V. NOTICES OF NEW BOOKS.

I. THE STRUCTURE AND DISTRIBUTION OF CORAL REEFS; *being the first Part of the Geology of the Voyage of the Beagle under the Command of Capt. Fitzroy,* R.N. *during the Years* 1832 *to* 1836. By CHARLES DARWIN, M.A., F.R.S., Naturalist to the Expedition. London, pp. 214. 1842.

MR. DARWIN, in addition to his journal of the voyage of the Beagle, has since published, with the approval of the Lords Commissioners of the Treasury, two volumes having reference to geological subjects — the results of investigations made during his expedition.

It is to be regretted, that the publication of these volumes was delayed in consequence of the ill health of the author, which long prevented the close attention necessary to prepare his observations for the press. We have reason to rejoice that the works themselves require no apology for the state in which they appear.

The object of the volume at present before us, is to describe in detail the general structure and the circumstances of formation of coral reefs, with the object of explaining and supporting certain views of the action of disturbing forces, assumed by the author to have produced elevations and depressions of the sea bottom, and in this way accounting for many geological phenomena in different parts of the world, and of various periods.

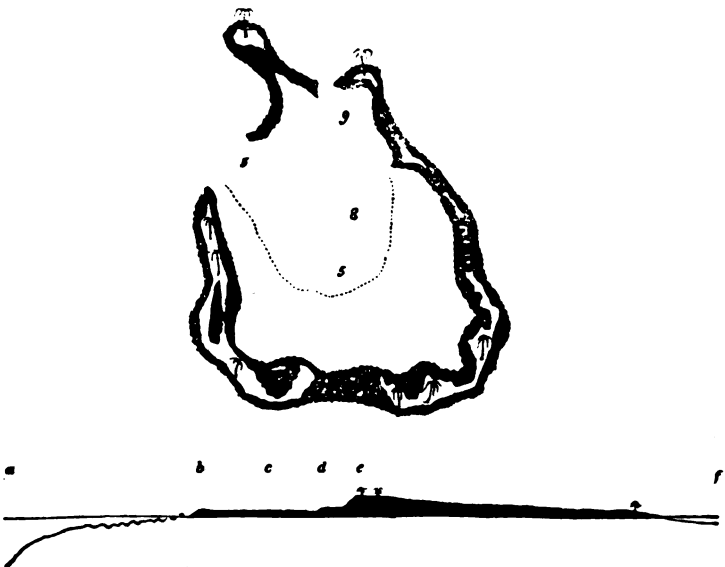
There are two great classes of coral-reefs, in one or the other of which the whole number may be included: those, namely, which exhibit near the surface no evidence of any solid rock from which they may have originated — *the barrier and atoll-formed reefs*, and those which are called *fringing-reefs* — where, owing to the nature of the slope and the vicinity of land, there can be no doubt as to the origin. The former class (including the lagoon islands) have attracted most attention, and offer the most striking phenomena, but both of them are extremely interesting.

The term "*atoll*" is used by the inhabitants of the islands in the Indian ocean to distinguish circular groups of coral islets sometimes called "Lagoon islands," a kind of salt-water lake or lagoon being often formed by a nearly continuous curved line of such reefs, only leaving one or two outlets. Barrier-reefs are little less marvellous in their structure than the atolls, the band of coral-reef sometimes forming a fringe of land, while sometimes

the existence of the reef is only indicated by a line of breakers, or a few small islets crowned with cocoa-nut trees; and the reef in this case is at a considerable distance from a central island, which is not itself due to the labours of the coral polyp.

Fringing, or shore-reefs, differ from barrier-reefs in not having within them a broad channel of deep water, and in not lying so far from the shore. There are other kinds of reefs allied more or less nearly to one or the other of these; but they possess comparatively little interest. With respect to the origin of all these reefs, the great difficulty lies in explaining the foundation of the barrier and atoll-formed class, the fringing-reefs requiring little consideration.

KEELING ATOLL
(Chart and Vertical Section).



a. Sea level at low water; depth 25 fathoms at 150 yards from the edge of the reef.

b. Outer edge of the flat part of the reef which dries at low water; this edge is either a mound or consists of jagged rugged points.

c. A flat of coral rock covered at high water.

d. A projecting ledge of brecciated coral rock washed by the waves at high water.

e. Loose fragments of coral only reached by the sea during gales, and its upper part (6 to 12 feet high) clothed with vegetation.

f. Low water level of the lagoon.

Note. The dotted line in the chart marks the limit of shallow water.

Mr. Darwin has described every existing coral-reef in geographical order so far as he possessed information (with the exception

of some on the coast of Brazil), and has marked them on a map with colours distinguishing the different kinds. He has thus illustrated his own hypothesis on the subject, namely, that in both atolls and barrier-reefs, the foundation on which the coral was primarily attached has subsided, and that during this downward movement the reefs have grown upwards.

In order to give as distinct an idea as possible of the nature of the various kinds of coral reefs, a detailed account is given of one example characteristic of each class: the one selected as illustrating the subject of lagoon islands or "atolls," is Keeling Atoll, of which a reduced chart and vertical section are here appended.

The first thing to be observed with regard to the formation of these reefs, is, that the living coral animal does not endure exposure to the rays of the sun even for a very short time; and that consequently it is only at the outer edge, below the level of low-water, that the reef increases, or at least that those species to which the great mass of the reef is due can exist. The most abundant coral on this outer edge was found to be the *Porites*, which forms great irregularly rounded masses from four to eight feet broad, and little less in thickness; but a species of *Millepora* (*M. complanata*) is also able to resist the fury of the waves, and grows in thick vertical plates, intersecting each other at various angles, forming an extremely strong honey-combed mass, which generally affects a circular form, the marginal plates only being alive. The corals inhabiting the protected crevices on the outer reef, and those in the interior of the lagoon, are quite distinct, and belong to much more delicate varieties.

From soundings taken outside the reef at Keeling Atoll, the water was found to deepen gradually for a space between 100 and 200 yards wide, but beyond this, the sides plunge into the unfathomable ocean at an angle of 45°. To the depth of 10 or 12 fathoms, the bottom seems to be, invariably, living coral; between that depth and 20 fathoms, about an equal number of times sand and coral; but of twenty-five soundings at a greater depth than 25 fathoms, every one showed the bottom covered with sand, the sand consisting of finely pounded fragments of stony corals. At a distance of a mile and a quarter from the breakers no bottom was found with a line 7200 feet in length, proving that the submarine slope was greater than that of any volcanic cone.

The chart and section represent a ring partly formed of small islets on a coral reef, but if the part above the level (*c*), which is just covered at high water, were removed, there would be a simple reef which forms what is essentially the "*atoll*," and it encloses the *lagoon* on all sides, except at the northern end, where there are two open spaces. The reef varies in width from 250 to 500 yards; its surface is level, or very slightly inclined towards the lagoon, and the islets are first formed between 200 and 300 yards from its outer edge, through the accumulation of a pile of fragments thrown together by some unusually strong gale. They are afterwards increased by the addition of fragments on their outer

side, and the fragments become in time cemented into a solid mass, either made up of partially rounded fragments of corals of various sizes, or of calcareous sandstone, formed of a conglomerate in which the structure of the coral has often become much obscured or entirely lost.

The interior of the lagoon is the next subject that requires notice. In the case before us, about half its area consists of sediment and half of coral reefs; but the corals are very different from those on the outside, and are much more delicate. The reefs also are softer, and increase very rapidly.

The sediment from the deepest parts in the lagoon consists of calcareous sand, and large soft banks of similar mud have been observed in other atolls. When dry, this mud so closely resembles chalk, that it can scarcely be distinguished from that substance. Large shoals of fishes, and many other animals, are found to feed upon the branches of the living coral, and the excrement of these must constantly produce vast quantities of fine calcareous mud.

Judging from old charts of Keeling Atoll, the coral polyp has added much to the solid matter of the reef within a very moderate period, and the islets have also greatly increased; but so far is this from being the consequence of any general elevation of the land, that there is good evidence in proof of a small subsidence. At any rate, there is evidence here of a severe struggle in progress between the nicely balanced powers of land and water, and if left undisturbed, it is manifest, that though the islets may increase, and the lagoon become partly filled up, the general increase seawards, and even the final conversion of the lagoon into land, must necessarily be exceedingly slow.

Keeling Atoll may be taken as a fair example of the very numerous rings of coral reefs and coral islands in the Pacific and Indian Oceans; but many of them are much larger, and some, on the other hand, exceedingly small, and the nature of the submarine slope is, in the great majority of cases, similar. But although such is the case, generally, there are two exceptions so remarkable, that some special notice is due to them. These exceptions consist of the reefs which form the Maldive Archipelago, and those which compose the great Chagos Bank.

The Maldive Archipelago is 470 miles in length, with an average breadth of about 50 miles, the dimensions of the largest atoll are 88 miles by 20, and like the other larger ones, it is breached by numerous deep-water channels leading into the lagoon. The separate portions of the reef between these channels are, in many cases, especially in the more northern atolls, true ring-shaped atolls differing only from those in the open sea by being based on a shallow foundation, and grouped closely together on one large platform, with the marginal rings, forming the external atoll, arranged in a rudely formed circle. The lagoons in the atolls of this large group are from 10 to 20 fathoms deeper in the southern than in the northern part. It is observed in this

group, as in atolls generally, that the channel is generally situated on the side least exposed to the prevailing winds and the heavy seas.

It appears, with regard to the islets formed in this group, that some of them have come into existence as land only within a few years, while others are fast wearing away.

The great Chagos Bank is described by Capt. Moresby, as "a half-drowned atoll." Its longer axis is about 90 miles, and it is 70 miles in width across the broadest part. The central part consists of a level muddy flat between 40 and 50 fathoms deep, surrounded on all sides, with the exception of some breaches, by the steep edges of a set of sand-banks, varying in breadth from 5 to 12 miles, and rudely arranged in a circle. These banks are about 16 fathoms beneath the surface, and are bordered by a rim about a mile wide, consisting of smooth hard rock, and only about 5 or 10 fathoms beneath the surface. At the distance of half a mile from one part of this rim, no bottom was found with 190 fathoms, and off another point, none with 210 fathoms. The circumstances and cause of this submerged condition will require subsequent consideration.

Barrier reefs resemble, in general form of structure, the atoll reefs already described, but they inclose land and a lagoon channel instead of a lagoon or mere sheet of water. They are, however, sometimes of vast dimensions, one on the west coast of New Caledonia being 400 miles in length and upwards of eight leagues from the shore, and the Australian barrier extending along the eastern and north-eastern coast of that vast island for nearly a thousand miles, its average distance from the coast being between 20 and 30 miles. It is observed in many of these reefs that the coral banks rise from far greater depths than the animal can exist in, and the living corals form a comparatively small proportion of the whole amount.

Fringing or shore reefs differ from barrier reefs, as has been already stated, by the absence of a lagoon channel and by the close relation in their horizontal extension with the probable slope beneath the sea of the adjoining land. The reefs round the island of Mauritius offer a good example of this class; and here, as in barrier reefs, the reef is breached by a straight passage in front of every river and streamlet.*

Many islands are fringed by reefs of this kind, but where the sea deepens rapidly, the reefs are narrow, often not more than 50 or 100 yards wide, and they have a nearly smooth hard surface scarcely uncovered at low water, and without an interior shoal channel. Their dimensions and structure, in fact, depend entirely

* This peculiarity is explained afterwards by Mr. Darwin, and an account is given of other causes unfavourable to the advance of the coral animal, but it is stated that one of these fringing reefs, if elevated in a perfect condition above the level of the sea, ought to present the singular appearance of a broad dry moat within a low mound. This, however, would be greatly modified by the action of the sea during the elevation. (See p. 54.)

on the degree of inclination of the submarine slope, conjoined with the fact, that reef-building polyps can only exist at limited depths; so that, where the sea is shallow, they lose their fringing character, and appear as separate and irregularly scattered patches, often of considerable area. These reefs also are generally higher and more perfect on the outer side, assuming the appearance of atolls, owing to the more vigorous growth of the coral where most exposed. They differ, however, from atolls in being less deep, in having their form less defined, and in being based on a shallow foundation.

Coral reefs are, for the most part, confined to the tropical seas, but extend as far as latitude 32° 15′ N. (at the Bermuda islands), and on the western shores of Australia to 29° S.

They do not seem to be influenced by the presence or absence of volcanic centres, but are totally absent in certain large districts within the tropical seas, and this apparently capricious distribution cannot be explained by any obvious causes. It seems beyond a doubt that the strongest and most massive corals flourish best where most exposed, while the presence of mud and sand, and of brackish or fresh water, is highly injurious. Different species abound in each of the different zones of depth, and in the case of some reefs there is no new material added above the lowest level which the water attains; although, in others, the growth continues to high water mark. There is also a fact of singular interest and importance with regard to this point in the occasional submerged reefs in the Chagos Bank and elsewhere, which, in some instances, appear to have remained stationary for a very long period, and have no tendency to grow upwards. It is supposed by the author that, in their case the whole group of reefs has subsided some seven or eight fathoms, so that the species building near the surface were destroyed, and other species preferring this depth having succeeded to them, there is now little tendency to grow upwards. There is, at any rate, no equal tendency to grow upwards in all coral reefs, but their growth is unequal and dependent on circumstances.

There is no doubt that coral, under favourable conditions of growth, increases to an enormous extent, and very rapidly; and although there are many instances on record of reefs which have not increased for many years, there are others telling a very different tale. The case of Matilda Atoll, described by Captain Beechey, is quoted as an example of this latter kind, this atoll having been converted in 34 years from being a reef of rocks into a lagoon island, 14 miles in length, with one of its sides covered nearly all the way with high trees. Some experiments are also mentioned in which it has been attempted to measure the rate of increase of different kinds of corals, and as one of the results of these is an instance of a growth two feet thick of coral accumulated on the copper bottom of a vessel in the course of twenty months.

Careful examination by soundings, together with such other observations as can be made on the subject, all unite in proving

that the reef-building coral animal does not generally live at a greater depth than about thirty fathoms, and this is not invalidated by the fact that living specimens have been found occasionally at much greater depth. The greatest depths at which the ordinary species grow appear to be those of the more northern parts of the Red Sea; but it is well known and has been already mentioned, that coral reefs occasionally exhibit a much greater thickness than this depth, although the lower portion is in such cases dead.

Having thus described the chief phenomena of coral reefs, and the circumstances of their growth, the author enters on the subject of the theory of the formation of the different classes of them, and shows the unsound nature of the theory most generally received, namely, that they are based on submarine craters, and also of the better theory of Chamisso, that the outer portions of a reef, being of the most vigorous growth, would first reach the surface. Neither of these theories, however, account for barrier reefs.

The cause that has given to atolls and barrier reefs their characteristic forms, is supposed by Mr. Darwin to have been the gradual subsidence of portions of the bed of the ocean over large areas, and is partly deduced from the consideration of these two circumstances, viz.: — first, that reef-building corals flourish only at limited depths, and, secondly, that vast areas are interspersed with coral reefs and coral islets, none of which rise to a greater height above the level of the sea than that attained by matter thrown up by the waves and winds. The foundation of each reef is assumed to have been rocky, but it cannot be thought probable that the broad summit of a mountain lies buried at the depth of a few fathoms beneath every atoll, with no one point of rock projecting above the surface over such a wide extent, and it is known that neither the flat disk of an abraded point, nor any other rocky foundation, is ever at the top of the reef. Besides the evidence in favour of a subsidence having taken place, derived from these and other considerations connected with the general appearance of the rocks, other evidence is adduced showing the probability of this view, which is then proved to explain in a very simple manner the ordinary phenomena of fringing reefs, barriers, and atolls, and some of the less regular forms of the two great classes of reefs, and it only remains to consider whether the actual distribution of coral reefs and their relative condition, agrees with such a theory of their formation. A chapter is added on this subject, and is accompanied by a coloured chart of all known coral reefs and islands, one colour being used to mark barrier reefs and atolls, and another distinguishing the fringing reefs which form a distinct type of structure. In this chart the difference between the atolls and barrier reefs is indicated by the tint; so that the one colour marks those districts in which it is supposed that subsidence has taken place at a slow but steady rate, allowing of the gradual accumulation of extensive coral reefs, while the other denotes that no such change of level to any sensible extent has taken place.

On examining the map with a view to determine the value of the theory of subsidence, it is at once seen, that while atolls and barrier reefs are generally near together, the fringing reefs are either distant from these, or in the exceptional cases, there is independent evidence of oscillations of level have taken place, subsubsidence having preceded the elevation of the latter, and elevation having preceded the subsidence of the former class.

There is however some direct evidence in the external appearance, of many of the atolls that subsidence has taken place; fissures formed by earthquakes and other recorded phenomen sufficiently proving that subterraneous movement of this kind is in progress, while, on the other hand, with regard to the fringing reefs, they are all situated in districts where elevation of the surface would seem to be going on. The Society Isles, and the numerous islands and reefs of the Low Archipelago, are remarkable instances of subsidence, while the Sandwich Islands and the Philippines are equally striking examples of recent elevation. It is worthy of notice also, that in the vicinity of those areas of subsidence which are marked by the presence of coral reefs of the barrier and atoll kind, there is a total absence of volcanoes of recent action, while they abound in the districts where ringing reefs occur.

In conclusion, Mr. Darwin directs attention to the vast extent of the areas of subsidence and elevation on the earth's surface, whether as indicated by the existence of coral reefs, or by the plain evidence of observed appearances. It seems that in the space of ocean extending from the southern end of the Low Archipelago to the northern end of Marshall Archipelago, a length of 4500 miles, every island with one exception is atoll-formed. With regard to the district we are told: —

"The eastern and western boundaries (the continents of Africa and S. America) are rising areas, the central spaces of the great Indian and Pacific oceans are mostly subsiding; between them, north of Australia, lies the most broken land on the globe, and there the rising parts are surrounded and penetrated by areas of subsidence, so that the prevailing movements now in progress seem to accord with the actual states of surface of the great divisions of the world" Page 148.

Since, therefore, it appears, that while the surface of different kinds of coral reefs differs but little, the barrier reef or ring of coral surrounding an island becoming an atoll when the land disappears, and being distinguished from the fringing reef by the presence of a deep water lagoon or moat between the reef and the central expanse; and since also the coral animal is found not to exist except at very limited depths compared with the actual depth of coral in the reefs, it results that —

"There is no difficulty respecting the foundations on which fringing reefs are based, while with barrier reef and atolls there is a great apparent difficulty on this head; — in barrier reefs, from the improbability of the rock of the coast or of banks of sediment extending in every instance so far seaward within the required depth; and in atolls, from the immensity of the spaces over which they are interspersed, and the apparent necessity for believing that they are all supported on mountain summits, which, although rising very near to the sur-

face level of the sea, in no one instance emerge above it. To escape this latter most improbable admission, which implies the existence of submarine chains of mountains of almost the same height extending over areas of many thousand square miles, there is but one alternative, namely, the prolonged subsidence of the foundations on which the atolls were primarily based, together with the upward growth of the reef-constructing corals. On this view every difficulty vanishes; fringing reefs are thus converted in barrier reefs, and barrier reefs, when encircling islands, are thus converted into atolls the instant the last pinnacle of land sinks beneath the surface of the ocean.

"Finally, when the two great types of structure — the barrier reefs and atolls on the one hand, and fringing-reefs on the other — are laid down in colours on the map, a magnificent and harmonious picture of the movements which the crust of the earth has within a late period undergone, is presented to us. We there see vast areas rising, with volcanic matter every now and then bursting forth through the vents or fissures with which they are traversed. We see other wide spaces slowly sinking without any volcanic outbursts, and we may feel sure that this sinking must have been immense in amount as well as in area, thus to have buried, over the broad face of the ocean, every one of those mountains above which atolls now stand, like monuments, marking the place of their former existence. Reflecting how powerful an agent with respect to denudation, and consequently to the nature and thickness of the deposits in accumulation, the sea must ever be when acting for prolonged periods on the land during either its slow emergence or subsidence: reflecting also on the final effects of these movements in the interchange of land and ocean-water on the climate of the earth, and on the distribution of organic beings, I may be permitted to hope, that the conclusions derived from the study of coral formations, originally attempted merely to explain their peculiar forms, may be thought worthy of the attention of geologists." Pages 146—148.

D. T. A.

II. Travels in North America, *with Geological Observations on the* United States, Canada, and Nova Scotia. By Charles Lyell, Esq. F. R. S. 2 Vols. 12mo. pp. 588. Map and Plates.

So far as regards geology, Mr. Lyell's work is eminently valuable, since it presents a connected view of the results of a large number of careful surveys of different parts of the Continent of North America, by means of a coloured geological map, in which the whole amount of information at present known on the subject of North American geology is incorporated. The importance of this as a means of simplifying and generalising the notions of English geologists with regard to the succession of strata on the other side of the Atlantic, it would be difficult to estimate too highly.

Mr. Lyell has also added much to the knowledge hitherto possessed on the subject of American geology by his own investigations in the field, and in the present notice we propose to point out in order the various geological matters touched on in the work before us, commencing with the older rocks, and so approaching last of all to those of newer date. The latter indeed, although perhaps the most important, we shall here scarcely allude to, because, having formed the subject of communications to the Geological Society, they either have been already or will be hereafter described in greater detail than even in the book itself