No. XIX.—THE STRUCTURE AND FORMATION OF ALDABRA AND NEIGHBOURING ISLANDS—WITH NOTES ON THEIR FLORA AND FAUNA.

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(Plates **22—29** and Text-Figures 1—3.)

(COMMUNICATED BY PROF. J. STANLEY GARDINER, M.A., F.R.S., F.L.S.)

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I. INTRODUCTION.

VOLUMES xii. and xiii. (Ser. 2, Zool.) of the Transactions of this Society contain a series of papers dealing with the various biological problems of the Indian Ocean, and constituting the results of the Percy Sladen Trust expedition in H.M.S. "Sealark," under the leadership of Professor J. Stanley Gardiner. In a previous expedition Stanley Gardiner had investigated the Maldivé and Laccadive Archipelagoes, and, before turning to what may perhaps be considered the last expedition of the series, it is necessary to refer in greater detail to its forerunners.

The Maldivé and Laccadive expedition was mainly devoted to an elaborate investigation of the formation of those archipelagoes, and the results show that their islands were formed by the elevation of flourishing coral reefs, and that the bases, on which these reefs grew, consist of the remnants of a continental bridge, which connected India and Africa approximately from carboniferous to tertiary times.

The two problems thus involved, that of the formation of coral reefs and of the continental land connection, were considered of such importance that the "Sealark" expedition was organised largely, though not entirely, for their further consideration; many of the islands in the western Indian ocean had never been visited by scientific observers, and their structure in most cases was but vaguely known.

The results of the "Sealark" expedition, taken in conjunction with those of the SECOND SERIES—ZOOLOGY, VOL. XIV.

previous expedition, show that the Indo-African bridge was in all probability reduced by subsidence to a narrow isthmus or chain of islands, and that then by the power of current erosion it was gradually cut down below sea-level, until at the present day the Seychelles archipelago alone remains above water. With the exception of the above archipelago and Mauritius all the islands visited by the "Sealark" were shown to be coralline in structure, and all indications as to their mode of formation, as in the case of the Maldives, favoured the theory of elevation and not of subsidence.

The "Sealark" expedition, however, found it impossible to investigate one group of islands, which Gardiner*, when classifying the islands of the Indian Ocean, has termed the Farquhar series, though, for reasons which will become obvious, I shall in future refer to it as the Aldabra series. It contains the islands of Aldabra, Assumption, Cosmoledo, Astove, Farquhar, Providence and St Pierre, of which the three latter only were visited by the "Sealark." The whole series lies to the north of Madagascar between longitudes 45° E. and 52° E. and between latitudes 9° S. and 10.5° S., the component islands being separated by from 20 miles (Aldabra and Assumption) to 180 miles (Astove and Farquhar). Of the various islands, Astove, Cosmoledo and Assumption were practically unknown, but Aldabra had become famous as the last home in the Old World of the giant land-tortoise; its land avi-fauna also was known to be peculiar, while contradictory reports made difficult any conception of its structure. In 1907 the analysis of samples of guano, received from the locality, pointed to the existence there of rocks other than those of reef formation, and it therefore appeared possible that a further remnant of the Indo-African bridge might yet be existing on Aldabra. Further investigation seemed desirable, and Professor Stanley Gardiner, who with Mr Hugh Scott was planning a further expedition to the Seychelles, made provision for the author to accompany the expedition and undertake the work of thoroughly investigating the Aldabra series of islands. This paper gives a brief history of the latter work, and the deductions made from it, though the reports of the specialists on the material collected must be consulted for confirmatory or contradictory evidence.

Before turning to the description of the expedition a few more facts of general bearing on the region must be mentioned, while in addition the scanty details of history about the islands may at once be disposed of. They first appear on the charts of the early sixteenth century, Aldabra itself being called Alhadara on the "Carte de Madagaskar d'après Pilestrina" in the year 1511. In subsequent charts one or more of the other islands are usually indicated but not sufficiently well to make sure as to which is really intended, though the name Joao de Nova for Farquhar is usually constant. In different times Aldabra is called Ya d'Arena, Y d'Areo, Ilhadara and Adarno, names which appear to indicate sand island—as will be seen later, a most inappropriate designation. Voeltzkow, who visited Aldabra in 1895, makes the reasonable suggestion that the island was first discovered by the Arabs†, who named it Al-Khadhra, "the Green," and the early European navigators, the Portuguese, translated it phonetically to Al-hadara, and so obtained the various names, by which it has since been known. No written records of the islands

* *Geographical Journal*, Oct. 1906, p. 326.

† Arab craft employed in the slave and other trades regularly plied between Zanzibar and the Comoros in very early times.

appear to exist, but we know that during the French occupation of Mauritius there was a regular trade in land-tortoises, which were much esteemed as food both in the Seychelles and Mascarenes; it is from the captains and ships employed in this trade that the names of the various places on Aldabra have been obtained.

As the tortoises became scarce the trade fell off, and eventually, after the Seychelles became British, was prohibited altogether.

Of scientifically-trained observers the first to visit Aldabra was Dr Abbott, who spent some months there in 1893, and obtained fairly complete collections of the larger forms of life*. Dr Voeltzkow, in the course of his travels in East Africa†, spent a month on the atoll, and made observations on its structure; but neither of these explorers in the time at his disposal was able to penetrate the dense jungle with which it is clothed, and so their observations only apply to scattered areas.

A bird collector for the Tring museum spent a year there, and in 1906 Lord Crawford in the "Valhalla"‡ touched for a day or two; in 1907 Messrs Thomasset and Dupont made a short visit, and obtained samples of the flora, rocks and guano. From a structural point of view, however, the atoll was quite unknown, and as the late Professor A. Agassiz even thought of investigating it himself§, no doubt was felt as to the advisability of further exploration.

Politically all the islands of the series are dependencies of the Seychelles, with the exception of Farquhar, which is under the administration of Mauritius. They are leased by the Crown at an annual rent, the lessee importing labourers and deriving what profit he can from the export of guano, mangrove bark and green turtle. The present lessee is M. D'Emmerez de Charmoy, of Mahé, to whom I am very grateful for permission to visit the islands, and for much assistance when there.

To complete this introduction a few more words must be said as to the general topography of the Aldabra series. Their position has already been roughly defined; it may be pointed out in addition that the neighbouring lands are the Seychelles to the north-east, the Amirantes to the north, Africa to the west, the Comoros, volcanic islands, to the south-west, Madagascar to the south, and the Saya de Malha Bank and the open expanse of the Southern Indian Ocean to the east. Of the various islands, Aldabra is the most westerly; Assumption lies 20 miles to the south-east, and Cosmoledo 70 miles to the east (E. by S.); Astove, the most southerly, is some 20 miles south of Cosmoledo, while 180 miles to the east is Farquhar, to the north of which at distances of about 70 miles are Providence and St Pierre.

Unlike the Maldive or the Seychelles series of islands, the Aldabra series has no shallow bank from which its various members arise, though it may be mentioned that there are indications of a deep bank some 1000 fathoms from the surface of the sea; all the islands therefore are separated by depths of at least 1000 fathoms.

* A short account of Aldabra by Dr Abbott is to be found in the Proc. of the U.S.A. Mus. Vol. xvi., p. 597: in the same volume are papers on the mammals, birds and reptiles which he obtained.

† Wissenschaftliche Ergebnisse der Reisen in Madagaskar und Ost-Afrika.

‡ *Vide* Three Voyages of a Naturalist, Nicoll.

§ The Geographical Journal, Sept. 1910, "The South-West Indian Ocean" (discussion on), Prof. J. Stanley Gardiner.

The ocean currents in the neighbourhood are both uniform in direction and strong (2—4 knots); they run from east to west, varying slightly to the north or south according to the seasons, which are respectively those of the S.E. Trades and of the N.W. Monsoon or calm season. The S.E. Trade winds blow strongly from May to October, and the season is one of drought, during which the vegetation on the islands becomes parched, trees lose their leaves, and life generally seems at a standstill. Owing to the partial coincidence of wind and ocean current, the latter is at its strongest during this season. In November the S.E. Trades break and the calm season sets in, for, though sometimes called the season of N.W. Monsoons, the latter winds rarely extend to such southern latitudes. The rainfall is very heavy, and, as a rule, a dead calm prevails, though at times heavy squalls may spring up from any point of the compass, and very occasionally a cyclone is experienced. The temperature is higher than that of the S.E. Trades, and often stands for long periods at or over 100° F., while the atmosphere is almost saturated. The calm season is the one of activity on the islands both for animals and plants. My visit lasted from August 1908 to February 1909, and both seasons were experienced.

With this introduction I now turn to Aldabra, taking this, the most important, island first.

II. ALDABRA. (Plates 22—27.)

A. PHYSICAL FEATURES. (Plate 22.)

Aldabra is situated in latitude 9° 22' 35" South and in longitude 46° 14' 41" East, and thus lies 240 miles from Cape Amber and 600 miles from the Seychelles, while the African coast is distant only some 400 miles. In form the island is an atoll measuring 25 miles long and from 4 to 10 miles wide, the long axis running approximately east and west. In total area the atoll perhaps measures 120 square miles, of which some 60 are land, though, owing to the presence of numerous islands in the lagoon and of a large area of mangrove swamp, half land half water, this estimate cannot be considered accurate.

The land consists of the land-rim, forming the circumference of the atoll, and of the various small islands in the lagoon. The former is unusually perfect, and is divided by narrow passes into four main islands, named respectively Picard, Polymnie, Malabar, and Main or South Island. Picard is a small island situated in the north-west, measuring about 2 square miles, and is divided from Polymnie by the Grande Passe, 750 yards wide, of which about 400 yards are deep channel. Polymnie, another small island about 1 square mile in area, may really be considered part of the larger Malabar Island, from which it is divided by a shallow pass, the Johnny Channel. Malabar itself is some 9 miles long, and averages $\frac{3}{4}$ mile in width; it is divided from Main Island by Passe Houareau, a large pass 400 yards wide, though the actual channel is narrower. Main island varies greatly in width, in the east measuring as much as 5 miles, while at one place in the south it is only $\frac{1}{4}$ mile from the lagoon to the sea: it forms at least two-thirds of the total circumference of the land rim, extending from the north-east round the south of the atoll to the west near Picard Island, from which it is divided by the western channels, a series

of shallow passes broken by small islands, which have obviously been cut away from the adjoining portions of the land rim.

Of the numerous islands in the lagoon immediate reference need only be made to the two largest, Michel in the east of the lagoon and Esprit in the west, of which the former is unimportant, the latter of great geological interest.

Other physical features, to which attention should be called, are the fringing reef and the mangrove swamp; the former extends entirely round the atoll, except that it is divided by the channels (passes) into the lagoon, and is indefinite to the east and south-east, where the sea is shallow for about a mile. The mangrove swamp is found round the shores of the entire lagoon and varies up to a mile in width, occupying all suitable spots between tide marks.

It will doubtless be noticed, without further reference to topographical features, that the atoll is divided into certain definite physical divisions, and for convenience in discussion it is proposed to deal with each separately. These sub-sections will be :—

- (1) The land.
- (2) The lagoon, comprising the lagoon shores (mangrove swamp) and the passes.
- (3) The fringing reef and also the outer slope, though as to the latter very little information can be given.

The animals and plants collected are being dealt with in subsequent papers and so lengthy reference would be out of place in this article: a short section will, however, be devoted to those which are not to be treated later, and to other forms of special interest, or from which definite deductions can be made.

B. LAND TOPOGRAPHY. (Plates 23—25.)

In this sub-section I propose to give some general description of the superficial features of the land of Aldabra, and then pass on to a more detailed account of its structure. All the various islands of which the atoll is composed are formed entirely of rock, which is usually found quite exposed on the surface, and is rarely covered by soil of any kind: exceptions to this generalisation are found in parts of Picard, Main, Michel and Esprit Islands, where sand has been piled up by the joint forces of wind and wave and forms a thin covering. In addition to this, in former times a large quantity of guano was distributed over the atoll, but now it is only found in holes and crevices, the greater bulk having been washed down by rain-water and to a large extent absorbed into the constitution of the rocks.

The rock itself comprises a variety of limestones, all of coral reef origin, though many have been much altered and phosphatised by the guano referred to above; there is no rock on Aldabra which has persisted from any continental connection and the atoll has had an entirely different origin.

The surface of the rock produces perhaps the most striking impression of anything on the atoll, for, instead of being smooth or slightly rough, it has been attacked by rain-water, which has gradually dissolved much of it away leaving a surface fretted as if by a powerful acid; sharp points, projecting pinnacles and deep pits are found everywhere, making work exceedingly trying. Under these circumstances it might be expected that

the Aldabra flora would be very poor even for a coral island, but this is not the case, for it is covered with a type of vegetation which appears to dispense easily with soil, provided there are crannies and fissures in the rock, into which roots can be driven: this vegetation takes the form of a low jungle or bush 10—20 feet high, which densely clothes every foot of rock.

The average height of the land above high tide-mark is about 12 feet, though an elevation of 15 feet is usually found near the seashore, from which point there is a gradual slope down to the lagoon.

Seaward the land is bounded by rocky cliffs (15 feet high), which are always much overhanging, obviously being washed away by the sea. Large fallen masses of rock are frequent, lying on the reef below, and at intervals caverns pass up into the cliff-face, often to find openings to the surface some distance inland. Where the cliffs have been washed away unevenly, small protected bays are formed and these get partly choked with sand and then form small sand-beaches known locally as "lances," the only landing-places for boats and favourite breeding-grounds of the green turtle (*Chelone mydas*). Within a short distance of the top of the cliffs the bush begins. To explore the country tracks about 6 feet wide were cut across the land-rim through the bush from the sea-cliffs to the lagoon and then by means of smaller paths the land surface on each side was examined. This somewhat laborious method was chosen on account of the extreme density of the vegetation, which is so impenetrable that it is quite impossible to proceed in any direction without employing several men to cut a path; in addition these "sections," as I shall in future term them, proved of great interest as showing the complete dependence of each class of vegetation on the type of rock which supports it.

In order to demonstrate more clearly the types of country encountered, two of these sections may be described, one typical of the north of the atoll and the other of the south.

The typical sectional track across the land-rim in the north of the atoll. This section passes across Malabar Island, about 3 miles from Passe Houareau, and is opposite an island in the lagoon known as Verte. From the sea cliffs the rock at first is moderately rough and strikes the observer forcibly from the fact that it is composed of corals which, though fossil, are but little broken and are undoubtedly in the same relative positions as when alive. This type of rock is always found in the sea cliffs and for some little distance inland. It is usually sparsely covered with sand blown up from the reefs forming a little soil which supports the type of vegetation usually found on coral sand islands; bushes of *Scaevola** and *Tournefortia*† are common and at intervals large clumps of screw-pines‡ occur. On the northern part of the land-rim this country is only a few yards wide, and then both rock and vegetation rapidly change; the edge of a dense jungle rises like a wall and thenceforward no natural paths or glades occur and every inch has to be gained at the expense of much time and labour. The rock becomes more rough until its surface resembles a miniature forest of little pinnacles and sharp jagged edges, which make progression difficult. The jungle is composed largely of *Pemphis acidula*, a tree known locally as "almond-tree"; it has a very hard wood and grows so thickly that the bush is

* *Scaevola koenigii*.

† *Tournefortia argentea*.

‡ *Pandanus vandermeeschii*.

like a continuous well-grown hedge about 15 feet in height. The trees have a short thick trunk, long slender branches, and are very uniform in size, so that it is impossible to climb a tree and obtain any view of the surrounding country. This type of bush is found wherever the jagged pointed rock occurs, and as the latter from its curious appearance is known* as "champignon," the country is always referred to as "champignon country."

Throughout the northern section the *Pemphis* jungle continues and the monotony is only broken by the frequent occurrence of curious natural pits in the rock; up to within a quarter of a mile of the sea they are partially choked with guano but after this are usually found to contain salt water, which fluctuates tidally, thus showing that the land-rim can be more or less completely traversed by sea-water. Naturally the water dissolves the rock away, and thus the sides of the pits overhang and break down, and the pits are always increasing in size.

After a mile of "champignon," creeks from the lagoon were met with and soon after the mangrove swamp was reached. At the junction of land and swamp are low cliffs 3 or 4 feet high which show the effects of erosion in that they are much overhanging, while small islands and large rocks are continually being cut off from the mainland. After a time the latter take on the mushroom shape typical of erosion; then, the "stalk" of the mushroom breaking down, the rock or island tumbles over and is itself gradually eroded away.

The mangrove swamp measured a quarter of a mile in breadth in the section. It is very flourishing, the trees standing in thick white mud, which may be very shallow or may have a thickness of many feet before rock is reached. The trees usually grow in this mud, but may also be found in numbers on the sides of the rocks and islands, and along the lagoon cliffs: their roots then pass down through holes and cracks in the overhanging portions of the rock to the mud underneath and by increasing in size form powerful instruments for breaking off large masses of rock. At high tide the swamp fills with water, which churns up the white mud and then, as it descends, sweeps it away into the lagoon and the finer particles out to sea, though the larger particles remain as sand in the lagoon until sufficiently triturated and reduced by sand-living animals to be carried away also. The loss in this manner must be very large and, as there is no evidence that the total quantity of mud is decreasing, it appears that rock disintegration must be speedy enough to counterbalance such loss, a subject which must be referred to again later.

The typical section for the south-east of the land-rim. The second section passes from the lagoon near a creek known as Abbot's creek past the wells of Takamaka (see Chart) to the south coast. Beginning again at the sea it is at once noticeable that the cliffs, though formed of the same rock as was noted in the cliffs of the northern section, are not so overhanging and are marked by projecting buttresses, indicative of a slower rate of erosion. Descending to the reef to find a reason for this, the quantity of sand was immediately remarked, and it appears that this sand forms a partial protection against the waves, even though the latter are particularly powerful on this, the windward side of the atoll.

* The language usually spoken is Creôle, a debased and often hardly recognisable French patois.

Inland from the cliffs for some distance sand is again the prominent feature; it has been blown up from the reef and further down the coast forms the high sand hills called "Dunes Jean Louis" and "Dunes de Maistre": in the region of our section it supports a somewhat stunted vegetation of coral-sand plants and forms a definite belt 200—300 yards wide, which may be called the "coast-zone." It is bounded by a rocky ridge 20 feet above sea level, which appeared to be the highest point on the section: thence inland a fresh type of country was met with, for the rock, instead of being of the "champignon" type, is flat and smooth. It is formed of fragments of corals and other organisms consolidated together. Under the influence of the weather it exhibits large pavement-like slabs on the surface and is called "platin" in Creôle. Pits and shallow depressions are frequent, the pits being usually deep and containing tidally fluctuating water; as was noticed on the northern section they are all increasing in size owing to erosion. The shallow depressions are not apparently homologous with the pits, for the latter are natural spaces left in the rock during formation, while the former are due to weathering; they usually contain guano mixed with vegetable humus and support a grove of trees. The vegetation of the "platin" country differs markedly from the *Pemphis* scrub, for it is composed of a large number of trees and shrubs, which form small groves separated by open bushy spaces; near the sea the trees were all much stunted by the prevalent winds, even the hardy *Pemphis* trees being dwarfed into a low thick scrub resembling patches of gorse in consistency. As the section passed further inland and the surface of the ground was lower, the vegetation became more luxuriant, the depressions in the rock serving to retain a little rain-water collected during the wet season. The rock remained of the same nature throughout almost the whole section with the exception of two belts of "champignon," overgrown with *Pemphis*, about $\frac{1}{2}$ and $\frac{3}{4}$ mile from the sea. Near Takamaka are found the only permanent wells of fresh water on the atoll: they consist of pits in the rock about 6 feet deep and 2 or 3 feet wide, with a spring at the bottom; apparently a rather impervious stratum of limestone in the immediate neighbourhood has prevented the ingress of salt water and enough rain falls in the wet season to preserve a steady though small flow in the dry. At Takamaka itself is a grove of large banyan and "takamaka"* trees (40 feet)†, the latter not occurring elsewhere on Aldabra. I suspect that the seeds were originally brought by the tortoise-hunters, who regularly visited the wells for water, though it is just possible that they were brought by birds, as the small pigeon, *Alectrocenas aldabranus*, eats them greedily.

The section ended in the mangrove swamp at Abbot's creek, which does not differ from any other creek found in the swamp into which it extends for about $\frac{1}{4}$ mile.

Other sections were cut from the lagoon to Point Hodoul, the most easterly part of the atoll; opposite Dunes Jean Louis; in the west of Main Island; on Picard Island; and at other places in the north of the atoll, but detailed description is unnecessary. The whole of the north of the atoll, Polymnie, Malabar, the north of main island, supports only *Pemphis*-bush growing on "champignon" rock. The east of Main Island and south as far as Dunes Jean Louis is of the "platin" type, interspersed with belts and patches of *Pemphis*; from Dunes Jean Louis to Dunes de Maistre there is a wide "shore zone,"

* *Calophyllum Inophyllum*.

† Where a number of feet is given in brackets, heights or elevations are intended.

a narrow belt of *Pemphis* and then the swamp. The west of Main Island belongs almost entirely to the "champignon" type of country, though at Couroupa a depression in the rock (2 or 3 acres) has been filled with sand and supports a thick jungle.

Picard Island has a narrow sandy belt along the south-west shore, on which the settlement is situated, and behind is a varied jungle and certain peculiar rocks which will be described later: the north of the island is largely *Pemphis* scrub, though opposite Grande Passe is a small sandy area covered with old *Casuarina* trees, marked on the chart as the "Admiralty Observation Spot."

I have now indicated the general nature of Aldabra and in the next subdivision I propose to deal in greater detail with its component rocks, from which even without expert knowledge certain deductions of great importance can be made.

Mr Hughes, of Bangor University, who has very kindly undertaken their examination, writes (19th June, 1910), "All my work up to the present seems to support your theories completely; I cannot think of any other possible explanation," so his paper, which will appear subsequently, may be expected to confirm the general principles of my deductions, though no doubt he will modify many of my details.

C. STRUCTURE*.

The rocks of Aldabra fall naturally into two divisions:

(a) those which have a high percentage of calcium in the form of calcium carbonate and are obviously of coral reef origin;

(b) certain exceptional rocks in which the acid radical in calcium carbonate has been replaced by phosphoric acid derived from guano.

(a) *Coralline Limestones.* There are three classes of coralline limestone, of which the first forms a zone encircling the atoll and constituting the outer portions of the land-rim. It is characterised by being composed very largely of reef corals, which have retained their structure very perfectly, and are in most cases in the position of growth, a phrase which means that the different coral colonies are still in the same positions as when alive and stand on the same bases. This rock therefore has been formed by a reef flourishing beneath the sea. From it we can deduce with certainty that the land has been formed by the elevation of a reef in relation to the surface of the sea, and not by the piling of broken fragments during a long period of subsidence, as is demanded by an explanation based on Darwin's theory. From the facies of the corals we can deduce that before elevation the reef was existing in quite shallow water. (Plates 23, 24.)

The outer portions of the whole atoll were searched diligently in relation to this type of rock and it was never found to be missing; indeed the most striking impression was given by these elevated corals, which on the face of the cliffs from top to bottom stood out in a way which can be realised only from the illustrations, while on the top of the cliffs so perfect were they, that it was difficult to believe they were long dead.

* [Mr J. O. Hughes, who has been examining the rocks chemically, has kindly read through this section. J. S. G.]

It is felt that this rock satisfactorily determines a most important point in the history of the atoll.

The second class of rock is that which was described as "platin." It also is obviously composed of corals to a large extent, but differs from the preceding class of rock in that the component corals are much broken and triturated, and are seldom if ever* in the position of growth. With the coral fragments are pieces of lithothamnia, numerous mollusc shells, echinoderm spines and pockets of foraminifera, among which *Orbitolites* is prominent. After weathering the surface of the rock becomes flat, and pavement-like slabs break away, leaving again a flat surface underneath. By means of the pits and wells it was possible to make observations at some distance from the surface (6—8 feet), but the components of the rock seemed to be similar, though in consistency they differed somewhat in being softer and more chalky. It is suggested that the pavement-like surface has been produced by successive solutions and re-depositions of calcium carbonate by rain-water. (Plate 25, fig. 2.)

The formation of this rock is to some degree a matter of speculation, but to me it appears to be strictly comparable with that of the rock found on the inner portions of a reef fringing an atoll, which consists in the consolidation of broken fragments washed from the growing edge. The first class of rock shows that Aldabra once lay beneath the sea and was fringed by a flourishing reef; the currents sweeping over it must have carried large quantities of débris and waste material away from the living corals. Now it is known that the latter are very intolerant of such substances and therefore towards the interior of the reef conditions were unsuitable for them. Consequently the inner portions of the reef must have been built up by débris rather than by live corals.

At present the débris rock or "platin" is found mainly in the east of the atoll, but, as the next class of rock has been much metamorphosed, it is uncertain what its former distribution may have been. Assuming that when Aldabra was under the sea the currents flowed in the same direction as at present (mainly from east to west), it is probable that the east of the reef inside the growing edge was then the most barren, while further west patches of live reef would have existed, becoming more numerous up to the growing edge in the west.

The third class of rock, the "champignon," is a metamorphosed rock, which must be regarded as a secondary derivative of coral-limestone. It is somewhat crystalline, and is always marked by the possession of inclusions of calcium phosphate, the pure calcium carbonate being white, while the inclusions show on a freshly fractured surface as sharply defined brown patches. (Plate 25, fig. 1.)

Metamorphosis is of course frequent in coral rock, but it must be regarded as peculiar that the metamorphosed coral limestones in Aldabra and the neighbouring islands always contain inclusions of calcium phosphate. The origin of the phosphate is certainly to be found in the deposit of guano, portions of which were washed into spaces in the rock and included during metamorphosis. There appears to be some connection between the metamorphosis and the presence of the phosphate. It is hoped that Mr Hughes may throw further light on the question.

The distribution of this rock is very wide, for it is found over the greater part of

* One large colony of *Cæloria* was noticed in position of growth near Takamaka.

the atoll and always supports the *Pemphis* type of vegetation. Its surface has already been sufficiently described and it will suffice to point out that it indicates extensive rain-water denudation. An experienced observer would without further data be able to hint at the extent of this, but fortunately I have more definite evidence in the abnormal rocks, with which I am about to deal.

(b) *Abnormal Rocks.* Rocks, which cannot be considered as normal forms of coral limestone, were found on Picard Island and on Esprit Island, of which the latter will be considered first.

Esprit consists of a crescent-shaped ridge of rock about $\frac{1}{2}$ mile long and 30 feet high, being thus the highest rocky point on the atoll. The ridge itself at its widest measures about 200 yards and is densely clothed in a varied jungle, containing several small forest trees not found elsewhere. The hollow of the crescent is occupied by mangrove swamp.

The ridge is composed of a curious conglomerate or pudding-stone, which is yellow or brown at the higher levels, but which contains a quantity of dark brown, almost black substance lower down: this in places along the shore projects as large boulders, which have been greatly wind-polished, giving the island an appearance most foreign to coral islands. On the top of the ridge is a small quantity of rock, which superficially resembles flint, while on the sides are pinnacles of a rock composed largely of mollusc shells, though a few fossil corals were also found. These pinnacles on the south side were but 3 or 4 feet high, but on the north measured 15 or 16 feet and were arranged like some fantastic natural maze, out of which it was difficult to find a path. The strange form of the rock had evidently been produced by great rain-water denudation and a natural chimney in the ridge appeared to prove that the shell rock penetrated the conglomerate, which must have been formed round it. (Plate 27.)

A rough analysis of specimens from the ridge shows that all (both conglomerate and flint-like rock) are chiefly composed of calcium phosphate, the colouring being probably due to a small percentage of iron. No evidence as to the mode of formation was found on Esprit, but fortunately similar rocks exist on Picard and here a clue was obtained. In the south-west is a small plain of "platin" rock, in which is a large basin (10 feet at deepest) partially filled with salt water, which is tidal, being in subterranean connection with the lagoon. Round the sides of the basin were found masses of phosphatic rock resembling that of Esprit, while in addition there was some quantity of a highly crystalline mineral resembling calcite, veins of which radiated into the surrounding "platin" rock. A conglomerate containing an anomalous assortment of vertebrate remains, such as teeth of *Carcharias*, of *Diodon*, of *Scarus*, with bones of giant land-tortoises, was also found, its components being apparently cemented together by the calcium phosphate.

The general mode of formation of these rocks was fairly obvious; the basin represents a large cavern, into which various marine deposits and, later, tortoise bones were washed. After the deposition of guano, it also was washed by the rain into the cavern and formed the various phosphatic rocks just described: under the influence of rain-water denudation, assisted by the breaking in of the lagoon, the cavern was thrown open to the surface, and now by erosion is rapidly increasing in size.

The details of this process of rock formation must be left to the specialist, but there seems no doubt that the general method is correct, and applies not only to Picard but also to Esprit Island. It appears, therefore, that the ridge of the latter island was formed underground in a large fissure or series of caverns in the rock, to which guano or a solution of its main constituents obtained entrance. It follows directly then that the general level of Aldabra was originally over 30 feet high and that it has been reduced to its present level by a process of rain-water denudation and erosion; the limestone, being soluble, has been washed away while the insoluble phosphatic rock remains.

Carrying our deductions further, we see that in early times there was no lagoon, for the land round Esprit must have been over 30 feet high. It was probably a low portion of the future atoll, for in order that such a large quantity of phosphate may have collected in one place it is necessary to suppose that the region above Esprit was the lowest part or sink of a large area*.

Though of less interest a word must be said about the shell rock, which was undoubtedly laid down beneath the sea. I have already shown it to be probable that the inner portions of the reef before elevation were built rather by the accumulation of débris than by active coral growth, and therefore were probably somewhat lower than the edge. This depression in the reef before elevation I call the "primary lagoon." As we see from the shell rock, it was a favourable position for mollusc beds. After elevation it must have become dry and was filled with guano, ultimately forming the collecting area from which the phosphatic material drained to form the present Esprit Island.

This small island in the Aldabra lagoon therefore plays a most important part in any attempt to reconstruct the past history of the atoll.

III. ALDABRA. LAGOON AND PASSES†, AND THEIR FAUNA. (Plate 26.)

The first point to be noticed about the lagoon is its extreme shallowness, for only in the channels radiating from the main passes are more than a few feet of water found. At low spring tides a large area becomes almost dry, and even at low neaps most of its surface is impassable to a large dug-out canoe. In the centre of the lagoon is a slight depression, which at low spring tides contains perhaps 4 feet of water and is known as "Barachois Torti" from the fact that green turtles often become imprisoned there until the tide rises. The channels in the lagoon are 8 or 9 fathoms deep near Grande Passe, but within a mile become very shallow and, except that they float a boat when the rest of the lagoon is impassable, would hardly be noticed by a casual observer.

A second feature of the lagoon is the great extent to which it is landlocked, the passes being wholly inadequate to allow the tides to flow evenly inside and outside

* [Mr Hughes suggests that birds may have especially congregated in this area. This seems to me to be not improbable since in my experience some islands and some areas of islands are occupied by "breeding fairs" while others in the neighbourhood, apparently equally suitable, are quite free from breeding birds. J. Stanley Gardiner.]

† The "passes" are the channels through the land-rim from the outer sea to the lagoon.

the atoll. As an instance of this it may be mentioned that, when the tide has flowed for 3 or 4 hours outside Passe Houareau, it is only just full ebb near Michel island, while at the same time the tide has been ebbing for 3 hours in the west of the lagoon. The currents, especially in the neighbourhood of the passes, are naturally very powerful.

The bottom of the lagoon is rock, but in the centre it is so covered with sand, and near the land-rim with mud, that it is difficult to determine its nature; the few observations made pointed to rock of the "champignon" type. The origin of the mud and sand is of great interest, for owing to the strength of the currents the falling tide is often rendered quite milky or white by the amount of suspended matter. Little material is carried in by the tides and there is no doubt that the mud is the product of lagoon erosion. When describing the typical northern section I pointed out the signs of erosion discovered round the lagoon shores there: these signs extend round the entire lagoon, while all the multitude of islands have overhanging cliffs, and the rocks are all mushroom-shaped owing to the removal of material between tide marks. The evidence leaves no doubt that all the lagoon islands were once connected and formed part of the main land-rim, and thus at least half the present lagoon is due to its own erosive powers. The latter are somewhat difficult to explain; but the low level of the land near the lagoon, when considered in connection with the mangrove swamp, may account for some of them. Mention has already been made of the power of the roots of the mangroves to split off overhanging pieces of rock. A more important factor in lagoon erosion is to be found in the mud of the swamp, which is extremely foul with decaying organic matter; it is therefore charged with carbon dioxide and various organic acids, all of which dissolve or react with the calcium carbonate. The lagoon shores are thus coated with a substance which has considerable power in breaking down limestone and this may be sufficient to account for the rapidity of erosion. In any case there is no doubt that the land-rim is rapidly decreasing in size and is gradually being split up into islands. At this point therefore it is opportune to consider the formation of passes.

An examination of the chart will show that sea erosion has acted very uniformly over long stretches of coast, while lagoon erosion on the other hand is very irregular and tends to the production of long creeks and bays. From this fact and from the foregoing remarks on erosion it will be readily understood that fresh passes must form from the lagoon and not from the sea. All stages of pass formation are demonstrated on Aldabra:

Stage 1. At Camp Frigate a long creek from the lagoon has passed almost through the land-rim, the mangrove swamp extending across and opening into what was formerly a basin in the rock but now is open both to sea and swamp. The sea is thus enabled to sweep right in but yet does not seem to have sufficient erosive power to force a channel, and it remains for the lagoon to dissolve away a little more rock, when a powerful tidal current will sweep through at each tide and speedily cut a pass.

Stage 2. The next stage is shown by several of the western channels, as for instance Passe Femmes, that nearest to Picard Island. The channel itself is fairly open though

a few rocks are still left standing well away from the land ; it is very shallow (2 fathoms), but yet, owing to the rapidity of the current, carries a large bulk of water. An important point to notice is that the fringing reef is not broken by a channel opposite the pass and the escaping water therefore has to spread over the reef instead of flowing directly into the ocean. There is evidence however that the reef is being worn away opposite the pass and in time doubtless will be divided by a channel.

Stage 3. The third stage is shown by Passe Johnny dividing Polymnie and Malabar Islands, and Passe Dubois, the oldest of the "Western Channels." They only differ from Passe Femmes in being deeper (4—6 fathoms) and in continuing through the fringing reef to the sea.

Stage 4. The final stage is represented by Grande Passe and Passe Houareau, which differ from passes in stage 3 in the channel being deeper (Grande Passe 10—14 fathoms, Passe Houareau 8 fathoms) and further in that they are fringed at the sides by a reef, which exactly resembles the fringing reef of the whole atoll. This last point is of considerable interest, for from large rocks of elevated coral limestone, still *in situ*, it was abundantly clear that the reef on either side of the pass had not been formed by the active growth of corals, but was in reality a ledge of elevated coral rock and the base of land now washed away.

As soon as the rock of the land-rim by a pass has been cut down below low water-mark it is colonised by corals and lithothamnia, which protect it from further erosion, while above low water-mark it is unprotected, and therefore the reef by the pass is due to the difference in rate of erosion above and below low water-mark. From this we see that the channel of a pass may speedily reach a limit in width, yet the reef will increase in size continually at the expense of the land. Thus ultimately the islands will become separated by increasing stretches of reef, a point which is of great assistance in considering the present state of the atoll of Cosmoledo, and also the formation of the fringing reefs of all the islands of the series.

Before proceeding it may be well to say a few words as to the distribution of life in the lagoon and passes, though for obvious reasons it was impossible to make complete collections of the marine as well as of the land-fauna. Collections were made of the more sedentary forms, and for details the reader must be referred to the papers by the specialists who have kindly consented to work them out. In general, it may be stated that the lagoon was extremely barren, a fact which is undoubtedly explained by the universal presence of mud in the water. The swamps themselves were excessively foul, and consequently no surprise was felt that the fauna was so limited.

Live corals in the lagoon were almost limited to the regions of the passes, though a few colonies of *Porites* were found along the various channels. In the neighbourhood of Grande Passe is a definite flourishing reef, which is almost dry at low spring tides. It is divided by numerous channels leading up to the pass, but does not seem to have the power to encroach on them. The reef itself contained a uniformly varied assortment of corals, although *Madrepora* of a branching *facies* in places formed definite fields to the exclusion of other forms. As compared with other reefs visited *Tubipora* was unusually common. Corals from this reef included species of *Millepora*, *Tubipora*, *Heliopora*,

Stylopora, *Pocillopora*, *Seriatopora*, *Cæloria*, *Hydnopora*, *Galaxea*, *Prionastrea*, *Acanthastrea*, *Favia*, various *Fungida*, *Dendrophyllia*, *Madrepora*, *Montipora*, *Astrepopora* and *Porites*. Towards the mouth of the pass itself the corals became stunted and often encrusted with lithothamnia* and finally ceased, with the exception of the hydrocoralline *Millepora*, which was very abundant in the channels and took on a branching *facies*. The reef by the side of the pass itself was covered with fragments of coral encrusted with lithothamnia, which appeared to flourish exceedingly in the strong current, to the dirt carried by which was attributed the scarcity of reef corals.

The Passe Houareau reef in most respects resembled that near Grande Passe, but was small and showed a tendency to block the channel somewhat; the corals were mainly of a massive type, though *Seriatopora*, scarce at Grande Passe, was quite common. In the mouth of the pass itself *Millepora* and lithothamnia were again abundant. Near Passe Johnny is a small and unimportant reef and in the channel itself few corals were noted except *Dendrophyllia*, which elsewhere seemed to frequent deeper water.

A large area between Esprit Island and the western channels was scattered diffusely with coral colonies, massive forms being scarce and the prevalent type a *Madrepora* of a slender, horizontally branching *facies*.

The sandy portions of the lagoon were searched at low tide but were disappointing; various holothurians were very common and no doubt play an important part in triturating and reducing the sand. *Amphioxus* was absent, but in the sand itself were found a few specimens of an enteropneust which Professor Spengel kindly informs me belong to the genus *Spengelia* or *Willeyia*; various polychæts, molluscs, burrowing echinoderms and geophyreans were also obtained, but on the whole the impression was one of great barrenness and absence of life.

The swamps were even worse in this respect; in the mud a small polychæt, a glycerid, was common, and a large sipunculid not infrequent. On the surface of the mud a large mollusc with a spiral shell was usually present and a few crabs (*Sesarma quadratum*, Fabr.) climbed about the roots of the mangroves. At high tide numerous free living forms were naturally washed up the creeks but the endemic swamp fauna was small, a fact which Mr Cyril Crossland tells me he also noted in the swamps near Zanzibar. Boring animals, chiefly sipunculids, were obtained from the rock near the shore, but they were very scarce as compared with the number found in the rock of the sea cliffs.

Fish were numerous in the lagoon at high tide: they all appeared to be widely distributed marine forms which drifted in with the tide, and no endemic species were obtained.

Further reference to this subject is however unnecessary, as subsequent reports will speak for themselves.

* Lithothamnia is throughout used collectively for the calcareous algæ, often erroneously termed nullipores in coral-reef literature. (*Vide* Foslie, Trans. Linn. Soc., Ser. 2, Zool. Vol. xii. pp. 177—192.)

IV. ALDABRA. FRINGING REEF—REEF FAUNA.

The fringing reef outside the islands of the atoll-rim varies in width, at its widest measuring about 500 yards, though near Point Vaquois it is hardly 200 yards between the cliffs and the breaking edge. In the composition of its surface there are two extremes (though with every intermediate grade) found respectively on the north and south coasts. To simplify description I give the chief characters of the reef in two places, first near the northern section across the land-rim, and secondly in the south near the Takamaka section. The reef to the north, bounded by the cliffs previously described, may be divided into four somewhat ill-defined zones. The first consists of a narrow depression in the rock at the foot of the cliffs: it is usually 5 or 6 yards wide and 6 feet deep, and owes its origin to the backwash from the waves which at high tide beat with great violence against the cliffs.

Outside this zone is the reef-flat, a broad flat zone with a surface consisting of a coarse rubble of broken coral fragments, all much encrusted with lithothamnia; in places are small accumulations of sand, which usually support a vigorous growth of the cotyledonous plant, *Cymodocea*. To seaward of the flat, which forms the greater part of the reef, is a narrow boulder zone, 20—30 yards wide, the boulders consisting of broken coral colonies rarely more than a foot high and hardly deserving the name "boulder"; they always become encrusted with lithothamnia, Squamariaceæ, and rarely *Polytrema*. Outside the boulder-zone is a rather indefinite buttress-zone, the buttresses being composed of coral rubble, while the intervening channels contain scattered and sickly coral colonies, mostly of the genus *Pocillopora*. Outside the breaking edge I was only able to make scattered observations, but the slope appeared to be steep and to support scattered colonies of massive corals. I append sections kindly taken for me by Captain Parcou, F.R.G.S., on the outer slopes of Assumption and Astove, which reefs appeared to have similar slopes to that of Aldabra. (Plate 29.)

The reef to the south of Takamaka differs from the reef of the north of the atoll in being very completely covered with sand, which is usually bound down by extensive beds of *Cymodocea*: areas covered with the usual coral rubble are scarce. The boulder-zone is almost absent, and the buttress-zone ill-defined, though it was interesting in that the buttresses were composed of sand held together by *Cymodocea*, the rhizomes of which were coated with lithothamnia and in a few cases with an encrusting form of *Millepora*, the sand being thus bound together by calcareous ropes. Live coral was naturally almost absent.

The outer slope seemed to be gradual and to be covered with sand, with here and there a coral colony or large mass of some colonial alcyonarian. Again I would call attention to the outer slopes to the south-east of Astove and Assumption which are probably similar.

These two types of reef cover almost all that are found round Aldabra, though intermediate stages are frequent. The reef on the north coast as far east as Point Hodoul is of the first type, while southwards it becomes more sandy as far as Dunes Jean Louis and Dunes de Maistre. After this it becomes less sandy round the west of Main Island

and rather more so near Picard Island, though much of the sand in the west disappears in the calm season and collects again in the south-east trade season. Under these conditions the forms of life usually found on a coral reef were naturally scarce: at low tide the most conspicuous animal was an eel (*Muraena mudivomer* sp.?) which crawled about with its mouth wide open, biting with great ferocity at whatever came in its way. A second eel (*Muraena chilospilus*) burrowed in the sand with astonishing rapidity, and it was noted that it could burrow backwards as well as forwards. On one occasion a sea-snake was seen but not captured. In the sand were found various polychæts, gephyreans, burrowing crustacea and, where coral rubble was overlaid by a layer of sand, there lived a large species of *Balanoglossus* (9 inches long), which gave out the characteristic smell of iodoform to a marked degree; owing to the fact that it lived in the rubble rather than in the sand it was most difficult to obtain unbroken. The cliffs formed the haunt of a large number of molluscs among which a chiton was prominent, while a small fish (*Periophthalmus* sp.?) frequented the rock pools, often lying outside on the bare rock and jumping from pool to pool with great agility when pursued. In the cliff face boring animals were not uncommon, a small sipunculid being sufficiently numerous to assist the sea materially in its work of destruction.

As a whole, however, the fringing reef was disappointing in comparison with the reefs I had visited in the Seychelles in company with Professor Stanley Gardiner, and the reason is probably to be ascribed to the presence of such large quantities of sand, while the mud of the lagoon must also contaminate the waters round the atoll to some extent.

The characters of the Aldabra fringing reef at first found no explanation, but the reefs on the sides of Grande Passe and Passe Houareau yielded a clue. Before I left I was quite satisfied that the fringing reef was merely a ledge of the elevated coral rock, piled with rubble, and protected to seaward by lithothamnia and corals. As in the case of the reef by the sides of the passes the rock below low water-mark is protected from speedy erosion, while that above is continually washed away. The fringing reef therefore is not a sign of the growth of the atoll seawards but of the amount of its loss of land due to erosion. Whether the outer edge of the reef is holding its own or slowly receding is impossible to say, but I am inclined to believe the latter, from the fact that it follows the present conformation of the coast line so closely.

A final problem to be dealt with is the presence of so much sand on the south coast. The destruction of rock round the whole coast has already been pointed out: the result of this disintegration is the production of sand. Owing to the fact that the current flows from east to west, and the prevalent winds are south-east, this destruction of land is greatest in the east of the atoll, and indeed it seems very probable that the shallow bank to the south-east is the site of lost land. The sand produced in this process is driven along the reef by the current and on the north coast the greater part is washed away: on the south coast, however, the south-east winds drive it inshore and pile it on the reef and against the cliffs, which in the region of the dunes are low and become almost covered up, the beach being sandy and sloping gradually up to a height of 60 ft. In other places it has formed numerous small sand "lances," and in the west of Picard has been heaped up

to form the sandy area on which the settlement stands*. This sand piling is comparatively unimportant at present, but in future times, as the atoll of Cosmoledo will show, it may be the cause of the existence of land on the atoll.

I have now dealt with the main physical features of Aldabra, and in summary I would emphasise that the atoll is losing on every side in its fight with sea and weather; the sea coast is being eaten away; the lagoon is getting larger; the rain is dissolving away the surface of the land and, to balance all, there is only a slight piling of sand.

V. ALDABRA. THE LAND FLORA AND FAUNA.

In this section it is intended to give a short account of the land flora and fauna of Aldabra, dealing rather with those groups which will not be the subjects of subsequent reports.

Flora. A collection was made containing specimens of the majority of the plants of the atoll, though a few trees were never found in flower and so perhaps cannot be identified. The flowering plants will be reported on at Kew, while a small collection of algæ are in the hands of Mr. and Mrs. Gepp.

A certain number of plants were such as could easily be recognised, but the majority, and perhaps the most interesting, were entirely unfamiliar. It is impossible therefore to do more than broadly indicate the œcology of the atoll flora, leaving a complete list to the Kew report. The floral seasons naturally coincide with the climatic, which were indicated in the Introduction. The season of south-east trades is generally a season of drought and rest and, many of the trees being leafless, all forms of bush have then an extremely barren and dead appearance.

At the end of October signs of renewed life are visible, and after the first rains in November many plants begin to flower often before their leaves have appeared. In December and January the remainder of the plants are in flower, with the exception of a few, which by their condition suggest that they flowered quite at the end of the calm season (March).

There are roughly four types of vegetation corresponding to four different classes of situation. These are:

1. Mangrove Swamp.
2. *Pemphis* Bush.
3. Varied or Open Bush.
4. Shore Zone.

1. The mangrove swamp fringes the lagoon, but is also found on the seaward coast of the atoll at Camp Frigate and on Magnan Island (in the western channels), where it is protected from the direct force of the waves. It is composed mainly of true mangroves (*Rhizophoraceæ*), the genera observed being *Rhizophora*, *Bruguiera*, and *Ceriops*. The

* See Geographical Journal, September 1910.

genus *Rhizophora** is uniformly scattered through almost every part of the swamp and also forms forests in one or two places, notably Picard and Camp Frigate, which contain but few trees of other species. In habit it prefers a deep mud and an abundant supply of water. The genus *Bruguiera* is represented by two species, *B. gymnorhiza* and another not yet determined, which together form a large proportion of the forest along Malabar and Main Islands and especially to the south of Michel Island. It is the largest tree on Aldabra and reaches a height of 60—70 ft. When old, the trunk is usually straight without any branches on the lower portions, and is consequently much used for timber.

Of the genus *Ceriops* there are apparently three species, *C. Candolleana* and two others. On Aldabra it is an uncommon genus and is most prevalent at "Lance Cavallier," south of Esprit Island, on Esprit itself, and on Main Island north-east of Michel. One species, known in Creôle as "manglier xerophé," forms a very straight trunk and is much used for poles and posts.

Both the last two genera do not require much mud, and are tolerant of a rocky situation, and one which the tide reaches for but a short period. *Rhizophora* and *Bruguiera* are both cut for the bark, which contains a high percentage of tannin and forms the chief export of the atoll.

Of other mangrove-swamp trees there are five genera, the most prevalent being *Avicennia* (*A. officinalis*) which is found all round the lagoon between tide marks, especially in sandy places; it also forms a large forest in the extreme east of the atoll, where the trees attain a large size.

Sonneratia acida, the second pseudo-mangrove, is decidedly scarce and occurs only on Esprit and on Picard Islands. It is known as "manglier fleurs" for its large and conspicuous flowers.

Carapa obovata and *moluccensis* are both found on Esprit Island, and the latter on Picard and on one of the islands in the western channels. At Esprit a small forest is formed by *C. moluccensis* between the ridge of rock, previously described, and the true mangrove swamp.

A comparison with other mangrove swamps is difficult, as the writer has had little further personal experience of them. It may however be mentioned that the Seychelles swamps compared with those on Aldabra were scattered and the trees small, while the latter, when compared with those further East, appear to be formed more entirely of true mangroves and to contain less undergrowth, the palm (*Nipa fruticans*) being absent.

2. *Pemphis* Bush. This type of bush is composed almost entirely of *Pemphis acidula* and is found in conjunction with the metamorphosed limestone. The habit of growth of the species has already been dealt with; it may be mentioned in addition that dead small branches do not always drop off but season in position, forming hard skewer-like spikes. The wood is extremely hard and speedily turns the edge of an axe, while it is hardly touched by insects, though occasionally a tree will be found to contain a nest of large ants.

* *Rhizophora mucronata*.

It covers the greater part of Aldabra, and in conjunction with the "champignon" rock forms the great obstacle to exploration. It is quite useless, for the timber is too small, and the bark, though reputed rich in tannin, would not pay removing.

3. Open bush is found in the neighbourhood of Takamaka and extends round the atoll eastward as far as a line drawn from Michel Island to Hodoul point; to the westward it extends nearly to Dunes Jean Louis, but in this direction is much reduced in size by the shore-zone passing far inland. Plain Cabris on Picard Island also supports the same type of vegetation. It is always coincident with "platin" rock which is such that a little soil (largely formed of guano) can collect on its surface. The vegetation is mostly formed by low trees and bushes. Herbaceous plants are scarce and are only found in the wet season, when a few sedges and grasses occur in places. The bushes and trees are usually leafless, or partially so, in the dry season and flower at the commencement of the rains, often before the leaves appear.

Almost all the Aldabra plants are to be found in this type of country. A few that are easily recognised are *Euphorbia Abbotti*, various species of *Ficus*, two species of *Grewia*, several papilionaceous plants (*Mimosa*?, *Cæsalpinia*, *Cassia*). A thorny (rosaceous?) bush is not uncommon, and large clumps of *Pandanus Vandermeeschii* are very frequent. The majority of the plants in this country, however, were not identified in the field.

4. The shore-zone extends all round the atoll varying much in size. It owes its existence to a little soil formed of sand blown up from the reef and is naturally therefore widest on the south-east coast. Characteristic plants are *Scaevola Kœnigii*, *Tournefortia argentea*, and in places *Cordia subcordata*. At intervals large clumps of *Pandanus* exist, and very stunted bushes of *Pemphis acidula* are found on the south coast.

A few exceptional patches of vegetation, almost jungle, occur, the chief being on Esprit Island, which contains several plants scarce elsewhere. Picard Island has a peculiar bush, which, though very dense, is formed of the same plants as ordinarily form the "open country." Couroupa, which has a deep sandy soil, supports a mixed vegetation, partly of "open country" plants but mainly of "shore-zone" forms.

*Casuarina** has established itself at Picard and Michel Islands, and on each side of Grande Passe and Passe Houareau; other introduced plants are found to some extent on Picard but the conditions are such that few fresh plants can obtain a foothold.

Fauna. (a) *Mammalia*. The only indigenous mammals belong to the order Chiroptera; the most interesting being a peculiar species of Fruit-eating Bat (*Pteropus aldabrensis*, True†). It is a rather small species and is peculiar in having the bony orbit complete, a feature which it shares with *Pteropus nicobaricus*. Its food consists of the fruit of the banyan (*Ficus* sp.?) and when obtainable of the "takamaka" (*Calophyllum inophyllum*), while coconut flowers are also much sought after. The species is often observed flying by day as well as night, though it was most active in the bright moonlight. It never forms large gatherings on a tree during the daytime, as is the case with the Seychelles flying fox (*Pteropus edwardsii*).

* *Casuarina equisetifolia*. [Of course introduced.]

† Proc. U.S.A. Mus. 1893, Vol. 16, p. 533.

Two insectivorous bats were noted; one, *Taphozous mauritanus*, was seen but was scarce, while a second, *Triænops furcula*, Trouessart, was not uncommon on Picard near the settlement. A specimen of the latter species was sent to M. Trouessart, who has kindly compared it with his type and confirms my identification.

Of introduced mammals there are rats (*Mus rattus*), mice (*Mus musculus*), cats and goats. Of these the rats alone deserve further mention, for they have spread over the whole atoll, extending even to the small lagoon islands where they catch and eat the land crabs (*Cardiosoma*, etc.) for want of other food. These must form serious antagonists to the land birds, and perhaps to the giant tortoise also, as they are reputed to eat its eggs. The cats*, which only exist at Takamaka, are, I think, decreasing, and consequently cannot be expected to keep down the rats, which will probably continue to increase until want of food sets a definite limit to their numbers.

(b) *Aves*. The resident land birds have been described by Ridgeway†. They are of interest in being almost all peculiar to the atoll. It is however noticeable that all are very closely related to Malagasy forms and doubtless their origin is thus indicated. Full descriptions need not be given here, but a few notes as to their natural history, which does not seem to be anywhere recorded, may be of interest.

Most conspicuous and typical of the atoll is undoubtedly the ibis (*Ibis abbotti*), which resembles the sacred ibis and is closely related to *Ibis bernieri* of Madagascar. It formerly was abundant, but now is absent from Picard Island and uncommon over the north of the atoll, though it is still fairly distributed along Main Island, in the east of which it is, indeed, common. In habit it is a shore bird, feeding along the edge of the lagoon in the mangrove swamp when the tide is low, and at high tide fighting inland, where it is to be found round the freshwater springs of Takamaka and the brackish pools which abound everywhere. Its food consists of small crabs and other marine creatures, but a few birds were always to be found picking through the rubbish from Michel Island camp and generally playing the part of scavengers. Night is spent roosting on a tree, the large *Calophyllum* trees round the wells being especially haunted. Its cry is a harsh wheeze. In flight the ibis is heavy and laboured, though its broad wings allow it to soar so that it occasionally circles round for some time on outstretched pinions when it is choosing a site on which to perch. In character it is tame and inquisitive, while owing to its peculiar form, colouration and a habit of continually twisting its head about, it has always a rather ludicrous appearance, and this is especially the case when it is draggled or soaked with rain.

The ibis nest in colonies in the trees, choosing especially those in the depths of the mangrove forests. Only one nesting tree was found tenanted. It was a small *Ceriops*, the top of which had been so trampled down as to be flat. The nests, seventeen in all, were composed of a few sticks and resembled those of the gannet (*Sula leucogaster*). Two chalky-shelled eggs of a greyish-white colour were the maximum found in one nest. If the following habit is general but a small percentage can reach maturity. Before the birds have commenced incubation, they leave *en masse* when the tide is low to feed, but

* If numerous they would completely kill out the rails and possibly other endemic species.

† Proceedings of the U.S. National Museum, Vol. xvi., p. 597.

return singly, and each bird reaches its nest by partly flying and partly running over the flat top of the tree, the result being that most of the eggs in the path of a returning bird are either broken or rolled off the nest into the water below. Out of eighteen eggs counted when the birds were away, but two remained whole after they had all returned. If this manœuvre is often repeated, it is difficult to understand how the birds are as numerous as they are.

Next perhaps to the ibis in point of interest is a small rail, *Dryolimnas aldabranus*, closely allied to *D. cuvieri* of Madagascar and Mauritius. It is a pretty bird, olive green above, and underneath a rich chestnut with white chin and neck. It is generally distributed over the atoll, though it is scarce on Picard, and has apparently been exterminated in the neighbourhood of Takamaka by the cats. It is extremely tame, and at Esprit Island would often come inside the hut, where several attempts were made to photograph it, but owing to its preference for dark places and its quick jerky movements, these always resulted in failure. Its most marked peculiarity is the astounding variety of noises which it can utter, the most curious being like a stroke on a native drum, which is usually followed by a long whistle, often an exact reproduction of a curlew's call: when the bird is excited it makes such a remarkable series of grunts and shrieks that Nicoll (*Three Voyages of a Naturalist*) has likened them to the noise produced by a drove of pigs. All these cries are produced with the head pointing upwards and the throat much distended, and are very loud for the size of the bird, which is smaller than that of a water-rail (*R. aquaticus*). Flight is but rarely indulged in, though the birds can flutter along, and are certainly not flightless as stated by Abbott. They are the only bird which inhabits the dense *Pemphis* bush, and are often to be found at low tide in the rocky pits, which abound in the "champignon." Their food consists of insects and small crustaceans. No nest was found or young birds seen, and it is probable that they do not breed until February or March.

Another interesting bird is the Aldabra cuckoo (*Centropus aldabranus*), which resembles the Madagascar *C. toulou* and is known locally as "toulouse." It inhabits chiefly the open country in the south-east of Main and Picard Islands. In character it is very terrestrial and is often found on the rock underneath the bushes, though, when disturbed, it climbs about among the trees and shrubs with actions like those of a parrot. Towards sunset the male flies to the top of a tree and utters repeatedly a peculiar and melodious call consisting of a series of notes (semitones) descending the scale for three or four tones: the birds do not all have the same range of notes, and it was not uncommon for two birds to call together producing a series of chords down the scale. The cry carries a long distance and can be heard at least a mile away: it forms one of the lasting impressions in connection with evening on Aldabra. Only one nest was seen, and this consisted of a large mass of sticks low down in a bush: it had no eggs in it.

Of doves there are two:—*Alectrocenas aldabranus* or "pigeon hollandais" and *Turtur aldabranus* (*saturatus?*). The latter, which resembles a small *T. picturatus*, was not uncommon near the settlement and also at Michel Island, while the former inhabits the less frequented parts of the atoll and was common at Takamaka. Both birds seem to have a definite time of flight in the evening.

A drongo (*Buchanga aldabrana*) is not uncommon, especially on Main Island. It is a glossy black bird, the size of a thrush, with a powerful beak and long forked tail: it is very pugnacious and attacks any frigate or crow (*Corvus scapularis*) which approaches near its perch.

A cardinal (*Foudia aldabrana*) is common round the settlement: it differs from *F. madagascar* in being larger and of a brighter red.

A beautiful species of sun-bird (*Cinnyris aldabrensis*) haunts the edge of the mangrove swamp: the male is velvet black, with a wonderful green iridescent gorget and, when hovering in the sun, is a most striking sight.

The remaining land birds consist of a "white-eye" (*Zosterops aldabrensis*), a little green bird with habits like a warbler, a bulbul [*Ixocincla* (*Hysipetes*) *rostrata*], a small kestrel (*Tinnunculus newtoni*), and a small goat-sucker (*Caprimulgus parvulus*, sp. ?), the last being very scarce.

Considering the land birds as a whole it will be seen that no land connection is necessary to explain their presence on Aldabra, for even the most flightless, the rail, can still fly and no doubt was once easily able to establish itself over the whole Madagascar region. The birds are all closely related to Malagasy forms and their origin is thus doubtless indicated, for isolation and new conditions will amply account for the slight differences which exist.

It is impossible to give any complete account of the littoral and marine birds. A few of the more important may be mentioned, most striking of which are undoubtedly the frigate birds, *Frigata aquila* and *F. minor*. These birds are present in countless numbers all the year round. Camp Frigate takes its name from the enormous breeding place (of both species) situated there, while another exists on Picard. The whole coast of Malabar Island is often patrolled by a long line of frigates, and there is no part of Aldabra in which these birds are not always in sight. They live almost entirely as parasites on the gannets (chiefly *S. leucogaster*), which also exist on the atoll in very great numbers. Each gannet on returning from fishing has to run the gauntlet of two or three frigates, which are usually successful in bullying it into disgorging its last meal. Considering this perpetual enmity it is curious that the two birds should frequently nest side by side. In addition to the fish looted from the gannets, frigates are very fond of young turtles newly hatched, and the damage caused by this propensity is very large; they were rarely seen to fish for themselves and never to plunge into the water. Towards evening there is a considerable flight back to Aldabra of the birds, which have followed the gannets to sea. They roost along the lagoon fringe of the mangrove swamp, their position when asleep being very curious, for their heads are allowed to fall loosely on their breasts.

The flight of the frigate is marvellous, and a sight never to be forgotten is that of a column of the birds wheeling round on motionless wings, the lowest individuals within shot and the highest only to be discovered by the aid of glasses. This however is a subject which has often been written on, and the other habits of the frigate have only been set forth at some length as they appear to differ somewhat from those previously recorded (cf. *Camb. Nat. Hist. Birds*).

Of other resident aquatic birds the flamingoes (*Phænicopias minor*) with their brilliant plumage and goose-like cry are sure to strike the attention of an observer.

Gannets are everywhere extremely abundant: the usual species is the red-footed *Sula leucogaster*, but *Sula piscator* (*cyanops*?) and *Sula capucina* also occur.

Of migratory birds a fair variety of waders were noticed. Curlews and whimbrels (*Numenius arquatus*, *N. phaeopus*) were very abundant in the swamps until January, when they commenced to leave. Turnstones (*Streptilas interpres*) were abundant along the beach and had not diminished at all in number when I left the atoll in January. It is presumed that all these birds go north to breed and therefore their winter wanderings must be extremely wide.

(c) *Reptilia*. Undoubtedly the most interesting animal on the atoll is the giant land tortoise (*Testudo elephantina*). It still occurs in fair numbers on the extreme east of Main Island and is scattered in small numbers in the rest of the island. It is also found on Malabar and Picard Islands, but it is stated to have been reintroduced. This is certainly the case in regard to Picard, but there is no evidence as regards Malabar.

The species obtained on Main Island is *Testudo elephantina*, and a further species, *T. daudinii**, is supposed by Voeltzkow and others to have inhabited Malabar Island and to have given rise to those at present existing on the Seychelles. Only two tortoises were found on Malabar, both young specimens, and these were indistinguishable from the Main Island tortoises.

The question as to the number of species is further complicated by the fact that *T. elephantina* has been divided into several species. It seems probable, however, that these animals, free from enemies, would be able to vary somewhat without harm to themselves, and that the species into which *T. elephantina* was divided were based on such minor variations. No evidence was obtained indicative of more than one species.

The most interesting point in connection with the land tortoises is undoubtedly their distribution. It is generally supposed either (1) that Aldabra had a previous land connection, or (2) that the tortoises were placed there by man. It has already been shown that the first alternative is not possible, and it remains to deal with the second. If it were possible to consider Aldabra alone human transportation might give a natural explanation. It is necessary, however, to consider the other islands on which giant land tortoises have occurred†. These are (1) the Seychelles Group, (2) the Mascarenes, (3) Madagascar, (4) the Galapagos, (5) Cosmoledo, (6) Assumption, and probably (7) St Pierre, the last three being added in the course of the expedition here described. A previous land connection may explain the existence of tortoises in the localities Nos. 2, 3, 4, and with the exception of Bird and Dennis Islands of No. 1 also. It is totally inapplicable however to Cosmoledo, Assumption, St Pierre and Bird and Dennis Islands, all of which are of purely oceanic origin. As regards Dennis Island a certain amount of history exists: it was discovered in 1773‡ and was described as being covered with land tortoises and sea turtles, a clear distinction being made between land and marine tortoises. Bird Island was also described in much the same terms. Both Bird and Dennis were visited by the author§ and they are merely sand cays built up by the waves. On Cosmoledo

* It may be stated, as a personal opinion, that the modern Seychelles tortoises are very probably true descendants of the original tortoises which occurred in the Archipelago when it was discovered.

† In recent times.

‡ *Geographical Journal*, 1907, p. 154.

§ *Trans. Linn. Soc. Ser. 2, Vol. xiv. p. 15* (Percy Sladen Trust Expedition, Vol. iii., p. 15).

the eggs were found sub-fossil in the phosphatic rock underneath the guano. At Assumption bones of several specimens were found in the pits in the rock, and they also seem of great age. The bones in the rock of Aldabra are deeply imbedded and cannot have been fossilised very lately, and consequently if human transportation is to account for the distribution of the tortoises it must have taken place in very early times.

The difficulty then arises that we know of no nation which could have sailed the Southern Indian Ocean in such early times and have acclimatised land tortoises on the majority of its islands. There is therefore this extraordinary problem to be solved, viz. that most of the islands of the South Indian Ocean, whether of coral or not, were inhabited by giant land tortoises which, to quote Dr Gadow (*Camb. Nat. Hist. Reptiles*), "are so absolutely terrestrial that wherever we find them, unless they have been brought artificially by man, these tortoises must have arrived by land." It has been shown that neither of Dr Gadow's alternatives will satisfactorily account for the facts. Tortoises are not the kind of animal to be distributed by drifting on logs, unless they belong to a small species. If the "giants" are derived from a small species distributed in this way then they show a wonderful case of parallel evolution, and further, if this is so, small tortoises must have been drifting about the Indian Ocean in considerable numbers to account for the colonisation of so many islands. Finally, it is generally held as impossible that land tortoises could have had aquatic ancestors*. All means of escape from the problem are therefore withdrawn and any explanation must be liable to great objections. Nothing further can therefore be said, and it remains to conclude with a short account of the natural history of the tortoise.

The day is spent in the midst of the densest jungle or in a large clump of *Pandanus*, a very favourite haunt being a clump of this tree near a brackish pool. At night they become active and move about in search of food, which in the wet season consists of grass and leaves, and in the dry of bark, if nothing else can be obtained: as a rule their movements are very slow and deliberate, but at times, perhaps when moving to fresh feeding grounds, they crash straight through the jungle at a pace which is astonishing for so clumsy an animal.

The breeding of the tortoises takes place about March, and the hard-shelled eggs are buried in small guano-filled concavities in the rock. As the atoll was left at the end of January only one nesting-place was found, and this contained no eggs, though the guano had been obviously disturbed. Tortoises are never found far within the *Pemphis* bush and as the latter appears to be increasing at the expense of the more open country it may in time seriously restrict them. Possibly the present greatest enemy of the tortoise is the rat, which is reputed to destroy the eggs. Frigate birds and herons would undoubtedly devour the young ones if accessible, but the thick bush affords abundant protection. There has recently been a suggestion put forward to remove the tortoises to some Seychelles island for safety: it is, however, quite unnecessary, for tortoises are already plentiful in the Seychelles and there does not appear to be any danger of their extinction on Aldabra unless hunted by man.

Of other chelonians the green turtle (*Chelone mydas*), the hawksbill (*Chelone*

* *Vide* Geographical Journal, Sept. 1910, Discussion on the "South-West Indian Ocean."

imbricata), and probably the logger-head (*Thalasseochelys caretta*) occur; and, though these can hardly be considered land animals, it is most convenient to consider them in conjunction with their relative, the land tortoise. The green turtle occurs in enormous numbers, which are perhaps only equalled in Assumption. There are two divisions, marked by the season at which they lay their eggs. In the season of S.E. Trades only a small number of turtles stay round the coast and breed, while in December, at the beginning of the N.W. Monsoon, an enormous horde of turtles arrives off the atoll and remains until May. The origin of this migratory horde is open to some doubt, for, since turtles only frequent shallow water where they can get food, they must either live near the shore or on a shallow bank: they have not been recorded from the latter and therefore it must be supposed that they come either from Madagascar or the coast of Africa. Presumably the number of suitable islands for breeding is now small on account of the fact that most have been long settled. Assumption, however, was only colonised in 1908, and Aldabra is so large that until recently the people of the settlement have not disturbed much of the coast. Turtles are now being killed so rapidly and the waste is such at both Assumption and Aldabra that their numbers are already markedly on the decrease.

The turtles on arrival extend round the shore and pair, during which process great fights take place among the males for the females. The latter ascend at night the small sand beaches, which occur at intervals along the coast, and dig deep holes in the sand, the fore-flippers being chiefly used for the task. The holes may be only a few feet above high-tide mark, or at some distance from the shore, as in the case of one found on the top of Dunes Jean Louis (60 ft. high). The number of eggs laid is about 200 and the females are supposed to come up the beach twice in each season. They always ascend with one flowing tide and go to sea again on the next; consequently a night with the tide becoming high at sunset is the most favourable.

The young turtles hatch in 40 days and go straight down the beach to the sea. The hatching of all the eggs in a nest takes place almost simultaneously, and the young turtles dig their way up out of the sand as fast as they can be counted and crawl down to the sea in a long procession. By what sense they find the right direction was not discovered; their eyes are not open but even if placed on a flat surface they know their way to the sea. The hatching of the whole nest only takes about 10 minutes and forms a remarkable and pretty sight. The mature turtles are either speared from a boat or are turned on the beach, the latter method being very destructive, for only females are caught and this occurs as a rule before they have time to lay their eggs. Steps will have to be taken to preserve the eggs, if the green turtle is to continue to exist.

The hawksbill turtle (*Chelone imbricata*) is much scarcer than the green turtle. It ascends the beach in the day to lay its eggs, which are said to take 60 days to hatch, and the female is supposed to come at least twice, at an interval of a fortnight, to lay in the same place. Those turtles, which have lived long in the lagoon, are always coated with a layer of mud, and this prevents the "tortoise shell" from developing dark markings, the absence of which adds considerably to its market value. Their natural food has been said to consist of fish, but this did not seem to be the case on Aldabra, as a fisherman, who had spent twenty years on the atoll fishing hawksbill, said he had never found fish in

those he caught but always "mousse," *i.e.* algæ. It was also an undoubted fact that certain beds of algæ in the lagoon were always the favourite haunts of hawksbill, which visited them with every high tide. It seems therefore that the evidence is in favour of the hawksbill, like the green turtle, being mainly a vegetarian.

The remaining turtle found on Aldabra is probably the logger-head (*Thalassochelys caretta*). It is scarce, and one was not obtained to make identification certain. The fisherman above mentioned said that this turtle came into the lagoon to eat a small kind of mussel: he had never found algæ inside it and did not know where it bred, for it never came up the Aldabra beach to lay its eggs. It appears to be commoner at Cosmoledo than at Aldabra.

Besides chelonians there are only three other reptiles (two geckoes and one skink) found on Aldabra; these are

Hemidactylus gardineri, Boul.,
Phelsuma madagascarensis, var. *abbotti*,
Ablepharus boutonii, var. *peronii*,

all of which were kindly identified for me by Mr Boulenger.

Amphibians were not present on the atoll, which is indeed quite unsuited to them.

(*d*) *Crustaceu.* All species of land crabs were carefully collected for comparison with those of other coral islands, a comparison which has proved of great interest, as will be seen from the paper by Mr Borrodaile, who was kind enough to take over my collection. The most common form was *Cardiosoma*, which lives in holes in the rock and appears to act as general scavenger. It was particularly objectionable from its habit of digging holes in the mud which had collected round the wells, which were thus so filled with dirt as to make the water undrinkable.

Birgus latro, the robber crab, was also very numerous, especially at Takamaka, where it was a great nuisance, for it carried off anything left out at night and also got into the house, unless it was securely closed, and, once inside, occupied itself in pulling everything to pieces in search of food. Eighty were killed on the first three nights, but their numbers did not seem much reduced, though afterwards the camp was left more in peace.

Their great chelæ have immense strength, as is instanced by the fact that a turtle turned on the beach one night had its tail completely hacked off before the morning and was quite dead.

Two species of land hermit crabs were exceedingly common and showed distinct signs of migration on Esprit Island, a swarm coming down to the sea in December, the females in all cases with eggs. It was most difficult to force the members of this migratory horde to alter their direction: all obstacles were surmounted instead of being avoided. My hut lay directly on the line of migration, but I was quite unable to turn them aside, and during my visit numberless crabs entered and crossed the hut on their way to the sea.

(*e*) *Insecta.* The insects of the atoll were collected as thoroughly as possible, as it was felt that this group would be large enough to compare both with the insect fauna of other islands and of neighbouring continental lands. The collections have been distributed to specialists on the various orders, whose papers will speak for themselves. It may be

mentioned that the majority of the insects belong either to Madagascar or East African forms, this being especially the case with the Lepidoptera. Dr Neils Holmgren, however, records the three species of termites obtained as belonging to East Indian forms (though two of the species are new). When it is remembered that termites are distributed by the sea on floating logs and that the current runs from east to west, this result is precisely the one which would be expected. In general it is probable that those insects which are distributed by flying will on Aldabra belong to Madagascar or African forms, while on the other hand those that are sea-distributed will be Oriental in origin.

(f) *Myriapoda*. One small species was very common among dead leaves in the jungle. It seemed to play the same part in reducing the vegetable débris to humus as is usually done by earthworms, which are extremely local and scarce in Aldabra.

Three different forms of Chilopoda were obtained, the largest about 3 inches long. All were found under stones, dead leaves, etc., but only one, the largest, was at all common.

(g) *Arachnida*. One species of scorpion is common, especially near the settlement. A large variety of spiders await determination. Phalangids were altogether absent. Chetifers (Chemeidæ) were represented by three kinds, all apparently of different genera. One was conspicuous for the large amount of silky web which it spins under stones in crevices in the rock.

(h) *Mollusca*. Especial attention was paid to the land mollusca. *Bulimnus aldabra* was found to be well distributed over the whole atoll, though most plentiful at Couroupa. The dry season is spent on the branches of bushes and trees, when the shell is always covered with a coat of what appears to be mud; but, from the fact that the latter is not obtainable in the dry season, it is more probable that the mollusc covers itself with mucus to which small particles of guano adhere. In the wet season it is hard to find, as it is completely hidden by the foliage. A fresh species of land shell, a Helicinid, was found on Esprit Island, but it did not seem to occur on any other part of the atoll.

About five species of minute land shells occurred in rotting trees (especially mangroves), and in the wet season in holes in rocks.

(i) *Oligochæta*. Worms were represented by one earth form which was scarce in drift rubbish on Esprit Island, and more common in the small area of sandy land on Picard. It occurred nowhere else on the atoll, and was not found at all in the dry season.

Malaria. In conclusion it may be of interest to mention a curious outbreak of malaria which occurred. Previous to May 1908 malaria was unknown on the atoll. At the end of April 1908 a steamer arrived viâ the Seychelles, bringing a number of labourers, among whom were several men from Nossi Bé, Madagascar. A little over a fortnight after their arrival several cases of malaria occurred, and during the dry season the number increased, the maximum being reached when the disease had as victims two-thirds of the entire population of the atoll, which at the time numbered 150.

During August the number of fresh cases decreased, and none were recorded after September, though many still suffered from the disease. It was at first thought that the epidemic could not be malaria, though showing every symptom of tertian fever. Men

suffering were conveyed to the Seychelles, where Drs Addison* and Power† made blood preparations (films) which showed sporulating plasmodia, seeming to prove the nature of the disease conclusively.

A search was then made by the author personally for *Anopheles*, both by observing the imagos and larvæ, but this was absolutely without success and never during the entire visit was an *Anopheles* found.

There are therefore two alternatives: the first is that *Anopheles* arrived in April 1908, propagated themselves so rapidly as to be able to infect over 100 people, and then died out, also with such speed as to be extinct in September. It is conceivable that *Anopheles* might not be able to persist at all in Aldabra, or that it might live for a short time and then gradually die out, but that it should do so with such suddenness seems highly improbable. This alternative therefore is not a likely one.

The second is that *Stegomyia* can be capable of a modified transmission of malaria. It is almost certain that no sexual processes of the plasmodium can take place in *Stegomyia*. It seems just possible however that this insect may act as a passive transmitter: it is present in such numbers even in the dry season that there is seldom a moment, night or day, when the inhabitants of Aldabra are not being bitten, and a transmission of blood is quite probable. Supposing this occurred when the plasmodia were about to sporulate, or even just after, it seems possible that a fresh patient might be affected. However, in the absence of sexual processes the stock of the protozoan would probably become senescent, and ultimately die out. This is exactly what occurred, for at the date of departure (end of January) there was not a single malarial patient in the atoll. Supposing that this explanation could be proved correct it would explain the occasional malarial epidemics which occur in other islands in which *Anopheles* is apparently unknown.

A few scattered notes have now been given concerning the fauna of Aldabra: as however these could not be put in a very explicit form, it may be permitted to make a short summary:—In the littoral fauna Aldabra resembles, or is perhaps somewhat poorer, than any of the coral islands in the same region. The land fauna, probably on account of the greater extent and age of the land, and also because of its more varied vegetation, is larger than that of any of the neighbouring coral islands. It is composed mainly of peculiar forms, but most of these are closely allied to Malagasy animals and are such, with the exception of the land tortoise, as might easily have arrived by sea, and then have altered somewhat under the fresh conditions found in an isolated land.

* Chief Medical Officer.

† Assistant Medical Officer and visiting Magistrate to the outlying islands.

VI. ASTOVE.

Astove is situated in latitude $10^{\circ} 6' S.$ and longitude $47^{\circ} 45' E.$; the chart shows it to be 2 miles long by $1\frac{1}{2}$ miles broad, but the survey appears inaccurate and the island is probably longer.

In form it is an atoll with an extremely perfect land-rim encircling a large though very shallow lagoon, which is in connection with the sea by one pass situate in the south-east. The atoll is surrounded by a fringing reef which I was only able to investigate near the pass where it is very narrow (about 200 yards). The long axis of the island runs nearly north and south dividing it into an eastern and western portion of which I only had time to visit the latter.

The land-rim in the west measures from $\frac{1}{4}$ to $\frac{1}{2}$ a mile in breadth and is slightly curved on the seaward side, thus enclosing an open bay, the shores of which are sandy, though at intervals coral rock cliffs intervene for short distances and also occupy the

Fig. 1. From the Admiralty Chart of Astove.

coast for half a mile to the north of the pass. Cliffs again form the north-western point but give way to a sandy beach on the north (north-east) coast of the atoll; here, as everywhere throughout the region, cliffs are always much overhanging and are evidently rapidly crumbling away.

Immediately inside the beach in the western "bay" there is a narrow (100 yards) sandy stretch somewhat resembling that on Picard Island, Aldabra; it is covered with a sparse scrub of common shore-zone plants, and may perhaps have an elevation of 18 feet above high tide mark. Rising somewhat abruptly from the sandy zone, and perhaps 4 feet higher, is a stretch of coral rock passing to the lagoon shores, which in the north-west are sandy but to the south-west are formed by low overhanging cliffs exactly like the lagoon cliffs of Aldabra. In the north-west, near the lagoon, the wind has covered the rock with low dunes, the sand being derived from the lagoon shore; further south

however it is either bare or (near the lagoon) is covered by a thick layer of dark brown guano. The surface of the rock is almost as rough as the "champignon" of Aldabra but, unlike it, was obviously composed of coral, which differed from anything I saw elsewhere in the region by forming fields of unbroken colonies all in position of growth, even the short spike-like form of *Madrepora* projecting from the surface as if still on a growing reef. At Aldabra corals in position of growth were abundant on the cliffs and cliff faces but never were they found seated on the surface of the ground as if elevated but yesterday. There is no doubt therefore that Astove is an elevated atoll, and in addition I deduced that no great rain-water denudation had occurred; but Professor Gardiner considers that the corals might still project undamaged on the surface even after the island had been much reduced in level by denudation, a supposition which is upheld by the fact that Aldabra, Assumption and Cosmoledo must all have suffered greatly from this cause, and it is almost inconceivable that an island distant less than a hundred miles should have escaped.

Metamorphosed rock is scarce, but a little was discovered near the lagoon to the south and as usual contains phosphatic inclusions.

The eastern part of the land-rim was not visited but it was obviously narrow and much heaped with sand.

The lagoon is extremely shallow and is hardly more than a foot deep at low tide; the bottom is covered with a very fine white sand or mud, which on windy days is so churned up that the whole lagoon looks white and the shores are covered with white foam. As the tide descends all suspended material is swept to sea and the loss is thus very large. Judging by this fact and by the form of the lagoon cliffs (where existing) it is evident that the lagoon is increasing both in size and depth. Considering its extreme shallowness and the absence of small islands and rocks, I am inclined to think that the Astove lagoon is a primary lagoon the greater part of which existed at the time of elevation.

The single pass is narrow (150 yards), and even shallower than the lagoon, being almost dry at low tide: the bottom is of coral rock, apparently metamorphosed, and practically devoid of any living corals or débris, though the east shore of the pass is somewhat piled with rounded lumps of coral rock. This pass is obviously of recent formation and there is no doubt that a little time ago the lagoon was absolutely enclosed except for subterranean connections, of which I remarked one in the north of the lagoon. In future, more passes will undoubtedly form, the land-rim in places on the north and east being very narrow. The reef outside the pass is obviously not a reef which has grown up *in situ* but a ledge of elevated coral rock cut down to low water-mark; owing to the rush of water from the pass, it has not been covered either with coral or débris, though it is somewhat encrusted with lithothamnium. There is a marked tendency to form a series of descending terraces, down which the water from the lagoon rushes on its way to the sea. The remainder of the atoll fringing reef is doubtless of the same character, though it has been piled with coral débris and sand much in the same way as the Aldabra reef.

The time I spent on Astove was insufficient to properly investigate its structure

and therefore the flora and fauna were quite neglected. Birds seemed scarce, but I noticed a *Cinnyris* and a rail (*Dryolimnus abbotti*?) which seemed to be the Assumption species. No remains of land tortoises were obtained, but I shall not be surprised to hear of their being found when the guano is dug*.

Insects were very numerous and it was a matter of great regret that few could be taken; butterflies were more common than on any other island and comprised one species, the beautiful *Precis rhadama*, not noted elsewhere. The bush in places resembles Aldabra *Pemphis* scrub and in others the open country of Assumption: it was very bare and dead during my visit and hardly a score of plants were obtained in flower, though during the dry season it is supposed to be the most luxuriant of all the Aldabra series. I had intended to revisit Astove to complete my investigation and take photographs on the homeward voyage; unfortunately during a dead calm the strong current carried the schooner altogether out of her course and it was impossible to put back.

VII. COSMOLEDO.

Cosmoledo is a large atoll about 9 miles long by 7 miles broad, situated in lat. $9^{\circ} 41' 20''$ S. and long. $47^{\circ} 32' 12''$ E. Contrasted with the other two atolls visited it is remarkable in having less than 10 miles of its 24 miles of circumference capped with land. The latter is divided into eight main islands, of which Menai and Wizard Islands are the most important.

The islands in all cases are fundamentally of coral rock, though sand has been blown on from all sides and in some cases has completely hidden the rock under large sand dunes and ridges. The rock is elevated coral rock, which in most places has been much metamorphosed, and which always contains varying amounts of phosphate. "Platin" rock was not found, and corals in position of growth were only occasionally observed. It was obvious that the islands were once larger and there is evidence in the form of small islets and rocks to show that the land-rim was formerly almost perfect. Erosion is still progressing rapidly in many parts of the atoll, an actual measurement being obtained at a point on the lagoon side of Wizard Island, which showed the loss of 15 yards in fifteen years (1893—1908).

The nature of the islands visited is as follows: the North-East Islands and Goëlette Island are almost entirely rocky†; the shores to seaward and towards the lagoon are formed by overhanging cliffs as at Aldabra. Extensive phosphate deposits have existed on all, and on West North-East Island is a certain amount of a phosphate rock, which appears to be composed of sand and rubble cemented together by phosphoric acid. It was interesting to find eggs of a giant land tortoise embedded in this rock, thus proving that once these reptiles lived on Cosmoledo.

Menai Island is rocky, but is also considerably overlaid with sand, which has been blown up from the lagoon. The shore is formed partly by cliffs and partly by sand:

* A letter from Capt. Parcou just received informs me of the find of large bones cemented into a rocky pinnacle. I have every confidence that these will be found to be those of giant tortoises.

† There is a small dune on the lagoon side of Great North-East Island.

on the lagoon side is a small mangrove swamp, which appeared to be decreasing in size owing to insufficient protection from the waves. It is perhaps the last remains of a mangrove swamp, which once extended completely round the lagoon.

Wizard Island is sandy, and coral rock hardly occurs on the surface, though it can be found by digging. Beach sand-stone is common round the shore. It appears likely that the island will soon be divided into two. Of all islands in this region Wizard was most like such a sand cay as Bird Island, Seychelles*, for it seems to have lost most of the peculiarities of such rocky atolls as Aldabra or Astove.

The reef was only visited at a point south-east of Moustique Island where it measured half a mile from lagoon to open sea. The seaward edge is conspicuous for

Fig. 2. From the Admiralty Chart of Cosmoledo.

vigorous massive lithothamnia, but no live coral was noted. Inside the edge lithothamnia is still abundant but consists chiefly of encrusting forms found on broken pieces of coral thrown up on the reef. Sloping towards the lagoon is a sort of buttress-zone with channels and pools containing some live coral, the whole resembling the seaward edge of an atoll reef. The lagoon at this point is largely choked with sand, and partially dry at low tide. In places are large beds of *Cymodocea*. There was no sign of any large blocks (negro-heads) thrown on the reef edge.

* Trans. Linn. Soc., Ser. 2, Zool. Vol. xiv., pp. 15—17, 1911.

The lagoon as a whole is not deep (2—3 fathoms); the bottom is sandy as far as can be seen and living coral colonies are scarce. There are two true passes through the reef, both to the south of the atoll, and there seems to be a tendency to form a deep basin in the south of the lagoon between the passes.

As Cosmoledo is important theoretically a summary of its chief structural points may be given:

- (1) Cosmoledo is an elevated atoll.
- (2) The land-rim was once almost perfect but has been broken up by erosion: the rock islands left are in process of disappearance from the same cause.
- (3) The reef dividing the islands is in just such a condition as should be required for the formation of land by wave-piling: there is, however, no sign of this.
- (4) Great quantities of sand are everywhere present, and much is being piled up on the islands.

There is no evidence as to the height of elevation of the atoll; the summit of the rock is now about 10 feet above high spring tides, and the elevation cannot have been less than 20 feet, and was probably more. If Aldabra and Cosmoledo were elevated simultaneously, the interior of the latter atoll must have been much more cavernous to account for the more rapid disintegration of land.

Of the flora and fauna little can be said, as the few days of my visit were all occupied in examining the formation of the atoll. The sandy islands, *e.g.* Wizard and Polyte, are clothed solely with coral-sand plants, the type of vegetation such as was found on Aldabra being quite absent. Menai Island, where sandy, resembled Wizard, but in the centre is a small piece of almost typical *Pemphis* bush, a form of vegetation which apparently clothed South Island on which I was unable to land. The North-East Islands had been too much disturbed by guano digging to determine their original state, but Goëlette was thickly covered with *Plumbago aphylla*, a herb which produces leaves at the beginning of the wet season but like the broom (*Spartium scoparium*) speedily loses them, and for the majority of the year assimilates by means of the chlorophyl in its stems. The fauna seemed rather poor, though a lizard, *Zonosaurus madagascarensis*, found on the North-East Islands was not observed elsewhere in the Aldabra region*. A rail (*Dryolimnas abbotti*?) still exists on South Island, and a *Cinnyris* perhaps forms a local race, but land birds were scarce on Cosmoledo, which as a whole seemed too broken into small islands to be suitable for a land fauna.

* The skink *Ablepharus boutonii* var. *peronii* and the gecko *Hemidactylus gardineri* were also obtained. *Vide* G. A. Boulenger, Report XVII. of this Volume.

VIII. ASSUMPTION. (Plates 28 and 29.)

Assumption Island is situated in lat. $9^{\circ} 46' 20''$ S. and long. $46^{\circ} 30' 30''$ E., and unlike the islands previously noted is not an atoll. It is crescent-shaped, about $3\frac{3}{4}$ miles long, and varies from 1 mile to about a third of a mile in width. In composition it is undoubtedly an elevated reef, corals in position of growth being abundantly seen, especially along the cliffs of the east coast and on the sides of large pits in the rock, which are extremely common. Much metamorphosis has occurred in places in the interior of the island, and as usual phosphatic inclusions are always present, and give

Fig. 3. Assumption Island.

evidence of the quantity of guano which was deposited on it. There is still a fair quantity of this substance in hollows in the rock and also along the east coast, where it forms a covering over the rock about 6 inches deep.

A conglomerate somewhat resembling the Aldabra "platin" is generally distributed, but from the nature of the component corals it appears probable that this limestone is the result of great denudation acting on a rock composed of corals in position of growth: it is in the nature of a superficial layer and does not extend downwards for many feet. Underneath it the corals in the rock are almost all in the position of growth.

Variations in level over the island were, owing to a thick bush, difficult to estimate, but judging from three tracks cut from the east coast to the west coast, there is a slight

ridge running from the north to the south near the west shore measuring some 18—20 feet above sea level, assuming that the rest of the island is about 12 feet (above sea level). In the south-west this ridge sinks gradually, but in the north-west the slope is steep and even forms low cliffs, leaving a sort of terrace or flat near the shore, which is piled with blown sand.

The pits, before referred to, are most common in the interior of the island, but also occur within a few yards of the sea. As at Aldabra they probably owe their origin to the imperfect consolidation of the reef before elevation. The pits vary exceedingly both in area, depth and contents; the largest measured 18 yards by 14 yards wide and 9 feet deep; the deepest was 45 feet. A considerable number contained water always salt and fluctuating tidally; others contained guano and mud, but even in these salt water could be reached within a few feet of the surface and usually showed tidal fluctuations; as at Aldabra therefore sea water can penetrate completely through the island.

The sides of the pits were always much overhanging and erosion was everywhere obvious in those which contained water, though even in the dry pits weathering seemed to cause an increase in size. The pits are gradually connecting, and will eventually divide the island into a number of islets or rocks, which will of course be rapidly removed by wave abrasion. It is important to notice that, if the reef had been basin-shaped before elevation, then the pits in the interior would naturally have connected before those near the outside, and thus a lagoon would have been formed and the island would have been an atoll.

Large sand dunes (90 feet high) occur in the south-east of the island; the soundings taken by Captain Parcou, previously mentioned, demonstrate much loss of land in the south-east and the sand resulting from the process of erosion is driven on to the coasts and forms the material from which the wind has built up these large dunes. The shore of the island is chiefly rocky, though there is a long stretch of sand in the west, and small sand "lances" are not uncommon elsewhere. Erosion is everywhere obvious.

Owing to the visit occurring during the neap tides the reef was imperfectly examined. It seemed to have a very ill-defined edge, to be very sandy and indeed hardly existant to the south-east. It is probably of the same nature as the Astove and Aldabra fringing reefs, but is less definite on account of the sand acting as a check to reef-building organisms.

The two chief points of theoretical interest in connection with Assumption are :

- (1) The fact that it is not an atoll, and
- (2) The bad consolidation of the rock as a whole.

Both are probably due to the same cause. The base on which the island is built has probably a narrow summit, and the reef was enabled to build vertically more quickly than it could form a talus slope on which to extend horizontally. Supposing it was elevated when it became nearly awash it presumably had not had sufficient time to form a reef of large area or of solid composition; there is therefore but little difference in primary rock structure throughout the island. Secondary rock changes again show the importance of phosphate in metamorphosis, and give evidence of great denudation. The

height to which it was elevated was probably the same as was Aldabra though we have no definite evidence as in the latter case.

The vegetation over the majority of the island consists of a tangled network of *Plumbago* (*P. aphylla* sp.?), *Astephanus* (*A. arenarius* sp.?) with numerous low bushes not identified. Small trees such as *Euphorbia Abbotti*, banyan (*Ficus* sp.?) were not uncommon, while *Dracæna* (*D. reflexa* sp.?) occurred in guano-filled pits. A few trees of *Pemphis acidula* occur near the west coast but do not unite to form bush.

The birds of the island include a *Cinnyris* (*C. abbotti*), the Aldabra cuckoo (*Centropus insularis*), rail (*Dryolimnus abbotti*), a brown turtle dove (*Turtur assumptionis*) resembling the Aldabra dove (*Turtur aldabranus*) and a gannet (*Sula abbotti*) which is peculiar to Assumption and Christmas Island (Indian Ocean). On Assumption it inhabits the large dune, never descending to low parts of the island, and only going a few miles to sea to fish; it was never seen on Aldabra*. Its distribution seems quite inexplicable. The giant land tortoise formerly occurred on the island, for I found the remains of several specimens in the pits in the rock. They do not seem to differ specifically from *Testudo elephantina* of Aldabra. Living reptiles consist of the skink (*Ablepharus boutonii* var. *peronii*) and the gecko (*Phelsuma madagascarensis* var. *abbotti*).

In one of the pits in the rock, which was at least 8 feet deep and about 10 feet square and contained salt water, I obtained an eel, for which Mr Tate Regan tells me a new family will have to be made. I could see no open connection between the pit and the sea, but presume one must exist, as the sides are overhanging and the water never reaches within 4 feet of the surface. Invertebrates are not numerous; Mr Dupont has since visited the island and has very kindly made a collection, which contained a series of several species, of which I only obtained single specimens and one or two I had failed to observe at all.

IX. FARQUHAR, PROVIDENCE AND ST PIERRE.

A page must here be devoted to summarising the peculiarities of the remaining islands of the Aldabra series though the reader will find full accounts with illustrations and charts on pp. 142—149 of the first volume of Percy Sladen Trust Expedition to the Indian Ocean (Trans. Linn. Soc. Ser. 2, Zool. Vol. xii. pp. 141—9).

Farquhar is an atoll 11 miles by 4 situated in lat. $18^{\circ} 6' 45''$ S. and long. $51^{\circ} 10' 3''$ E. The points to which I would call attention are as follows:

(a) The atoll has a very imperfect land-rim.

(b) The land is mainly in the form of sand islands formed by wind and wave piling, though a few minute islands of elevated coral rock still remain to show that the atoll is elevated and resembles Cosmoledo, except that the process of erosion has been carried further.

* This species is also recorded on Christmas Island. I have not compared my specimens with those from this island but if identical the distribution becomes even more curious.

(c) The reef is undoubtedly holding its own and may quite probably be gaining by means of the vigorous growth of lithothamnia. This reef, if, as seems probable, it resembles that of Cosmoledo, is really elevated coral rock cut down below low tide mark and now protected from further loss.

(d) The lagoon is shallow but shows a tendency to form basins which are deeper (6 fathoms, 9 fathoms) than the basin forming on Cosmoledo (3—4 fathoms).

(e) The vegetation consists of coral sand plants.

In the concluding section I shall show that Farquhar accurately represents the future condition of any of the three atolls visited.

Providence, which lies 40 miles north of Farquhar, is uninteresting, being a sand cay without evidence of coral rock. A dredging taken to the west of the island in 744 fathoms obtained coral rock coated with manganese and nodules of volcanic mud, also similarly coated. These are of great interest as tending to show that the Providence bank is based on a volcanic mound.

St Pierre, 17 miles west of Providence Bank, apparently resembles Assumption in most respects, being an elevated coral rock island with overhanging cliffs. It differs in containing a dry primary lagoon which however has been elevated to such an extent that it is improbable that St Pierre can ever form an atoll.

The vegetation rather resembles that of Assumption than that of a sand island, for numerous *Pemphis* and *Euphorbia* trees are recorded.

The present lessees of the island, the Mahé Syndicate, are exporting guano and, while on the Seychelles, I was shown by Mr Stephens, a member of the firm, an egg obtained in the guano, apparently that of a giant land tortoise.

Before proceeding it may be well to add a word of warning as to the heights and measurements given. No surveying instruments were taken and estimations of height were made very roughly and indeed could often be only guessed at. Professor Stanley Gardiner records the cliffs of St Pierre as varying up to 30 feet and I feel it quite possible that many of my elevations are underestimated. On the other hand I have every confidence that the various measurements are correct in relation to each other and for purposes of theorisation may be entirely relied on.

X. THE FORMATION AND FUTURE OF THE ISLANDS.

In this, the concluding chapter, I wish to consider from a wider point of view, first, the formation of the Aldabra series of islands, and secondly, their future, basing the various deductions on the processes which can be seen taking place at the present day. A certain amount of repetition is unavoidable, but is perhaps excusable as this section may be regarded as in part a summary of the results of the whole work.

Before a reef can be built up underneath the sea by the active growth of corals, it is first necessary for there to be some base rising to within at least 40 fathoms of the surface, since reef-building corals, which feed largely by means of symbiotic algæ, cannot flourish at greater depths. Of this base in the case of the various members of the

Aldabra series we have no actual knowledge; but, as there are only a limited number of methods by which such a base could be obtained, the matter can be carried somewhat further. By the most famous theory of coral islands, that of Darwin, it would be supposed that, as the Indo-African bridge disappeared, mountain-tops were left projecting above the sea and in tropical regions would naturally be surrounded by a fringing reef. As the mountains continued to sink, the fringing reef would become a barrier-reef and the barrier-reef an atoll, which by active growth and wave piling could remain at the surface in spite of the subsidence. We have seen however that all evidence gained on Aldabra and its neighbours points to a method of formation by elevation and not by subsidence, and Darwin's theory is therefore untenable.

In the case of the Maldives, Gardiner showed that the base on which this archipelago is built, is probably the higher part of the Indo-African bridge, cut down below the surface of the sea by current erosion, and at first it was felt probable that the same explanation might apply to the Aldabra series, but, on learning that its members arise abruptly from a depth of 1000 fathoms, this supposition seemed unlikely*. There remains but one alternative. It is known that during submarine volcanic action mounds of ashes and mud are produced, which can even form islands, as in the case of Graham's Island†, and these mounds arise abruptly from the sea-bottom as appears to be the case with the members of the Aldabra series. In addition we know of an active volcano in the Comoros, of volcanoes but recently extinct in Madagascar, and the "Sealark" dredged undoubted volcanic mud from off the slope of Providence, and therefore the whole area of the South-West Indian Ocean appears to be liable to volcanic action and it does not seem too rash a theory to suppose that the bases in the case of the Aldabra series are volcanic mounds.

These mounds may have reached to within 40 fathoms of the surface when formed; may have been volcanic islands, which were cut down to that depth by the sea or may have been built up from great depths by the gradual deposition of animal remains from the surface; these are problems which we cannot decide, but it is quite certain that in the case of each island or atoll some base reached to within 40 fathoms and was colonised by reef-building corals.

Up to this point I have referred to the members of the series collectively, but henceforward I shall take Aldabra as my type on account of the superior historical evidence it contains. The shape of the Aldabra reef before elevation has already been dealt with in relation to the "platin" and phosphatic rocks‡, and without further discussion it will suffice to say that it is supposed to have been that of a shallow basin with the outer edge formed by flourishing corals and perhaps lithothamnium, while the inner portions were covered with rubble and sand with here and there a live colony of corals and in parts extensive mollusc beds. From the facies of the fossil corals we know that this reef had nearly reached the surface (within 10 fathoms) but its exact depth is naturally indeterminable.

* It is of course just possible that low peaks of the submerged bridge have been built up by deposition of material from the surface, but Gardiner's proof of the existence of deep currents in the South Indian Ocean makes this unlikely.

† *Vide* Lyell, *Principles of Geology*, Vol. ii., p. 59.

‡ *Ante* p. 405.

The reefs of Cosmoledo, Farquhar and perhaps St Pierre, when under the sea, presumably resembled that of Aldabra, though it is not assumed that they had all reached the same distance from the surface. Astove differs from the above in that its whole reef seems to have been in a flourishing condition, while Assumption, perhaps because the base on which it is built is elongated and narrow, had no primary lagoon.

The next stage in the history of our atoll was its "elevation" in relation to the surface of the sea and here again we can only guess at the means by which it took place. The natural method would have been for a slight local elevation of the ocean-floor to have placed all the reefs near the surface out of water, but in this connection it must be pointed out that numerous points throughout the whole south-western Indian Ocean show a simultaneous elevation of about an equal amount; thus Mauritius has coral rock at 65 feet, the Aldabra series formerly at 50 feet. Zanzibar has been slightly elevated (coral rock at 200 feet) as also the Seychelles (30 feet), while the Maldives were probably elevated to something under 100 feet. I am not aware of any similar elevation being recorded on either Ceylon or Madagascar, but it must be remembered that, owing to its small extent, its effects are so slight that they might easily be removed by nature or neglected by observers. However this may be, there is no doubt that an area approximately between lat. 9° N.— 9° S. (without including Mauritius), and long. 40° E.— 75° E., has been "elevated" through at most 100 feet, and it seems most improbable that there should occur an elevation of the earth's crust which should be so very regular even in extent over such a large area. The only alternative is a change in the level of the sea and it may be well to point out the possibilities of such a theory in order to obtain, if possible, more information on the subject. It has been shown that the level of the sea at Karachi is 300 feet higher than the level of the sea near Ceylon, this being due to a banking of the water in the north owing to the attraction of the large mass of the Himalayas. Again observations show that there is an even greater difference of level between the centre of the Pacific and that near the South American coast, a phenomenon attributed to the attraction of the large land mass of South America and the Andes. It is possible therefore that during the last great land changes (late miocene) an alteration occurred in the level of the sea, sufficient to elevate the land in the Indian Ocean, though it remains for the geologist to say whether this suggestion is reasonable.

A further, but to me less probable explanation, of a change in ocean level is that water has been accumulating as ice in Antarctic regions for a long period and that this is sufficient to account for a considerable drop. Against such an explanation applying to the Indian Ocean islands I would urge first that the effect so produced would be world-wide, and secondly that such a movement would have been too slow to have formed such an island as Aldabra which would have had to be cut down by the sea more quickly than it was being raised in relation to the sea level.

After the elevation of our reef and the formation of an island a series of retrograde processes commences and the senescence of the reef, if such an expression is permissible, dates from this period.

At first Aldabra was not a true atoll, for the primary lagoon was elevated to such an extent that it became dry, a statement which is also true of St Pierre and probably of Cosmoledo and Farquhar. Astove is different, for the lagoon of this atoll is probably

to a large extent the primary lagoon of the reef when under the sea; from the luxuriance and distribution of the fossil corals it is probable that it was not so near the surface before elevation as that of Aldabra, and consequently did not rise to such a height.

The next event of importance which happened to Aldabra (and also to the neighbouring islands) was the deposition of a large quantity of guano, and though we do not know exactly when this took place, yet it is fairly certain that it occurred before the secondary lagoon was formed. The guano was deposited solely by marine birds, which at the present day, though very plentiful in the Indian Ocean, do not exist in sufficient numbers to form guano at all rapidly on more than one or two islands (cp. Bird Island, Seychelles*, Cargados Carajos†). So great is the quantity of guano on the various islands of the South Indian Ocean, that it probably amounts even now to over a million tons, and it is a matter of interest as to why there were formerly such vast numbers of birds where now there are relatively few. Two explanations have been offered; firstly, that the birds were driven from their breeding places by man, and secondly, that the increasing vegetation gradually reduced and obliterated the open spaces necessary for ground-breeding birds. Against the former is the fact that many of the guano islands have only just been colonised and have never been known to be "bird islands," while against the latter I might mention that on Bird Island, Seychelles, on which I spent a fortnight, the birds are quite capable of preventing the continuous growth of any form of vegetation on their breeding places by means of fresh guano, which is quite unsuitable to plant life. To provide an alternative theory I would question the effects of the last glacial period (post-pliocene) on the bird-life of the northern hemisphere. The birds must have been driven south, and marine birds would find it necessary to breed on oceanic islands, for the shores of continental lands for many reasons could not be suitable. A temporary congestion might thus have been produced which, with the retreat of the ice in the north, would have been relieved by a return wave of migration.

Whatever may be the true explanation of this enormous quantity of guano, there is no doubt that the derived phosphoric acid has played a most important part in the post-elevation history of the Aldabra series; its universal inclusion in the metamorphosed limestones has already been mentioned; in addition it shows that the reef when first elevated must have been very porous and slightly consolidated, for the guano has been washed into the greater part of the rock on the atoll. At the present day we know that the land-rim can be completely penetrated by salt water, and from the phosphatic inclusions it appears certain that at first the island was equally, if not more, porous; from the beginning therefore sea water could penetrate far into the land, enlarging caverns and crevices by solution and erosion, though at the same time, this process, by allowing concavities to collapse, must have resulted ultimately in better consolidation at the expense of a reduction in surface level. Rain water denudation has probably been an even more potent factor in reducing the level of the land from its original 50 feet or more above sea level to its present average of about 12 feet. This gradual surface sinkage was apparently more or less equal over the whole island and thus the primary

* Percy Sladen Trust Expedition, Vol. xiv., p. 15 (Trans. Linn. Soc.).

† *Op. cit.*, Vol. i., p. 125.

lagoon continued to be the lowest area. When it had decreased to some 20 feet or less above sea level, the formation of the secondary lagoon could begin, and this is supposed to have taken place as follows. The pits in the rock both at Aldabra and Assumption have been mentioned as also the fact that they are usually filled with tidal water and are continually increasing in size owing to erosion. On Assumption it was also easy to see that they had been underground caverns, which owing to erosion and denudation had become open to the surface, while in several cases pits were seen which had evidently been formed by the interconnection of two or more smaller concavities. It is supposed that at some point in the primary lagoon of Aldabra several such pits by coalescing formed a small secondary lagoon, filled with salt water and in subterranean connection with the sea. Gradually this increased in size by erosion and ultimately obtained a free channel to the sea probably on the site of Grande Passe (the oldest pass). Continued decrease in level by denudation made the centre of the atoll progressively more subject to erosion and in time a second opening to the exterior was gained in the neighbourhood of Passe Houareau. There was thus formed a small lagoon with two openings to the exterior. From this point onward it is easy to imagine a gradual increase in the area of the lagoon, the formation of more passes and a decrease in level of the land until the present stage is reached.

A similar history perhaps applies to Cosmoledo and Farquhar; Astove however, if my deductions are correct, always had a lagoon (the primary lagoon) though it is only recently that it has obtained a free channel to the sea. St Pierre is very small and the primary lagoon is not deep enough to convert it into an atoll, while Assumption has no marked depression in the centre, but on account of the interconnection of pits is gradually being split up into a number of rocks.

Sea erosion appears to have been of small importance when compared with lagoon erosion, but it must not be forgotten that it is responsible for the fringing reef, and in connection with the ocean current for the shallow area, the site of lost land, which occurs to the east and south-east of Aldabra and Assumption.

Enough has now been said to indicate the early history, which is supposed to be common to the atolls and islands of the Aldabra series, and it remains to point out their probable future which is more easy than the discovery of their past, for various members of the series illustrate each probable stage. These may be briefly tabulated as follows, though the atolls for convenience are considered apart from the islands without lagoons.

Stage 1. This is represented by two atolls, Aldabra and Astove. They are characterised by a very perfect land-rim, which is composed almost entirely of coral rock, though a tendency to sand piling is noticeable, locally, on each. In both sea erosion has formed a fringing reef, which is very barren and is not extending seawards, while lagoon erosion is forming new passes and reducing the area of land. The lagoon, very shallow in both atolls, is increasing in depth and Aldabra, with the greatest number of passes, has the deepest lagoon. The latter atoll is also somewhat in advance of Astove in that process of subdivision of the islands by stretches of reef is already noticeable in the formation of the reefs by the sides of Grande Passe and Passe Houareau.

The lagoon of Astove is a primary lagoon, and that of Aldabra is secondary and therefore the two atolls should perhaps be placed in different classes, though they are in much the same stage.

The vegetation on each is of a varied type.

Stage 2. Cosmoledo Atoll is characterised by an imperfect land-rim, less than half of its circumference being capped with land. The atoll circumference between the islands is formed by a reef awash which consists of rubble and débris piled on elevated coral rock, but in places the edge of this reef is covered with flourishing lithothamnium and is perhaps beginning to grow seawards.

The land, which once almost encircled the atoll, has been cut up by lagoon erosion into the islands which exist at present. The latter consist of elevated coral rock, which may be uncovered as at Aldabra—and in this case are obviously suffering great erosion on both faces—or may be so piled with sand as to be almost hidden, in which case gain or loss are difficult to determine*.

The lagoon is deeper than those of atolls in Stage 1, but contains little coral growth. The true passes (with channels) are not more numerous than at Aldabra, for after they reach a certain size a balance is struck between the power of growth of the calcareous organisms on the sides of the pass, and the speed of the tidal current (which broadly speaking determines both its erosive power and its power of preventing coral growth).

The vegetation on rock is varied, but on the sand is typical of any sand cay.

Stage 3. This stage is shown by Farquhar Atoll, which has little land on its circumference, and this land is mainly in the form of sand cays, though enough elevated coral rock is found to make it not improbable that Farquhar once had an almost complete rocky land-rim. The reef between the islands is more flourishing than at Cosmoledo and definitely shows signs of growth seawards. The lagoon is somewhat deeper than those of the previous atolls, and is perhaps becoming more so. The vegetation is almost entirely of a coral sand type.

Among the non-atolls the series is not so complete, but Assumption and St Pierre are an early state of Stage 1, while Providence corresponds to the sandy Stage 3.

Considering the important features of the three stages, it does not seem to be straining the imagination to predict in the case of Aldabra or Astove a gradual reduction of the land-rim into small islands, which will be divided at first by stretches of barren reef. The islands, as they are reduced in size, will become more sandy, until elevated coral rock may appear quite absent, and at this period the vegetation will consist of the regular coral sand plants. The lagoon will continue to grow deeper, and the "Farquhar" stage will be the result. Beyond this it is impossible to foresee, for the ultimate fate of the atoll depends on various conditions of which we have no data, though without further elevation we can feel sure that no coral rock land will continue to exist. The atoll may continue for ever with its reef awash and bearing a few sand islands, or on the other hand it may be cut down fathoms beneath the sea to form the base on which corals can build a fresh reef.

* Loss is shown on Wizard Island by the presence of beach sand-stone.

The Aldabra series thus provides an interesting comparison between the various phases in the life-history of an atoll, and it might perhaps be asked as to how it is that several atolls, if they came into existence simultaneously, can have reached such different stages in the same time, and in this connection it may be pointed out that the rapidity of the various retrograde processes will depend (1) on the height to which the atoll was elevated, (2) on the depth of the primary lagoon, (3) on the width and perfection of the land-rim, of all of which we know little in the case of atolls in an advanced stage, such as Cosmoledo and Farquhar.

Further speculation would suggest the questions as to whether the Chagos and Amirantes were once completely formed of coral rock, and whether the Saya de Malha and Nazareth Banks represent the site of former coral rock islands, or whether they are new formations. The data to determine such points however no longer exist, and speculation without the necessary basis of facts is unsatisfactory, and indeed useless.

In conclusion I desire to place on record my indebtedness to the Master and Fellows of Gonville and Caius College for electing me Shuttleworth Research Student of the College, to His Excellency W. E. Davidson, Governor of the Seychelles, and to the many gentlemen, who by their advice and kindness materially assisted me in my work.

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DESCRIPTION OF PLATES.

PLATE 22.

Map of Aldabra Island. (Reproduced by permission of the Cambridge Philosophical Society.)

PLATE 23. Aldabra.

- Fig. 1. Sea cliffs and reef on the north coast near Passe Houareau. Note overhanging cliffs and large fallen mass of rock due to sea erosion. On the top of the cliffs is a *Casuarina* tree and a belt of *Pemphis* and *Scaevola*.
- Fig. 2. Portion of the cliff-face (to seaward) of Malabar Island to show fossil corals in position of growth. The cliff at this point measures 12 feet in height. On the top of the cliffs is the beginning of the *Pemphis* bush.

PLATE 24. Aldabra.

- Fig. 1. Sea cliffs to the south of Main Island (the end of the Takamaka section). Note the sloping buttressed cliffs and the "shore zone" piled with sand and carrying a short dune grass.
- Fig. 2. Portion of the sea cliff of Picard Island to show the composition of the rock. The coral colonies are all in same relative positions as when alive.

PLATE 25. Aldabra.

- Fig. 1. "Champignon country" on Picard Island. The rock is metamorphosed coral limestone pitted and denuded by rain-water. In the distance is the edge of the bush.
- Fig. 2. "Platin country" on Picard Island. The rock consists of a conglomerate of worn coral fragments and reef débris. The shallow depressions are caused by rain-water denudation.
- Fig. 3. A typical example of a small island or large rock in the lagoon. The birds on the rock are Noddy Terns (*Anous leucocapillus*).
- Fig. 4. View in Lagoon showing island masses off the shore of the land-rim of the atoll.

PLATE 26. Aldabra.

- Fig. 1. A natural pit in the rock on Picard Island. It is in subterranean connection with the lagoon (distant $\frac{1}{4}$ mile) and is filled with tidally fluctuating water. The pit is rapidly becoming larger owing to erosion.
- Fig. 2. "Basin Cabris" on Picard Island. It forms a small lake with a subterranean connection to the lagoon, its waters being tidal.
- Fig. 3. Camp Frigate on Malabar Island. The mangrove swamp has penetrated through the land-rim and is here seen arriving at the sea. After the lagoon has washed away a little more land a tidal current will be enabled to sweep through and cut a fresh pass.
- Fig. 4. One of the Western Channels (from the lagoon looking seawards). The lagoon has cut a passage through the land-rim to the sea but has not yet removed two small islands. These are being cut away by current erosion (as is shown by their overhanging cliffs) and in time an open pass will be formed.

PLATE 27. Aldabra.

- Fig. 1. Esprit Island, showing its wall of shell rock (see pp. 401, 402) with a Banyan tree (*Ficus* sp.?) to the left.
- Fig. 2. Esprit Island: cliffs of south shore showing pinnacles of shell rock with phosphatic rock below.

PLATE 28. Assumption.

Fig. 1. A typical scene in the interior of the island. The surface of the land is fairly rough, and jagged pinnacles, the result of rain-water denudation, are not uncommon.

The vegetation consists of low trees and shrubs separated by stretches of rock covered with tangled herbaceous plants among which *Plumbago aphylla* is conspicuous. The tree in the foreground is *Euphorbia Abbotti*.

Fig. 2. A stretch along the east coast of the island is covered with guano. The illustration shows an area from which the guano has been cleared while in the distance on the cliffs are trees of *Pemphis acidula*.

PLATE 29. Sectional Diagrams.

Fig. 1. Assumption.

Fig. 2. Astove.

These sections are drawn up from soundings kindly made for me by Captain R. Parcou. I would call attention to the steep slope to the west and the long gradual slope to the east or windward. It is believed that the latter has been caused partly by the loss of land due to sea erosion and partly by the piling of sand (foraminiferal) by the sea.

In order to bring the diagrams within reasonable dimensions it was necessary to greatly magnify the vertical scale in relation to the horizontal. The heights are in feet and the depths in fathoms.

The seaward slope to the west is in each section inset in natural scale.

ALDABRA ATOLL
(From the Admiralty Chart with additions by J. C. F. Fryer)

FIG. 1. Cliffs near Passe Houareau.

FIG. 2. Cliff-face of Malabar Island.

FIG. 1. South shore of Main Island.

FIG. 2. Corals in cliff of Picard Island.

FIG. 2. "Platin" of Picard Island.

FIG. 4. View in Lagoon.

FIG. 1. "Champignon" of Picard Island.

FIG. 3. Lagoon Rock.

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FIG. 1. Pit on Picard Island.

FIG. 2. "Basin Cabris" on Picard Island.

FIG. 3. Camp Frigate on Malabar Island.

FIG. 4. One of the Western Channels.

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FIG. 1. Esprit Island: wall of shell rock.

FIG. 2. Esprit Island: cliffs of South shore.

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FIG. 1. Scene in the island.

FIG. 2. A Stretch of guano.

ASSUMPTION

FIG. 1. Assumption.

FIG. 2. Astove.
SECTIONS ACROSS ASSUMPTION AND ASTOVE