

Pimpernel), *Ranunculus Flammula*, and, at Kilchattan Bay, *Listera ovata*.

Rock.—The outcrops of igneous rock afford a suitable habitat particularly for *Cotyledon umbilicus*, the Wall Pennywort. It is accompanied by Ivy, *Teucrium Scordonia* and Juniper.

PASTURES.—Here flourish Bracken, *Digitalis purpurea* and *Linum catharticum*. *Geranium sanguineum*, a plant not very common in the Clyde area, is found at Garroch Head.



THE GREAT BARRIER REEF EXPEDITION, 1928-1929.

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(Read 17th December, 1929.)

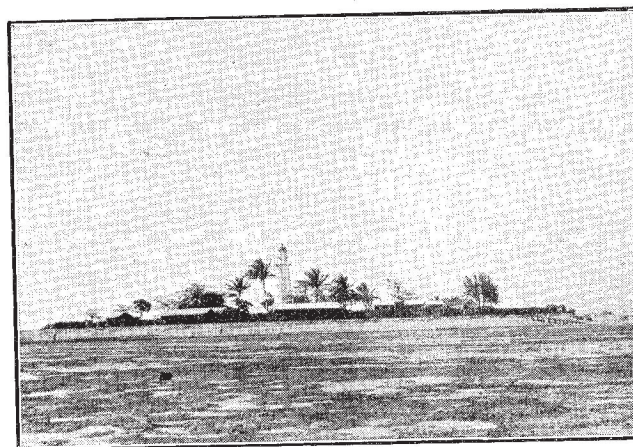
Coral reefs can be classified into three main types—fringing reefs, barrier reefs and atolls. Of the second type the Great Barrier Reef of Australia is the largest example. It runs along the north east coast of Queensland for over twelve hundred miles, sometimes within ten miles of the shore, at the southern end separated from it by as much as a hundred miles. It is not one continuous reef, but consists of an enormous number of small reefs separated from one another by channels of varying depth. Inside the main series of outer barrier reefs, in the so-called lagoon, are numerous other reefs, some wholly below the surface, some with sand-cays upon them, and some with both sand cay and mangrove swamp. It was on one of the last type, Low Island, that the expedition had its headquarters.

Low Island was actually the first coral island sighted by Captain Cook in June, 1770, in his historic voyage up the east coast of Australia. He did not recognise it as a coral island, however, and sailed on to run upon a reef only a few miles to the north. His ship, the *Endeavour*, was holed, but the worst hole was filled by a piece of coral which had broken off in it, and they managed to drag a sail over the rest and refloat her. Cook's passage up the coast can be traced by the names he has left on it—*Endeavour Reef*, *Cape Tribulation*, *Weary Bay* and *Hope Islands* tell their own tale. Finally Cook managed to get his boat ashore at the place which now bears his name, and there she was repaired. There, too, Cook climbed the hill behind the bay and saw, to his horror, the huge extent of reefs stretching both north and south. It is a long time

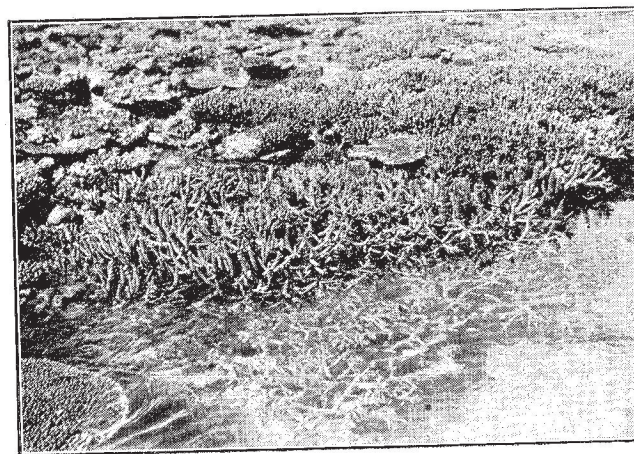
from Cook's day to our own, and in the meantime the reefs have been charted, though by no means fully even yet. They have been an object of interest and enquiry ever since, and in 1928 influential committees, both in this country and in Australia, organised an expedition to settle for a year in that region and study the life of a coral reef. It was financed by the Commonwealth Government, the British Empire Marketing Board, and several societies and private individuals in both countries. The personnel of the expedition was chosen almost entirely in Great Britain and various sciences, zoology, physiology, botany, chemistry, and geography were represented.

Low Island (fig. 1) is situated half-way between the outer barrier and the mainland, about seven miles from each, in lat. $16^{\circ}23'$ S. Like most of the reefs in this part of the world it is more or less crescent-shaped with the convexity towards the S.E., and a deeper bay on the N.W. between the horns of the crescent. On the eastern side of the reef there is a mangrove swamp, and on the N.W. corner a sand-cay, a little island formed of coral sand flung up by the wind and waves. It was 700 feet long, 400 feet wide, and about 6—8 feet high, and on this inconsiderable sand-heap we settled down for a year's work. The Queensland Government had put up wooden huts for us to live in, a small one for our aboriginal servants, two larger ones for sleeping quarters, and a large hut which served as laboratory, dining room, living room and library. There was a lighthouse on the island, too, with three lighthouse keepers. In spite of its being composed entirely of coral sand, the island bears a considerable amount of vegetation. There are coconut palms and big shady *Terminalia* trees; round the shore there is a fringe of bushes, and much of the sand between the trees is carpeted by a creeping convolvulus.

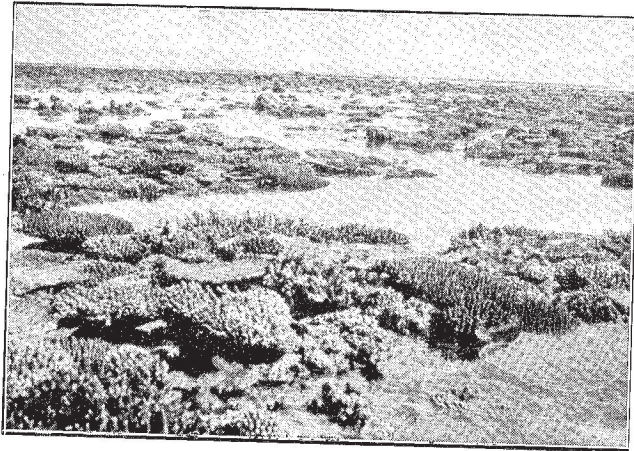
There was not much animal life on the island apart from insects, and of these the mosquitos and sand-flies were troublesome only in summer. Small lizards were common,



(1) LOW ISLAND.



(2) MADREPORES CORAL.



(3) PIXIE REEF.



(4) MICHAELMAS BAY.

scorpions, fortunately, less so, but the place was over-run by small brown ants who acted as scavengers, cleaning out shells and removing dead insects, but turned their attentions just as readily to the bread, jam or sugar. A few honey-birds nested on the island, and in summer the Torres Strait pigeons came south to nest in the mangroves, from where they flew every day to feed on the mainland.

When we arrived in July it was winter, the dry season there, and we did not feel the heat too much. The weather was pleasant, with clear skies and sunshine, and a cool breeze blowing. The S.E. trade wind is the most noticeable feature of the weather in this part of the world. It blows persistently for nine months of the year, and at intervals during the other three. It is this constant wind which is responsible for the shape of the island and possibly of the reef also. In summer, when the wind changed to the north, it was very interesting to notice how the contour of the island changed. The slope of the shore became much steeper and new sand-spits grew out in the course of a few days. In November the S.E. wind slackened, we had occasional calm spells or even wind from the N. or W., and the rains began. There was, of course, no fresh water on the island, and up till then we had depended for our supply on water brought over from a river on the mainland. We used about five hundred gallons a week, and since this had all to be carried from the shore up to the tanks we were glad to see the first November showers fill our tanks to overflowing. The rainfall is high in this part of Queensland, sometimes above 100 inches a year, and this all falls in the summer months. The combination of great heat and a damp atmosphere is very trying, and for about three months we thought with envy of the people in Europe who were actually feeling cold. The temperature of the sea round the island rose to 90-93° F., while in the pools left by the tide it got much hotter than that. Mr Orr once took the temperature of some rock oysters living on the

beach rock and found that it was over 113° F. In winter their temperature would be from $60-65^{\circ}$ F., and this gives one some idea of the enormous variations which shore living animals in the tropics have to put up with. Every week or two during this hot weather, the wind would go round to the S.E., the temperature would fall several degrees and we would have some days of high wind and pouring rain. About the end of February it began to cool off, the S.E. wind came back as a constant force and there was a gradual return to winter conditions.

The scientists of the expedition were divided into three groups; the physiological party under the direction of Dr. C. M. Yonge, the leader of the expedition; the boat party in charge of Mr. F. S. Russell for the first five months and afterwards in that of Mr. A. P. Orr; and the shore party in charge of Dr. T. A. Stephenson. The boat party worked mainly on the plant and animal life in the seas round about coral reefs and on the chemical changes occurring there. The shore party studied the distribution of plants and animals on the reef itself, along with their rate of growth and habits of reproduction. The physiological party worked on the metabolism of coral and other reef animals, studying their respiration, digestion, and the influence upon them of various environmental conditions. By working in this way from several different aspects, it is possible to get some idea of the biology of a coral reef and the conditions governing its existence.

For the examination of the sea, a station was chosen midway between Low Isles and the Great Barrier Reef and this was visited weekly. Samples of sea water were taken every five metres from surface to bottom and the plankton, (the floating population of the sea) was sampled by means of long conical silk nets which were towed obliquely through the water from surface to bottom. The samples were taken home to be worked out in the laboratory and while the chemist examined the water, measuring, for example, the

salinity and the oxygen and phosphate content, the zoologists counted all the plants and animals in that sea water and all those which had been captured by the nets. By repeating this work every week, some idea was got of the seasonal variation in the life of the sea and in the chemical constitution of the sea water. This was of importance, not only for a comparison with similar work done in temperate waters, but also because, here as elsewhere, most of the life in the sea depends eventually on the minute plants of the plankton for food. The coral which has built up the enormous mass of the Great Barrier Reef system is carnivorous and depends on the small animals of the plankton for food, and these in turn eat the microscopic plants which are present. These microscopic plants, or diatoms, are found in the surface waters all over the oceans and those found in the tropical waters of Australia were very much the same as those to be found in the waters round our own coasts, as for example in the Clyde sea-area. When diatoms are studied in temperate waters it is found that their numbers vary greatly with the season. Great outbursts of diatom growth, the biggest of which comes in early spring, are separated by periods when the sea is almost free of diatoms. Each outburst is accompanied by a rise in the oxygen content of the sea water and a fall in its phosphate content, since growing diatoms, like plants on land, give out oxygen and take up phosphate and other nutrient salts as food. In the tropical waters of the Great Barrier Reef region things were quite different. The number of diatoms remained low all the year round and such small increases as did come appeared suddenly and lasted only a very short time. The actual numbers were usually much lower than those found in temperate waters so that the chemical conditions of the sea water were not affected by these increases to any appreciable extent. The oxygen content remained the same and the phosphate content remained low all the year round and there was little seasonal variation in any of the factors affecting plant

life. The animal plankton, too, was neither so variable nor so abundant as in temperate waters.

Conditions in the water close to, or over, a coral reef are however quite different. While the tide is high the water of the coral pools is continuous with the sea surrounding the reef and its chemical constitution is the same, but when the pools are isolated during low tide at night, the oxygen content falls very low, since both plants and animals use up oxygen at night. During low tide through the day on the other hand, the oxygen content rises very high indeed, and this great production of oxygen during the daylight hours shows that an abundant plant life is present. This plant life is not present in the form of seaweeds or diatoms, but as innumerable microscopic algal cells living in the tissues of the corals themselves. All reef-building corals contain these plant cells in enormous numbers and in only a few deep water corals are they absent. It is the countless millions of these cells present in their tissues which give to most living corals their brownish yellow colour. Their presence has been known for a long time but there has been much discussion about the exact part they play in the metabolism of the coral.

If a piece of coral is kept in a closed bottle in the light, the oxygen content will rise, showing that the coral as a whole behaves like a plant. At the same time the phosphate content of the water goes down, showing that the algae have used up the excretions of the coral as well as some phosphate from the sea water, for a coral kept for long in the dark, or one which does not contain algae, adds phosphate to the water. The algae therefore get both food and shelter out of the association. What does the coral get? It has generally been supposed that the coral could use these cells for food—indeed some corals were supposed to eat nothing else. An interesting experiment was carried out to test this point. Four lots of coral were kept for some months in the aquarium, two lots in the

dark and two in the light, and in each of these one lot was starved and one fed with plankton. The starved corals, both in light and in the dark, immediately threw out by the mouth all the algal cells which they contained, and, although they could live for some weeks without food, they gradually lost flesh and died. Those which were fed remained quite healthy whether in the light or in the dark although the latter grew pale owing to the death of their algal cells. This shows clearly that a coral does not eat its contained algae even when starving. A study of the digestive ferments secreted by the coral led to the same conclusions. It was found that they were equipped for digesting animal food, but not for digesting starchy or plant food, and must therefore depend entirely on such small animals as they can capture from the plankton. All the coral species examined, and these were many, were in fact provided with some mechanism for catching and taking in animal prey.

Corals belong to the same group of animals as sea-anemones and, but for the fact it secretes a massive skeleton of calcium carbonate, a simple coral resembles a sea-anemone very closely. It possesses a mouth, usually surrounded by a ring of tentacles and opening into a sac which digests the food, excretes the waste products, and serves also as a nursery for the larval corals until they are old enough to be set free in the sea. Most corals expand fully only at night; during the day their mouths are shut, the tentacles are withdrawn, and the flesh is drawn down close over the skeleton. At night the appearance of a coral colony is strikingly different, the tissues are raised off the skeleton and the tentacles, often beautifully coloured, expand. Each tentacle is armed with batteries of stinging thread cells with which to catch and kill their prey, and so it is at night, and usually only at night that corals are found feeding. The living tissue forms only a thin skin over a coral, and in a large colony the greater part of the mass consists of skeleton which was secreted by the coral

but has been left behind as the colony grew outwards. This mass of dead carbonate of lime is often used as a home by various kinds of worm or shell-fish which bore long tunnels through it. Sponges and seaweeds penetrate it too and often the whole mass is quite rotten inside.

Corals reproduce both by budding and by means of eggs. The former is the method by which a single colony grows, and the latter is the means of starting new colonies and settling in fresh places. The eggs develop in the cavity of the parent until they are about the size of a pin's head, and are then liberated through the mouth as minute free-swimming pear-shaped bodies. These swim for a day or two and then attach themselves by one end to a solid substratum and proceed to develop a mouth, a ring of tentacles, and a limy skeleton. Presently the tiny polyp develops a ring of buds round it, but they all remain attached to one another and the process is repeated until a colony is formed, consisting of hundreds of individual polyps. The earliest stages of this life history are not well known, and so it was interesting to study them in two common species of coral. A series of measurements was also made to find out something about the rate of growth in adult colonies. A large number of living coral colonies of different species were fastened to cement blocks and, after being carefully photographed, were put in the sea, and left for six months. Most of them survived, and they were then taken out again and photographed from exactly the same position as before. The solid and massive types of coral showed very little change, but the branching types, such as the Madreporae (fig. 2) showed great changes. It is these branching types which form the bulk of living coral reefs to-day.

One factor which may be of great importance to the growth of a coral colony is the amount of sediment falling on its surface. A certain amount of break down is always taking place on a reef, for the sea, beating continually on

the outer edge, breaks off bits of dead coral and shells and grinds them into sand. This is carried over the edge of the reef and may drop on the coral growing in the stiller water inside. It has sometimes been supposed that this rain of sediment was fatal to coral growth and so several experiments were carried out to test the point. Numerous pots were put out in various positions on the reef and the amount of sediment falling into them was measured. The results were surprising for it was found that coral was growing luxuriantly where most sediment was collected. Large quantities of sand were then put on the top of certain marked colonies and these were examined next day. Most of them got rid of the sand within twenty-four hours although the quantity was greater than they were ever likely to get under natural conditions. A good deal of the removal could, however, be ascribed to water movements caused by wind and tide, and the sand was usually got rid of more easily in windy weather. Experiments were also carried out with small colonies kept in glass jars in the aquarium, where the removal of sand or mud from the surface could be watched easily. In this case the corals had to do it without any external help and although some of them were still very efficient, others, especially those with small polyps, were hardly able to remove any at all.

Some work was also done on the animals of economic importance. Fisheries of various kinds are of great value to Queensland, but so far no attempt has been made to organize or develop them in any way. Apart from fish, which are not of great importance, there is a large shell-fish industry, yielding pearls and pearlshell, while a smaller trade is done in beche-de-mer or trepang, turtles, and dugong. The most important is the large gold-lip pearl oyster from which most mother-of-pearl articles are made. This did not grow on Low Island but the smaller and closely allied black-lip pearl oyster did, and its life history and growth rate were studied. Like the gold-lip, it has

two breeding periods in the year, at full moon in November and May, and it is possible that by collecting the spat and bringing it up under favourable conditions, the industry might be expanded. The black-lip oyster is fished mainly for the pearls it produces, but in the gold-lip it is the shell itself which is valuable and any pearls found are the property of the diver.

Another rather inferior type of pearl-shell is got from the *Trochus* (closely related to the Top shell of our own coasts), which is common on all the reefs. A large number of boats is constantly employed in *Trochus*-fishing and the shells are then sent to be made into buttons in Japan. Most of the boats come from the Torres Strait and are either manned entirely by Torres Strait islanders, who are Polynesians, or are manned by natives and officered by Japanese. They dive naked, that is without a diving dress of any kind, so that they have to hold their breath all the time, yet a skilled diver will search for, collect, and bring up ten *Trochus* all at one time. They sometimes fish for *beche-de-mer* also. The *beche-de-mer* is a sea cucumber, closely related to the starfish and sea-urchins, but it looks like nothing so much as an animated black sausage as it creeps about the reef. There are various qualities, some of them very common, and they are slit up, cleaned, dried, and then sent to China where the best varieties fetch up to £200 a ton. They are used as a basis for soup.

Occasionally one of these fishing luggers would take shelter behind our island, and at night the crew would come ashore to hold a corroboree or native dance. It was a picturesque sight. The men, wearing only their lava-lavas, with wreaths of *convolvulus* round neck, arms, and ankles, danced on a bare patch of sand under the coconut palms with the moon shining down from above and the ground lit by a few kerosene lamps. Music was provided by the beating of an empty kerosene tin with two sticks. All the dances were really action songs and represented some story

which to us was quite unintelligible. All of them sounded, and many of them looked very war like, but they were not really so. Two about which we enquired were called 'Carrying Wood,' and 'Washing the Baby.'

Although an occasional turtle was seen on or around our island, they are much commoner further north and further south. A turtle-soup factory has been set up on one of the Capricorn islands in Lat. $23\frac{1}{2}$ S. The female turtles are captured when they come ashore to lay their eggs in the sand.

One factor of great importance to us all was the tide. It was not long before we realized that the tides in this part of the world are peculiar, and after Christmas a recording tide gauge was set up and we then had reliable records. All winter, that is from May till October inclusive, the best tides (which from our point of view meant the lowest tides) are during the day at new moon. All summer, that is from November till April, the best tides are during the night at full moon. During the summer, the day tides were very poor all the time and at neaps the reef did not uncover at all, while even at spring tides only a few inches uncovered for a short time. This made collecting and all reef work very difficult, for it had to be done through the night at full moon. As winter approached the tides got better and better until the new moon tides in June were the best day-tides we had during the whole year. During the hours that the tide was out, the reef was quite irresistible; one could walk among and examine coral which was normally covered by six or eight feet of water and all sorts of species new to us were first seen then. Most photographs of coral reefs are taken during these very low tides and are apt to be misleading. Such a view as is shown for example in Fig. 2 may be seen perhaps half-a-dozen times in the course of the year. Usually far less coral is exposed.

During the poor tides of summer there was one piece of apparatus which was found useful by everyone, the

diving-helmet. It was a simple contrivance, rather like a dust-bin, which fitted over the head, resting on the shoulders, and was weighted back and front with pieces of lead. Air was supplied by a rubber hose pipe attached at one end to the helmet and at the other to a motor tyre pump worked by hand in a rowing boat. A plate glass window was let in to the front of the helmet and the diver could walk about at a depth of two or three fathoms and see the coral and reef animals under absolutely natural conditions. It is a wonderful sight to see great bushes of coral higher than one's head, with the polyps sometimes expanded and waving gently in the current. Shoals of tiny brilliantly coloured fish swim past, while larger fish, striped or spotted, can be seen nibbling at dead bits of coral or swimming among the branches. In summer, when the water was warm, it was possible to stay down for over an hour, and many observations on growth and regeneration in marked corals were made in this way. One scientist used to go down with a piece of opal glass and a pencil, and make maps of the distribution of coral species under the water.

Our island was only a third of a mile in circumference and we could walk round it in five minutes, but fortunately we were not restricted to this small space. As mentioned before, the island was situated on the N.W. corner, and the mangrove swamp on the east side of the reef. At low tide these were joined by a sandy flat and the edge of the reef swept to the S.E. in a wide curve. All round this edge there was a ridge made of fragments of shells and coral shingle washed up by the sea. On the seaward side it sloped gently into the sea among larger stones and boulders, but on the inner side it fell steeply into a channel two or three feet deep even at low tide. The rest of the reef flat was sandy and dried out almost completely at low tide, so there was not much animal life to be seen on it beyond an occasional clam or block of coral. A great many animals, however, lived below the surface in holes or burrows in the

sand. These included numerous shell-fish, brittle-stars, worms and crustaceans, which could be obtained by digging. The greatest variety of living coral was naturally to be obtained in the deeper channel just inside the shingle ridge, since there was always two or three feet of water there. A walk along this channel never lost its fascination for there was always something fresh to be seen. Most of the types of animals we find on the shore at home were to be found there also, but they were as a rule much bigger and more brightly coloured. Great blue starfishes or green brittle-stars lie about the pools or hide under the stones. Large shellfish, some with very beautiful shells, creep about among the coral. Clams which grow up to two or three feet in length are common objects with brilliantly coloured mantles. In several places may be seen collections of the black sea-urchin *Centrechinus*, whose long sharp spines it is as well to avoid.

On the east side there is a great development of the shingle ridge, which here sends off long tongues into the mangrove swamp. Mangroves are trees which live in salt water marshes or in the sea, and they must be firmly rooted to withstand the strain of the wind and waves. They are, therefore, provided with numerous hooped, branching, stilt-roots, which spring from the trunk like flying buttresses and make an inextricable tangle with the roots of neighbouring trees. Fortunately, there were several narrow winding paths into the interior of the swamp where there was a shallow sandy pool. Shoals of little garfish were very common here, sting rays were often to be seen lying on the bottom, and the much dreaded stone-fish, which has poisonous spines on its back, was occasionally found among the roots of the mangroves. Towards the south this pool dried out at low water, leaving a layer of thick black mud on which were scattered innumerable gastropod shells. Some of these were tenanted by their original owners, but many of them were occupied by hermit crabs. Here too was

found the mud-skipper, a little fish which uses its pectoral fins as legs and runs over the mud like a lizard.

Low Island reef, with its sand-cay, its mangrove-swamp, its shingle ridge, and channel of deeper water, is typical of many of the reefs lying near the coast inside the Great Barrier Reef lagoon, but the reefs of the outer barrier differ from it considerably. During the last few months of our stay we visited some of the other reefs in the neighbourhood to compare the different types.

One such visit was paid to Pixie Reef (fig. 3) during the good tides in June. Pixie Reef is a very small but very beautiful reef lying at the mouth of one of the wider channels through the Outer Barrier, and it has the usual more or less crescentic shape. It had been visited the previous November, when one small cay was to be seen, but when we arrived in June, two small cays, neither more than a few yards across, were there, one on each horn of the crescent. It is probable that in the early stages of cay formation, an island may be formed and washed away again very quickly if the wind alters suddenly in direction or force. There was no mangrove swamp, and the reef flat was only just uncovered during these good tides, showing that the general level is lower than that of Low Island reef-flat. Michaelmas Cay is a much bigger reef lying just to the south of one of the larger passages through the Great Barrier. We spent two nights in the shelter of its sand-cay, which is many times as large as that of Low Island. It has no trees, but is covered with a coarse vegetation and is tenanted by innumerable sea birds (see fig. 4), mostly sooty terns. At a distance they are seen above the island as a thick cloud, and the noise of their crying does not cease day or night. Their nests were scattered all over the cay and we collected a tinfal of eggs which made a pleasant addition to our table.

A reef of the Outer Barrier series is very different. The approach from the western side is through a maze of coral

heads rising from five or six fathoms of water. Between the coral heads are patches of clean sand which give the water its clear green colour. As one approaches the reef, the water shallows and the coral heads rise so close together that they are almost continuous. A large boat has to drop anchor here, and even a small boat may find it difficult to make a passage through the maze of coral to a landing place. From there coral gets gradually scarcer and there is a gentle rise up to the reef crest and a gentle slope down again to the open sea. This strip of reef, uncovered only at very low water, may be 100-300 yards across, and is made of hard consolidated material swept bare of any loose stones or coral fragments, and bare also of living forms. Only a few large 'nigger heads'—blocks of coral torn off and flung up by some storm—stand on it. On the seaward edge coral growth begins again and the reef drops sharply into the ocean. On this edge the rollers of the Pacific break continually, and nothing is to be seen for miles but a white north and south wall of breaking surf. The reefs as a whole have a slight convexity to the E. or S.E.

These are only a few types of coral formation and in the open ocean there are many more to be found, but they can all be divided into the three types, fringing reefs, barrier reefs and atolls. Fringing reefs are those which form on the shores of islands, that is, not islands made simply of coral sand like ours, but those of volcanic or continental origin. Barrier reefs, like that of Australia, are found at a greater distance from the shore, usually several miles, rarely as much as twenty or thirty. Atolls are simply large ring-shaped reefs enclosing a lagoon of 15-20 fathoms depth, on whose rim a ring-shaped island, or a ring of separate islands is formed. There is usually a gap through the reef into the lagoon on the leeward side.

The problem of the origin of coral reefs has puzzled science for many years and it is by no means settled yet. Reef-building coral is never found at a depth greater than

20-30 fathoms, and the foundation of every coral reef must therefore have been originally at a depth not greater than this. The main problem is to account for the presence of such vast numbers of these shallow platforms as all the reefs of the coral seas require.

The first theory was that of Charles Darwin, formed after his voyage round the world in the "Beagle," and he concluded that most coral reefs were built upon subsiding foundations, so that fringing reefs, barrier reefs and atolls, were all stages in the same process. Thus, if a fringing reef were formed on the shores of a volcanic island, and this island began to sink under the sea, the reef would be found at a greater and greater distance from shore and would become a barrier reef. The final stage would be when the island had sunk entirely beneath the surface, leaving only a ring of coral reef or atoll. This theory gives a full and satisfying explanation of most coral reefs and is supported by several facts. Thus most coral islands have deep winding bays, and this is just what would appear if subsidence had drowned the river valleys of a partly eroded island. The theory requires, however, that there should have been an enormous amount of subsidence all over the tropical part of the Pacific and Indian Oceans. Various anomalies of geographical distribution have led to the hypothesis that there was once a continent between India and Africa, which has since foundered, leaving only Madagascar, the Seychelles, and the Maldivé and Laccadive archipelagos as relics. This sort of thing may have happened in the Pacific also, but these are large assumptions and have not been proved.

The second group of theories holds that reefs have been built up on stationary foundations, either on banks of sediment built up from the ocean deeps, or else on the remains of islands which have been worn down, first by aerial erosion, and then by the waves. When the reef is formed, either on an island shore or on one of these submarine

foundations, the coral on the inside, which, as a rule, grows less luxuriantly than the coral outside, is supposed to be attacked by various organisms, weakened, and finally dissolved and washed away by the sea water. This process would turn a fringing reef into a barrier reef, and a large reef on a submarine foundation into an atoll. This explanation held the field for some years, but has now been generally given up. It has been discovered that the sea is saturated with carbonate of lime and will dissolve no more, and it is also true that lagoons, far from being hollowed out, are either being silted up or remain at a constant depth.

Wood Jones, largely from a study of the Cocos Keeling atoll, came to the conclusion that subsidence played no part in the formation of reefs, but that they could be accounted for by the action of the wind and sediment. Coral islands are mostly situated in the trade-wind region, and this constant force has gradually moulded them into their present form. The waves, dashing upon a flat topped reef near the surface or the sea, break off bits of coral, grind them down, and gradually build up a barrier of crushed fragments which is eventually consolidated by the desposition of carbonate of lime and the action of organisms. This barrier naturally forms first on the windward side and gradually extends till it forms almost a circle with a gap on the leeward side. At the same time islands are formed on this barrier by the piling up of coral sand and fragments by the wind and sea. Sediment, washed up continually by the waves, adds to these islands at their edges and gradually kills off the coral in the central part of the reef, thus forming the lagoon. Each little island tends to repeat the process, to become crescent shaped and finally circular, enclosing a tiny lagoon. Sediment also accounts for the changing of a fringing reef into a barrier reef. In many ways this theory is convincing, and there is probably a good deal of truth in it, but if the process of silting were going on as actively as is supposed, one would

expect to find many very shallow atoll lagoons, whereas these are of remarkably constant depth, usually 10-20 fathoms. There remains also the difficulty of reef foundations for it is as yet unproved that submarine banks of sediment can become sufficiently consolidated to support coral growth. There is another point against the theory of stationary foundations. Several coral islands have been elevated above the sea surface, and their reefs, now on dry land, are seen to rest unconformably on their foundations, that is, the foundations have been changed by denudation and erosion before the coral began to grow. Now, if the reefs had really been formed on submarine banks, their foundations should have shown no signs of alteration from their original condition.

The most recent theory, put forward by Daly depends on the effect of the last ice-age. During this period it was supposed that the ice-cap at the poles became much enlarged, and this great mass, besides consisting of frozen sea water and thus locking up a proportion of the sea, also exerted, by reason of its mass, a considerable attractive force on the rest of the sea, so that the sea surface in the region of the equator was lowered, Daly supposes to the extent of 30 or 40 fathoms. At the same time the sea was cooled so that most of the pre-glacial coral reefs were killed off. The waves of the glacial ocean then had full access to the coasts no longer protected by reefs, and eroded them so as to produce wide sea-level platforms. When the ice began to melt again, the sea rose slowly, and coral reefs established themselves on these wave-cut platforms and grew upwards, keeping pace with the rise in sea-level.

In its results, this theory is much the same as Darwin's. From the point of view of a coral, a rising sea and a subsiding land come to much the same thing, and some of the geographical results will also be similar, e.g. the coasts will show drowned valleys. This theory, although attractive in its simplicity, is still in an extremely hypothetical

stage, for we have no certain knowledge of the amount of ice in the ice-age, and some geologists even hold that it was caused by the shifting of the poles rather than by any great increase in the ice-cap. There are also indications that, near the equator at any rate, the sea was never cold enough to kill off coral reefs.

One way of testing out the various theories would be by making a large number of bores right through coral reefs to their foundations. Darwin's theory demands a great thickness of coral reef, the other theories only 20-30 fathoms, and the foundations of the reef should differ according to the various theories. Boring so deeply as this is an expensive business, however, and it will probably be long before we have enough information of this kind to be certain. The results from the one deep bore which has already been made (on Funafuti atoll) have been interpreted in two completely different ways. Possibly no one explanation can be true of all coral reefs. In the meantime it is interesting to see that the latest worker on the subject, Professor Davis of Harvard, has gone back wholeheartedly to Darwin's subsidence theory, supporting it with a great weight of evidence, and making only slight modifications adapted from the ice-age hypothesis.

This short survey shows, I hope, that an enormous and most interesting field still waits for any worker on coral reefs. Perhaps the most satisfactory result of the expedition has been that the Queensland Government has founded a marine station to carry on the work.

I have pleasure in thanking Dr. C. M. Yonge and the Trustees of the British Museum for permission to publish this account.

Those interested could consult the following books:—

"The Coral Reef Problem"—W. M. Davis (1928.)

"Corals and Atolls"—F. Wood Jones (1912.)

"A Year on the Great Barrier Reef"—C. M. Yonge (1930.)