CHAPTER XX.

KEELING ISLAND:—CORAL FORMATIONS.

Keeling Island—Singular appearance—Scanty Flora—Transport of Seeds—Birds and Insects—Ebbing and flowing Springs—Fields of dead Coral—Stones transported in the roots of Trees—Great Crab—Stinging Corals—Coral-eating Fish—Coral Formations—Lagoon Islands or Atolls—Depth at which reef-building Corals can live—Vast Areas interspersed with low Coral Islands—Subsidence of their foundations—Barrier Reefs—Fringing Reefs—Conversion of Fringing Reefs into Barrier Reefs, and into Atolls—Evidence of changes in Level—Breaches in Barrier Reefs—Maldiva Atolls; their peculiar structure—Dead and submerged Reefs—Areas of subsidence and elevation—Distribution of Volcanos—Subsidence slow, and vast in amount.

April 1st.—WE arrived in view of the Keeling or Cocos Islands, situated in the Indian Ocean, and about six hundred miles distant from the coast of Sumatra. This is one of the lagoon-islands (or atolls) of coral formation, similar to those in the Low Archipelago which we passed near. When the ship was in the channel at the entrance, Mr. Liesk, an English resident, came off in his boat. The history of the inhabitants of this place, in as few words as possible, is as follows. About nine years ago, Mr. Hare, a worthless character, brought from the East Indian archipelago a number of Malay slaves, which now, including children, amount to more than a hundred. Shortly afterwards, Captain Ross, who had before visited these islands in his merchant-ship, arrived from England, bringing with him his family and goods for settlement: along with him came Mr. Liesk, who had been a mate in his vessel. The Malay slaves soon ran away from the islet on which Mr. Hare was settled, and joined Captain Ross's party. Mr. Hare upon this was ultimately obliged to leave the place.

The Malays are now nominally in a state of freedom, and certainly are so, as far as regards their personal treatment; but in most other points they are considered as slaves. From their discontented state, from the repeated removals from islet to islet, and perhaps also from

a little mismanagement, things are not very prosperous. The island has no domestic quadruped, excepting the pig, and the main vegetable production is the cocoa-nut. The whole prosperity of the place depends on this tree: the only exports being oil from the nut, and the nuts themselves, which are taken to Singapore and Mauritius, where they are chiefly used, when grated, in making curries. On the cocoa-nut, also, the pigs, which are loaded with fat, almost entirely subsist, as do the ducks and poultry. Even a huge land-crab is furnished by nature with the means to open and feed on this most useful production.

The ring-formed reef of the lagoon-island is surmounted in the greater part of its length by linear islets. On the northern or leeward side, there is an opening through which vessels can pass to the anchorage within. On entering, the scene was very curious and rather pretty; its beauty, however, entirely depended on the brilliancy of the surrounding colours. The shallow, clear, and still water of the lagoon, resting in its greater part on white sand, is, when illumined by a vertical sun, of the most vivid green. This brilliant expanse, several miles in width, is on all sides divided, either by a line of snow-white breakers from the dark heaving waters of the ocean, or from the blue vault of heaven by the strips of land, crowned by the level tops of the cocoa-nut trees. As a white cloud here and there affords a pleasing contrast with the azure sky, so in the lagoon, bands of living coral darken the emerald green water.

The next morning after anchoring, I went on shore on Direction Island. The strip of dry land is only a few hundred yards in width; on the lagoon side there is a white calcareous beach, the radiation from which under this sultry climate was very oppressive; and on the outer coast, a solid broad flat of coral-rock served to break the violence of the open sea. Excepting near the lagoon, where there is some sand, the land is entirely composed of rounded fragments of coral. In such a loose, dry, stony soil, the climate of the intertropical regions alone could produce a vigorous vegetation. On some of the smaller islets, nothing could be more elegant than the manner in which the young and full-grown cocoa-nut trees, without destroying each other's symmetry, were mingled into one wood. A beach of glittering white sand formed a border to these fairy spots.

I will now give a sketch of the natural history of these islands, which, from its very paucity, possesses a peculiar interest. The cocoa-nut tree, at the first glance, seems to compose the whole wood; there are, however, five or six other trees. One of these grows to a very large size, but, from the extreme softness of its wood, is useless; another sort affords excellent timber for ship-building. Besides the trees, the number of plants is exceedingly limited, and consists of insignificant weeds. In my collection, which includes, I believe, nearly the perfect Flora, there are twenty species, without reckoning a moss, lichen, and fungus. To this number two trees must be added; one of which was not in flower, and the other I only heard of. The latter is a solitary tree of its kind, and grows near the beach, where, without doubt, the one seed was thrown up by the waves. A Guilandina also grows on only one of the islets. I do not include in the above list the sugar-cane, banana, some other vegetables, fruit-trees, and imported grasses. As the islands consist entirely of coral, and at one time must have existed as mere water-washed reefs, all their terrestrial productions must have been transported here by the waves of the sea. In accordance with this, the Florula has quite the character of a refuge for the destitute: Professor Henslow informs me that of the twenty species nineteen belong to different genera, and these again to no less than sixteen families![*]

In Holman's[†] Travels an account is given, on the authority of Mr. A. S. Keating, who resided twelve months on these islands, of the various seeds and other bodies which have been known to have been washed on shore. "Seeds and plants from Sumatra and Java have been driven up by the surf on the windward side of the islands. Among them have been found the Kimiri, native of Sumatra and the peninsula of Malacca; the cocoa-nut of Balci, known by its shape and size; the Dadass, which is planted by the Malays with the pepper-vine, the latter intwining round its trunk, and supporting itself by the prickles on its stem; the soap-tree; the castor-oil plant; trunks of the sago palm; and various kinds of seeds unknown to the Malays settled on the islands. These are all supposed to have been driven by the N.W. monsoon to the coast of New Holland, and thence to these

* These plants are described in the Annals of Nat. Hist., vol. i., 1838, p. 337.

† Holman's Travels, vol. iv., p. 378.

islands by the S.E. trade-wind. Large masses of Java teak and Yellow wood have also been found, besides immense trees of red and white cedar, and the blue gum-wood of New Holland, in a perfectly sound condition. All the hardy seeds, such as creepers, retain their germinating power, but the softer kinds, among which is the mangostin, are destroyed in the passage. Fishing-canoes, apparently from Java, have at times been washed on shore." It is interesting thus to discover how numerous the seeds are, which, coming from several countries, are drifted over the wide ocean. Professor Henslow tells me, he believes that nearly all the plants which I brought from these islands, are common littoral species in the East Indian archipelago. From the direction, however, of the winds and currents, it seems scarcely possible that they could have come here in a direct line. If, as suggested with much probability by Mr. Keating, they were first carried towards the coast of New Holland, and thence drifted back together with the productions of that country, the seeds, before germinating, must have travelled between 1800 and 2400 miles.

Chamisso,* when describing the Radack Archipelago, situated in the western part of the Pacific, states that "the sea brings to these islands the seeds and fruits of many trees, most of which have yet not grown here. The greater part of these seeds appear to have not yet lost the capability of growing." It is also said that palms and bamboos from somewhere in the torrid zone, and trunks of northern firs, are washed on shore: these firs must have come from an immense distance. These facts are highly interesting. It cannot be doubted that if there were land-birds to pick up the seeds when first cast on shore, and a soil better adapted for their growth than the loose blocks of coral, that the most isolated of the lagoon-islands would in time possess a far more abundant Flora than they now have.

The list of land animals is even poorer than that of the plants. Some of the islets are inhabited by rats, which were brought in a ship from the Mauritius, wrecked here. These rats are considered by Mr. Waterhouse as identical with the English kind, but they are smaller, and more brightly coloured. There are no true land-birds; for a snipe and a rail (Rallus Phillippensis), though living entirely in the dry herbage, belong to the order of Waders. Birds of this order are said to occur on several of the small low islands in the Pacific. At Ascension,

* Kotzebue's First Voyage, vol. iii., p. 155.

where there is no land bird, a rail (Porphyrio simplex) was shot near the summit of the mountain, and it was evidently a solitary straggler. At Tristan d'Acunha, where, according to Carmichael, there are only two land birds, there is a coot. From these facts I believe that the waders, after the innumerable web-footed species, are generally the first colonists of small isolated islands. I may add, that whenever I noticed birds, not of oceanic species, very far out at sea, they always belonged to this order; and hence they would naturally become the earliest colonists of any remote point of land.

Of reptiles I saw only one small lizard. Of insects I took pains to collect every kind. Exclusive of spiders, which were numerous, there were thirteen species.* Of these, one only was a beetle. A small ant swarmed by thousands under the loose dry blocks of coral, and was the only true insect which was abundant. Although the productions of the land are thus scanty, if we look to the waters of the surrounding sea, the number of organic beings is indeed infinite. Chamisso has described† the natural history of a lagoon-island in the Radack Archipelago; and it is remarkable how closely its inhabitants, in number and kind, resemble those of Keeling Island. There is one lizard and two waders, namely, a snipe and curlew. Of plants there are nineteen species, including a fern; and some of these are the same with those growing here, though on a spot so immensely remote, and in a different ocean.

The long strips of land, forming the linear islets, have been raised only to that height to which the surf can throw fragments of coral, and the wind heap up calcareous sand. The solid flat of coral rock on the outside, by its breadth, breaks the first violence of the waves, which otherwise, in a day, would sweep away these islets and all their productions. The ocean and the land seem here struggling for mastery: although terra firma has obtained a footing, the denizens of the water think their claim at least equally good. In every part one meets

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* The thirteen species belong to the following orders:—In the *Coleoptera* , a minute Elater; *Orthoptera*, a Gryllus and a Blatta; *Hemiptera*, one species; *Homoptera*, two; *Neuroptera*, a Chrysopa; *Hymenoptera*, two ants: *Lepidoptera nocturna*, a Diopæa, and a Pterophorus (?);*Diptera*, two species.

† Kotzebue's First Voyage, vol. iii., p. 222.

hermit crabs of more than one species,* carrying on their backs the shells which they have stolen from the neighbouring beach. Overhead, numerous gannets, frigate-birds, and terns, rest on the trees; and the wood, from the many nests and from the smell of the atmosphere, might be called a sea-rookery. The gannets, sitting on their rude nests, gaze at one with a stupid yet angry air. The noddies, as their name expresses, are silly little creatures. But there is one charming bird: it is a small snow-white tern, which smoothly hovers at the distance of a few feet above one's head, its large black eye scanning, with quiet curiosity, your expression. Little imagination is required to fancy that so light and delicate a body must be tenanted by some wandering fairy spirit.

Sunday, April 3rd.—After service I accompanied Captain Fitz Roy to the settlement, situated at the distance of some miles, on the point of an islet thickly covered with tall cocoa-nut trees. Captain Ross and Mr. Liesk live in a large barn-like house open at both ends, and lined with mats made of woven bark. The houses of the Malays are arranged along the shore of the lagoon. The whole place had rather a desolate aspect, for there were no gardens to show the signs of care and cultivation. The natives belong to different islands in the East Indian archipelago, but all speak the same language: we saw the inhabitants of Borneo, Celebes, Java, and Sumatra. In colour they resemble the Tahitians, from whom they do not widely differ in features. Some of the women, however, show a good deal of the Chinese character. I liked both their general expressions and the sound of their voices. They appeared poor, and their houses were destitute of furniture; but it was evident, from the plumpness of the little children, that cocoa-nuts and turtle afford no bad sustenance.

On this island the wells are situated, from which ships obtain water. At first sight it appears not a little remarkable that the fresh water should regularly ebb and flow with the tides; and it has even been imagined, that sand has the power of filtering the salt from the sea-water. These ebbing wells are common on some of the low islands in the West Indies. The compressed sand, or porous coral rock, is

* The large claws or pincers of some of these crabs are most beautifully adapted, when drawn back, to form an operculum to the shell, nearly as perfect as the proper one originally belonging to the molluscous animal. I was assured, and as far as my observation went I found it so, that certain species of the hermit-crabs always use certain species of shells.

permeated like a sponge with the salt water; but the rain which falls on the surface must sink to the level of the surrounding sea, and must accumulate there, displacing an equal bulk of the salt water. As the water in the lower part of the great sponge-like coral mass rises and falls with the tides, so will the water near the surface; and this will keep fresh, if the mass be sufficiently compact to prevent much mechanical admixture; but where the land consists of great loose blocks of coral with open interstices, if a well be dug, the water, as I have seen, is brackish.

After dinner we stayed to see a curious half superstitious scene acted by the Malay women. A large wooden spoon dressed in garments, and which had been carried to the grave of a dead man, they pretend becomes inspired at the full of the moon, and will dance and jump about. After the proper preparations, the spoon, held by two women, became convulsed, and danced in good time to the song of the surrounding children and women. It was a most foolish spectacle; but Mr. Liesk maintained that many of the Malays believed in its spiritual movements. The dance did not commence till the moon had risen, and it was well worth remaining to behold her bright orb so quietly shining through the long arms of the cocoa-nut trees as they waved in the evening breeze. These scenes of the tropics are in themselves so delicious, that they almost equal those dearer ones at home, to which we are bound by each best feeling of the mind.

The next day I employed myself in examining the very interesting, yet simple structure and origin of these islands. The water being unusually smooth, I waded over the outer flat of dead rock as far as the living mounds of coral, on which the swell of the open sea breaks. In some of the gullies and hollows there were beautiful green and other coloured fishes, and the forms and tints of many of the zoophytes were admirable. It is excusable to grow enthusiastic over the infinite numbers of organic beings with which the sea of the tropics, so prodigal of life, teems; yet I must confess I think those naturalists who have described, in well-known words, the submarine grottoes decked with a thousand beauties, have indulged in rather exuberant language.

April 6th.—I accompanied Captain Fitz Roy to an island at the head of the lagoon: the channel was exceedingly intricate, winding through fields of delicately branched corals. We saw several turtle,

and two boats were then employed in catching them. The water was so clear and shallow, that although at first a turtle quickly dives out of sight, yet in a canoe or boat under sail, the pursuers after no very long chase come up to it. A man standing ready in the bow, at this moment dashes through the water upon the turtle's back; then clinging with both hands by the shell of its neck, he is carried away till the animal becomes exhausted and is secured. It was quite an interesting chase to see the two boats thus doubling about, and the men dashing head foremost into the water trying to seize their prey. Captain Moresby informs me that in the Chagos archipelago in this same ocean, the natives, by a horrible process, take the shell from the back of the living turtle. "It is covered with burning charcoal, which causes the outer shell to curl upwards; it is then forced off with a knife, and before it becomes cold flattened between boards. After this barbarous process the animal is suffered to regain its native element, where, after a certain time, a new shell is formed; it is, however, too thin to be of any service, and the animal always appears languishing and sickly."

When we arrived at the head of the lagoon, we crossed a narrow islet, and found a great surf breaking on the windward coast. I can hardly explain the reason, but there is to my mind much grandeur in the view of the outer shores of these lagoon-islands. There is a simplicity in the barrier-like beach, the margin of green bushes and tall cocoa-nuts, the solid flat of dead coral-rock, strewed here and there with great loose fragments, and the line of furious breakers, all rounding away towards either hand. The ocean throwing its waters over the broad reef appears an invincible, all-powerful enemy; yet we see it resisted, and even conquered, by means which at first seem most weak and inefficient. It is not that the ocean spares the rock of coral; the great fragments scattered over the reef, and heaped on the beach, whence the tall cocoa-nut springs, plainly bespeak the unrelenting power of the waves. Nor are any periods of repose granted. The long swell caused by the gentle but steady action of the trade-wind, always blowing in one direction over a wide area, causes breakers, almost equalling in force those during a gale of wind in the temperate regions, and which never cease to rage. It is impossible to behold these waves without feeling a conviction that an island, though built of the hardest rock, let it be porphyry, granite, or quartz, would ultimately yield and be demolished by such an ir-

resistible power. Yet these low, insignificant coral-islets stand and are victorious: for here another power, as an antagonist, takes part in the contest. The organic forces separate the atoms of carbonate of lime, one by one, from the foaming breakers, and unite them into a symmetrical structure. Let the hurricane tear up its thousand huge fragments; yet what will that tell against the accumulated labour of myriads of architects at work night and day, month after month? Thus do we see the soft and gelatinous body of a polypus, through the agency of the vital laws, conquering the great mechanical power of the waves of an ocean which neither the art of man nor the inanimate works of nature could successfully resist.

We did not return on board till late in the evening, for we staid a long time in the lagoon, examining the fields of coral and the gigantic shells of the chama, into which, if a man were to put his hand, he would not, as long as the animal lived, be able to withdraw it. Near the head of the lagoon, I was much surprised to find a wide area, considerably more than a mile square, covered with a forest of delicately branching corals, which, though standing upright, were all dead and rotten. At first I was quite at a loss to understand the cause; afterwards it occurred to me that it was owing to the following rather curious combination of circumstances. It should, however, first be stated, that corals are not able to survive even a short exposure in the air to the sun's rays, so that their upward limit of growth is determined by that of lowest water at spring tides. It appears, from some old charts, that the long island to windward was formerly separated by wide channels into several islets; this fact is likewise indicated by the trees being younger on these portions. Under the former condition of the reef, a strong breeze, by throwing more water over the barrier, would tend to raise the level of the lagoon. Now it acts in a directly contrary manner; for the water within the lagoon not only is not increased by currents from the outside, but is itself blown outwards by the force of the wind. Hence it is observed, that the tide near the head of the lagoon does not rise so high during a strong breeze as it does when it is calm. This difference of level, although no doubt very small, has, I believe, caused the death of those coral-groves, which under the former and more open condition of the outer reef had attained the utmost possible limit of upward growth.

A few miles north of Keeling there is another small atoll, the lagoon of which is nearly filled up with coral-mud. Captain Ross found embedded in the conglomerate on the outer coast, a well-rounded fragment of greenstone, rather larger than a man's head: he and the men with him were so much surprised at this, that they brought it away and preserved it as a curiosity. The occurrence of this one stone, where every other particle of matter is calcareous, certainly is very puzzling. The island has scarcely ever been visited, nor is it probable that a ship had been wrecked there. From the absence of any better explanation, I came to the conclusion that it must have come entangled in the roots of some large tree: when, however, I considered the great distance from the nearest land, the combination of chances against a stone thus being entangled, the tree washed into the sea, floated so far, then landed safely, and the stone finally so embedded as to allow of its discovery, I was almost afraid of imagining a means of transport apparently so improbable. It was therefore with great interest that I found Chamisso, the justly distinguished naturalist who accompanied Kotzebue, stating that the inhabitants of the Radack archipelago, a group of lagoon-islands in the midst of the Pacific, obtained stones for sharpening their instruments by searching the roots of trees which are cast upon the beach. It will be evident that this must have happened several times, since laws have been established that such stones belong to the chief, and a punishment is inflicted on any one who attempts to steal them. When the isolated position of these small islands in the midst of a vast ocean—their great distance from any land excepting that of coral formation, attested by the value which the inhabitants, who are such bold navigators, attach to a stone of any kind,*—and the slowness of the currents of the open sea, are all considered, the occurrence of pebbles thus transported does appear wonderful. Stones may often be thus carried; and if the island on which they are stranded is constructed of any other substance besides coral, they would scarcely attract attention, and their origin at least would never be guessed. Moreover, this agency may long escape discovery from the probability of trees, especially those loaded with stones, floating beneath the surface. In the channels of Tierra del Fuego large quantities of drift timber are cast upon the beach, yet it is

* Some natives carried by Kotzebue to Kamtschatka collected stones to take back to their country.

extremely rare to meet a tree swimming on the water. These facts may possibly throw light on single stones, whether angular or rounded, occasionally found embedded in fine sedimentary masses.

During another day I visited West Islet, on which the vegetation was perhaps more luxuriant than on any other. The cocoa-nut trees generally grow separate, but here the young ones flourished beneath their tall parents, and formed with their long and curved fronds the most shady arbours. Those alone who have tried it, know how delicious it is to be seated in such shade, and drink the cool pleasant fluid of the cocoa-nut. In this island there is a large bay-like space, composed of the finest white sand: it is quite level, and is only covered by the tide at high water; from this large bay smaller creeks penetrate the surrounding woods. To see a field of glittering white sand, representing water, with the cocoa-nut trees extending their tall and waving trunks round the margin, formed a singular and very pretty view.

I have before alluded to a crab which lives on the cocoa-nuts: it is very common on all parts of the dry land, and grows to a monstrous size: it is closely allied or identical with the Birgos latro. The front pair of legs terminate in very strong and heavy pincers, and the last pair are fitted with others weaker and much narrower. It would at first be thought quite impossible for a crab to open a strong cocoa-nut covered with the husk; but Mr. Liesk assures me that he has repeatedly seen this effected. The crab begins by tearing the husk, fibre by fibre, and always from that end under which the three eye-holes are situated; when this is completed, the crab commences hammering with its heavy claws on one of the eye-holes till an opening is made. Then turning round its body, by the aid of its posterior and narrow pair of pincers, it extracts the white albuminous substance. I think this is as curious a case of instinct as ever I heard of, and likewise of adaptation in structure between two objects apparently so remote from each other in the scheme of nature, as a crab and a cocoa-nut tree. The Birgos is diurnal in its habits; but every night it is said to pay a visit to the sea, no doubt for the purpose of moistening its branchiæ. The young are likewise hatched, and live for some time, on the coast. These crabs inhabit deep burrows, which they hollow out beneath the roots of trees; and where they accumulate surprising quantities of the picked fibres of the cocoa-nut husk, on which they rest as on a bed. The Malays sometimes take advantage of this, and

collect the fibrous mass to use as junk. These crabs are very good to eat; moreover, under the tail of the larger ones there is a great mass of fat, which, when melted, sometimes yields as much as a quart bottle full of limpid oil. It has been stated by some authors that the Birgos crawls up the cocoa-nut trees for the purpose of stealing the nuts: I very much doubt the possibility of this; but with the Pandanus* the task would be very much easier. I was told by Mr. Liesk that on these islands the Birgos lives only on the nuts which have fallen to the ground.

Captain Moresby informs me that this crab inhabits the Chagos and Seychelle groups, but not the neighbouring Maldiva archipelago. It formerly abounded at Mauritius, but only a few small ones are now found there. In the Pacific, this species, or one with closely allied habits, is said† to inhabit a single coral island, north of the Society group. To show the wonderful strength of the front pair of pincers, I may mention, that Captain Moresby confined one in a strong tin-box, which had held biscuits, the lid being secured with wire; but the crab turned down the edges and escaped. In turning down the edges, it actually punched many small holes quite through the tin!

I was a good deal surprised by finding two species of coral of the genus Millepora (M. complanata and alcicornis), possessed of the power of stinging. The stony branches or plates, when taken fresh from the water, have a harsh feel and are not slimy, although possessing a strong and disagreeable smell. The stinging property seems to vary in different specimens: when a piece was pressed or rubbed on the tender skin of the face or arm, a pricking sensation was usually caused, which came on after the interval of a second, and lasted only for a few minutes. One day, however, by merely touching my face with one of the branches, pain was instantaneously caused; it increased as usual after a few seconds, and remaining sharp for some minutes, was perceptible for half an hour afterwards. The sensation was as bad as that from a nettle, but more like that caused by the Physalia or Portuguese man-of-war. Little red spots were produced on the tender skin of the arm, which appeared as if they would have formed watery pustules, but did not. M. Quoy mentions this case of the Millepora; and I have heard of stinging corals in the West Indies.

* See Proceedings of Zoological Society, 1832, p. 17.

† Tyerman and Bennett. Voyage, &c., vol. ii., p. 33

Many marine animals seem to have this power of stinging: besides the Portuguese man-of-war, many jelly-fish, and the Aplysia or sea-slug of the Cape de Verd Islands, it is stated in the voyage of the Astrolabe, that an Actinia or sea-anemone, as well as a flexible coralline allied to Sertularia, both possess this means of offence or defence. In the East Indian sea, a stinging sea-weed is said to be found.

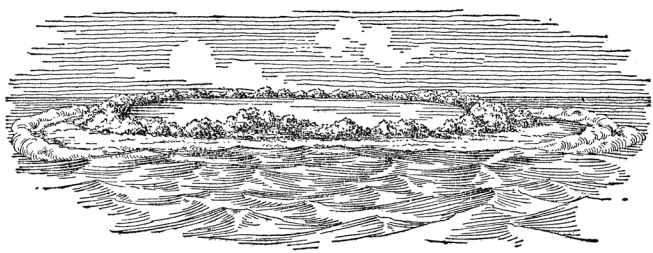
Two species of fish, of the genus Scarus, which are common here, exclusively feed on coral: both are coloured of a splendid bluish-green, one living invariably in the lagoon, and the other amongst the outer breakers. Mr. Liesk assured us, that he had repeatedly seen whole shoals grazing with their strong bony jaws on the tops of the coral branches: I opened the intestines of several, and found them distended with yellowish calcareous sandy mud. The slimy disgusting Holuthuriæ (allied to our star-fish), which the Chinese gourmands are so fond of, also feed largely, as I am informed by Dr. Allan, on corals; and the bony apparatus within their bodies seems well adapted for this end. These holuthuriæ, the fish, the numerous burrowing shells, and nereidous worms, which perforate every block of dead coral, must be very efficient agents in producing the fine white mud which lies at the bottom and on the shores of the lagoon. A portion, however, of this mud, which when wet strikingly resembled pounded chalk, was found by Professor Ehrenberg to be partly composed of siliceous-shielded infusoria.

April 12th.—In the morning we stood out of the lagoon on our passage to the Isle of France. I am glad we have visited these islands: such formations surely rank high amongst the wonderful objects of this world. Captain Fitz Roy found no bottom with a line 7200 feet in length, at the distance of only 2200 yards from the shore; hence this island forms a lofty submarine mountain, with sides steeper even than those of the most abrupt volcanic cone. The saucer-shaped summit is nearly ten miles across; and every single atom,* from the least particle to the largest fragment of rock, in this great pile, which however is small compared with very many other lagoon-islands, bears the stamp of having been subjected to organic arrangement.

* I exclude, of course, some soil which has been imported here in vessels from Malacca and Java, and likewise some small fragments of pumice, drifted here by the waves. The one block of green-stone, moreover, on the northern island must be excepted.

We feel surprise when travellers tell us of the vast dimensions of the Pyramids and other great ruins, but how utterly insignificant are the greatest of these, when compared to these mountains of stone accumulated by the agency of various minute and tender animals! This is a wonder which does not at first strike the eye of the body, but, after reflection, the eye of reason.

I will now give a very brief account of the three great classes of coral-reefs; namely, Atolls, Barrier, and Fringing-reefs, and will explain my views* on their formation. Almost every voyager who has crossed the Pacific has expressed his unbounded astonishment at the lagoon-islands, or as I shall for the future call them by their Indian name of atolls, and has attempted some explanation. Even as long ago as the year 1605, Pyrard de Laval well exclaimed, "C'est une meruille de voir chacun de ces atollons, enuironné d'un grand banc de pierre tout autour, n'y ayant point d'artifice humain." The accompanying sketch of Whitsunday Island in the Pacific, copied from Capt. Beechey's admirable Voyage, gives but a faint idea of the singular aspect of an atoll: it is one of the smallest size, and has its narrow islets united together in a ring. The immensity of the ocean, the



fury of the breakers, contrasted with the lowness of the land and the smoothness of the bright green water within the lagoon, can hardly be imagined without having been seen.

The earlier voyagers fancied that the coral-building animals instinctively built up their great circles to afford themselves protection in the inner parts; but so far is this from the truth, that those massive kinds, to whose growth on the exposed outer shores the very

* These were first read before the Geological Society in May, 1837, and have since been developed in a separate volume on the 'Structure and Distribution of Coral Reefs.'

existence of the reef depends, cannot live within the lagoon, where other delicately-branching kinds flourish. Moreover, on this view, many species of distinct genera and families are supposed to combine for one end; and of such a combination, not a single instance can be found in the whole of nature. The theory that has been most generally received is, that atolls are based on submarine craters; but when we consider the form and size of some, the number, proximity, and relative positions of others, this idea loses its plausible character: thus, Suadiva atoll is 44 geographical miles in diameter in one line, by 34 miles in another line; Rimsky is 54 by 20 miles across, and it has a strangely sinuous margin; Bow atoll is 30 miles long, and on an average only 6 in width; Menchicoff atoll consists of three atolls united or tied together. This theory, moreover, is totally inapplicable to the northern Maldiva atolls in the Indian Ocean (one of which is 88 miles in length, and between 10 and 20 in breadth), for they are not bounded like ordinary atolls by narrow reefs, but by a vast number of separate little atolls; other little atolls rising out of the great central lagoon-like spaces. A third and better theory was advanced by Chamisso, who thought that from the corals growing more vigorously where exposed to the open sea, as undoubtedly is the case, the outer edges would grow up from the general foundation before any other part, and that this would account for the ring or cup-shaped structure. But we shall immediately see, that in this, as well as in the crater-theory, a most important consideration has been overlooked, namely, on what have the reef-building corals, which cannot live at a great depth, based their massive structures?

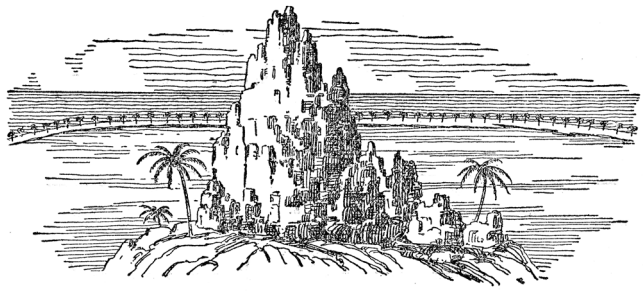
Numerous soundings were carefully taken by Captain Fitz Roy on the steep outside of Keeling atoll, and it was found that within ten fathoms, the prepared tallow at the bottom of the lead, invariably came up marked with the impressions of living corals, but as perfectly clean as if it had been dropped on a carpet of turf; as the depth increased, the impressions became less numerous, but the adhering particles of sand more and more numerous, until at last it was evident that the bottom consisted of a smooth sandy layer: to carry on the analogy of the turf, the blades of grass grew thinner and thinner, till at last the soil was so sterile, that nothing sprang from it. From these observations, confirmed by many others, it may be safely inferred that the utmost depth at which corals can construct reefs is

between 20 and 30 fathoms. Now there are enormous areas in the Pacific and Indian Oceans, in which every single island is of coral formation, and is raised only to that height to which the waves can throw up fragments, and the winds pile up sand. Thus the Radack group of atolls is an irregular square, 520 miles long and 240 broad; the Low archipelago is elliptic-formed, 840 miles in its longer, and 420 in its shorter axis: there are other small groups and single low islands between these two archipelagoes, making a linear space of ocean actually more than 4000 miles in length, in which not one single island rises above the specified height. Again, in the Indian Ocean there is a space of ocean 1500 miles in length, including three archipelagoes, in which every island is low and of coral formation. From the fact of the reef-building corals not living at great depths, it is absolutely certain that throughout these vast areas, wherever there is now an atoll, a foundation must have originally existed within a depth of from 20 to 30 fathoms from the surface. It is improbable in the highest degree that broad, lofty, isolated, steep-sided banks of sediment, arranged in groups and lines hundreds of leagues in length, could have been deposited in the central and profoundest parts of the Pacific and Indian Oceans, at an immense distance from any continent, and where the water is perfectly limpid. It is equally improbable that the elevatory forces should have uplifted throughout the above vast areas, innumerable great rocky banks within 20 to 30 fathoms, or 120 to 180 feet, of the surface of the sea, and not one single point above that level; for where on the whole face of the globe can we find a single chain of mountains, even a few hundred miles in length, with their many summits rising within a few feet of a given level, and not one pinnacle above it? If then the foundations, whence the atoll-building corals sprang, were not formed of sediment, and if they were not lifted up to the required level, they must of necessity have subsided into it; and this at once solves the difficulty. For as mountain after mountain, and island after island, slowly sank beneath the water, fresh bases would be successively afforded for the growth of the corals. It is impossible here to enter into all the necessary details, but I venture to defy* any one to explain in

* It is remarkable that Mr. Lyell, 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

any other manner, how it is possible that numerous islands should be distributed throughout vast areas—all the islands being low—all being built of corals, absolutely requiring a foundation within a limited depth from the surface.

Before explaining how atoll-formed reefs acquire their peculiar structure, we must turn to the second great class, namely, Barrier-reefs. These either extend in straight lines in front of the shores of a continent or of a large island, or they encircle smaller islands; in both cases, being separated from the land by a broad and rather deep channel of water, analogous to the lagoon within an atoll. It is remarkable how little attention has been paid to encircling barrier-reefs; yet they are truly wonderful structures. The following sketch represents part of the barrier encircling the island of Bolabola in the Pacific, as seen from one of the central peaks. In this instance the



whole line of reef has been converted into land; but usually a snow-white line of great breakers, with only here and there a single low islet crowned with cocoa-nut trees, divides the dark heaving waters of the ocean from the light-green expanse of the lagoon-channel. And the quiet waters of this channel generally bathe a fringe of low alluvial soil, loaded with the most beautiful productions of the tropics, and lying at the foot of the wild, abrupt, central mountains.

Encircling barrier-reefs are of all sizes, from three miles to no less than forty-four miles in diameter; and that which fronts one side, and encircles both ends, of New Caledonia, is 400 miles long. Each reef includes one, two, or several rocky islands of various heights; and in one instance, even as many as twelve separate islands. The

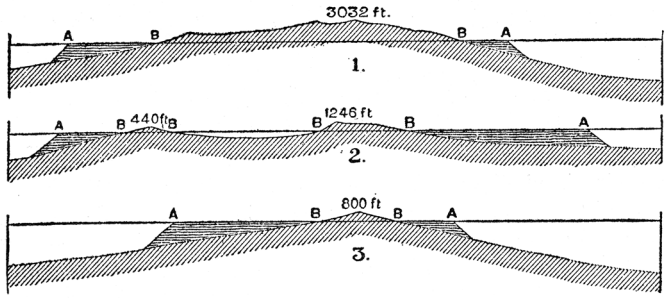
relatively to the agents there tending to form it, namely, the growth of coral and volcanic action.

reef runs at a greater or less distance from the included land; in the Society archipelago generally from one to three or four miles; but at Hogoleu the reef is 20 miles on the southern side, and 14 miles on the opposite or northern side, from the included islands. The depth within the lagoon-channel also varies much; from 10 to 30 fathoms may be taken as an average; but at Vanikoro there are spaces no less than 56 fathoms or 336 feet deep. Internally the reef either slopes gently into the lagoon-channel, or ends in a perpendicular wall sometimes between two and three hundred feet under water in height: externally the reef rises, like an atoll, with extreme abruptness out of the profound depths of the ocean. What can be more singular than these structures? We see an island, which may be compared to a castle situated on the summit of a lofty submarine mountain, protected by a great wall of coral-rock, always steep externally and sometimes internally, with a broad level summit, here and there breached by narrow gateways, through which the largest ships can enter the wide and deep encircling moat.

As far as the actual reef of coral is concerned, there is not the smallest difference, in general size, outline, grouping, and even in quite trifling details of structure, between a barrier and an atoll. The geographer Balbi has well remarked, that an encircled island is an atoll with high land rising out of its lagoon; remove the land from within, and a perfect atoll is left.

But what has caused these reefs to spring up at such great distances from the shores of the included islands? It cannot be that the corals will not grow close to the land; for the shores within the lagoon-channel, when not surrounded by alluvial soil, are often fringed by living reefs; and we shall presently see that there is a whole class, which I have called Fringing Reefs from their close attachment to the shores both of continents and of islands. Again, on what have the reef-building corals, which cannot live at great depths, based their encircling structures? This is a great apparent difficulty, analogous to that in the case of atolls, which has generally been overlooked. It will be perceived more clearly by inspecting the following sections, which are real ones, taken in north and south lines, through the islands with their barrier-reefs, of Vanikoro, Gambier, and Maurua; and they are laid down, both vertically and horizontally, on the same scale of a quarter of an inch to a mile.

It should be observed that the sections might have been taken in any direction through these islands, or through many other encircled islands, and the general features would have been the same. Now bearing in mind that reef-building coral cannot live at a greater depth than from 20 to 30 fathoms, and that the scale is so small that the plummets on the right hand show a depth of 200 fathoms, on



1. Vanikoro. 2. Gambier Islands. 3. Maurua.
The horizontal shading shows the barrier-reefs and lagoon-channels. The inclined shading above the level of the sea (AA) shows the actual form of the land; the inclined shading below this line, shows its probable prolongation under water.

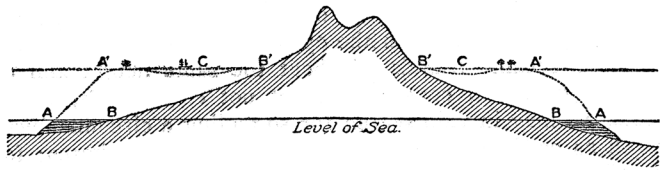
what are these barrier-reefs based? Are we to suppose that each island is surrounded by a collar-like submarine ledge of rock, or by a great bank of sediment, ending abruptly where the reef ends? If the sea had formerly eaten deeply into the islands, before they were protected by the reefs, thus having left a shallow ledge round them under water, the present shores would have been invariably bounded by great precipices; but this is most rarely the case. Moreover, on this notion, it is not possible to explain why the corals should have sprung up, like a wall, from the extreme outer margin of the ledge, often leaving a broad space of water within, too deep for the growth of corals. The accumulation of a wide bank of sediment all round these islands, and generally widest where the included islands are smallest, is highly improbable, considering their exposed positions in the central and deepest parts of the ocean. In the case of the barrier-reef of New Caledonia, which extends for 150 miles beyond the northern point of the island, in the same straight line with which it fronts the west coast, it is hardly possible to believe, that a bank of sediment could thus have been straightly deposited in front of a lofty island, and so far beyond its termination in the open sea. Finally, if we look to other

oceanic islands of about the same height and of similar geological constitution, but not encircled by coral-reefs, we may in vain search for so trifling a circumambient depth as 30 fathoms, except quite near to their shores; for usually land that rises abruptly out of water, as do most of the encircled and non-encircled oceanic islands, plunges abruptly under it. On what then, I repeat, are these barrier-reefs based? Why, with their wide and deep moat-like channels, do they stand so far from the included land? We shall soon see how easily these difficulties disappear.

We come now to our third class of Fringing Reefs, which will require a very short notice. Where the land slopes abruptly under water, these reefs are only a few yards in width, forming a mere ribbon or fringe round the shores: where the land slopes gently under the water the reef extends further, sometimes even as much as a mile from the land; but in such cases the soundings outside the reef, always show that the submarine prolongation of the land is gently inclined. In fact the reefs extend only to that distance from the shore, at which a foundation within the requisite depth from 20 to 30 fathoms is found. As far as the actual reef is concerned, there is no essential difference between it and that forming a barrier or an atoll: it is, however, generally of less width, and consequently few islets have been formed on it. From the corals growing more vigorously on the outside, and from the noxious effect of the sediment washed inwards, the outer edge of the reef is the highest part, and between it and the land there is generally a shallow sandy channel a few feet in depth. Where banks of sediment have accumulated near to the surface, as in parts of the West Indies, they sometimes become fringed with corals, and hence in some degree resemble lagoon-islands or atolls; in the same manner as fringing-reefs, surrounding gently-sloping islands, in some degree resemble barrier-reefs.

No theory on the formation of coral-reefs can be considered satisfactory which does not include the three great classes. We have seen that we are driven to believe in the subsidence of those vast areas, interspersed with low islands, of which not one rises above the height to which the wind and waves can throw up matter, and yet are constructed by animals requiring a foundation, and that foundation to lie at no great depth. Let us then take an island surrounded by fring-

ing-reefs, which offer no difficulty in their structure; and let this island with its reef, represented by the unbroken lines in the woodcut, slowly subside. Now as the island sinks down, either a few feet at a time or quite insensibly, we may safely infer, from what is known

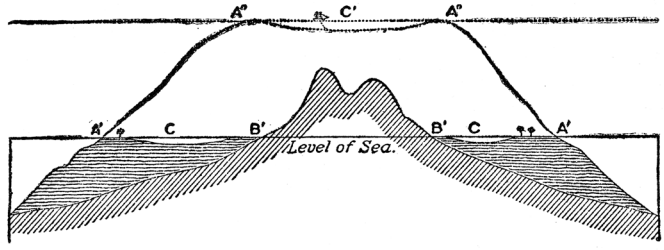


AA. Outer edges of the fringing-reef, at the level of the sea. BB. The shores of the fringed island.
A′A′. Outer edges of the reef, after its upward growth during a period of subsidence, now converted into a barrier, with islets on it. B′B′. The shores of the now encircled island. CC. Lagoon-channel.
N. B.—In this and the following woodcut, the subsidence of the land could be represented only by an apparent rise in the level of the sea.

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 inner 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 reef; and a ship is anchored in the lagoon-channel. This channel will be more or less deep, according to the rate of subsidence, to the amount of sediment accumulated in it, and to the growth of the delicately branched corals which can live there. The section in this state resembles in every respect one drawn through an encircled island: in fact, it is a real section (on the scale of ·517 of an inch to a mile) through Bolabola in the Pacific. We can now at once see why encircling barrier-reefs stand so far from the shores which they front. We can also perceive, that a line drawn perpendicularly down from the outer edge of the new reef, to the foundation of solid rock beneath the old fringing-reef, will exceed by as many feet as there have been feet of subsidence, that small limit of depth at which the effective corals can live:—the little architects having built up their great wall-like mass, as the whole sank down, upon a basis formed of other corals and their consolidated fragments. Thus the difficulty on this head, which appeared so great, disappears.

If, instead of an island, we had taken the shore of a continent fringed with reefs, and had imagined it to have subsided, a great straight barrier, like that of Australia or New Caledonia, separated from the land by a wide and deep channel, would evidently have been the result.

Let us take our new encircling barrier-reef, of which the section is now represented by unbroken lines, and which, as I have said, is a real section through Bolabola, and let it go on subsiding. As the barrier-reef slowly sinks down, the corals will go on vigorously



A′A′. Outer edges of the barrier-reef at the level of the sea, with islets on it. B′B′. The shores of the included island. CC. The lagoon-channel. A″A″. Outer edges of the reef, now converted into an atoll. C′. The lagoon of the new atoll.
N. B.—According to the true scale, the depths of the lagoon-channel and lagoon are much exaggerated.

growing upwards; but as the island sinks, the water will gain inch by inch on the shore—the separate mountains first forming separate islands within one great reef—and finally, the last and highest pinnacle disappearing. The instant this takes place, a perfect atoll is formed: I have said, remove the high land from within an encircling barrier-reef, and an atoll is left, and the land has been removed. We can now perceive how it comes that atolls, having sprung from encircling barrier-reefs, resemble them in general size, form, in the manner in which they are grouped together, and in their arrangement in single or double lines; for they may be called rude outline charts of the sunken islands over which they stand. We can further see how it arises that the atolls in the Pacific and Indian oceans extend in lines parallel to the generally prevailing strike of the high islands and great coast-lines of those oceans. I venture, therefore, to affirm, that on the theory of the upward growth of the corals during the sinking of the land,* all the leading features in those wonderful structures, the

* It has been highly satisfactory to me to find the following passage in a pamphlet by Mr. Couthouy, one of the naturalists in the great Antarctic

lagoon-islands or atolls, which have so long excited the attention of voyagers, as well as in the no less wonderful barrier-reefs, whether encircling small islands or stretching for hundreds of miles along the shores of a continent, are simply explained.

It may be asked, whether I can offer any direct evidence of the subsidence of barrier-reefs or atolls; but it must be borne in mind how difficult it must ever be to detect a movement, the tendency of which is to hide under water the part affected. Nevertheless, at Keeling atoll I observed on all sides of the lagoon old cocoa-nut trees undermined and falling; and in one place the foundation-posts of a shed, which the inhabitants asserted had stood seven years before just above high-water mark, but now was daily washed by every tide: on inquiry I found that three earthquakes, one of them severe, had been felt here during the last ten years. At Vanikoro, the lagoon-channel is remarkably deep, scarcely any alluvial soil has accumulated at the foot of the lofty included mountains, and remarkably few islets have been formed by the heaping of fragments and sand on the wall-like barrier-reef; these facts, and some analogous ones, led me to believe that this island must lately have subsided and the reef grown upwards: here again earthquakes are frequent and very severe. In the Society archipelago, on the other hand, where the lagoon-channels are almost choked up, where much low alluvial land has accumulated, and where in some cases long islets have been formed on the barrier-reefs—facts all showing that the islands have not very lately subsided—only feeble shocks are most rarely felt. In these coral formations, where the land and water seem struggling for mastery, it must be ever difficult to decide between the effects of a change in the set of the tides and of a slight subsidence: that many of these reefs and atolls are subject to changes of some kind is certain; on some atolls the islets appear to have increased greatly within a late period; on others they have been partially or wholly washed away. The inhabitants of parts of the Maldiva archipelago know the date

Expedition of the United States:—"Having personally examined a large number of coral-islands, and resided eight months among the volcanic class having shore and partially encircling reefs, I may be permitted to state that my own observations have impressed a conviction of the correctness of the theory of Mr. Darwin."—The naturalists, however, of this expedition differ with me on some points respecting coral formations.

of the first formation of some islets; in other parts, the corals are now flourishing on water-washed reefs, where holes made for graves attest the former existence of inhabited land. It is difficult to believe in frequent changes in the tidal currents of an open ocean; whereas, we have in the earthquakes recorded by the natives on some atolls, and in the great fissures observed on other atolls, plain evidence of changes and disturbances in progress in the subterranean regions.

It is evident, on our theory, that coasts merely fringed by reefs cannot have subsided to any perceptible amount; and therefore they must, since the growth of their corals, either have remained stationary or have been upheaved. Now it is remarkable how generally it can be shown, by the presence of upraised organic remains, that the fringed islands have been elevated: and so far, this is indirect evidence in favour of our theory. I was particularly struck with this fact, when I found to my surprise, that the descriptions given by MM. Quoy and Gaimard were applicable, not to reefs in general as implied by them, but only to those of the fringing-class; my surprise, however, ceased when I afterwards found that, by a strange chance, all the several islands visited by these eminent naturalists, could be shown by their own statements to have been elevated within a recent geological era.

Not only the grand features in the structure of barrier-reefs and of atolls, and of their likeness to each other in form, size, and other characters, are explained on the theory of subsidence—which theory we are independently forced to admit in the very areas in question, from the necessity of finding bases for the corals within the requisite depth—but many details in structure and exceptional cases can thus also be simply explained. I will give only a few instances. In barrier-reefs it has long been remarked with surprise, that the passages through the reef exactly face valleys in the included land, even in cases where the reef is separated from the land by a lagoon-channel so wide and so much deeper than the actual passage itself, that it seems hardly possible that the very small quantity of water or sediment brought down could injure the corals on the reef. Now, every reef of the fringing-class is breached by a narrow gateway in front of the smallest rivulet, even if dry during the greater part of the year, for the mud, sand, or gravel, occasionally washed down, kills the corals on which it is deposited. Consequently, when an island thus fringed

subsides, though most of the narrow gateways will probably become closed by the outward and upward growth of the corals, yet any that are not closed (and some must always be kept open by the sediment and impure water flowing out of the lagoon-channel) will still continue to front exactly the upper parts of those valleys, at the mouths of which the original basal fringing-reef was breached.

We can easily see how an island fronted only on one side, or on one side with one end or both ends encircled by barrier-reefs, might after long-continued subsidence be converted either into a single wall-like reef, or into an atoll with a great straight spur projecting from it, or into two or three atolls tied together by straight reefs—all of which exceptional cases actually occur. As the reef-building corals require food, are preyed upon by other animals, are killed by sediment, cannot adhere to a loose bottom, and may be easily carried down to a depth whence they cannot spring up again, we need feel no surprise at the reefs both of atolls and barriers becoming in parts imperfect. The great barrier of New Caledonia is thus imperfect and broken in many parts; hence, after long subsidence, this great reef would not produce one great atoll 400 miles in length, but a chain or archipelago of atolls, of very nearly the same dimensions with those in the Maldiva archipelago. Moreover, in an atoll once breached on opposite sides, from the likelihood of the oceanic and tidal currents passing straight through the breaches, it is extremely improbable that the corals, especially during continued subsidence, would ever be able again to unite the rim; if they did not, as the whole sank downwards, one atoll would be divided into two or more. In the Maldiva archipelago there are distinct atolls so related to each other in position, and separated by channels either unfathomable or very deep (the channel between Ross and Ari atolls is 150 fathoms, and that between the north and south Nillandoo atolls is 200 fathoms in depth), that it is impossible to look at a map of them without believing that they were once more intimately related. And in this same archipelago, Mahlos-Mahdoo atoll is divided by a bifurcating channel from 100 to 132 fathoms in depth, in such a manner, that it is scarcely possible to say whether it ought strictly to be called three separate atolls, or one great atoll not yet finally divided.

I will not enter on many more details; but I must remark that the curious structure of the northern Maldiva atolls receives (taking

into consideration the free entrance of the sea through their broken margins) a simple explanation in the upward and outward growth of the corals, originally based both on small detached reefs in their lagoons, such as occur in common atolls, and on broken portions of the linear marginal reef, such as bounds every atoll of the ordinary form. I cannot refrain from once again remarking on the singularity of these complex structures—a great sandy and generally concave disk rises abruptly from the unfathomable ocean, with its central expanse studded, and its edge symmetrically bordered with oval basins of coral-rock just lipping the surface of the sea, sometimes clothed with vegetation, and each containing a lake of clear water!

One more point in detail: as in two neighbouring archipelagoes corals flourish in one and not in the other, and as so many conditions before enumerated must affect their existence, it would be an inexplicable fact if, during the changes to which earth, air, and water are subjected, the reef-building corals were to keep alive for perpetuity on any one spot or area. And as by our theory the areas including atolls and barrier-reefs are subsiding, we ought occasionally to find reefs both dead and submerged. In all reefs, owing to the sediment being washed out of the lagoon or lagoon-channel to leeward, that side is least favourable to the long-continued vigorous growth of the corals; hence dead portions of reef not unfrequently occur on the leeward side; and these, though still retaining their proper wall-like form, are now in several instances sunk several fathoms beneath the surface. The Chagos group appears from some cause, possibly from the subsidence having been too rapid, at present to be much less favourably circumstanced for the growth of reefs than formerly: one atoll has a portion of its marginal reef, nine miles in length, dead and submerged; a second has only a few quite small living points which rise to the surface; a third and fourth are entirely dead and submerged; a fifth is a mere wreck, with its structure almost obliterated. It is remarkable that in all these cases, the dead reefs and portions of reef lie at nearly the same depth, namely, from six to eight fathoms beneath the surface, as if they had been carried down by one uniform movement. One of these "half-drowned atolls," so called by Capt. Moresby (to whom I am indebted for much invaluable information), is of vast size, namely, ninety nautical miles across in one direction, and seventy miles in another line; and is in many respects eminently

curious. As by our theory it follows that new atolls will generally be formed in each new area of subsidence, two weighty objections might have been raised, namely, that atolls must be increasing indefinitely in number; and secondly, that in old areas of subsidence each separate atoll must be increasing indefinitely in thickness, if proofs of their occasional destruction could not have been adduced. Thus have we traced the history of these great rings of coral-rock, from their first origin through their normal changes, and through the occasional accidents of their existence, to their death and final obliteration.

In my volume on 'Coral Formations' I have published a map, in which I have coloured all the atolls dark-blue, the barrier-reefs pale-blue, and the fringing-reefs red. These latter reefs have been formed whilst the land has been stationary, or, as appears from the frequent presence of upraised organic remains, whilst it has been slowly rising: atolls and barrier-reefs, on the other hand, have grown up during the directly opposite movement of subsidence, which movement must have been very gradual, and in the case of atolls so vast in amount as to have buried every mountain-summit over wide ocean-spaces. Now in this map we see that the reefs tinted pale and dark-blue, which have been produced by the same order of movement, as a general rule manifestly stand near each other. Again we see, that the areas with the two blue tints are of wide extent; and that they lie separate from extensive lines of coast coloured red, both of which circumstances might naturally have been inferred, on the theory of the nature of the reefs having been governed by the nature of the earth's movement. It deserves notice, that in more than one instance where single red and blue circles approach near each other, I can show that there have been oscillations of level; for in such cases the red or fringed circles consist of atolls, originally by our theory formed during subsidence, but subsequently upheaved; and on the other hand, some of the pale-blue or encircled islands are composed of coral-rock, which must have been uplifted to its present height before that subsidence took place, during which the existing barrier-reefs grew upwards.

Authors have noticed with surprise, that although atolls are the commonest coral-structures throughout some enormous oceanic tracts, they are entirely absent in other seas, as in the West Indies:

we can now at once perceive the cause, for where there has not been subsidence, atolls cannot have been formed; and in the case of the West Indies and parts of the East Indies, these tracts are known to have been rising within the recent period. The larger areas, coloured red and blue, are all elongated; and between the two colours there is a degree of rude alternation, as if the rising of one had balanced the sinking of the other. Taking into consideration the proofs of recent elevation both on the fringed coasts and on some others (for instance, in South America) where there are no reefs, we are led to conclude that the great continents are for the most part rising areas; and from the nature of the coral-reefs, that the central parts of the great oceans are sinking areas. The East Indian archipelago, the most broken land in the world, is in most parts an area of elevation, but surrounded and penetrated, probably in more lines than one, by narrow areas of subsidence.

I have marked with vermilion spots all the many known active volcanos within the limits of this same map. Their entire absence from every one of the great subsiding areas, coloured either pale or dark blue, is most striking; and not less so is the coincidence of the chief volcanic chains with the parts coloured red, which we are led to conclude have either long remained stationary, or more generally have been recently upraised. Although a few of the vermilion spots occur within no great distance of single circles tinted blue, yet not one single active volcano is situated within several hundred miles of an archipelago, or even small group of atolls. It is, therefore, a striking fact that in the Friendly Archipelago, which consists of a group of atolls upheaved and since partially worn down, two volcanos, and perhaps more, are historically known to have been in action. On the other hand, although most of the islands in the Pacific which are encircled by barrier-reefs, are of volcanic origin, often with the remnants of craters still distinguishable, not one of them is known to have ever been in eruption. Hence in these cases it would appear, that volcanos burst forth into action and become extinguished on the same spots, accordingly as elevatory or subsiding movements prevail there. Numberless facts could be adduced to prove that upraised organic remains are common wherever there are active volcanos; but until it could be shown that in areas of subsidence, volcanos were either absent or inactive, the inference, however probable in itself,

that their distribution depended on the rising or falling of the earth's surface, would have been hazardous. But now, I think, we may freely admit this important deduction.

Taking a final view of the map, and bearing in mind the statements made with respect to the upraised organic remains, we must feel astonished at the vastness of the areas, which have suffered changes in level either downwards or upwards, within a period not geologically remote. It would appear, also, that the elevatory and subsiding movements follow nearly the same laws. Throughout the spaces interspersed with atolls, where not a single peak of high land has been left above the level of the sea, the sinking must have been immense in amount. The sinking, moreover, whether continuous, or recurrent with intervals sufficiently long for the corals again to bring up their living edifices to the surface, must necessarily have been extremely slow. This conclusion is probably the most important one, which can be deduced from the study of coral formations;—and it is one which it is difficult to imagine, how otherwise could ever have been arrived at. Nor can I quite pass over the probability of the former existence of large archipelagoes of lofty islands, where now only rings of coral-rock scarcely break the open expanse of the sea, throwing some light on the distribution of the inhabitants of the other high islands, now left standing so immensely remote from each other in the midst of the great oceans. The reef-constructing corals have indeed reared and preserved wonderful memorials of the subterranean oscillations of level; we see in each barrier-reef a proof that the land has there subsided, and in each atoll a monument over an island now lost. We may thus, like unto a geologist who had lived his ten thousand years and kept a record of the passing changes, gain some insight into the great system by which the surface of this globe has been broken up, and land and water interchanged.