On Coral Islands and Reefs, as described by Mr Darwin. By Charles Maclaren, Esq., F.R.S.E.*

Coral islands are one of the wonders of Natural History. That masses of rock, many leagues in extent, should be founded in the depths of the ocean, and built up to the height of hundreds of feet, by minute animalculæ scarcely visible to the naked eye, is a phenomenon calculated to stagger the unlearned, and which even philosophers were slow to believe. The structure and arrangement of the mineral masses thus produced, are not less singular than their origin, and present problems which have puzzled and divided men of science. An excellent work on the latter branch of the subject has been recently published by Mr Charles Darwin, in which this able naturalist has condensed and systematized his own observations and those of his predecessors, and, for the first time, presented us with a complete view of these singular objects. The facts have led him to some new and highly curious conclusions bearing on the past and future physical history of the globe. An outline of these may not be without interest.

Corals—What they are.—The term coral includes two objects—the animal, called the Polype or Polypifer, and the tenement in which it lodges, called the Polypidom, or, more usually, the "Coral." The solid massive corals, which form reefs and islands, are chiefly found in tropical seas, and it is of these we mean to speak.

Polypes cannot live unless constantly immersed in water, or beaten by the surf: even a short exposure to the sun kills them; and hence the reefs they build terminate below the surface, sometimes one or two feet, sometimes several fathoms. Different species inhabit different depths. Some slender branching corals are found living (that is, tenanted by *living* animalculæ) at the depth of a thousand feet; but the massive corals which constitute reefs, do not exist at a greater depth than 20 or 30 fathoms; and there are species which delight in the surf, and carry on their labours amidst breakers which would swamp a boat. All the varieties included in coral reefs are not known with certainty. Those found near the top by Mr Darwin were the Porite and Millepore,

* This Article is slightly abridged from the original.

and at a greater depth the Madrepore and Astrea are believed to exist. On the exterior margin of the reef at the surface, the Porites were in irregularly rounded masses from four to eight feet broad, nearly of equal thickness, and divided from each other by narrow crooked channels about six feet deep. Other parts of the reef were composed of thick vertical plates (*Millepora complanata*), intersecting each other at various angles, and "forming an exceedingly strong honeycombed mass." Between these plates and in protected crevices, a multitude of branching corals live, and the lagoon is inhabited by a distinct set of corals, generally brittle and thinly branched. The Nulliporæ, which have no visible cells, and though resembling corals, are supposed to be plants, occasionally cover the Porites and Millipores up to the level of high water.

Coral Reefs and Atolls.—These reefs are submarine rocks of coral, usually ascending so near to the surface of the sea that their existence is indicated to the navigator by breakers. They are found remote from land, are in vast numbers, and often of great extent, and generally affect an irregularly circular form, having a pool of comparatively still water in the middle, called a *lagoon*. Storms throw up masses of broken coral upon them, which accumulate to the depth of some feet above high-water, forming chains of islets along the reef. The whole reef in this condition is called a "lagoon island," or more conveniently an "atoll," a word borrowed from the South Sea islanders. Some reefs have many islands upon them, some have few, and some have none.

A coral reef may be defined a wall or mound of coral rock, built up in the ocean from a considerable depth, and generally returning into itself, so as to form a ring, with a sheet of still water in the interior. "Every one," says Mr Darwin, "must be struck with astonishment when he first beholds one of these vast rings of coral rock, often many leagues in diameter, here and there surmounted by a low verdant island with dazzling white shores, bathed on the outside by the foaming breakers of the ocean, and on the inside surrounding a calm expanse of water, which, from reflection, is of a bright but pale green colour." The wall of coral rock forming the ring, is generally from a furlong to half a mile in breadth, averaging about a quarter of a mile. In one rare case it is three miles. The

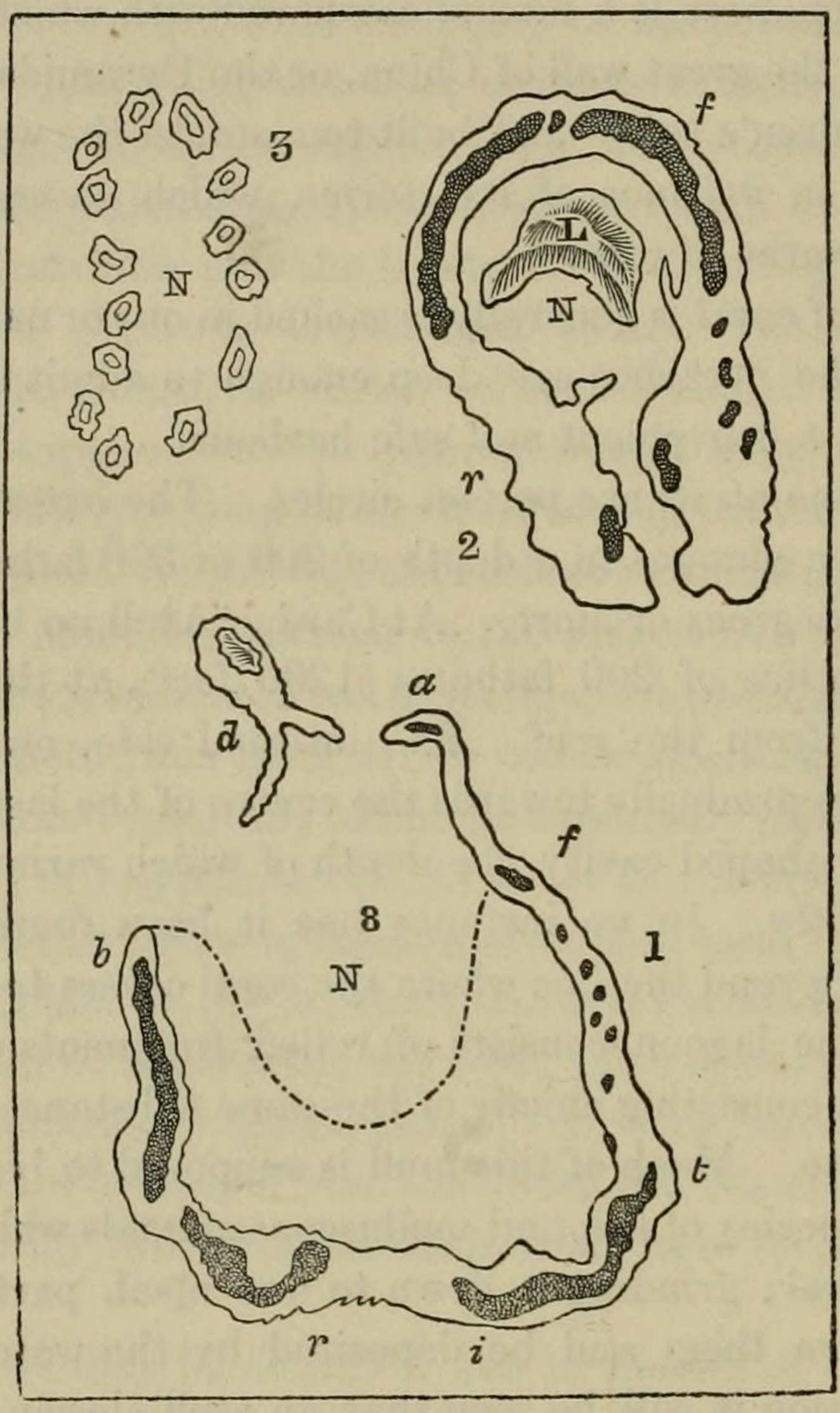
diameter of the atoll, or circle formed by the reef, varies from less than one mile to 30 or 40. There is one 50 miles in length by 20 in breadth; so that, if the ledge of coral rock forming the ring were extended in one line, it would be 120 miles in length. Assuming it to be a quarter of a mile in breadth, and 150 feet deep, here is a mound compared with which the walls of Babylon, the great wall of China, or the Pyramids of Egypt, are but children's toys—and built too, amidst the waves of the ocean, and in defiance of its storms, which sweep away the most solid works of man.

The wall of coral is generally breached in one or more places; and when the breaches are deep enough to admit a ship, the atoll affords a convenient and safe harbour.

Some of the atolls are perfect circles. The external side of the reef often plunges to a depth of 200 or 300 fathoms, at an angle of 45 degrees or more. At Cardoo Atoll no bottom was found with a line of 200 fathoms (1200 feet), at the distance of 60 yards from the reef. The internal side, on the other hand, shelves gradually towards the centre of the lagoon, forming a saucer-shaped cavity, the depth of which varies from one fathom to fifty. In no instance has it been found entirely filled up. Beyond the line where the coral ceases to grow, the bottom of the lagoon consists of rolled fragments of it, or a whitish mud consisting chiefly of the same substance in a comminuted state. Much of this mud is supposed to be produced by certain species of fish and molluscous animals which browse upon the coral; grinding it down to fine meal, part of which will pass from them and be deposited by the water. From this description it will be seen that an atoll closely resembles in form the cone of a submarine volcano, the coral reef representing the rim, the lagoon occupying precisely the place of the crater.

The islets formed on these reefs are very singular objects. In storms, the sea throws up fragments of coral, sometimes mixed with sand. The outer and lowest stratum of this matter, which is bathed by the sea at high tide, is sometimes converted into a brecciated coral rock by calcareous infiltrations from the water. Above this, and generally at the distance of 200 or 300 yards from the outer margin of the reef, the loose fragments cast up in strong gales, mixed occasionally with sand

and shells, accumulate till they form a bank rising from six to twelve feet above high water, with the highest side towards the sea, from which the surface slopes inward to the lagoon. The ordinary width of these islets is under a quarter of a mile, and their length varies from a few yards to several miles.



In the above cut, No. 1 is a plan of Keeling Atoll, in S. latitude 12°., and E. longitude 96.54°, the structure of which Mr Darwin examined with peculiar care.

a, d, b, r, i, t, f, the coral reef; the scale being $\frac{1}{4}$ of an inch to the mile, the largest diameter of the atoll is 9 miles, and the shortest 7.

N, the lagoon, which, a little northward of the centre, is 8 fathoms deep, as marked in the figure. The part south of the dotted line is nearly dry at low water.

i, t, the dark space here on the surface of the reef, is a long narrow islet of an irregular figure. There are other two between *b* and *r*; smaller ones at *f, d,* and *a*; and others of very minute size between *f* and *t*.

There is a wide breach in the reef between *b* and *d,* and a narrower one between *d* and *a,* either of which admits a ship.

The island abounds in cocoa trees, sprung from nuts brought by the currents of the ocean from Sumatra or Java, 600 miles distant. Turtles browse on the sea-weeds which grow in the lagoon. The islands are inhabited, and these two articles supply the people with food. What is singular, fresh water is obtained from wells which ebb and flow with the tides. Mr Darwin thinks that the rain water being specifically lighter than the salt, keeps floating on its surface, and is subject to the same movements.

Barrier Reefs.—Besides the atolls, which have merely a sheet of water in the interior, there are many reefs in the Pacific and Indian Oceans which encircle one or more islands of primary, secondary, or volcanic rock. To these Mr Darwin gives the name of "barrier reefs," and the water which separates the islands from the reef is called "the lagoon channel." These reefs resemble the others in all respects. They support scattered lineal islets; they are pierced by breaches; their exterior sides are steep and deep, while their interior are shallow and slope gently. Fig. 2. represents one of these (Maurua) on the same scale as the last.

r, f, the reef, with two long narrow islets at its northern end, and some smaller ones at other parts.

N, the lagoon channel. The narrow entrance on its south side ha from four to five fathoms of water.

L, an island 2 miles long, and 800 feet high in the lagoon.

In this instance, the lagoon channel, separating the island from the reef, is of small depth and narrow, the breadth ranging from a furlong to a mile; but in other cases, it is 20 miles broad and 60 fathoms deep; and, instead of one or two islands, almost filling the lagoon (as at Raiatea), there are sometimes four, six, or more, of small size, forming mere spots in it. This is exemplified at Hogoleu and Gambier Islands. There are two very remarkable barrier reefs known. The first is that which runs along the north-east coast of Australia 1000 miles in length. It is divided from the land by a lagoon channel from 10 to 30 miles broad, and from 10 to 60 fathoms deep. The other runs parallel to the shores of New Caledonia for a length of 400 miles. It accompanies the shores for 250 miles, and continues for 150 miles more in the same direction, affording presumptive evidence that the island has a submarine pro-

longation of this extent. At some places it is but a few yards from the island; at others it is 20 miles; and so steep was its exterior side found to be in one instance, that at two ship-lengths from the reef no bottom was found with a line of 900 feet.

Double and triple Atolls.—There are small atolls sometimes placed in elliptical rows, with a sheet of water in the centre, and thus becoming constituent parts of a large atoll. This is shewn at fig. 3, where 14 small atolls, each with its little lagoon, are so arranged as to form one large atoll, with a large lagoon, N, in its centre. The figure is ideal, but we have an example in the Maldiva Archipelago, where the combination is carried a stage higher. This group extends over a space of 470 miles in length by 50 in breadth, and forms, as it were, three orders of atolls. First, you have a hundred of these little reefs, with pools in the centre, so disposed as to form one large atoll, 50 or 60 miles long, by 10 or 15 broad, with a lagoon 25 fathoms deep. Next, twenty of these large atolls of the second order, are arranged in the shape of a narrow ellipse, so as to form one vast atoll of the third order, 470 miles in length by 50 in breadth, with a lagoon in the interior of unfathomable depth.

The atolls and barrier reefs are dispersed in great numbers over the Pacific and Indian Oceans. *Are they the remnants of a former continent which has disappeared, or is disappearing,* from that vast watery waste?—*or are they the harbingers of a new continent which is coming into existence?* These are the questions which Mr Darwin has discussed with great learning and ingenuity.

Fringing Reefs.—The third form in which coral-reefs present themselves is, that of *Fringing Reefs*, the difference between which and the other two must be pointed out. "Atolls" are rings of coral-rock, rising nearly to the surface of the sea, with or without islets of drifted coral generally having a great depth of water on the outside, and a lagoon from 5 to 50 fathoms deep in the centre. "Barrier reefs" are exactly similar, except that they encircle one or more islands of sedimentary or volcanic rock, from which they are divided by a lagoon-channel, which, like the lagoons of the atolls, is generally from 5 to 50 fathoms deep. "Fringing reefs" resemble barrier reefs, except that they have a comparatively small

depth of water on the outside, and small shallow lagoon channels between them and the land. They are generally found in seas that shelve gradually. The distinction between the last two classes of reefs has reference chiefly to theoretical considerations, as will be shewn by and by.

Theory of Atolls—Land that has subsided or is subsiding.—It must be kept in mind, as already stated, that reef-building corals do not live at a greater depth than 20 or 30 fathoms, or, to take the extreme in round numbers, say 200 feet. This fact is of fundamental importance in reference to every theory of coral reefs.

1. The earliest opinion was, that these reefs were built up in the ocean from unfathomable depths. But this is at once disposed of by the fact just stated.

2. At a more recent period some naturalists, struck by the generally circular form of the reefs, and the steepness of their exterior sides in many instances, supposed that they were based on the craters of submarine volcanoes. To this idea there is the conclusive objection, that it does not apply to long narrow reefs like Bow Atoll, 30 miles by 6, or Menchikoff Atoll 60 miles in length, or the larger rings, composed of smaller rings, of the Maldives. That submarine craters, if they reached the proper height, would afford fit foundations for atolls, is probable, and such may exist; but that all the numerous atolls scattered over the ocean rest on such a basis is inadmissible.

3. It has been supposed that the atolls rest on the summits of the submarine mountains. But this fails in explaining the existence of those which appear in groups. The low Archipelago, for instance, contains 80 atolls, scattered over a space of 840 geographical miles by 420, and not a single island of ordinary rock. How can we believe that a chain or group of mountains extending over such a vast area had 80 summits, all reaching within less than 200 feet of the surface, and not one rising above it? And this is not a solitary case; for the objection applies equally to the Gilbert group, 300 miles in length; the Marshall group, 520 miles by 240; and the Maldive and Lacadive group, 1000 miles in length by 100 in breadth—none of which contain a single island of any other

material than drifted coral, resting on the edge of the submarine reef. The argument holds equally good against the hypothesis of submarine craters; for so many hundreds of these could not approach within a few fathoms of the surface, without some of them rising above it.

4. Banks of sediment might (as some suppose) serve for a basis to atolls in shallow seas; but to assume the existence of hundreds of such banks of moveable matter in the profound depths of the ocean, is absurd; and it is positively disproved in the case of those atolls whose exterior sides are steeper than the cone of a volcano, descending, as some of them do, at an angle of 40 or 50 degrees.

The theory adopted, whatever it is, should also explain the existence of barrier reefs, which are analogous to atolls in every point, except that of having solid land within them. How, for instance, on any of the theories proposed, are we to account for the great barrier reef of Australia, with 60 fathoms of water even on its inner side, and descending on its outer side to unfathomable depths at a high angle? Are we to assume that there is a submarine precipice here 1000 miles in length, on which it rests.

The only hypothesis, Mr Darwin observes, *which solves all difficulties, is that which assumes that the atolls rest on land which has subsided*, and part of which was once dry. Detached atolls far from others, *may* stand on submarine rocks which have undergone no change of position; but those found in groups mark the site of land which has subsided. In short, the *atolls*, according to Mr Darwin's theory, *may be regarded as the vestiges or foot-prints of land which has disappeared; and the islands, encircled by barrier reefs, as remnants of land now partly submerged, and perhaps in progress towards final disappearance.*

As the coral animalculæ do not live at a greater depth than 200 feet, it follows that all reefs, however deep, must have begun in shallow seas; in other words, they must have been originally of the nature of "Fringing Reefs."

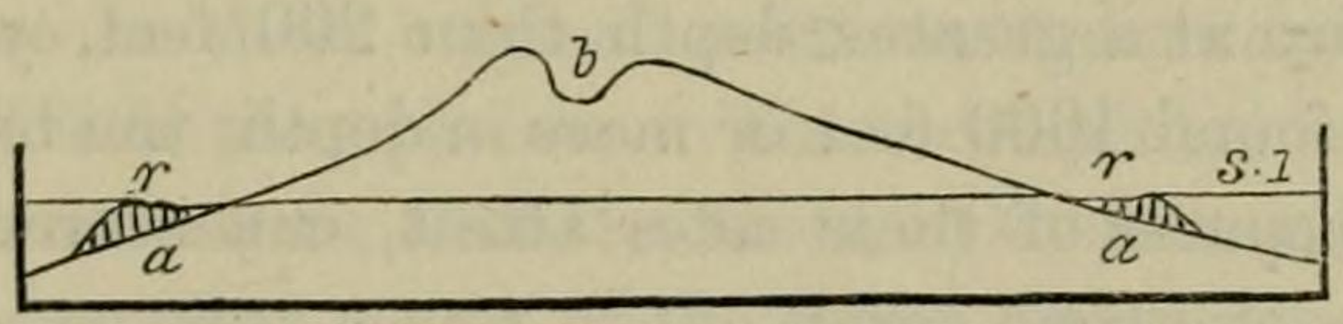
Let us suppose an island 350 feet high to exist in the tropical seas. The animalculæ commence their labours on some spot, and at a distance from the shore, as turbid water is pernicious to them. But since they cannot exist at more than

200 feet beneath the surface, they are checked in their progress seaward, and therefore continue their work to the right or left, keeping always within the requisite depth; and thus their instinct guides them to form the reef in the shape of a girdle round the island, following the sinuosities of its shores, keeping nearer them where the water deepens rapidly, and farther off where it deepens slowly. Here we have a reason why reefs may be circular, oblong, or of any other form which islands assume. Mr Darwin's plates of Raiatea and Vanikoro are good examples of the manner in which reefs adapt themselves to the outline of the islands they encircle.

The little architects carry up their fabric to the level of the low water line, and there they stop. Suppose the island now to subside 200 feet, either suddenly or slowly. They then commence a new fabric on the top of the old, and again carry it up to the low water level. But the island itself, besides losing 200 feet of height, is contracted in breadth from its low shores being covered with water; the channel between it and the reef becomes broader and deeper; and the reef having its basis at a depth beyond that where living coral exists becomes a "barrier reef."

Suppose the island to subside other 200 feet. A third fabric of coral now rises on the top of the second, till the reef again reaches the low water level. But the island itself has disappeared, and the lagoon which occupies its place, with the encircling reef, now forms an "atoll."

The subjoined figures illustrate what has been stated, and shew the process by which a "Fringing reef" passes into a "Barrier reef," and a barrier reef into an "Atoll."

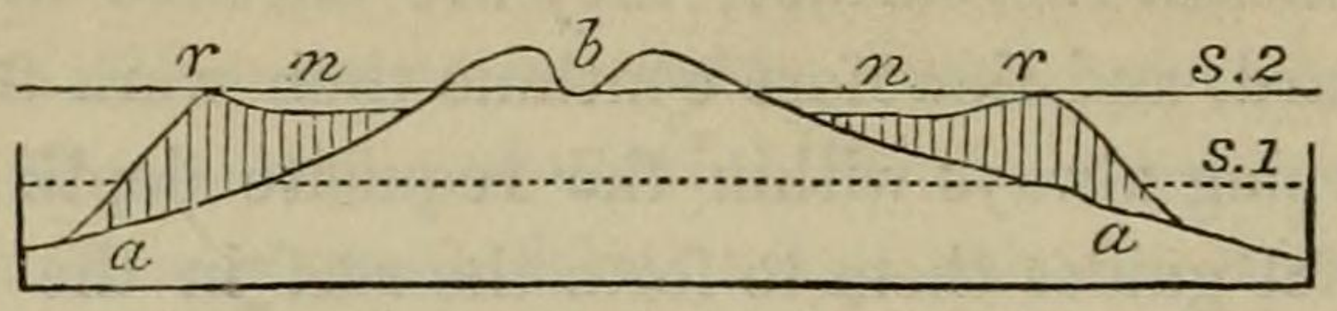


First Stage—The Fringing reef.

a b a—A section of an island, roughly copied from one given by Mr Darwin.

S 1—The surface of the sea.

r r—A fringing reef formed within a small distance of its shores.



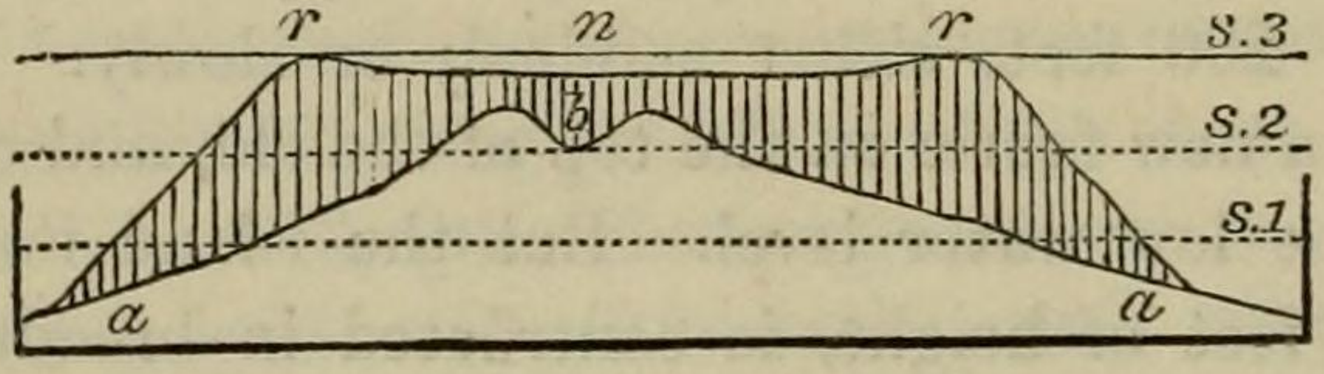
Second Stage—The Barrier reef.

a b a—The island having subsided 200 feet, is now more than half submerged; but its double summit is still visible.

S 2—The surface of the sea in its second position.

The fringing reef now raised to the level of *S* 2, forms *r r*, a "Barrier reef."

The small gutter which divided the reef from the island, is enlarged to the wider and deeper cavity *n n*, and forms a "lagoon channel."



Third Stage—The Atoll.

a b a—The island having subdivided other 200 feet, is now completely submerged.

S 3—The sea in its third position.

The barrier reef having 200 feet added to its height, now rises to *r r*.

A broad lagoon *n*, now occupies the place of the island, and the reef becomes an "Atoll."

Mr Darwin endeavoured to collect some positive evidence of subsidence in the islands, but it is not very satisfactory. Geology, however, renders it certain that some portions of the earth's surface have sunk to a lower level. The subsidence assumed, therefore, involves no inconsistency; and it enables us to account for the otherwise puzzling fact, that though corals do not live at a greater depth than 200 feet, yet numerous reefs are found 1000 feet or more in depth, the basis of which, as the steepness of their sides attest, can scarcely consist of any thing else than coral.

It explains also the appearance of the atolls in groups. Suppose a tropical island, like Ireland in size, to sink under the waves by slow stages. The hills being of different heights, the corals would begin their work on those first submerged—that is, the lowest—and new reefs would be founded successively on the higher ones as they descended, one after another,

to the proper depth. When the whole island had disappeared, a group of isolated atolls, scattered over a space of 250 miles by 150, would mark the place it occupied, and indicate its figure. All the atolls would be built up to the level of low water; and while the last founded might be only two or three fathoms deep, the first might be two or three hundred. In this way, the lower hills might have their representative reefs as well as the higher, though the creatures that construct them can work only at limited depths.

Again, if the principle be correct, we would expect to find occasionally an unsubmerged remnant of land (an island), accompanied with *barrier* reefs, in a region where subsidence was going on, that is, amidst a group of atolls. Now, this occurs in the Caroline Archipelago, and one or two other places. Moreover, as the conditions necessary to the life of corals (which are imperfectly known) may cease at some spots where they once existed, we might also expect (admitting the principle of subsidence) to find reefs, in which the coral being dead, could not raise itself to the low water level. Such a case is met with in the Great Chagos Bank, 90 miles by 70. It has a border from 5 to 10 fathoms under water, a second border, or inner ledge, about 16 fathoms under water, and its central parts, consisting of mud, are from 40 to 50 fathoms deep. It is conceived to be "a half-drowned atoll."

In New Caledonia, as Mr Darwin observes, we seem to witness the effects of subsidence in actual progress. It is an island 200 miles in length by 45 in breadth, quite straight, and consisting of a single ridge of mountains. Now, the coral reefs, which run parallel to its shores on the two sides, instead of turning round the north end and uniting, as we would expect, continue in their original north-west direction for 150 miles beyond it in the open sea. The most probable explanation of this anomaly is, that the reefs, in their northern prolongation, accompany a part of the ridge, which, owing to the island having subsided, is *now submarine*, but consisted of *dry land* at an earlier period when the reefs were founded. The reefs, in short, follow the ancient line of the shore, a large part of which is now under water, and the process of submergence is perhaps still going on.

Lands recently raised, or still rising from the ocean.—While

ancient lands have sunk under the waves in some parts of the Indian and Pacific Oceans, Mr Darwin thinks that new lands have risen, or are rising, in others. The corals furnish the evidence of the latter change as well as the former.

As all corals are formed in the sea, it follows that when we find them *in situ* on dry land, they afford distinct proof of the land having been upraised. Now, coral banks are found in most of the Sandwich Islands many yards above the sea. In one they form three strata, each 10 feet thick. In Oahu, Mr Pierce, an intelligent European who has lived there sixteen years, is convinced that elevation is at present going on "at a very perceptible rate." Elizabeth Island (S. lat. 24, W. long. 129) 80 feet high, is entirely composed of coral. Five of the "Cook and Austral" islands (S. lat. 20, W. long. 160) are of coral *rock*. The sixth Mangaia, 300 feet high, is, with the exception of a little basalt, entirely of coral; and having a flat top with a lagoon-shaped cavity in it, is evidently an upraised atoll. Tongataboo, one of the Friendly Isles, is entirely of coral; Eoua and Vavao, in this group, the former 200 or 300 feet high, are of the same substance. Anamouka, another, 20 or 30 feet high, with a salt-water lake in the middle, is, in truth, an atoll, only a very little elevated. Savage Island, 40 feet high (south-east of the Friendly group), exhibits tree-shaped corals still unbroken, a proof that its elevation is recent. In the Navigators' group (S. lat. 14, W. long. 170) large fragments of coral were found on a steep hill at the height of 80 feet, embedded in a base of decomposed lava and sand. On the new Hebrides (S. lat. 18, E. long. 168), coral, seemingly of recent origin, is found at a great altitude. New Ireland (S. lat. 4, E. long. 153), which belongs to the Salomon group, presents beds of madreporite rock, with the corals little altered, forming a newer line of coast modelled round an ancient one. In the Mariana group (N. lat. 15, E. long. 146), a succession of cliffs of madreporite limestone present themselves. In the great circular chain of islands extending from the Bay of Bengal to Japan, embracing Sumatra, Java, Timor, Ceram, the Philippines, and Loo Choo, corals or beds of sea-shells at considerable heights, afford abundant evidence of elevation; but for details we refer to Mr Darwin's book. Where reefs occur on the shores of these islands, they are fringing reefs,

indicating either that the shores are stationary, or that they are now rising.

Mr Darwin went painfully over every work in which any account of coral reefs was to be found, and marked by colours on a map to which of the three classes they belonged—of "fringing reefs," "barrier reefs," or "atolls." On classifying them in this way, the following general facts arrested his attention :—

1. They are not mingled indiscriminately, but generally those of each class appear in groups, spread over a considerable area.

2. Where they are mingled, the barrier reefs and atolls, both of which indicate *subsidence*, are found together.

3. On the other hand, fringing reefs and coral beds on *terra firma*, indicating that the land is either stationary or *uprising*, are generally found together.

4. Active volcanoes, the agents of elevation, are numerous in the stationary or *uprising* groups, and, except in a very few cases, are absent from the *subsiding* groups.

Mr Darwin was thus led to conclude that the ocean contains *areas of elevation* and *areas of subsidence ;* in other words, that in some parts its bottom is sinking, and burying ancient lands under the waves ; while in others, it is rising, and unveiling to us the germs of future islands and continents. Let us pursue this idea into a few details.

The Maldive and Lacadive Atolls and Great Chagos Bank, probably mark the former existence of an island extending 1500 miles from north to south, or equal in length to Britain, France, and Spain united.

In the Caroline Archipelago, northward of New Britain, we have perhaps the traces of a second island of similar size, of which two or three small portions are still above water ; in the Marshall, and Gilbert, and Ellice groups, traces of a third ; in the Society Isles and Low Archipelago, a few remnants of a fourth ; and in the Fidgi Islands, remnants of a fifth. According to the theory also, New Caledonia and the north-east coast of Australia have subsided, and may still be subiding.

On the other hand, Sumatra, Java, Sumba, Timor, with Gilolo, the Philippines, Formosa, and Loo Choo, which abound in active volcanoes, and perhaps also Borneo and Celebes, belong to the category of uprising lands. If we suppose that the ele-

vatory movement is still proceeding, its ultimate result, some thousand years hence, may be to unite that vast chain of islands to one another, and to the continent of Asia, by the peninsula of Malacca on the one side, and the eastern coast of China on the other, converting the Chinese sea into a vast inland lake. Further eastward, the Salomon Isles, which are also uprising, may be united into one narrow ridge, 500 miles long; and the New Hebrides, Sandwich Isles, and Navigators' Isles, may undergo a similar change. For other examples we refer to the work.

This theory explains the phenomena under consideration better than any other which has been proposed, and it is not at variance with the principles of geology, which teach us, that some parts of the crust of the globe are rising, and others subsiding at the present day. It seems to us, however, that it is attended with difficulties, of which some are perhaps apparent but others are real.

First, The anomalous facts are rather numerous. An inspection of the map shews that atolls and barrier reefs occur in "areas of elevation," and fringing reefs and volcanoes in "areas of subsidence," unless we confine these areas within very narrow limits. We grant, however, that this objection may admit of an answer. For instance, in an area that is rising, corals may take root upon a subaqueous rock or bank when it comes within less than 200 feet of the surface, and raise upon it an atoll. Again, a volcano like that of Monte Nuovo, near Naples, may break out in an area that is stationary or subsiding; and thus the indications of elevation and subsidence may be found intermingled.

Secondly, If the theory is correct, we would expect to find in areas of elevation, fringing reefs in a great variety of stages — some 2 or 3 feet above low water, some 2 or 3 yards, some with the lagoon channel almost, and others with it altogether, obliterated. That there are examples of this transition from the fringing reef to the coral rock on dry land, and that corals are found at considerable heights, we do not deny; but they occur, in our opinion, much more rarely than they ought to do, considering that the areas supposed to be uprising are of great extent, and many of them often visited and well known.

Thirdly, What seems to us the most serious objection to the theory, remains to be stated. On the outside of coral reefs very highly inclined, no bottom is sometimes found with a line of 2000 or 3000 feet, and this is by no means a rare case. It follows that the reef ought to have this thickness; and Mr Darwin's diagrams, pages 48 and 98, shew that he understood it so. Now, if such masses of coral exist under the sea, they ought somewhere to be found on *terra firma*; for there is evidence that all the lands yet visited by geologists have been at one time submerged. But neither in the great volcanic chain, extending from Sumatra to Japan, nor in the West Indies, nor in any other region yet explored, has a bed or formation of coral, even 500 feet thick, been discovered, so far as we know. We state this objection, not as conclusive against the theory, but as one deserving the able and ingenious author's consideration.

Remarks on the preceding paper, in a Letter from Charles Darwin, Esq., to Mr Maclaren.

Down near Broomley, Kent.

Dear Sir,—I have been so much pleased with the very clear, and, at the same time, in many points quite original manner in which you have stated and explained my views, that I cannot refrain from troubling you with my thanks. Your third objection appears to me much the most, indeed the only, formidable one, which has hitherto occurred to me. I fear I shall be tempted to reply to it at great length, but perhaps sometime you will find leisure to read my attempted vindication. With respect to the first objection, I can hardly admit that we know enough of the laws of elevation and subsidence to argue against the theory, because the areas of different movements are not more distinct. Some have been startled at my view on directly the reverse grounds to your objection, viz. that, according to their notions of probability, the areas of the same movements were too large and uniform. With respect to your second objection, all those who believe that exceedingly slow and gradual elevations are the order of nature, must admit a great amount of contemporaneous denudation, which would tend to annihilate the characteristic form of the fringing-reefs during their upheaval, and leave merely a coating on the upraised land of coral-rock either thicker or thinner, according to the original thickness, rate of growth of the reef at each successive level, and the rate of elevation; indeed I am surprised that there exists even one case, viz. at Mauritius, where the peculiar moat-like structure of a mere fringing-reef has been partially preserved on dry land.

Your third criticism strikes me as a very weighty and perplexing one.

It had passed through my head, but I had not considered it with nearly the attention it deserved, otherwise I assuredly would have noticed it in my volume. I had always intended to examine the limestone formations of England for comparison, but was prevented by bad health ; I was, however, led away from the subject, and baffled when I consulted published accounts, for the limestones all appeared to be uniformly spread out, and most, if not all of them, to be associated with layers of earthy matter, whereas a formation of the nature of a group of atolls, would consist of separate large patches of calcareous rock, which would be quite pure.—I was thus led from the subject, and did not reflect on their want of thickness. The want of thickness, however, in any limestone formation, until it be first shewn to be analogous in structure, form, and composition, to a barrier-reef, an atoll or group of atolls, evidently cannot be brought forward as any argument against the theory of the long-continued subsidence of reefs of these classes. During the elevation of all reefs in open seas, I think there can be no doubt (as is dwelt on at p. 117, 3d. vol.) that a considerable thickness of the exterior would be denuded, and the only parts preserved would be those which had accumulated in lagoons or lagoon-channels ; these would be chiefly sedimentary, and in some cases might contain (p. 117) scarcely any coral ; within barrier-reefs such beds would often be associated with much earthy sediment. Mr Lyell, in a note just received, in which he alludes to your criticisms, speaks of the limestones of the Alps and Pyrenees, as being of enormous thickness, namely, about 4000 feet. I do not know what their composition is, but I have no doubt that the strata now accumulating *within* the barrier-reef of Australia and New Caledonia, are chiefly formed of horizontal layers of calcareous sediment and not of coral.

I suspect that denudation has acted on a far grander scale than in merely peeling the outsides of upraised reefs. My theory leads me to infer that the areas, where groups of atolls and barrier-reefs stand, have subsided to a great amount and over a wide space. Now it appears to me probable, that a subterranean change, producing a directly opposite movement, namely, a great and widely extended elevation, would be extremely slow, and would be interrupted by long periods of rest, and perhaps of oscillation of level. When I think of the denudation along the fault, which goes across the northern carboniferous counties of England, where 1000 feet of strata have been smoothed away ; when I think how commonly volcanic islands, formed of very hard rock, are eaten back in cliffs from 100 or 200 to 800 or 1000 feet in height, I hardly see where we can stop, with respect to the probable limits of erosion on the comparatively soft, generally cavernous, tabular, though wide, masses of coral rock, standing exposed in great oceans during very slow changes of level. Most of the atolls which have been raised a few hundred feet are mere wrecks, and at the Friendly Archipelago where there are upraised atolls, there are large irregular reefs, also, which I have always thought were probably the basal vestiges of worn down atolls. Many submerged reefs, which may have had this same origin, occur outside the line of elevation of the Salomon and New Hebrides archipelagoes. The great steepness of the shores of upraised reefs (p. 65. Ehrenberg quoted, and p. 51.) would probably be unfavourable to the growth of new

reefs, and therefore to the protection afforded by them. I can conceive it very possible, that should, at some period, as far in futurity as the secondary rocks are in the past, the bed of the Pacific, with its atolls and barrier reefs, be raised in reefs, by an elevation of some thousand feet, and be converted into a continent, that scarcely any, or none of the existing reefs would be preserved; but only widely spread beds of calcareous matter derived from their wear and tear. As a corollary from this, I suspect that the reefs of the secondary periods (if any, as is probable, existed), have been ground into sand, and no longer exist. This notion will certainly at first appear preposterous; its only justification lies in the probability of upward movements after long periods of subsidence, being exceedingly slow and often interrupted by pauses of rest, and perhaps of oscillations of land, during all which the soft coral rock would be exposed to the action of waves never at rest.

This notion, preposterous as it will probably appear, would not have occurred to me, had I not several times, from independent reasons, been driven to the conclusion, that a formation to be preserved to a very distant æra (or which probably is the same thing, to be elevated to a great height from its original level *over a wide area*) must be of great extent, and must be covered by a great thickness of superincumbent matter in order to escape the chances of denudation. I have come to this conclusion chiefly from considering the character of the deposits of the long series of formations piled one upon another, in Europe, with evidence of land near many of them. I can explain my meaning more clearly by looking to the future; it scarcely seems probable, judging from what I see of the ancient parts of the crust of the earth, that any of the numerous sub-littoral formations (*i. e.* deposits formed along and near shores, and not of great width or breadth), now accumulating on most parts of the shores of Europe (and indeed of the whole world), although, no doubt, many of them must be of considerable thickness, will be preserved to a period as far in the future, as the lias or chalk are in the past, but that only those deposits of the present day will be preserved which are accumulating *over a wide area, and which shall hereafter chance to be protected by successive thick deposits.* I should think that most of the sublittoral deposits of the present day will suffer, what I conclude the sublittoral formations of the secondary æras have generally suffered, namely, denudation. Now, barrier and atoll coral reefs, though, according to my theory, of great thickness, are, in the above sense, not widely extended; and hence I conclude they will suffer, as I suspect ancient coral reefs have suffered—the same fate with sublittoral deposits.

With respect to the vertical amount of subsidence, requisite by my theory to have produced the spaces coloured blue on the map, more facts regarding the average heights of islands and tracts of land are wanted than all those, even if perfectly known, which this one world of ours would afford; for the question of the probable amount, or, which is the same thing, the probable thickness of the coral-reef, resolves itself into this,—What is the ordinary height of tracts of land, or groups of islands

of the size of the existing groups of atolls (excepting as many of the highest islands or mountains in such groups, as there usually occur of "encircled islands" in groups of atolls)? and likewise what is the ordinary height of the single scattered islands between such groups of islands?—subsidence sufficient to bury all these islands (with the above exception) my theory absolutely requires, but no more. In my volume, I rather vaguely concluded that the atolls, which are studded in so marvellous a manner over wide spaces of ocean, marked the spots where the mountains of a great continent lay buried, instead of merely separate tracts of land or mountainous islands; and I was thus led to speak somewhat more strongly than warranted, of the probable vertical amount of subsidence in the areas in question.

Mr Lyell in the note alluded to, thinks we are much too ignorant of intra-tropical geology (and ignorant enough we certainly are) to affirm that calcareous rocks of the supposed thickness of coral reefs, do not occur. I am inclined to lay considerable stress on this. I do not expect the foregoing view will appear at all satisfactory to any one besides myself,—I believe, however, there is more in it than mere special pleading. The case, undoubtedly, is very perplexing; but I have the confidence to think, that the theory explains so well many facts, that I shall hold fast by it, in the face of two or three puzzles, even as good ones as your third objection. Believe me, my Dear Sir, yours very truly,

CHARLES DARWIN.

Description of an improved Tilting Apparatus for emptying Waggons at the termini of Railways, Shipping-Places, &c., as used at the Magheramorne Lime-Works, Ireland. With a Plate. By JAMES THOMSON, Esq., F.R.S.E., M.R.I.A., F.R.S.S.A., Civil Engineer, Glasgow. Communicated by the Royal Scottish Society of Arts.*

The apparatus may be generally described as consisting of three parts, viz:—

1*st*, The cast-iron brackets or quadrants for supporting the machine, Plate I. *a a a*.

2*d*, The tilting-frame upon which the waggon is placed, *b b*,—and

3*d*, The malleable iron-swings for suspending the frame to the brackets, *c c*.

The supporting brackets *a a a*, are bolted to the wooden frame *d d*, of a moveable shipping platform, by means of which

* Read before the Royal Scottish Society of Arts, and working model exhibited, 10th January 1842, and the Society's Honorary Silver Medal awarded, 14th November 1842.