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NINETY-SEVENTH SESSION.

Monday, 5th April 1880.

SIR WYVILLE THOMSON, Vice-President, in the Chair.

The following Communication was read:—

1. On the Structure and Origin of Coral Reefs and Islands. By John Murray.

(*Abstract.*)

Darwin's Theory.—During the voyage of the "Beagle" and subsequently, Mr Darwin made a profound study of coral reefs, and has given a theory of their mode of formation which has since been universally accepted by scientific men.

Darwin's theory may be said to rest on two facts—the one physiological, and the other physical—the former, that those species of corals whose skeletons chiefly make up reefs cannot live in depths greater than from 20 to 30 fathoms; the latter, that the surface of the earth is continually undergoing slow elevation or subsidence.

The corals commence by growing up from the shallow waters surrounding an island, and form a fringing reef which is closely attached to the shore. The island slowly sinks, but the corals continually grow upwards, and keep the upper surface of the reef at a level with the waves of the ocean. When this has gone on for some time a wide navigable water channel is formed between the reef and the shores of the island, and we have a barrier reef. These processes have but to be continued some stages further, when the island will disappear beneath the ocean, and be replaced by an atoll with its lagoon where the island once stood.

According to this simple and beautiful theory, the fringing reef becomes a barrier reef, and the barrier reef an atoll by a continuous process of development.

Object of the Present Paper.—Professor Semper,* during his examination of the coral reefs in the Pelew group, experienced great difficulties in applying Darwin's theory. Similar difficulties presented themselves to the author in those coral reef regions visited during the cruise of the "Challenger."

The object of the present paper is to show, *first,* that, while it must be granted as generally true that reef-forming species of coral do not live at a depth greater than 30 or 40 fathoms, yet that there are other agencies at work in the tropical oceanic regions by which submarine elevations can be built up from very great depths so as to form a foundation for coral reefs; *second,* that while it must be granted that the surface of the earth has undergone many oscillations in recent geological times, yet that all the chief features of coral reefs and islands can be accounted for without calling in the aid of great and general subsidences.

Nature of Oceanic Islands and Submarine Elevations.—It is now known that, with scarcely an exception,† all oceanic islands other than coral atolls are of volcanic origin. Darwin, Dana, and others have noticed the close resemblance between atolls and ordinary islands in their manner of grouping as well as in their shapes. In a previous paper the author pointed out the wide distribution of volcanic debris over the bed of the ocean in tropical regions, and the almost total absence of minerals, such as quartz, which are characteristic of continental land.‡ There is every reason for believing that atolls are primarily situated on volcanic mountains and not on submerged continental land as is so often supposed.

* Zeitschr. für Wissen. Zoologie, vol. xiii. p. 563.

† New Zealand, New Caledonia, and the Seychelles have primitive rocks, if these can be regarded as oceanic islands. Some of the islands between New Caledonia and Australia may have primitive rocks, and the atolls in these regions may be situated on foundations of this nature.

‡ Proc. Roy. Soc. Edin., 1876–77, p. 247.

The soundings of the "Tuscorora" and "Challenger" have made known numerous submarine elevations: mountains rising from the general level of the ocean's bed, at a depth of 2500 or 3000 fathoms, up to within a few hundred fathoms of the surface. Although now capped and flanked by deposits of Globigerina and Pteropod ooze, these mountains were most probably originally formed by volcanic eruptions. The deposits in deep water on either side of them were almost wholly made up of volcanic materials.

Volcanic mountains situated in the ocean basins, and which during their formation had risen above the surface of the water, would assume a more or less sharp and pointed outline owing to the denuding action of the atmosphere and of the waves, and very extensive banks of the denuded materials would be formed around them. Some, like Graham's Island, might be wholly swept away, and only a bank with a few fathoms of water over it be left on the spot. In this way numerous foundations may have been prepared for barrier reefs and even atolls.

Those volcanoes which during their formation had not risen above the surface of the sea (and they were probably the most numerous) would assume a rounded and dome-like contour,* owing to the denser medium into which the eruptions had taken place, and the deposits which had been subsequently formed on their summits.

In order to clearly understand how a submarine mountain, say half a mile beneath the sea, can be built up sufficiently near the surface to form a foundation on which reef-forming corals might live, it is necessary to consider attentively the

Pelagic Fauna and Flora of Tropical Regions.—During the cruise of the "Challenger," much attention was paid to this subject. Every day while at sea tow-nets were dragged through the surface waters; and while dredging they were sent down to various depths beneath the surface. Everywhere life was most abundant in the surface and sub-surface waters. Almost every haul gave many calcareous, siliceous, and other Algæ; great numbers of Foraminifera and Radiolaria, Infusoria, Oceanic Hydrozoa, Medusæ, Annelids; vast numbers of microscopic and other Crustacea, Tunicates, Pelagic Gastropods, Pteropods, Heteropods, Cephalopods,

* Scrope on Volcanoes, chap. viii.

Fishes, and fish-eggs; larvæ of Echinoderms, and of many of the above creatures, &c.

Most of these organisms live from the surface down to about 100 fathoms.* In calm weather they swarm near the surface, but when it is rough they are to be found several fathoms beneath the waves. They are borne along in the great oceanic currents which are created by the winds; and meeting with coral reefs, they supply the corals on the outer edge of the reefs with abundant food. The reason why the windward side of a reef grows more vigorously appears to be this abundant supply of food, and not the more abundant supply of oxygen as is generally stated. The "Challenger" researches showed that oxygen was particularly abundant in all depths inhabited by reef-forming corals.

When these surface animals die, either by coming in contact with colder water or from other causes, their shells and skeletons fall to the bottom, and carry down with them some organic matter which gives a supply of food to deep-sea animals. The majority of deep-sea animals live by eating the mud at the bottom.

An attempt was made to estimate the quantity of carbonate of lime, in the form of calcareous Algæ, Foraminifera, Pteropods, Heteropods, Pelagic Gastropods, in the surface waters. A tow-net, having a mouth $12\frac{1}{2}$ inches in diameter, was dragged for as nearly as possible half a mile through the water. The shells collected were boiled in caustic potash, washed, and then weighed. The mean of four experiments gave 2·545 grammes. If these animals were as abundant in all the depth down to 100 fathoms as they were in the track followed by the tow-net, this would give over 16 tons of carbonate of lime in this form in a mass of the ocean one mile square by 100 fathoms.†

* The Challengeridæ, and many of the other members of Haeckel's new order *Phæodaria*, certainly live deeper, as we never got them in the tropics except when the net was sent down to a depth of 200 or 300 fathoms.

† Among the varieties of Foraminifera recognised by Mr Brady in the "Challenger" collections, the following have a Pelagic habitat:—

Pulvinulina Menardii.	*Pullenia obliquiloculata.*
,, *canariensis.*	*Sphærodina dehiscens.*
,, *crassa.*	*Caudeina nitida.*
,, *Micheliniana.*	*Hastigerina Murrayi.*
,, *tumida.*	,, *pelagica.*

Bathymetrical Distribution of the Calcareous Shells and Skeletons of Surface Organisms.—Although these lime-secreting organisms are so abundant in tropical surface waters, their cast-off shells and skeletons are either wholly or partially absent from by far the greater part of the floor of the ocean. In depths greater than 3000 fathoms we usually met with only a few shells of Pelagic Foraminifera of the larger and heavier kinds; a few hundred fathoms nearer the surface they became more numerous, and we get a few of the smaller kinds and some Coccoliths and Rhabdoliths. At about 1900 or 1800 fathoms a few shells of Pteropods and Heteropods are met with; and in all depths less than a mile we have a deposit in which the shell and skeletons of almost every surface organism is to be found. In the equatorial streams and calms the calcareous Algæ, Pelagic Foraminifera, Pteropods, and Heteropods are more abundant on the surface than elsewhere; and it is in these same regions that we found their dead shells at greater depths than in

Orbulina universa.	*Globigerina dubia.*
Globigerina bulloides.	,, *rubra.*
,, *æquilateralis.*	,, *conglobata*
,, *sacculifera* (hirsuta).	,, *inflata.*

It is the dead shells of these Pelagic Foraminifera which chiefly make up the calcareous oozes of the deep sea. The living shells of all the above varieties swarm in the tropical and sub-tropical waters near the surface. It is especially in the region of the equatorial calms that the largest and thickest shelled specimens are found. As we go north or south into colder water they become smaller, and many varieties die out. In the surface waters of the Arctic and Antarctic regions, only some dwarfed specimens of *Globigerina bulloides* are met with. The author is unable to agree with Dr Carpenter and Mr Brady in thinking that these Pelagic Foraminifera also live on the bottom. This question was made the subject of careful investigation during the cruise. The shells from the surface and from the bottom were compared at each locality, and it was found, by micrometric measurement, that surface specimens were as large and as thick shelled as any average specimens from the soundings. It is quite unlikely that the same individuals should pass a part of their lives in the warm sunny surface waters, at a temperature of from 70° to 80° Fahr., and another part in the cold dark waters two or three miles beneath, at a temperature of 30° or 40° Fahr. The geographical distribution of these Pelagic forms over the bottom coincides exactly with the distribution of the same forms on the surface; that is to say, both on the surface and on the bottom, the distribution is ruled by surface temperature. No specimens of these Pelagic varieties were ever obtained from the bottom with the shells filled and surrounded with sarcode. Whereas creeping and attached forms (like Truncatulina, Discorbina, Anomalina, and some Textulariæ) were taken in this condition in almost every dredge. These last-mentioned forms which we know live on the bottom have a distribution quite independent of surface temperature.

the deposits of other parts of the ocean. Another circumstance influences the bathymetrical distribution of these surface shells. When there is a complete and free oceanic circulation from the top to the bottom, these dead shells are found at greater depths in the deposits than where the circulation is cut off by submarine barriers.

The agent by which these shells are removed is, as Sir Wyville Thomson suggested, carbonic acid. Analysis shows that carbonic acid is most abundant in sea water, and especially so in deep water. Pteropod and Heteropod shells are very much larger than the Foraminifera, yet are very much thinner; and hence, for the quantity of lime contained in them, they present a much greater surface to the action of the sea water. This seems to be the reason why all large and thin shells are first removed from the deposits with increasing depth, and not the fact that some shells are composed of arragonite and some of calcite, as has been suggested.

There is a continual struggle in the ocean with respect to the carbonate of lime. Life is continually secreting it and moulding it into many varied and beautiful forms. The carbonic acid of ocean waters attacks these when life has lost its hold, reduces the lime to the form of a bicarbonate, and carries it away in solution. In all the greater depths of the ocean these surface shells are reduced to a bicarbonate either during their fall through the water or shortly after reaching the bottom.

In the shallower depths—on the tops of submarine elevations or volcanoes—the accumulation of the dead silicious and calcareous shells is too rapid for the action of the sea water to have much effect. Long before such a deposit reaches sufficiently near the surface to serve as a foundation for reef-forming corals, it is a bank on which flourish numerous species of Foraminifera, Sponges, Hydroids, deep-sea Corals, Annelids, Alcyonarians, Molluscs, Polyzoa, Echinoderms, &c. All these tend to fix and consolidate such a bank, and add their shells, spicules, and skeletons to the relatively rapid accumulating deposits. Eventually coral-forming species attach themselves to such banks, and then commences the formation of

Coral Atolls—Mr Darwin has pointed out that "reefs not to be distinguished from an atoll might be formed" * on submerged banks such as those here described. However, the improbability of

* Coral Reefs, p. 118.

so many submerged banks existing in the open ocean caused him to reject this mode of formation for atolls. As here stated, recent deep-sea investigations have shown that submerged banks are continually in process of formation in the tropical regions of the ocean, and it is in a high degree probable that the majority of atolls are seated on banks formed in this manner.

Mr Darwin has also pointed out that the corals on the outer margin of a submerged bank would grow vigorously, whilst the growth of those on the central expanse would be checked by the sediment formed there, and by the small amount of food brought to them.* Very early in the history of such an atoll, and while yet several fathoms submerged, the corals situated on the central parts would be placed at a disadvantage, and this would become greater and greater as the coral plantations approached the surface. When the coral plantation was small there was a relatively large periphery for the supply of food to the inner parts, and also for the supply of sediment; and hence, in small atolls the lagoon was very shallow, and was soon filled up. For the same reasons coral islands situated on long and narrow banks have no lagoons. An atoll one mile square has a periphery of four miles. In an atoll four miles square—the periphery increasing in arithmetical progression and the area as the square—we have for each square mile only a periphery of one mile over which food may pass to the interior, and from which sediment is supplied for filling up the lagoon.

With increasing size, then, the conditions become more and more favourable to the formation of lagoons, and as a consequence we have no large or moderate sized coral islands without lagoons. Tow-net experiments always showed very much less Pelagic life (food) in the lagoon waters than on the outer edge of the reef. The lagoon becomes less favourable for the growth of all the more massive kinds of coral as the outer edge of the reef reaches the surface, and cuts off the free supply of ocean waters. Many species of corals die.† Much dead coral, coral rock, and sediment is exposed to the solvent action of the sea water. Larger quantities of lime are carried away in solution as a bicarbonate from the lagoon than are

* Coral Reefs, p. 134.

† There are no living corals or shells in some small lagoons, the waters of which become highly heated, and in some cases extremely saline.

secreted by the animals which can still live in it; the lagoon thus becomes widened and deepened.*

On the other hand a vigorous growth and secretion of lime takes place on the outer margins of the reef; and when the water outside becomes too deep for reef-forming corals to live, these still build seawards on a talus made up of their own debris:—the whole atoll expands somewhat after the manner of a Fairy Ring.

It is not necessary to call in disseverment of large atolls in order to explain the appearances presented in the Great Maldiva group of atolls.† The coral fields rising from very many parts of these extensive submarine banks form atolls. The marginal atolls have from the first the advantage of a better supply of food. They elongate in the direction of the margin of the bank where the water is shallower than to seaward. Many of these marginal atolls have coalesced, and as this growth and coalescence have continued, a large part of the food-supply has been cut off from the small atolls situated towards the interior of the bank. Ultimately a large atoll like Suadiva atoll would be formed. The atolls in the interior would be perhaps wholly removed in solution, and the atoll-like character of small marginal but now coalesced atolls would be wholly or partially lost by the destruction of their inner sides.‡ A study of the charts shows all the stages in this mode of development.

In the case of the Lakadivh, Caroline, and Chagos archipelagos we have submarine banks at various stages of growth towards the surface, some too deep for reef-forming species of coral, others with coral plantations, but all submerged several fathoms, and scattered amongst these some of the oldest and most completely-formed atolls and coral islands. It is most difficult to conceive how these sub-

* Complete little Serpula-atolls, with lagoons from 3 to 50 feet in diameter, and formed in this way without subsidence, were numerous along the shores of Bermuda.

† Mr Darwin's application of his theory to this group—where the disseverment of large atolls is called in, and a destructive power attributed to oceanic currents, which it is very unlikely they can ever possess—has often been considered unsatisfactory.

‡ "In speaking of Bow Island, Belcher mentions the fact that several of its points had undergone material change, or were no longer the same when visited after the lapse of fourteen years. These remarks refer particularly to islets situated within the lagoon. I could myself quote many instances of the same description."—"Wilkes' Exploring Expedition," vol. iv. p. 271.

merged banks could have been produced by subsidence, situated as they are in relation to each other and with respect to the perfectly-formed atolls of the groups.

It is a much more natural view to regard these atolls and submerged banks as originally volcanoes reaching to various heights beneath the sea, and which have subsequently been built up to and towards the surface by accumulations of organic sediment and the growth of coral on their summits. It is a remarkable fact that, in all coral atolls which have been raised several hundred feet above the sea, the base is generally described as composed of solid limestone, or "of various kinds of coral evidently deposited after life had become extinct." * This base is probably often made up of such a rock as that brought by the missionaries from New Ireland, and described by Professor Liversidge, † as composed chiefly of Pelagic Foraminifera, the same as those taken by the "Challenger" in the surface waters of the Pacific.

Microscopic sections of a rock taken from 50 feet below sea level at Bermuda show that a deposition of carbonate of lime is going on. The small shells are filled with, and the broken pieces of shells and corals are cemented by, calcite. The wells in coral islands rise and fall with the tide, so that the whole atoll is filled like a sponge with sea water. This water is very slowly interchanged, and by the solution of the smaller and thinner particles, becomes saturated, and a deposition of lime follows. In this way we may explain the absence of many of the more delicate shells from some limestones. ‡

Barrier Reefs.—During the visit of the "Challenger" to Tahiti, a careful examination was made of the reefs by dredging, sounding, &c., in a steam pinnace, both inside and outside the reefs. Lieutenant Swire of the "Challenger" made a careful trigonometrical survey of the profile of the outer reefs on six different lines; and while associated with him in this work, the author was indebted to that officer for many valuable suggestions.

A ledge ran out from the edge of the reef to about 250 yards, where we got a depth of from 30 to 40 fathoms. It was covered with a most luxuriant growth of coral bosses and knobs.

* U. S. Ex. Exp., vol. iv. p. 269. † Geol. Mag., Dec. 1877.

‡ Fuchs, Über die Entstehung der Aptychenkalke. Sitzb. der k. Akad. der Wissensch. 1877.

Between 250 and 350 yards from the edge of the reef there was generally a very steep and irregular slope; about 100 fathoms was got at the latter distance, and the angles between these last-mentioned distances often exceeded 45 degrees. The talus here appeared to be composed of huge masses and heads of coral, which had been torn by the waves from the upper ledge and piled up on each other. They were now covered with living Sponges, Alcyonarians, Hydroids, Polyzoa, Foraminifera, &c.*

From 350 to 500 yards from the edge of the reef, we had a slope with an angle of about 30°, and made up chiefly of coral sand. Beyond 500 yards the angle of the slope decreased till we had at a distance of a mile from the reef an angle of 6°, a depth of 590 fathoms, and a mud composed of volcanic and coral sand, Pteropods, Pelagic and other Foraminifera, Coccoliths, &c.

In the lagoon channel the reefs were found to be fringed with living coral, and to slope downwards and outwards for a few feet, and then plunge at once to a depth of 10 or 16 fathoms. Many portions of these inner reefs were overhanging, and at some places overhanging masses had recently fallen away. Everywhere much dead coral rock was exposed to the solvent action of the sea water. The reefs of Tahiti are at some places fringing, at other places there is a boat passage within the reef, and at Papiete there is a large ship channel with islets within, and the outer edge of the reef is a mile distant from the shore. The island itself is surrounded with a belt of fertile low land, frequently three or four miles wide; this shows that the island has not in recent times undergone subsidence; there are, indeed, reasons for supposing it has recently been slightly elevated. Everything appears to show

* This ledge and steep slope beyond where a depth of 30 or 40 fathoms was reached, was characteristic of a large number of atoll and barrier reefs, and seemed due to wave action. Experiments had been made with masses of broken coral, and it was found that these could (on account of their rough and jagged surface) be built up into a nearly perpendicular wall by letting them fall on each other. A talus formed in water deeper than 40 fathoms where there was little if any motion would be different from one formed on land. In the latter case the disintegrating forces at work always tended to set the talus in motion; in the former case everything tended to consolidate and to fix the blocks in the positions first assumed. A removal of lime in solution would take place from the blocks forming this steep slope, but, except in very deep water, this would not be sufficient to check the outward extension of the reef.

that the reefs have commenced close to the shore and have extended seawards, first on a foundation composed of the volcanic detritus of the island, and afterwards on a talus composed of coral debris, and the shells and skeletons of surface organisms.*

The lagoon channel was subsequently slowly formed by the solvent action of the sea water thrown over the reefs at each tide, and the islets in the lagoon channel are portions of the original reef still left standing. The reefs have extended outwards from the island and have been disintegrated and removed behind in the same way as the atoll has extended outwards after reaching the surface.

Where reefs rise quite to the surface, and are nearly continuous, we find relatively few coral patches and heads in the lagoons and lagoon channels. Where the outer reefs are much broken up, the coral growths in the lagoon are relatively abundant. Where the water was deep and the talus to be formed was great, the outward growth has been relatively slow,† and the disintegrating forces in the lagoons and lagoon channels gaining in the struggle, the reefs would become very narrow and might indeed be broken up. This, however, would admit the oceanic waters and more food, and growth would again commence on the inner as well as the outer sides of the still remaining portions. In the great barrier reef of Australia, where the openings are numerous and wide, the reefs have a great width. Where the openings are few and neither wide nor deep (as in lat. 12° 30′) the reefs are very narrow and "steep to"—on their inner side.

At the Admiralty Islands, on the lagoon side of the islets on the barrier reefs, the trees were found overhanging the water, and in some cases the soil washed away from their roots. It is a common observation in atolls that the islets on the reefs are situated close to the lagoon shore. These facts point out the removal of matter which is going on in the lagoons and lagoon channels.

Elevation and Subsidence.—Mr Darwin has given many reasons for believing that those islands and coasts which have fringing reefs had recently been elevated, or had long remained in a state of rest.

* A dredging in 155 fathoms, close to the barrier reef of Australia (between it and Raine Island), gave a coral sand, which was, I estimate, more than two-thirds made up of the shells of surface animals.

† Hence in barrier reefs, where the depth outside is very great, we find the reefs running closer to the shore than where the depth is less, and consequently the talus to be formed is smaller.

Throughout the volcanic islands of the great ocean basins the evidence of recent elevations are everywhere conspicuous. Jukes has given most excellent reasons for believing that the coast of Australia fronted by the barrier reef, and even the barrier reef itself, have recently been elevated.* Dana and Couthouy have given a list of islands in almost every barrier reef and atoll region which have recently been elevated.†

This is what we should expect. Generally speaking, all the volcanic regions which we know have in the main been areas of elevation, and we would expect the same to hold good in those vast and permanent hollows of the earth which are occupied by the waters of the ocean. It must be remembered that, probably, all atolls were seated on submarine volcanoes. Areas of local depression are to be looked for in the ocean basins on either side of and between groups of volcanic islands and atolls, and not on the very site of these islands. This is what the deep-sea soundings show if they show any depression at all. Subsidence has been called in in order to account for the existence of lagoons and lagoon channels, and the narrow bands of reef which enclose these; but it has been shown that these were produced by quite other causes,—by the vigorous growth of the corals where most nourishment was to be had, and their death solution and disintegration by the action of sea-water and currents ‡ at those parts which cannot be, on account of their situation, sufficiently supplied with food.

All the chief and characteristic features of barrier reefs and atolls may, indeed, exist with slow elevation, for the removal of lime from the lagoons and the dead upper surface of the reefs by currents, and in solution by rain and sea-water might keep pace with the upward movement.

The most recent charts of all coral reef regions have been examined, and it is found possible to explain all the phenomena by the principles here advanced; while on the subsidence theory, it is most difficult to explain the appearances and structures met with in

* Voyage of the Fly, vol. i. p. 335.

† Dana's Corals and Coral Islands, p. 345. Couthouy's "Remarks on Coral Formations," Bost. Jour. Nat. Hist. See also Stutchbury, West of England Journal.

‡ Very strong currents run out of the entrances into lagoons and lagoon channels, and when the tow-net was used in these entrances it showed that a large quantity of coral detritus was being carried seawards.

many groups; for instance in the Fiji Islands, where fringing reefs, barrier reefs, and atolls, all occur in close proximity, and where all the other evidence seems to point to elevation, or at least a long period of rest. In instances like the Gambier group, the reefs situated on the seaward side of the outer islands would grow more vigorously than those towards the interior; they would extend in the direction of the shallower water, and ultimately would form a continuous barrier around the whole group. The distinguishing feature of the views now advanced is that they do away with the great and general subsidences required by Darwin's theory,* and are in harmony with Dana's views of the great antiquity and permanence of the great ocean basin, which all recent deep-sea researches appear to support.

Summary.—It was shown (1) that foundations have been prepared for barrier reefs and atolls by the disintegration of volcanic islands, and by the building up of submarine volcanoes by the deposition on their summits of organic and other sediments.

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

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

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

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

In conclusion it was pointed out that all the causes here appealed

* "We may conclude that immense areas have subsided, to an amount sufficient to bury not only any formerly existing lofty table-land, but even the heights formed by fractured strata and erupted matter."—"Coral Reefs," p. 190.

to for an explanation of the structure of coral reefs are proximate, relatively well known, and continuous in their action.

The author expressed his indebtedness to all his colleagues, to Professor Geikie, to the Hydrographer and officers of the hydrographic department, and in a special manner to Sir Wyville Thomson, under whose direction and advice all the observations had been conducted.

BUSINESS.

The following candidates were balloted for, and declared duly elected Fellows of the Society:—Major-General Bayly, R.E.; Mr W. J. Sollas, M.A.; and Mr Henry Drummond, F.G.S.

Monday, 19th April 1880.

SIR WYVILLE THOMSON, Vice-President, in the Chair.

The following Communications were read:—

1. Rock-Weathering, as illustrated in Edinburgh Churchyards. By Professor Geikie, F.R.S. (Plate XVI.)

Comparatively little has yet been done in the way of precise measurement of the rate at which the exposed surfaces of different kinds of rock are removed in the processes of weathering. A few years ago, some experiments were instituted by Professor Pfaff of Erlangen to obtain more definite information on this subject. He exposed to ordinary atmospheric influences carefully measured and weighed pieces of Solenhofen limestone, syenite, granite (both rough and polished), and bone. At the end of three years he found that the loss from the limestone was equivalent to the removal of a uniform layer 0·04 mm. in thickness from its general surface. The stone had become quite dull and earthy, while on parts of its surface fine cracks and incipient exfoliation had appeared.* The time during which the observations were continued was, however, too brief to allow any general deductions to be drawn from them as to the real average rate of disintegration. Professor Pfaff relates that during the period a severe hail storm broke one of the plates of stone. An exceptionally powerful cause of this nature might make

* Allgemeine Geologie als exacte Wissenschaft, p. 317.