidence, the central portion of the lagoon of an atoll, and the inner portions of the lagoon channel of a barrier reef, are more recently produced than any other portion of the area of such reefs.' The smallness of the outer corals is 'only to be explained on the hypothesis that the reef has gradually grown outwards as from a centre, and quite independently of any movement of subsidence.' Further, the low coral limestone cliffs, which not seldom back the present reef flats, are probably lines of erosion, indicative of an epoch anterior to the formation of the shore reefs, when these cliffs were washed by the sea. The disposition both of the vegetation and of the humus on the wooded islets shows that the lee side of such an islet is its oldest portion, and its weather side is its growing margin.

Illustrative of the question of the removal of dead coral by solution, cases are mentioned of masses of *madrepora* and *porites* several feet across, the centres of which were dead and were depressed a few inches below the living exterior. During the bright sunlight the increased temperature [1] of the sea water covering the reef flats probably assists in the solution of the dead coral; moreover its destruction by organisms, to which other authors have called attention, must not be overlooked. Holothurians and echinids play an important part in this respect.

The author concludes by stating that the calcareous sand and gravel which strew the outer slopes below the zone of living coral are largely composed of reef *débris*, of the tests of *Orbitolites complanata* and *O. heterostegina*, of the joints of the calcareous alga *Halimeda opuntia* and of nullipores. Of these the foraminifera were found living between 2 feet and 75 fathoms; the alga does not appear to live below 10 fathoms. At greater depths than 100 fathoms the sea bottom consists generally of volcanic mud

[1] About 16° F. higher than the open sea where the water was only 3 or 4 inches deep, and 8 higher where it was a foot deep.

(with or without organisms), which however forms also at all depths, from a few feet beneath the low tide level, in the case of large islands, the coasts of which, owing to the sediment brought down by streams, are bare of reefs.

In a paper printed in the 'Proceedings of the Royal Society' (vol. xliii. p. 440, 1888), Mr. G. C. Bourne gives a minute description of the atoll of Diego Garcia, and discusses the theories of coral-reef formation in connection with the Chagos group. In the Laccadive, Maldive and Chagos group, 'there is no instance of a fringing or a barrier reef; nothing but coral structure rises above the waves; all the islands are atolls.' The three groups are believed to stand on a submarine bank lying 1,000 fathoms below the surface, in an ocean of an average depth of 2,000 fathoms. At Diego Garcia, the shores externally 'slope away very rapidly to considerable depths, the sounding line giving depths of 250 fathoms and upwards at a distance of a few hundred yards from the edge of the reef,' except in one case. The depths inside the lagoon vary up to 19 fathoms. Mr. Bourne describes the different kinds of coral rock, and gives reasons for supposing that there has been a recent elevation of a few feet. He calls attention to the changes produced by the action of waves and currents, and to the effect of the latter upon the growth of coral: showing how the living coral may be killed by a change in a current which, formerly clear, now brings sand. This material proceeds to entomb the dead coral, and then, on a return to the former conditions, a new growth of coral may take place upon the stratum of sand. He is of opinion that the subsidence theory cannot be applied to explain the Great Chagos Bank (see p. 53), because its rim is 'on an average not more than 6 fathoms below the surface, and therefore situated in a depth eminently favourable for coral growth, and there are actually six islets on the northern and western edges, rising above the water and some of them inhabited.' He indicates further difficulties in applying the theory of subsidence to the Chagos Bank, especially pointing out that the Six Islands atoll, within a few miles distance, has not been affected; still he admits that the 'Saya de Malha Bank appears to have the characters of a submerged atoll, having a central depression of 65 fathoms surrounded by a rim which has only 8 to 16 fathoms on its eastern side, but 22 fathoms on the western.' On the whole, however, he considers that 'most of the coral formations of the Indian Ocean mark areas of elevation rather than of rest; certainly they are not evidence of subsidence.'

In regard to the explanation of the formation of lagoons by solution of the interior parts of the reef, and by the more rapid growth of the corals on its periphery, as being more directly in the track of food-bearing currents, Mr. Bourne observes:—'Neither of these explanations has completely satisfied me. That sea-water exercises a solvent action upon carbonate of lime does not admit of doubt, and that the scour of tides, combined with this solvent action of the water, does affect the extent and depth of a lagoon is obvious. But I challenge the statement that the destructive agencies within an atoll or a submerged bank are in excess of the constructive. It would be nearer the mark to say that they nearly balance one another. In the first place the carbonate of lime held in solution by sea-water is deposited as crystalline limestone in the interstices of dead corals or coral *débris*. Anyone who is acquainted with the structure of coralline rock knows how such a porous mass as a *mæandrina* head becomes perfectly solid by the deposition of lime within its mass. This deposition can only be effected by the infiltration of sea-water. In reckoning the solvent action of sea-water, therefore, account must be taken of the fact that a not inconsiderable proportion of the carbonate of lime held in solution is re-deposited in the form of crystalline limestone. Of this, it seems, Mr. Murray has not taken sufficient account, and has, therefore, overstated the destructive agency of the sea. Secondly, the growth of corals, and the consequent formation of coral rock within the lagoon, is generally overlooked.

'Whilst diving for corals at Diego Garcia I had abundant opportunities of studying the formation of coral rock within the lagoon, in depths under 2 fathoms. The layers of tolerably compact rock thus formed are of no mean extent or thickness; they soon become covered with sand, and are thus protected from the solvent action of the water. I have found it impossible to reconcile Mr. Murray's views with what I saw of coral growth within a lagoon. Not only do the more delicate branching species of the *madreporaria* flourish in considerable numbers, but true reef-building species, *porites*, *mæandrina*, *pocillopora*, and various stout species of *madrepora*, are found there. It is a mistake to suppose that certain species of corals are restricted to the external shores, others to the lagoon. My collections proved that many of the species growing in the lagoon at distances of five miles and upwards from its outlet are identical with those growing on the outer reef. In addition to them are numerous species, such as *Seriatopora stricta*, *Mussa corymbosa*, *Favia lobata*, *Fungia dentata*, and many others that are not found on the outside. The reason is that the last-named are either free forms such as *fungia*, or are attached by such slender and fragile stems to their supports that they could not possibly obtain a foothold and maintain themselves among the powerful currents and waves of the open ocean.

'These various species, numbers of which grow close together, form knolls and patches within the lagoon, and it cannot be doubted that their tendency is to fill it up. Again, in reefs which do not rise above the surface, or are awash for the greater part of their extent at low tides, great quantities of *débris*, torn from the outer slopes, are constantly carried over the rim of the reef and tend to fill it up. Hence it follows that in a lagoon entirely surrounded by dry land, or nearly so, as is the case at Diego Garcia, the tendency to accumulation of material within the lagoon would be less than in submerged or incomplete atolls, for *débris* cannot be swept over into the lagoon, and the only constructive agency is the growth of coral. If the power of solution of sea-water is so great, it must be supposed that in complete or nearly complete atolls the lagoon would be deepening rather than shallowing; yet at Diego Garcia the lagoon is obviously shallowing in many places, and has nowhere increased in depth since Captain Moresby's survey in 1837. Indeed, the southern part seems to have shoaled a fathom since that time, and this is the more remarkable, since the S.E. trade winds are by far the most constant and strongest winds there and tend to accumulate material at the northern rather than at the southern end. The fact is, that these winds sweep the sand out of the southern part, and thus leave an area particularly favourably situated for the growth of corals. Mr. Murray points out that larger atolls generally have deeper lagoons than small atolls, and urges this fact in support of his theory; but here again the facts in the Chagos group are against him. Victory Bank is a submerged atoll, the Solomons is an atoll with a large extent of dry land; in each the lagoon attains a depth of 17–18 fathoms, and in Diego Garcia the lagoon, although far larger, does not attain a greater depth. Peros Banhos is far smaller than the Great Chagos Bank, yet in both the lagoons attain nearly the same maximum depth, viz., 41 fathoms for Peros Banhos, 44 fathoms for the Great Chagos Bank. Speaker's Bank is very little larger than Peros Banhos; its lagoon is far shallower, having a maximum depth of 24 fathoms.'

Mr. Bourne passes on to consider the opinion expressed by certain authors that the favourable conditions for coral growth in the external slopes of a reef consist in the increased food supply brought by the superficial currents of the ocean. This explanation, for reasons given, he regards as incomplete, being of opinion that the direction and velocity of currents are the most important circumstances. His observations, he states, are confirmed in every particular by those made by Dr. Hickson in Celebes, and communicated by him to the British Association in 1887.[1] Mr. Bourne expresses the result of his observations in the following words:—

'Corals grow best in places where a moderate current flows constantly over them. They are killed in still water by the deposition of sediment, and they will not grow in places where a strong current sets directly against them. I noticed at Diego Garcia in many places, but particularly at the east end of East Islet, that a strong and direct ocean current is most unfavourable to coral growth, and that the reef is barren and suffering rapid erosion at such exposed spots as allow the whole force of the current to fall directly upon them. As the current parts and flows round the obstacle, one meets with a reef covered with *débris*, but barren of live coral; further on, as the current moderates in force, one finds a few growing heads of coral; and, finally, at the further end of the reef, where the current has abated its force considerably, there is a luxuriant bed of living corals and Alcyonaria. This can be seen in perfection on the southern reef of East Islet. Dr. Hickson tells me that he has observed the same facts at Celebes, that direct and strong currents are unfavourable to coral growth, that moderate tangential currents are extremely favourable, and sluggish or still water again unfavourable. This view, which both of us can support

[1] The paper is not printed in the volume for that year.

by many observations, is much at variance with the old accepted saying that corals grow best where the breakers are the heaviest. It appeared to me that heavy breakers are not favourable to coral growth, because of the quantity of shingle which they dash against the soft-bodied polyps. Some massive forms might withstand the force of breakers and violent currents if the polyps could be sufficiently protected from the shingle, but the branching madrepores are soon broken off and swept away, and even the more massive *mæandrina* soon follows, for whilst the surface of the colony grows the base is dead, is soon riddled by boring sponges, serpulæ, &c., and is no longer able to bear the strain put upon it. The great mass then breaks off and is rolled along the reef, pounding other corals in its course.'

Still, as a rule, the outward portions of the reef are the most favourable for coral growth. Hence, if a bank of coral be established below water, there is a tendency in the coral at its margin to grow both outwards and upwards, so that at last an atoll form is developed. As the rim approaches the surface, it is raised by the piling up of *dêbris*, broken off by the waves, and may, in some cases, also be upheaved. But the waves, tides, currents, &c., tend also to destroy parts of the island, so that there is a constant struggle going on between the constructive and destructive agencies. The author then proceeds to apply his theories to the formation of the Maladive atolls, remarking in conclusion :—'However one looks at the subject one must realise that the laws governing the formation of coral reefs are exceedingly complex, and that many circumstances have to be taken into account before any perfect explanation of their structure can be obtained.'

While these sheets were passing through the press a letter written by Mr. H. B. Guppy to Mr. J. Murray appeared in *Nature* (vol. xxxix. p. 236), giving some account of the results of a visit to Keeling Atoll[1] (known also as the Cocos Island). As the letter is only a preliminary note, it is difficult to analyse or appreciate the writer's arguments, so it may suffice to say that he is convinced that 'several important characters of these islands escaped the attention of Mr. Darwin,' that 'these features throw considerable light on the mode of origin of lagoon islands, and give no support to the theory of subsidence.' According to Mr. Guppy's description 'Keeling Atoll consists essentially of a ring of horseshoe or crescentic islands, including a lagoon, and presenting their convexities seawards. The crescentic form is possessed in varying degrees by different islands; some of the smaller ones are perfect horseshoe atollons and inclose a shallow lagoonlet, others again exhibit only a semi-crescentic form, while the larger islands have been produced by the union of several islands of this shape.' He states that from the effects of gales, &c., the islands are constantly altering in shape, and expresses his decided opinion that the 'small atolls and horseshoe islands only assume their horseshoe form after the island has been thrown up by the waves.' This is due to the sand and *débris*, which are swept along by a current, accumulating under the lee of the ends of a shoal on the face of which the current impinges, so that the island tends to extend, both laterally and to leeward, and thus gradually to assume, more or less, the shape of a crescent or horseshoe. Some estimates are given of the amount of material transported by the currents.

Outside the seaward edge of the present reef, Mr. Guppy has observed a series of submerged lines of growing corals separated from each other by sandy intervals. Thus the outward extension of a reef is effected 'not so much by the seaward growth of the present edge of the reef, as by the formation outside of it of a line of growing corals

[1] See ch. i. sect. i. of the present work.

which, when it reaches the surface, reclaims, so to speak, the space inside it, which is soon filled up with sand and reef-*débris*. The evidence, in fact, goes to show that a reef grows seaward rather by jumps than by a gradual outward growth. This inference is of considerable importance since it connects all classes of reefs together in the matter of their seaward growth, the degree of inclination of the submarine slope being the chief determining factor.'

Proceeding now to the papers favourable to Mr. Darwin's views we may quote first a passage in Professor Bayley Balfour's description of the physical features of Rodriguez [1] which has an important bearing on one point in recent controversies. After stating that the island is substantially a hilly mass of volcanic rock, the highest point being 1,300 feet above sea level; that the western slopes of this terminate in a wide coralline limestone plain, diversified with elevations; and that a fringing reef of coral, studded with islets, skirts the island on every side, extending on the west about three miles from land, but with its edge at the eastern end within about one hundred yards of the beach; he proceeds:—'On the south-west the central volcanic ridge gradually descends, the ravines become less deep, and the ground spreads out into a large coralline limestone plain. The demarcation betwixt the limestone and the volcanic rock is very sharp, but isolated patches of limestone are met with on the surface of the volcanic region in the vicinity of the main mass. . . . The limestone is not found along the northern or southern shores, until we near the eastern extremity, where patches occur at the mouths of valleys, and even at some distance from the shore. . . . On the southern shore between Rivière Palmiste and Rivière Poursuite, indications of raised beaches are seen, reaching about 20 feet above the sea

[1] Philosoph. Transact. R. S. vol. clxviii. (1879), p. 289.

level. The existence of these masses of coralline limestone indicates clearly a lower level of the island, and the evidence of raised beaches confirms this. But a consideration of the coral reefs points as clearly to a time when the island stood at a higher level. The present coral reef fringes the coast, extending, as I have mentioned, about three miles on the south-west side, but coming close in shore on the east. An older reef, however, exists, now quite submerged in some places to a depth of over 90 fathoms. Upon it the present reef rests, and it extends westwards nearly fifteen miles from the present coast, while on the east it stretches about six miles. We have thus proof of great and intermittent oscillations of the level of the island. Of the islets scattered over the reef some are volcanic and the others are composed of coralline limestone and sand. They are all within the compass of the present reef, and only occur on its wider parts.' Eight islets are of volcanic origin; the coralline limestone and small islets are more numerous, and are confined to the southern and western reefs; none occur on the north.

Mr. W. O. Crosby[1] states that level terraces with vertical walls, resting against the rugged mountains of the interior, and forming the shore of the island, are conspicuous features in the scenery of Cuba. They may be observed at various levels up to nearly 2,000 feet. The first preserves a sensibly uniform altitude of about 30 feet for hundreds of miles. It is breached by the rivers which flow into the sea, and is seen to be composed of coral: in short, it is an elevated fringing reef, similar to that which is now forming on the adjacent sea bottom. It varies in width from a few rods to a mile or more. Sand and gravel are occasionally interstratified, especially near the rivers, showing that they are older than the reef.

[1] On the elevated Coral Reefs of Cuba, by W. O. Crosby. Proc. Boston Nat. Hist. Soc. vol. xxii. (1882-3), p. 124.

The second reef rises steeply, often vertically from the inner edge of the first, and along the north coast varies from 200 to 250 feet, being more affected by atmospheric denudation. It is older than the other, and the organic structures therein are in part obliterated by crystallisation, but of their identity of origin there can be no doubt. The third has an altitude of about 500 feet, and is yet older, more solid and more crystalline. A fourth reef has an elevation probably of not less than 800 feet. These ancient coast-reefs, with slight interruption, extend round the whole coast of Cuba. Moreover, the limestone plateau of El Yunque is considered by Mr. Crosby to be an old coral reef. Its top is about 1,800 feet above the sea; its sides for the upper 500 or 600 feet are an almost continuous wall of cliffs.

Now, these terraces, of which the lowest is the most recent, obviously prove that Cuba has been elevated, and they mark stages in the uprising. But there is also evidence that, at the present day, the coast is sinking. This is indicated by the condition of the lower part of the valleys, which are invaded by the sea and are filled to a considerable depth with land detritus. Moreover, if El Yunque be an ancient reef, it is even now, after undergoing considerable denudation, more than 1,000 feet thick, and in any case, the third reef, mentioned above, consists of not less than 400 feet (in vertical thickness) of coral rock. But the reef-building corals do not flourish, generally speaking, in water deeper than about 25 fathoms. Hence, the maximum thickness of a coral reef would be about 150 feet, and to obtain even this we must assume that, from the time when its growth became possible, till it reached the surface, the bed of the sea remained at rest. Thus the conclusion seems inevitable that the elevation of the island of Cuba was interrupted and diversified by periods of movement in the opposite direction.

Professor J. D. Dana's paper[1] 'On the Origin of Coral Reefs and Islands,' though it deals with facts already published more than it adduces those which are novel, is so important, as the work of a naturalist whose personal knowledge of coral reefs is perhaps unequalled, that it calls for a rather full abstract. Professor Dana obtained the experience, upon which his independent testimony is founded, in the course of three years spent in travelling among coral reefs and islands in the Pacific, during which the reefs of Tahiti, the Samoan (or Navigator) Islands, the Hawaian Islands, and the Feejees were examined with care, and fifteen other coral islands visited, 'seven of these in the Paumotu Archipelago, one, Tongatabu, in the Friendly Group, two, Taputeuea and Apia, in the Gilbert Group, and five others near the equator east of the Gilbert Group—Swain's, Fakaafo, Oatafu (Duke of York's), Hull and Enderbury Island.'

Professor Dana calls special attention to the eastern half of the Feejee Archipelago, where several of the great barrier reefs, from ten to twenty miles long, have but one or two emergent peaks of land. Nanuku, for instance, has one little point near its south-eastern angle, 'a mile of peak within a barrier island 200 square miles in area. Bacon's Isles are the last two little peaks of a still larger lagoon . . . a dozen of the easternmost islands are actual atolls—the last peak gone.' But in case it should be answered that these are the emergent portions of submarine volcanos, in which case the ring-shaped barriers become difficult of explanation, while they are easy on the theory of subsidence, Professor Dana adds, that movement in this direction is proved by the existence of deep fiord-like indentations in the rocky coasts of islands, both of those inside of barriers, and those not bordered by reefs. As examples of this structure, generally admitted to be

[1] Amer. Jour. Sci. (1885), Ser. III. vol. xxx. pp. 89, 169.

one of the strongest evidences of subsidence all the world over, he quotes the Marquesas Islands with the Gambier and Hogolen Islands, Raiatea and Bolabola of the Tahiti Group and the Exploring Isles of the Feejees. Professor Dana also calls attention to the general parallelism between the average trends of coral islands and the courses, not only of the groups of which they form part, but also of the groups of high islands not far distant,[1] and refers to the arguments drawn by Mr. Darwin from the fact that the larger coral islands have the same diversity of form as is found in the barrier-reefs of high islands and exhibit groupings such as would result from the sinking of a large island of ridges and peaks with encircling reefs. The depth of the lagoon, and of the channels inside of barrier reefs—in many cases two or three times greater than twenty fathoms—is very difficult to explain if there has been no subsidence; so is that of the ocean near to atolls.

Professor Dana, after noticing one or two considerations of a general nature, points out that 'if an atoll reef is not undergoing subsidence, the coral and shell material produced which is not swept away and distributed by currents serves: (1) to widen the reef; (2) to steepen, as a consequence of the widening, the upper parts of the submarine slopes; (3) to accumulate, on the reef, material for beaches and dry land; and (4) to fill the lagoon. But if, while subsidence is in progress, the contributions from corals and shells barely compensate for the loss by subsidence and current waste, the atoll-reef, unable to supply sufficient *débris* to raise the reef above tide level by making beaches and dry land accumulations, would (1) remain mostly a bare tide-washed reef; (2) lose in diameter or size because the *débris* that is not used to keep the reef at

[1] This, however, I conceive, would not offer a difficulty to those who advocate submarine volcanic masses as a foundation for the reefs.

tide-level is carried over the narrow reef to the lagoon by the waves whose throw on all sides is shoreward; (3) lose in irregularity of outline and thus approximate towards an annular form; (4) lose the channels through the reef into the lagoon by the growth of corals and by consolidating *débris*; and (5) become at last a small bank of reef-rock with a half-obliterated lagoon basin.

'The Pacific contains reefs of the three kinds: (1) atolls with much of the reef overgrown by trees and shrubbery; (2) others, of large and small size, with the reefs mostly or wholly tide-washed; (3) others, only two or three square miles in area without lagoons. Further, the different kinds are generally grouped separately and gradationally: (1) the islands of the Paumotu and Gilbert Archipelagos have usually half or more of the reef dry and green; (2) the northern Carolines and the northern Marshall Islands and the eastern Feejees, although in fact of large size, are mostly bare reefs; while (3) the islands of the Phœnix Group, of the equatorial Pacific east of the line of 180°, are, with one exception (Canton or Mary), not over four miles long. The three more southern of the Phœnix Islands, Gardner's, Hull's and Sydney, between 4° 25′ S. and 4° 35′ S., are two to four miles long and have lagoons; five (islands), including Phœnix, Birnie's and Kean's between 3° 10′ S. and 3° 30′ S., and Howland and Baker's, north of the equator, are a mile and a half, and less, in length, and have depressions at the centre but no lagoons. The depressions contain guano, and one of them, Kean's, has much gypsum mixed with the guano; Kean's and Phœnix have a foot or two of water at high tide, the tide rising six feet. Another of the number, Enderbury's, is three miles long, and has a half-dried lagoon which is very shallow and has no growing corals. To the north of these islands for fifteen degrees of latitude, the sea is an open one, and in the next ten degrees, to the line of the Hawaiian chain, the only islets not marked doubtful are "Coral Reef, Awash" and Johnston Island. A similar gradation in size takes place in the Ellice, Ratack, and many other groups of the ocean.' Smallness of size and dried lagoon basins, with occasionally a deposit of gypsum from evaporated sea water, are just the results which should be expected if the cause which had regulated the coral growth had been subsidence; and gradation in it would result from gradation in the amount of subsidence.

Professor Dana states that he also came to the conclusion (and this appeared to be sustained by the 'Tuscarora' and 'Challenger' soundings) that the belt of maximum subsidence in the Pacific ran from the south of Japan in a south-easterly direction, passing south of the Marquesas Group towards Easter Island. The 'Tuscarora' soundings indicated that transverse to the trend of the Phœnix Islands (*i.e.* transverse to the belt of maximum subsidence), the mean submarine slopes appear to be 1 to 1·5 or 1 to 1·7 (the former being nearly the maximum slopes of Cotopaxi, Mount Shasta, and several other volcanic summits of Western America), while the slopes along the trend are much less. This fact is more in accordance with a theory of extensive subsidence than of extensive upheaval.

Subsidence also is indicated by the deeply indented shores of the Marquesas Islands, but here, probably owing to the boldness of the coast line, reefs are few. Tahiti on the contrary affords no direct proof of subsidence, and none of elevation, beyond that of one or two feet. But its broad reefs are favourable, in Professor Dana's opinion, to the idea of subsidence, and he suggests that it has amounted to about 45 or 50 fathoms. In one island of the Navigator Group the indented shores seem to favour a local subsidence, but in the others there is no direct proof of movement in either direction. Subsidence, however, is indicated by the broad reefs, barrier islands, and atolls of the Feejee groups.

Elevation undoubtedly has occurred in several localities, *e.g.* in the Austral, Hervey, Friendly, and even in the Sandwich Islands, but in all the amount is small—not, so far as he knows, anywhere exceeding 300 feet. These Professor Dana considers to be merely local phenomena, and he passes in review several facts showing the uncertainty of evidence as to little or no subsidence, or as to recent elevation from narrow reefs and the volcanic character of islands. Further, these local elevations in coral seas, where they do occur, are spread over very large areas. For instance, the Paumotu Archipelago, consisting of more than eighty atolls and two barrier islands, contains only three or four atolls that are over 12 feet high. Of these Metia is 250 feet high. Dean's, probably at its highest 15 or 20 feet, is 60 miles to the N.N.E.; far to the S.E. of that, nearly 1,450 miles from Metia, is Elizabeth Island, 80 feet. 'Locate these points on a continent, and Pacific distances and the length of Pacific chains of atolls will be appreciated.'

Professor Dana next reviews the arguments in favour of hypotheses other than that of subsidence, and deals with the soundings of the 'Challenger' off Northern Tahiti, upon which great stress has been laid by Mr. Murray and others. Here, from the edge of the barrier reef, the sea bottom, covered partly with growing corals, deepened gradually in about 250 yards to 40 fathoms (*i.e.* to considerably below the depth at which reef-building corals usually can grow), then from this limit the bottom dropped down in about 100 yards to 100 fathoms; at first precipitately at an angle of 75°, then more gradually, but above 45°; and for another 150 yards the sea bed still shelved down at 30°, but beyond this the slope diminished in the course of a mile to 6°, where at last the depth was 590 fathoms.

In other words, we may regard this part of Tahiti as a submerged mountain 3,600 feet high. Up to a contour line of 3,000 feet the ground shelves upwards, at first gently, then more steeply, till it attains a slope of 30°; from the top of this rises a line of cliffs about 350 feet high crowned by a slope of which the angle is 18°. The craggy zone is strewn, we are told, with large masses of coral—like a talus beneath a line of cliff—mingled with fine *débris*; in about 100 yards there is only sand, which continues to the lower part of the mountain, where it gives place to mud, composed of volcanic and coral sand and various organisms, generally minute.

Great stress is laid on the occurrence of this area of coral crags and 'screes' as indicative of the mode in which a reef is enabled to grow outwards on a foundation, built from its own ruins. Such a mode of enlargement (as Professor Dana points out) had, however, been obviously admitted as possible in particular cases,[1] and so cannot be regarded as contrary to the general hypothesis put forward by Mr. Darwin. But he calls attention to the fact that the above observations prove: (1) that the currents round Tahiti are evidently weak because they carry little coral *débris* so far as a mile from the edge of the reef; (2) that very large masses of coral are lying about below the submarine cliffs at depths of from 240 to 600 feet, *i.e.* far below the depth at which the waves could exert any serious rending force. The position of these blocks, always below 240 feet—too far from the edge of the reef to have been borne from it and washed at last over the brow of the steep declivity—seems only to be explicable when it is regarded as indicating a stage in the past history of the reef, and is a memorial of a time when this declivity was the edge of a growing reef, and its brow was beaten by the waves.[2]

[1] See pp. 22, 67, &c. of the present volume.

[2] Professor Dana considers that waves do little rending below the

The case at Tahiti appears to be confirmed by other instances; such as Captain Fitzroy's sounding (in the 'Beagle' Voyage) at Keeling Atoll, 2,200 yards from the breakers, when no bottom was found at a depth of 1,200 fathoms; and the sounding by Captain Wilkes off Clermont Tonnerre (Paumotu Archipelago), where 'the lead brought up an instant at 350 fathoms, then dropped off and descended to 600 fathoms, coming up bruised with small pieces of red and white coral attached'; as well as that by the same 'a cable's length from Ahii,' where the lead struck a ledge of rock at 150 fathoms, and brought up finally at 300 fathoms. Still, it would be well that the older soundings should be repeated, and the subject be more fully investigated.[1]

In regard to Professor Agassiz's argument that the Florida reefs are the result of drifting material (see p. 287), and in no way require or indicate subsidence, Professor Dana points out that there is little in the great barrier reef of Eastern Australia, which has some correspondence in position with the sand reefs off eastern North America, to suggest a similarity of origin. Full of irregularities of direction and of interruptions, it follows in no part an even line. In the northern part, the barrier, while varying much in its course, is barely 30 miles from the land; in the southern half it extends out 150 miles from the coast, and includes a large atoll-formed reef. Further, in the Pacific Ocean, the trends, whether of coral island groups, or of the single islands, frequently do not correspond with the direction of the oceanic currents, or indeed of any current

depth to which they can bare the bottom, so as to obtain an effective broadside stroke, which he thinks rarely exceeds in the most extreme cases 20 feet vertical. At 240 feet he believes the displacement of the water would be at most only a few inches, and thus the battering power would obviously be *nil.*

[1] See below, p. 319, for an account of Masámarhu Island in the Red Sea.

which is not determined by their existence. Moreover, to prove formation from drifting does not suffice to disprove subsidence. The length of Sandy Hook varies in consequence of the action of currents, yet this does not disprove Professor Cook's conclusion that the New Jersey Coast is subsiding.

Further, it must be borne in mind that subsidence has undoubtedly taken place in the region around Florida, though at present we can only prove this to have lasted into the earlier Pleistocene, the difficulty of dealing with this being augmented by the occurrences of elevated coral reefs, in Jamaica at 2,000 feet above the sea, and in Cuba perhaps even at the same, and certainly at 1,000 feet. The former, while obviously proving elevation, are considered by Mr. Crosby to prove also the occurrence of epochs when movement was in the opposite direction (see p. 309).

The next section calls attention to the vague character of the evidence adduced for the building up from deep waters of important banks, composed of organic *débris*, to serve as the foundations of a coral reef, though doubtless such a thing may occasionally occur. But in regard to the existence of submerged mountain masses, which have been indicated as suitable for the like purpose, it may be well to give Professor Dana's quotation of the argument, and his comment thereon. Mr. Murray 'observes that the "soundings of the Tuscarora and Challenger have made known numerous submarine elevations: mountains rising from the general level of the ocean's bed, at a depth of 2,500 or 3,000 fathoms up to within a few hundred fathoms of the surface." But "a few hundred fathoms," if we make "a few" equal 2, means 1,200 feet or more, which leaves a long interval yet unfilled.'

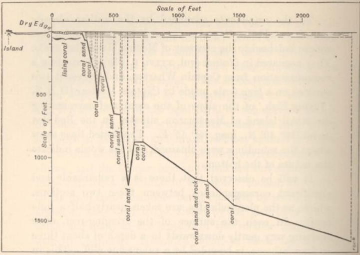
Lastly, Professor Dana reviews the proposed explanation of the ring-like shape of atolls, and of the channels which exist in the enclosure of atolls or between atolls;

and points out that the larger the atoll the purer the sea-water of the lagoon, so that the latter would speedily reach a limit to its expansion in consequence of the non-growth of coral; indeed, as a matter of fact, these larger lagoons contain plenty of living coral. The second (and ultimately more important) factor in the enlargement of a lagoon, viz. the corrosion of the dead coral by the solvent action of water, he regards as a hypothesis which has little direct evidence in its favour and much indirect against it. The connection of channels with prevailing currents cannot be shown, and the former in many cases are sufficiently deep to be well below the limit of abrasion. Indeed, as a rule, so far from these channels being enlarged by solution and abrasion, they tend to be closed by the growth of living coral, and many of the lagoons in the smaller islands are without channels. Hence in them, as there can be no appreciable transference of water, the action of solution must be reduced to a minimum. Yet these closed atolls are by no means exceptional. For instance, in the case of about sixty coral islands mapped by the Wilkes expedition, of those which range from $1\frac{1}{2}$ to 3 miles in the longer diameter of the reef, nine have no lagoon, but only a small depression in its place, which is dry, except in the case of two where water gets in at high tide. Of those under 6 miles in length, having lagoons, 17 in number: 16 have no entrance to the lagoon at low tide; the other has an entrance of large size. Of those 6 miles or over in length, 29 in number: 17 have channels and 12 have none; those having channels are generally over 10 miles long. It must also be understood that the opponents of the subsidence theory are compelled to admit it in order to explain the depth of certain lagoons. Hence Professor Dana considers that the hypothesis of elevation or lateral spreading during a period of rest is inadequate as a general explanation of the problem.

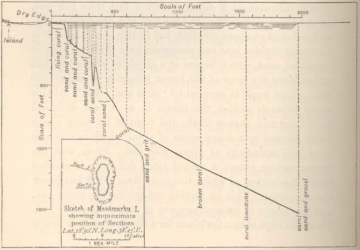
To the arguments advanced by the author already quoted we add the diagrams annexed, for the use of which we are indebted to the courtesy of Messrs. Macmillan & Co. They appeared in *Nature* (vol. xxxvi. p. 413), illustrating a communication from Captain Wharton, and represent two sections on a true scale, made by Captain Maclear (H.M.S. 'Flying Fish,' of the slope of the coral reef surrounding the small island of Masámarhu, situated in the Red Sea in lat. 18° 49′ N., long. 38° 45′ E. The dotted lines show where the soundings were obtained, and the words indicate the nature of the bottom.

It will be observed that there is a remarkable and significant correspondence between these two sections, which, as the plan indicates, are taken nearly half a mile apart. In each the surface of the fringing-reef, after shelving very gently downwards to a depth of about three or four fathoms, is bounded by a submarine cliff. This in one section (No. I.) continues almost unbroken to a depth of about 500 feet, except that a kind of ledge or terrace is clearly indicated at a depth of rather less than 100 feet. In the other section (No. II.) the foot of a great submarine cliff is found at about 500 feet, but in this case the cliff is distinctly divided into two precipices by a shelving bank of coral and sand, which begins at a depth of about 140 feet and reaches the brow of the lower precipice at about 260 feet. This bank is covered by 'sand and coral.' At this depth in each section the island is, as it were, defended by a deep and narrow ditch, the edge of its steep glacis being formed by a sharp arête of coral which in one case rises into soundings of about 250 feet. From this the former section shows a second rapid fall down to another ditch, the bottom of which lies more than 1,200 feet below the sea level. This in section resembles the other one, and the height of its counterscarp is more than 300 feet. From the edge of this the glacis for a short distance is nearly

No. I.


Scale of Feet
0
500
1000
1500
2000
Dry Edge
Island
living coral
coral sand
coral
coral
coral sand
coral sand
coral sand
coral
coral
coral sand
coral sand and rock
coral sand
coral
rock
Scale of Feet
500
1000
1500

No. II.


Scale of Feet
500
1000
1500
2000
Dry Edge
Island
living coral
sand and coral
sand and coral
sand and coral
coral sand
coral sand
coral
sand and grit
broken coral
coral limestone
coral sand and gravel
Scale of Feet
500
1000
1500
Sketch of Masámarhu I.
showing approximate
position of Sections
Lat. 18°50'N. Long. 38°45'E.
1 SEA MILE

level, and then descends at an angle of some thirty degrees. In the lower diagram we find no indication of this second ditch, but a long slope begins at the foot of the submarine cliff at a depth of about 850 feet, which is very nearly identical with that of the flat part of the glacis in the former section.

It will be observed that the upper ditch (that common to both sections) has its bottom at a depth of full 500 feet, or about 85 fathoms—that is, at more than three times the average depth at which reef-building corals cease to live, while the least depth of the final submarine slope is 850 feet, or more than 140 fathoms. These ditches seem irreconcilable with any idea of an outward-spreading growth of the reef, and must, I think, be indicative of a subsidence which isolated the outward and more flourishing edge of a shore reef, and progressed rather too rapidly to allow its corals to extend across the trench thus formed and effect a union with the main mass. Of course if a fissure-like hollow were once established between two masses of growing coral in a subsiding area, it would not be readily filled up, unless the edge of its outer wall were sufficiently near the surface to suffer much from the violence of the waves.

The former section seems to me inexplicable under the conditions ordinarily admitted for coral growth, unless we suppose that the bottom of the lower ditch, now at a depth of over 1,200 feet (200 fathoms), was formerly situated within about 25 fathoms of the surface; so that a subsidence of more than 1,000 feet may fairly be claimed for the coral reef of Masámarhu.

Professor Dana,[1] in an article which appeared while this sheet was in the press, adduces some new and very

[1] Points in the Geological History of the islands Maui and Oahu. By J. D. Dana, Amer. Jour. Sci. vol. xxxvii. p. 81 (February 1889). I am indebted to my friend Professor Judd for calling my attention to this article.

important evidence in regard to the Sandwich Islands. Oahu, the island on which is the town of Honolulu, gives indications of a recent upward change of level, amounting to 60 feet at least on its northern, and about 20 feet less on its southern side. But this is not all. Several deep borings have been made in different parts of the island, the particulars of which are recorded. The following may be taken as examples.

I. *James Campbell's Well, at west foot of Diamond Head, not far from sea-level.*

	Thickness Feet	Depth Feet
Gravel and beach sand	50	
Tufa like that of Diamond Head	270	320
Hard coral rock, like marble	**505**	**825**
Dark brown clay	75	900
Washed gravel	25	925
Deep red clay	95	1,020
Soft white coral	**28**	**1,048**
Soapstone-like rock	20	1,068
Brown clay and *broken coral*	110	1,178
Hard blue lava	45	1,223
Black and red clay	28	1,251
Brown lava	249	1,500

II. *King's Well No.* 2, *about half a mile west of Diamond Hill, and* 350 *yards from the sea-shore.*

	Thickness Feet	Depth Feet
Sand and coral	38	
White coral rock	**22**	**60**
Yellow sand	43	103
Hard lava	47	150
White coral rock	**110**	**260**
Blue clay	25	285
Tough clay and *coral*	65	350
Blue clay	30	380
Hard coral rock	**40**	**420**
Soft coral	**30**	**450**

King's Well, etc.—continued.

	Thickness Feet	Depth Feet
Tough clay	5	455
White coral rock	40	495
Tough clay	30	525
White coral rock	100	625
Tough clay	5	630
Coral and clay	70	700
Tough clay	28	728
Black sand	2	730
Lava	120	850

III. *Well in Thomas Square, Honolulu.*

	Thickness Feet	Depth Feet
Soil 6 feet, with 6 feet of black sand, and clay 4 feet	16	
White coral rock	200	216
Brown clay	44	260
Coral rock	10	270
Brown clay	60	330
White coral rock	50	380
Brown clay	80	460
Bed rock or lava, penetrated	49	509

The evidence of these borings, which is corroborated by others quoted in the paper, points to a very considerable subsidence in this region, to the amount of at least 800 feet, and in all probability of considerably more than 1,000 feet. Moreover, the 'hard coral rock, like marble' (No. I.) can hardly be anything but a 'fossil reef'; the base of this, it will be observed, after some upheaval, is even now at a depth of 825 feet ($137\frac{1}{2}$ fathoms), and the reef has a continuous thickness of 505 feet (full 84 fathoms).

The above abstracts may suffice, I hope, to give a fair representation of the arguments for and against Mr. Darwin's theory, which have been advanced during the last fourteen years. That theory is regarded by some enthusiastic opponents, as already on the threshold of the limbo appointed for exploded hypotheses. To this opinion I cannot declare myself a convert, for reasons which, in conclusion, I shall endeavour to indicate.

First, however, I may remark that certain of Mr. Darwin's critics occasionally appear to have perused his book with overmuch haste, and to have overlooked the fact that he admits such possibilities as local upheavals, the lateral growth of reefs, and modes of formation similar to those asserted for the Florida reefs ;[1] that in short, most of the causes on which stress has been laid by his critics have been already noticed by him, so that he differs from them, not in overlooking such causes, but in assigning to them a subordinate value. Moreover, it may not be unfair to call attention to the want of unanimity among his opponents : some advocating solution as a primary cause in the shaping of atolls, while others rely chiefly on the mode of growth of the polyps. Such a divergence obviously does not prove Mr. Darwin right, but it does indicate that as yet no other hypothesis has been able to secure a general acceptance, and that the problem still demands the exercise of cautious induction, which was his method of procedure, and does not justify the over-confident boldness of assertion which has characterised at least one critic of his work.

The chief arguments which have been advanced against Mr. Darwin's theory, as it appears to me, may be thus summarised :—1. That such evidence as can be obtained in regions where extensive coral reefs exist is favourable to upheaval rather than to subsidence. 2. That lateral growth is a most important factor in the formation of a reef, the polyps, as they advance, being supported on a foundation composed partly of the broken fragments of the reef, partly of other marine organisms, and that by means of the latter deeply submerged banks are sometimes augmented vertically until they are brought within the zone of reef-coral

[1] See pp. 22, 23, 79, 120, 121, 174, etc.

life. 3. That lagoons and lagoon channels are materially enlarged by the destruction of dead coral through the solvent effects of sea-water. 4. That in the past history of the earth we find no evidence in favour of the formation of coral reefs in areas of subsidence, or in other words that fossil coral reefs are less than some 25 fathoms thick.

1. Much stress is evidently laid upon the fact that many coral islands afford evidences of a certain amount of upheaval. This amount, in most cases, is but slight, and its significance appears to me to have been exaggerated. Undoubtedly, it proves that the record which is the most obvious indicates an upward and not a downward motion, but in so doing it introduces a difficulty which will presently be noticed. These indications, however, do not of themselves prove a general upheaval, but only oscillation. Every geologist is aware that movements in any given direction are frequently neither uniform nor continuous. For instance, no one doubts that the western coast of Scandinavia, and, in a less degree, that of Great Britain, have very considerably subsided since the sculpture of their leading physical features, and yet from the Land's End to the North Cape we constantly find proofs that the latest movements have been in an upward direction. Even in the case of the more important, but much rarer, upheaval of reefs, as at the island of Cuba, the coral masses are so thick that we must assume the practical arrest of all upward movement during the growth of the reef. In this case also, if the coral reef be only a sort of cap concealing a hill of pre-existent rock, we may reasonably be surprised that the 'ashlar-work' of coral limestone has in no case so far yielded to the action of the atmospheric agencies as to lay bare its inner support.

Doubtless there are many reefs to which either explanation might be applied, but there are some which, unless coral polyps can build at depths much greater than 25 fathoms, can only be explained by subsidence. It is sought to elude this difficulty by supposing that the reef builders, under specially favourable circumstances, may commence operations at depths considerably greater than the usual limit. It is indeed true that reef corals are sometimes dredged alive from depths much exceeding 25 fathoms, but the result of all recent researches has certainly been to confirm the general correctness of this bathymetrical limit, and the proposed evasion of the difficulty is at present a mere hypothesis, which bears a suspicious resemblance to the epicycles devised to prop up the Ptolemaic system of astronomy.

While the existence of 'continental rocks,' as they may be called, in oceanic islands would have almost proved a general subsidence, I do not see that the frequent occurrence of volcanic rocks is seriously opposed to it. The arrangement of the majority of coral islands, whether wholly composed of organic material, or incrusting a nucleus of volcanic rocks, is indicative of lines of weakness in the earth's crust, which would give rise to movements in either direction, and in each case the islands would be connected with extruded masses of volcanic rocks, ejected at various points along these lines.[1] Thus, we have to consider which of two hypotheses is the more probable: (*a*) that mounds thus formed have, in the majority of cases, failed to reach the surface, but have nevertheless generally arrived within a comparatively short distance of that goal; or (*b*), that they, after having in many cases overtopped the surface, have again subsided. The latter,

[1] It must not be forgotten that though the peaks of mountain ranges are frequently composed of 'continental rocks,' instances are by no means wanting, as in the Andes, Caucasus, &c., where the higher portions are volcanic. In more insulated mountain masses, as those of Etna, Kilimanjaro, Ararat, of some of the islands of the Malay Archipelago and on the western coast of North America, we have instances of volcanoes forming the highest part of the land.

I must confess, seems to me the more probable, especially when we remember that subsidence very commonly occurs in a district when it has recently ceased to be the scene of volcanic disturbances on a large scale.

2. In regard to the lateral spreading of reefs, like a 'fairy ring,' as it has been happily expressed, there is no doubt that, as has been admitted by Mr. Darwin,[1] some augmentation may occur in this way; but to regard this as a factor of prime importance in the development of a reef seems to me to import new and serious difficulties. Let us assume that the submarine mound or shoal on which the reef is founded remains at rest during the whole period of the growth of the latter, and that this commences on the area (regarded, for simplicity, as a plain) included within the bathymetrical contour line of 25 fathoms. For a considerable period, until the edge of the reef arrives within a few fathoms, probably less than ten (see p. 315), of the surface of the sea—that is, for full three-fifths of its whole vertical growth—the exterior slopes will only be augmented by the accumulation of marine organisms, a process which cannot be rapid. Hence, for a considerable time, until the reef itself has completed the greater part of its growth, and begins to augment the talus with its own ruins, the process of laying the foundation for a new coral growth, and thus the lateral spreading of the reef, will be slow.

Consider, then, the case of a reef where this process has begun, and for simplicity regard it as a cylinder capping a flat-topped cone. Obviously, if the reef begin to spread laterally, the volume of the foundation required to support the new growth increases far more rapidly than the area from which material can be supplied. Hence, as the reef advances outwards, the rate of increase will rapidly diminish, unless we suppose either an extraordinary annual destruction of growing coral, or an increased

[1] See pp. 22, 67, 70 of this work.

accumulation of other organisms. Moreover, unless we rely on solution for enlarging the lagoon, this will remain of its original size, and thus will be small in comparison with the ultimate area of the atoll. No doubt, for a time, as the reef is approaching the surface of the sea, the more rapid growth of the coral at its outer margin will cause it to be saucer-like in section, and thus somewhat enlarge the lagoon, but as soon as the upward growth ceases this process is arrested and the atoll can only spread laterally and thus must increase in breadth, while the lagoon, if there be no solution, tends rather to diminish in size.

It is, however, stated on good authority[1] that coral growth, as a rule, is by no means entirely arrested in a lagoon, and we cannot suppose that so long as there is free passage for a considerable stratum of water above the reef—*i.e.* so long as there are soundings of 8 or 10 fathoms over it—the polyps on its inner part will suffer materially from want of food or properly aërated water. Hence the lagoon will not be formed at all until the reef has made some progress upwards, so that it should always be comparatively shallow, not exceeding a few fathoms in maximum depth. From the above considerations it appears to me that the 'fairy-ring' hypothesis is inadequate unless it be inseparably linked with that of 'solution.'

At this period we may not unfitly notice another consideration which has been urged, viz. that many shoals, chiefly of volcanic origin, which lie at too great a depth to be colonised by reef-building polyps, may be raised up to the proper level by the accumulation of marine organisms. That this may sometimes occur cannot be denied, but it must be remembered that, unless the shoal lie at a very moderate depth below the required level, the process of accumulation will be extremely slow. Mr. Murray's estimate of the quantity of carbonate of lime present in the

[1] See pp. 302, 318 of this work.

minute organisms which inhabit the upper stratum of the ocean water seems at first considerable, but when we estimate its thickness in a given area, this proves to be extremely small. Hence, unless we assign a very brief existence to each individual, and thus suppose a heavy rain of shells on the ocean floor, the foundation for the future reef will rise but slowly, and its initiation, in the case of those which now exist, must be carried back to a rather remote epoch. Here, again, we may inquire whether a cause, which must not be wholly overlooked, has not, through an error in mental perspective, been brought into undue prominence.

3. The solution theory, which indeed by no means meets with universal acceptance among Mr. Darwin's critics, appears to me beset with considerable difficulties. The solubility of carbonate of lime in ocean-water cannot of course be denied; but is there satisfactory evidence that this is a factor of primary importance to the case of a coral reef? The apparently rapid solution of calcareous organisms at great depths has but little bearing on what occurs at small depths, and the good preservation of the 'globigerina ooze' down to depths of some 2,000 fathoms, in itself indicates that solution to any important amount takes place under very exceptional conditions. The rottenness frequently noted in dead coral is mainly due to the decomposition of the animal tissues with which the mineral constituent is incorporated: thus the process is one of disintegration more than of solution. The dead coral is no doubt to some extent dissolved, but it mainly forms a sand or mud. This of course, in some cases, will be swept out by currents into the open ocean, and thus the coral will be removed from its place of growth, but it may well be doubted whether this substitute for a true solution will be for long a factor of prime importance in the genesis of a lagoon. There is moreover some evidence directly opposed to the theory of solution at a moderate depth, as, for

example, the blocks of recent limestone which were dredged by Professor A. Agassiz off the Florida reef.[1] Under what circumstances, then, will the sea-water act as a solvent on the dead coral? I think we must reply, When the fluid is rather rapidly altering its position in regard to the substance attacked. Thus rain and streams are important solvents, and so might be breaking waves or tidal ebb and flow, but when the water is at rest or is only spreading with a slow, diffusive movement, its solvent action is extremely slight. For instance, chalk often is, and must often have been, saturated with water, yet numbers of the minute organisms which enter into its composition are still perfectly distinguishable. The same is true of many other limestones; indeed the effect of water often seems conservative rather than destructive. It sinks down into the body of the rock, carrying with it the carbonate of lime which has been obtained from the exposed superficial part of the mass, but on reaching the level of saturation, when it only percolates by diffusion, it commonly deposits its burden, filling up with mineral calcite the interstices of the organic materials. Hence the comparatively quiet waters of a lagoon would be favourable to the consolidation rather than to the destruction of the dead coral, save only within a very limited distance from the surface. Moreover, the remains of organisms, when once the interstitial animal tissues have been replaced, appear to be less soluble than the other parts of a rock, as is indicated by the familiar 'weathering out' of fossils. Reef rock also appears very apt to assume a solid and semi-crystalline condition (p. 17), and in regard to this we must not overlook a peculiarity of coral which, as it seems to me, has an important bearing on the subject. Dead coral is very readily converted into dolomite, which is a much less soluble salt than calcite. Further, the conditions which

[1] See p. 288 of this work.

would prevail in a lagoon, when its waters had become unsuitable for coral life, would be those which would be exceptionally favourable to the formation of dolomite. It seems, then, from the above considerations that we cannot regard the corrosive effect of sea-water as an agent of more than very secondary importance in modifying the structure of an atoll.

4. In regard to the negative geological evidence. Here we must not overlook two considerations—one that the structure of a coral reef is very commonly more or less composite; broken coral, shells, &c., forming a part, and sometimes predominating when from one cause or another the growth of the polyps is temporarily checked (p. 155); hence in some cases, what is really a continuous reef may be supposed, if only an occasional section be visible, to be a series of thin reefs—the other (the more important and general) that the characteristic structure of dead coral becomes rapidly inconspicuous and may be only discoverable in thin sections under the microscope. Where dolomitisation has occurred it may be actually obliterated, for the molecular changes involved in the process are often sufficient to destroy every trace of an organism. We may thus be prevented from recognising many ancient coral reefs. Moreover, the *aporosa* and *madreporaria*, which are now the chief reef-builders, have only become common since the conclusion of Palæozoic ages, so that the largest volume of the geological history of the earth is excluded from consideration, because in the times which it covers the habits of the reef-builders may have been different. Reefs also, it must be remembered, are restricted at the present day to almost tropical regions, so that, notwithstanding any variation of climate, they must always have been less frequent and less luxuriant in northern latitudes—that is to say, in those regions with which geologists are best acquainted. Still, instances of thick reefs of comparatively

late date are on record,[1] and if those geologists are right who consider the Schlern dolomites as being to a great extent due to reef-building corals, we have in the Triassic deposits of the Italian Tyrol reefs thick enough to satisfy the most exacting requirements.

It is then, I think, premature to regard the theory which was advanced by Mr. Darwin, and has received the approval of an observer of such an exceptional experience as Professor Dana, as conclusively disproved by the results of the more recent investigations. That this theory may have been expressed in terms a little too comprehensive, that there may be a larger number of exceptional cases than was at first supposed, is quite possible. This, however, is the almost inevitable lot of every great generalisation. Its author concentrates, and rightly concentrates, his attention on the salient features, as one who gazes first at a mountain group fixes his eyes upon the principal peaks and for a time pays little attention to, perhaps even under-estimates the importance of, the subordinate ranges; nevertheless his conception of the physical structure of the region, though modified, is not overthrown by the work of subsequent travellers. This may prove to be the case in regard to the present controversy. It may very possibly be found that, as remarked by Mr. Bourne, the history of coral reefs is more varied and complicated than was at first supposed, but it seems to me that, as the evidence at present stands, it is insufficient to justify a decision adverse to Mr. Darwin's theory as a general explanation.

[1] See pp. 309, 322 of this work.

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The names in italics are all names of places, and refer exclusively to the Appendix; in well-defined archipelagoes, or groups of islands, the name of each separate island is not given. References in square brackets refer to the new appendix.

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Plate 1._ SHE

r. & Co. Waterloo

J. & C. Walker, Sculp.t

Note. Scale ¼ of an inch to a mile, except in Figs. 2, 3 and 4 in which it is ⅒ of an inch to a mile.
Soundings in fathoms, a few of the deepest being given.

Plate 1.— SHEWING THE RESEMBLANCE IN FORM BETWEEN BARRIER CORAL-REEFS SURROUNDING MOUNTAINOUS ISLANDS, AND ATOLLS OR LAGOON-ISLANDS.

Published by Smith, Elder, & Co. Waterloo Place.

J. & C. Walker. Sculpt.


PLATE II.
GREAT CHAGOS BANK
Fig. 1. 1/10 of an Inch to a mile
The shaded parts are from 4 to 10 f.ms under water
4 to 10 fathoms
15 to 20 f.ms
40 to 50 f.ms
Level of the Sea
East & West Section across the Gr. Chagos Bank 76 miles in length
Fig. 2. 1/10 of an inch to a mile
MENCHICOFF ATOLL
Fig. 3. 1/10 of an Inch to a mile
NEW
CALEDONIA
Fig. 5. one inch to 60 miles
Powells Is.d
MAHLOS
MAHDOO ATOLL
Fig. 4. 1/10 of an Inch to a mile
Horsburgh Atoll
MALDIVA ARCHIP.o
Fig. 6.
One Inch to 60 miles
Tilla dou Matte
Milla dou Madou
Mahlos Mahdoo
Male
Ross
Ari
Phaleedoo
Nillandoo
Moluque
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