and the further concession that all vital action may, with equal propriety, be said to be the result of the molecular forces of the protoplasm which displays it. And if so, it must be true, in the same sense and to the same extent, that the thoughts to which I am now giving utterance, and your thoughts regarding them, are the expression of molecular changes in that matter of life which is the source of our other vital phænomena.

ON CORAL AND CORAL REEFS

THE marine productions which are commonly known by the names of "Corals" and "Corallines," were thought by the ancients to be sea-weeds, which had the singular property of becoming hard and solid, when they were fished up from their native depths and came into contact with the air.

> "Sic et curalium, quo primum contigit auras
> Tempore durescit: mollis fuit herba sub undis,"

says Ovid (*Metam.* xv); and it was not until the seventeenth century that Boccone was emboldened, by personal experience of the facts, to declare that the holders of this belief were no better than "idiots," who had been misled by the softness of the outer coat of the living red coral to imagine that it was soft all through.

Messer Boccone's strong epithet is probably undeserved, as the notion he controverts, in all likelihood, arose merely from the misinterpretation of the strictly true statement which any coral fisherman would make to a curious inquirer; namely, that the outside coat of the red coral is quite soft when it is taken out of the sea. At any rate, he did good service by eliminating this much error from the current notions about coral. But the belief that corals are plants remained, not only in the popular, but in the scientific mind; and it received what appeared to be a striking confirmation from the researches of Marsigli in 1706. For this naturalist, having the opportunity of observing freshly-taken red coral, saw that its branches were beset with what looked like delicate and beautiful flowers each having eight petals. It was true that these "flowers" could protrude and retract themselves, but their motions were hardly more extensive, or more varied, than those of the leaves of the sensitive plant; and therefore they could not be held to militate against the conclusion so strongly suggested by their form and their grouping upon the branches of a tree-like structure.

Twenty years later, a pupil of Marsigli, the young Marseilles physician, Peyssonel, conceived the desire to study these singular sea-plants, and was sent by the French Government on a mission to the Mediterranean for that purpose. The pupil undertook the investigation full of confidence in the ideas of his master, but being able to see and think for himself, he soon discovered that those ideas by no means altogether corresponded with reality. In an essay entitled "Traité du Corail," which was communicated to the French Academy of Science, but which has never been published, Peyssonel writes: —

"Je fis fleurir le corail dans des vases pleins d'eau de mer, et j'observai que ce que nous croyons être la fleur de cette prétendue plante n'était au vrai, qu'un insecte semblable à une petite Ortie ou Poulpe. J'avais le plaisir de voir remuer les pattes, ou pieds, de cette Ortie, et ayant mis le vase plein d'eau où le corail était à une douce chaleur auprès du feu, tous les petits insectes s'épanouirent. — L'Ortie sortie étend les pieds, et forme ce que M. de Marsigli et moi avions pris pour les pétales de la fleur. Le calice de cette prétendue fleur est le corps même de l'animal avancé et sorti hors de la cellule." [1]

[1] This extract from Peyssonel's manuscript is given by M. Lacaze Duthiers in his valuable *Histoire Naturelle du Corail* (1866).

The comparison of the flowers of the coral to a "petite ortie," or "little nettle," is perfectly just, but needs explanation. "Ortie de mer," or "sea-nettle," is, in fact, the French appellation for our "sea-anemone," a creature with which everybody, since the great aquarium mania, must have become familiar, even to the limits of boredom. In 1710, the great naturalist, Réaumur, had written a memoir for the express purpose of demonstrating that these "orties" are animals; and with this important paper Peyssonel must necessarily have been familiar. Therefore, when he declared the "flowers" of the red coral to be little "orties," it was the same thing as saying that they were animals of the same general nature as sea-anemones. But to Peyssonel's contemporaries this was an extremely startling announcement. It was hard to imagine the existence of such a thing as an association of animals into a structure with stem and branches altogether like a plant, and fixed to the soil as a plant is fixed; and the naturalists of that day preferred not to imagine it. Even Réaumur could not bring himself to accept the notion, and France being blessed with Academicians, whose great function (as the late Bishop Wilson and an eminent modern writer have so well shown) is to cause sweetness and light to prevail, and to prevent such unmannerly fellows as Peyssonel from blurting out unedifying truths, they suppressed him; and, as aforesaid, his great work remained in manuscript, and may at this day be consulted by the curious in that state, in the *Bibliothèque du Muséum d'Histoire Naturelle.* Peyssonel, who evidently was a person of savage and untameable disposition, so far from appreciating the kindness of the Academicians in giving him time to reflect upon the unreasonableness, not to say rudeness, of making public statements in opposition to the views of some of the most distinguished of their body, seems bitterly to have resented the treatment he met with. For he sent all further communications to the Royal Society of London, which never had, and it is to be hoped never will have, anything of an academic constitution; and finally he took himself off to Guadaloupe, and became lost to science altogether.

Fifteen or sixteen years after the date of Peyssonel's suppressed paper, the Abbé Trembley published his wonderful researches upon the fresh-water *Hydra*. Bernard de Jussieu and Guettard followed them up by like inquiries upon the marine sea-anemones and corallines; Réaumur, convinced against his will of the entire justice of Peyssonel's views, adopted them, and made him a half-and-half apology in the preface to the next published volume of the "Mémoires pour servir à l'Histoire des Insectes;" and, from this time forth, Peyssonel's doctrine that corals are the work of animal organisms has been part of the body of established scientific truth.

Peyssonel, in the extract from his memoir already cited, compares the flower-like animal of the coral to a "poulpe," which is the French form of the name "polypus," — "the many-footed," — which the ancient naturalists gave to the soft-bodied cuttlefishes, which, like the coral animal, have eight arms, or tentacles, disposed around a central mouth. Réaumur, admitting the analogy indicated by Peyssonel, gave the name of *polypes*, not only to the sea-anemone, the coral animal, and the fresh-water *Hydra*, but to what are now known as the *Polyzoa*, and he termed the skeleton which they fabricate a "*polypier*," or "polypidom."

The progress of discovery, since Réaumur's time,

has made us very completely acquainted with the structure and habits of all these polypes. We know that, among the sea-anemones and coral-forming animals, each poylpe has a mouth leading to a stomach, which is open at its inner end, and thus communicates freely with the general cavity of the body; that the tentacles placed round the mouth are hollow, and that they perform the part of arms in seizing and capturing prey. It is known that many of these creatures are capable of being multiplied by artificial division, the divided halves growing, after a time, into complete and separate animals; and that many are able to perform a very similar process naturally, in such a manner that one polype may, by repeated incomplete divisions, give rise to a sort of sheet, or turf, formed by innumerable connected, and yet independent, descendants. Or, what is still more common, a polype may throw out buds, which are converted into polypes, or branches bearing polypes, until a tree-like mass, sometimes of very considerable size, is formed.

This is what happens in the case of the red coral of commerce. A minute polype, fixed to the rocky bottom of the deep sea, grows up into a branched trunk. The end of every branch and twig is terminated by a polype; and all the polypes are connected together by a fleshy substance, traversed by innumerable canals which place each polype in communication with every other, and carry nourishment to the substance of the supporting stem. It is a sort of natural coöperative store, every polype helping the whole, at the same time as it helps itself. The interior of the stem, like that of the branches, is solidified by the deposition of carbonate of lime in its tissue, somewhat in the same fashion as our own bones are formed of animal matter impregnated with lime salts; and it is this dense skeleton (usually turned red by a peculiar colouring matter) cleared of the soft animal investment, as the hard wood of a tree might be stripped of its bark, which is the red coral.

In the case of the red coral, the hard skeleton belongs to the interior of the stem and branches only; but in the commoner white corals, each polype has a complete skeleton of its own. These polypes are sometimes solitary, in which case the whole skeleton is represented by a single cup, with partitions radiating from its centre to its circumference. When the polypes formed by budding or division remain associated, the polypidom is sometimes made up of nothing but an aggregation of these cups, while at other times the cups are at once separated and held together, by an intermediate substance, which represents the branches of the red coral. The red coral polype again is a comparatively rare animal, inhabiting a limited area, the skeleton of which has but a very insignificant mass; while the white corals are very common, occur in almost all seas, and form skeletons which are sometimes extremely massive.

With a very few exceptions, both the red and the white coral polypes are, in their adult state, firmly adherent to the sea-bottom; nor do their buds naturally become detached and locomotive. But, in addition to budding and division, these creatures possess the more ordinary methods of multiplication; and, at particular seasons, they give rise to numerous eggs of minute size. Within these eggs the young are formed, and they leave the egg in a condition which has no sort of resemblance to the perfect animal. It is, in fact, a minute oval body, many hundred times smaller than the full grown creature, and it swims about with great activity by the help

of multitudes of little hair-like filaments, called cilia, with which its body is covered. These cilia all lash the water in one direction, and so drive the little body along as if it were propelled by thousands of extremely minute paddles. After enjoying its freedom for a longer or shorter time, and being carried either by the force of its own cilia, or by currents which bear it along, the embryo coral settles down to the bottom, loses its cilia, and becomes fixed to the rock, gradually assuming the polype form and growing up to the size of its parent. As the infant polypes of the coral may retain this free and active condition for many hours, or even days, and as a tidal or other current in the sea may easily flow at the speed of two or even more miles in an hour, it is clear that the embryo must often be transported to very considerable distances from the parent. And it is easily understood how a single polype, which may give rise to hundreds, or perhaps thousands, of embryos, may, by this process of partly active and partly passive migration, cover an immense surface with its offspring.

The masses of coral which may be formed by the assemblages of polypes which spring by budding, or by dividing, from a single polype, occasionally attain very considerable dimensions. Such skeletons are sometimes great plates, many feet long and several feet in thickness; or they may form huge half globes, like the brainstone corals, or may reach the magnitude of stout shrubs or even small trees. There is reason to believe that such masses as these take a long time to form, and hence that the age a polype tree, or polype turf, may attain, may be considerable. But, sooner or later, the coral polypes, like all other things, die; the soft flesh decays, while the skeleton is left as a stony mass at the bottom of the sea, where it retains its integrity for a longer or a shorter time, according as its position affords more or less protection from the wear and tear of the waves.

The polypes which give rise to the white coral are found, as has been said, in the seas of all parts of the world; but in the temperate and cold oceans they are scattered and comparatively small in size, so that the skeletons of those which die do not accumulate in any considerable quantity. But it is otherwise in the greater part of the ocean which lies in the warmer parts of the world, comprised within a distance of about eighteen hundred miles on each side of the equator. Within the zone thus bounded, by far the greater part of the ocean is inhabited by coral polypes, which not only form very strong and large skeletons, but associate together into great masses, like the thickets and the meadow turf, or, better still, the accumulations of peat, to which plants give rise on dry land. These masses of stony matter, heaped up beneath the waters of the ocean, become as dangerous to mariners as so much ordinary rock, and to these, as to the common rock ridges, the seaman gives the name of "reefs."

Such coral reefs cover many thousand square miles in the Pacific and in the Indian Oceans. There is one reef, or rather great series of reefs, called the Barrier Reef, which stretches, almost continuously, for more than eleven hundred miles off the east coast of Australia. Multitudes of the islands in the Pacific are either reefs themselves, or are surrounded by reefs. The Red Sea is in many parts almost a maze of such reefs, and they abound no less in the West Indies, along the coast of Florida, and even as far north as the Bahama Islands. But it is a very remarkable circumstance that, within the area of what we may call the "coral zone," there

are no coral reefs upon the west coast of America, nor upon the west coast of Africa; and it is a general fact that the reefs are interrupted, or absent, opposite the mouths of great rivers. The causes of this apparent caprice in the distribution of coral reefs are not far to seek. The polypes which fabricate them require for their vigorous growth a temperature which must not fall below 68° Fahrenheit all the year round, and this temperature is only to be found within the distance on each side of the equator which has been mentioned, or thereabouts. But even within the coral zone this degree of warmth is not everywhere to be had. On the west coast of America, and on the corresponding coast of Africa, the currents of cold water from the icy regions which surround the South Pole set northward, and it appears to be due to their cooling influence that the sea in these regions is free from the reef builders. Again, the coral polypes cannot live in water which is rendered brackish by floods from the land, or which is perturbed by mud from the same source, and hence it is that they cease to exist opposite the mouths of rivers, which damage them in both these ways.

Such is the general distribution of the reef-building corals, but there are some very interesting and singular circumstances to be observed in the conformation of the reefs, when we consider them individually. The reefs, in fact, are of three different kinds; some of them stretch out from the shore, almost like a prolongation of the beach, covered only by shallow water, and in the case of an island, surrounding it like a fringe of no considerable breadth. These are termed "fringing reefs." Others are separated by a channel which may attain a width of many miles, and a depth of twenty or thirty fathoms or more, from the nearest land; and when this land is an island, the reef surrounds it like a low wall, and the sea between the reef and the land is, as it were, a moat inside this wall. Such reefs as these are called "encircling" when they surround an island; and "barrier" reefs, when they stretch parallel with the coast of a continent. In both these cases there is ordinary dry land inside the reef, and separated from it only by a narrower or a wider, a shallower or a deeper, space of sea, which is called a "lagoon," or "inner passage." But there is a third kind of reef, of very common occurrence in the Pacific and Indian Oceans, which goes by the name of "atoll." This is, to all intents and purposes, an encircling reef, without anything to encircle; or, in other words, without an island in the middle of its lagoon. The atoll has exactly the appearance of a vast, irregularly oval, or circular, breakwater, enclosing smooth water in its midst. The depth of the water in the lagoon rarely exceeds twenty or thirty fathoms, but, outside the reef, it deepens with great rapidity to two hundred or three hundred fathoms. The depth immediately outside the barrier, or encircling, reefs, may also be very considerable; but, at the outer edge of a fringing reef, it does not amount usually to more than twenty or twenty-five fathoms; in other words, from one hundred and twenty to one hundred and fifty feet.

Thus, if the water of the ocean should be suddenly drained away, we should see the atolls rising from the sea-bed like vast truncated cones, and resembling so many volcanic craters, except that their sides would be steeper than those of an ordinary volcano. In the case of the encircling reefs, the cone, with the enclosed island, would look like Vesuvius with Monte Nuovo within the old crater of Somma; while, finally, the island with a fringing reef would have the appearance of an ordinary hill, or mountain, girded by a vast parapet, within which would lie a shallow moat. And the dry bed of the Pacific might afford grounds for an inhabitant of the moon to speculate upon the extraordinary subterranean activity to which these vast and numerous "craters" bore witness!

When the structure of a fringing reef is investigated, the bottom of the lagoon is found to be covered with fine whitish mud, which results from the breaking up of the dead corals. Upon this muddy floor there lie, here and there, growing corals, or occasionally great blocks of dead coral, which have been torn by storms from the outer edge of the reef, and washed into the lagoon. Shellfish and worms of various kinds abound; and fish, some of which prey upon the coral, sport in the deeper pools. But the corals which are to be seen growing in the shallow waters of the lagoon are of a different kind from those which abound on the outer edge of the reef, and of which the reef is built up. Close to the seaward edge of the reef, over which, even in calm weather, a surf almost always breaks, the coral rock is encrusted with a thick coat of a singular vegetable organism, which contains a great deal of lime — the so-called *Nullipora*. Beyond this, in the part of the edge of the reef which is always covered by the breaking waves, the living, true, reef-polypes make their appearance; and, in different forms, coat the steep seaward face of the reef to a depth of one hundred or even one hundred and fifty feet. Beyond this depth the sounding-lead rests, not upon the wall-like face of the reef, but on the ordinary shelving sea-bottom. And the distance to which a fringing reef extends from the land corresponds with that at which the sea has a depth of twenty or five-and-twenty fathoms.

If, as we have supposed, the sea could be suddenly withdrawn from around an island provided with a fringing reef, such as the Mauritius, the reef would present the aspect of a terrace, its seaward face, one hundred feet or more high, blooming with the animal flowers of the coral, while its surface would be hollowed out into a shallow and irregular moat-like excavation.

The coral mud, which occupies the bottom of the lagoon, and with which all the interstices of the coral skeletons which accumulate to form the reef are filled up, does not proceed from the washing action of the waves alone; innumerable fishes, and other creatures which prey upon the coral, add a very important contribution of finely-triturated calcareous matter; and the corals and mud becoming incorporated together, gradually harden and give rise to a sort of limestone rock, which may vary a good deal in texture. Sometimes it remains friable and chalky, but, more often, the infiltration of water, charged with carbonic acid, dissolves some of the calcareous matter, and deposits it elsewhere in the interstices of the nascent rock, thus glueing and cementing the particles together into a hard mass; or it may even dissolve the carbonate of lime more extensively, and re-deposit it in a crystalline form. On the beach of the lagoon, where the coral sand is washed into layers by the action of the waves, its grains become thus fused together into strata of a limestone, so hard that they ring when struck with a hammer, and inclined at a gentle angle, corresponding with that of the surface of the beach. The hard parts of the many animals which live upon the reef become imbedded in this coral limestone, so that a block may be full of shells of bivalves and univalves, or of sea-

urchins; and even sometimes encloses the eggs of turtles in a state of petrification. The active and vigorous growth of the reef goes on only at the seaward margins, where the polypes are exposed to the wash of the surf, and are thereby provided with an abundant supply of air and of food. The interior portion of the reef may be regarded as almost wholly an accumulation of dead skeletons. Where a river comes down from the land there is a break in the reef, for the reasons which have been already mentioned.

The origin and mode of formation of a fringing reef, such as that just described, are plain enough. The embryos of the coral polypes have fixed themselves upon the submerged shore of the island, as far out as they could live, namely, to a depth of twenty or twenty-five fathoms. One generation has succeeded another, building itself up upon the dead skeletons of its predecessor. The mass has been consolidated by the infiltration of coral mud, and hardened by partial solution and redeposition, until a great rampart of coral rock one hundred or one hundred and fifty feet high on its seaward face has been formed all round the island, with only such gaps as result from the outflow of rivers, in the place of sally-ports.

The structure of the rocky accumulation in the encircling reefs and in the atolls is essentially the same as in the fringing reef. But, in addition to the differences of depth inside and out, they present some other peculiarities. These reefs, and especially the atolls, are usually interrupted at one part of their circumference, and this part is always situated on the leeward side of the reef, or that which is the more sheltered side. Now, as all these reefs are situated within the region in which the tradewinds prevail, it follows that, on the north side of the equator, where the trade-wind is a northeasterly wind, the opening of the reef is on the southwest side: while in the southern hemisphere, where the trade-winds blow from the southeast, the opening lies to the northwest. The curious practical result follows from this structure, that the lagoons to these reefs really form admirable harbours, if a ship can only get inside them. But the main difference between the encircling reefs and the atolls, on the one hand, and the fringing reefs on the other, lies in the fact of the much greater depth of water on the seaward faces of the former. As a consequence of this fact, the whole of this face is not, as it is in the case of the fringing reef, covered with living coral polypes. For, as we have seen, these polypes cannot live at a greater depth than about twenty-five fathoms; and actual observation has shown that while, down to this depth, the sounding-lead will bring up branches of live coral from the outer wall of such a reef, at a greater depth it fetches to the surface nothing but dead coral and coral sand. We must, therefore, picture to ourselves an atoll, or an encircling reef, as fringed for one hundred feet, or more, from its summit, with coral polypes busily engaged in fabricating coral; while, below this comparatively narrow belt, its surface is a bare and smooth expanse of coral sand, supported upon and within a core of coral limestone. Thus, if the bed of the Pacific were suddenly laid bare, as was just now supposed, the appearance of the reef-mountains would be exactly the reverse of that presented by many high mountains on land. For these are white with snow at the top, while their bases are clothed with an abundant and gaudily-coloured vegetation. But the coral cones would look grey and barren below, while their summits would be gay with a richly-coloured parterre of flower-like coral polypes.

The practical difficulties of sounding upon, and of bringing up portions of, the seaward face of an atoll or of an encircling reef, are so great, in consequence of the constant and dangerous swell which sets towards it, that no exact information concerning the depth to which the reefs are composed of coral has yet been obtained. There is no reason to doubt, however, that the reef-cone has the same structure from its summit to its base, and that its sea-wall is throughout mainly composed of dead coral.

And now arises a serious difficulty. If the coral polypes cannot live at a greater depth than one hundred or one hundred and fifty feet, how can they have built up the base of the reef-cone, which may be two thousand feet, or more, below the surface of the sea?

In order to get over this objection, it was at one time supposed that the reef-building polypes had settled upon the summits of a chain of submarine mountains. But what is there in physical geography to justify the assumption of the existence of a chain of mountains stretching for one thousand miles or more, and so nearly of the same height, that none should rise above the level of the sea, nor fall one hundred and fifty feet below that level?

How, again, on this hypothesis, are atolls to be accounted for, unless, as some have done, we take refuge in the wild supposition that every atoll corresponds with the crater of a submarine volcano? And what explanation does it afford of the fact that, in some parts of the ocean, only atolls and encircling reefs occur, while others present none but fringing reefs?

These and other puzzling facts remained insoluble until the publication, in the year 1840, of Mr. Darwin's famous work on coral reefs; in which a key was given to all the difficult problems connected with the subject, and every difficulty was shown to be capable of solution by deductive reasoning from a happy combination of certain well-established geological and biological truths. Mr. Darwin, in fact, showed that, so long as the level of the sea remains unaltered in any area in which coral reefs are being formed, or if the level of the sea relatively to that of the land is falling, the only reefs which can be formed are fringing reefs. While if, on the contrary, the level of the sea is rising relatively to that of the land, at a rate not faster than that at which the upward growth of the coral can keep pace with it, the reef will gradually pass from the condition of a fringing, into that of an encircling or barrier reef. And, finally, that if the relative level of the sea rise so much that the encircled land is completely submerged, the reef must necessarily pass into the condition of an atoll.

For, suppose the relative level of the sea to remain stationary, after a fringing reef has reached that distance from the land at which the depth of water amounts to one hundred and fifty feet. Then the reef cannot extend seaward by the migration of coral germs, because these coral germs would find the bottom of the sea to be too deep for them to live in. And the only manner in which the reef could extend outwards, would be by the gradual accumulation, at the foot of its seaward face, of a talus of coral fragments torn off by the violence of the waves, which talus might, in course of time, become high enough to bring its upper surface within the limits of coral growth, and in that manner provide a sort of factitious sea-bottom upon

which the coral embryos might perch. If, on the other hand, the level of the sea were slowly and gradually lowered, it is clear that the parts of its bottom originally beyond the limit of coral growth would gradually be brought within the required distance of the surface, and thus the reef might be indefinitely extended. But this process would give rise neither to an encircling reef nor to an atoll, but to a broad belt of upheaved coral rock, increasing the dimensions of the dry land, and continuous seawards with the fresh fringing reef.

Suppose, however, that the sea-level rose instead of falling, at the same slow and gradual rate at which we know it to be rising in some parts of the world, — not more, in fact, than a few inches, or, at most, a foot or two, in a hundred years. Then, while the reef would be unable to extend itself seaward, the sea-bottom outside it being gradually more and more removed from the depth at which the life of the coral polypes is possible, it would be able to grow upwards as fast as the sea rose. But the growth would take place almost exclusively around the circumference of the reef, this being the only region in which the coral polypes would find the conditions favourable for their existence. The bottom of the lagoon would be raised, in the main, only by the coral *débris* and coral mud, formed in the manner already described; consequently, the margins of the reef would rise faster than the bottom, or, in other words, the lagoon would constantly become deeper. And, at the same time, it would gradually increase in breadth; as the rising sea, covering more of the land, would occupy a wider space between the edge of the reef and what remained of the land. Thus the rising sea would eventually convert a large island with a fringing reef into a small island surrounded by an encircling reef. And it will be obvious that when the rising of the sea has gone so far as completely to cover the highest points of the island, the reef will have passed into the condition of an atoll.

But how is it possible that the relative level of the land and sea should be altered to this extent? Clearly, only in one of two ways: either the sea must have risen over those areas which are now covered by atolls and encircling reefs; or, the land upon which the sea rests must have been depressed to a corresponding extent.

If the sea has risen, its rise must have taken place over the whole world simultaneously, and it must have risen to the same height over all parts of the coral zone. Grounds have been shown for the belief that the general level of the sea may have been different at different times; it has been suggested, for example, that the accumulation of ice about the poles during one of the cold periods of the earth's history necessarily implies a diminution in the volume of the sea proportioned to the amount of its water thus permanently locked up in the Arctic and Antarctic ice-cellars; while, in the warm periods, the greater or less disappearance of the polar ice-cap implies a corresponding addition of water to the ocean. And no doubt this reasoning must be admitted to be sound in principle; though it is very hard to say what practical effect the additions and subtractions thus made have had on the level of the ocean; inasmuch as such additions and subtractions might be either intensified or nullified, by contemporaneous changes in the level of the land. And no one has yet shown that any such great melting of polar ice, and consequent raising of the level of the water of the ocean, has taken place since the existing atolls began to be formed.

In the absence of any evidence that the sea has ever risen to the extent required to give rise to the encircling reefs and the atolls, Mr. Darwin adopted the opposite hypothesis, viz., that the land has undergone extensive and slow depression in those localities in which these structures exist.

It seems, at first, a startling paradox, to suppose that the land is less fixed than the sea; but that such is the case is the uniform testimony of geology. Beds of sandstone or limestone, thousands of feet thick, and all full of marine remains, occur in various parts of the earth's surface, and prove, beyond a doubt, that when these beds were formed, that portion of the sea-bottom which they then occupied underwent a slow and gradual depression to a distance which cannot have been less than the thickness of those beds, and may have been very much greater. In supposing, therefore, that the great areas of the Pacific and of the Indian Ocean, over which atolls and encircling reefs are found scattered, have undergone a depression of some hundreds, or, it may be, thousands of feet, Mr. Darwin made a supposition which had nothing forced or improbable, but was entirely in accordance with what we know to have taken place over similarly extensive areas, in other periods of the world's history. But Mr. Darwin subjected his hypothesis to an ingenious indirect test. If his view be correct, it is clear that neither atolls, nor encircling reefs, should be found in those portions of the ocean in which we have reason to believe, on independent grounds, that the sea-bottom has long been either stationary, or slowly rising. Now it is known that, as a general rule, the level of the land is either stationary, or is undergoing a slow upheaval, in the neighborhood of active volcanoes; and, therefore, neither atolls nor encircling reefs ought to be found in regions in which volcanoes are numerous and active. And this turns out to be the case. Appended to Mr. Darwin's great work on coral reefs, there is a map on which atolls and encircling reefs are indicated by one colour, fringing reefs by another, and active volcanoes by a third. And it is at once obvious that the lines of active volcanoes lie around the margins of the areas occupied by the atolls and the encircling reefs. It is exactly as if the upheaving volcanic agencies had lifted up the edges of these great areas, while their centres had undergone a corresponding depression. An atoll area may, in short, be pictured as a kind of basin, the margins of which have been pushed up by the subterranean forces, to which the craters of the volcanoes have, at intervals, given vent.

Thus we must imagine the area of the Pacific now covered by the Polynesian Archipelago, as having been, at some former time, occupied by large islands, or, may be, by a great continent, with the ordinarily diversified surface of plain, and hill, and mountain chain. The shores of this great land were doubtless fringed by coral reefs; and, as it slowly underwent depression, the hilly regions, converted into islands, became, at first, surrounded by fringing reefs, and then, as depression went on, these became converted into encircling reefs, and these, finally, into atolls, until a maze of reefs and coral-girdled islets took the place of the original land masses.

Thus the atolls and the encircling reefs furnish us with clear, though indirect, evidence of changes in the physical geography of large parts of the earth's surface; and even, as my lamented friend, the late Professor Jukes, has suggested, give us indications of the manner

in which some of the most puzzling facts connected with the distribution of animals have been brought about. For example, Australia and New Guinea are separated by Torres Straits, a broad belt of sea one hundred or one hundred and twenty miles wide. Nevertheless, there is in many respects a curious resemblance between the land animals which inhabit New Guinea and the land animals which inhabit Australia. But, at the same time, the marine shellfish which are found in the shallow waters of the shores of New Guinea are quite different from those which are met with upon the coasts of Australia. Now, the eastern end of Torres Straits is full of atolls, which, in fact, form the northern termination of the Great Barrier Reef which skirts the eastern coast of Australia. It follows, therefore, that the eastern end of Torres Straits is an area of depression, and it is very possible, and on many grounds highly probable, that, in former times, Australia and New Guinea were directly connected together, and that Torres Straits did not exist. If this were the case, the existence of cassowaries and of marsupial quadrupeds, both in New Guinea and in Australia, becomes intelligible; while the difference between the littoral molluscs of the north and the south shores of Torres Straits is readily explained by the great probability that, when the depression in question took place, and what was, at first, an arm of the sea became converted into a strait separating Australia from New Guinea, the northern shore of this new sea became tenanted with marine animals from the north, while the southern shore was peopled by immigrants from the already existing marine Australian fauna.

Inasmuch as the growth of the reef depends upon that of successive generations of coral polypes, and as each generation takes a certain time to grow to its full size, and can only separate its calcareous skeleton from the water in which it lives at a certain rate, it is clear that the reefs are records not only of changes in physical geography, but of the lapse of time. It is by no means easy, however, to estimate the exact value of reef-chronology, and the attempts which have been made to determine the rate at which a reef grows vertically have yielded anything but precise results. A cautious writer, Mr. Dana, whose extensive study of corals and coral reefs makes him an eminently competent judge, states his conclusion in the following terms: —

"The rate of growth of the common branching madrepore is not over one and a half inches a year. As the branches are open, this would not be equivalent to more than half an inch in height of solid coral for the whole surface covered by the madrepore; and, as they are also porous, to not over three-eighths of an inch of solid limestone. But a coral plantation has large bare patches without corals, and the coral sands are widely distributed by currents, part of them to depths over one hundred feet where there are no living corals; not more than one-sixth of the surface of a reef region is, in fact, covered with growing species. This reduces the three-eighths to *one-sixteenth.* Shells and other organic relics may contribute one-fourth as much as corals. At the outside, the average upward increase of the whole reef-ground per year would not exceed *one-eighth* of an inch.

"Now some reefs are at least two thousand feet thick, which at one-eighth of an inch a year, corresponds to one hundred and ninety-two thousand years." [1]

[1] Dana, *Manual of Geology*, p. 591.

Halve, or quarter, this estimate if you will, in order to be certain of erring upon the right side, and still there remains a prodigious period during which the ancestors of existing coral polypes have been undisturbedly at work; and during which, therefore, the climatal conditions over the coral area must have been much what they are now.

And all this lapse of time has occurred within the most recent period of the history of the earth. The remains of reefs formed by coral polypes of different kinds from those which exist now, enter largely into the composition of the limestones of the Jurassic period; and still more widely different coral polypes have contributed their quota to the vast thickness of the carboniferous and Devonian strata. Then as regards the latter group of rocks in America, the high authority already quoted tells us: —

"The Upper Helderberg period is eminently the coral reef period of the palæozoic ages. Many of the rocks abound in coral, and are as truly coral reefs as the modern reefs of the Pacific. The corals are sometimes standing on the rocks in the position they had when growing: others are lying in fragments, as they were broken and heaped by the waves; and others were reduced to a compact limestone by the finer trituration before consolidation into rock. This compact variety is the most common kind among the coral reef rocks of the present seas; and it often contains but few distinct fossils, although formed in water that abounded in life. At the fall of the Ohio, near Louisville, there is a magnificent display of the old reef. Hemispherical *Favosites,* five or six feet in diameter, lie there nearly as perfect as when they were covered by their flower-like polypes; and besides these, there are various branching corals, and a profusion of *Cyathophyllia*, or cup-corals." [1]

Thus, in all the great periods of the earth's history of which we know anything, a part of the then living matter has had the form of polypes, competent to separate from the water of the sea the carbonate of lime necessary for their own skeletons. Grain by grain, and particle by particle, they have built up vast masses of rock, the thickness of which is measured by hundreds of feet, and their area by thousands of square miles. The slow oscillations of the crust of the earth, producing great changes in the distribution of land and water, have often obliged the living matter of the coral-builders to shift the locality of its operations; and, by variation and adaptation to these modifications of condition, its forms have as often changed. The work it has done in the past is, for the most part, swept away, but fragments remain, and, if there were no other evidence, suffice to prove the general constancy of the operations of Nature in this world, through periods of almost inconceivable duration.

[1] Dana, *Manual of Geology*, p. 272.

NOTES

AUTOBIOGRAPHY

PAGE 1

Autobiography : Huxley's account of this sketch, written in 1889, is as follows: "A man who is bringing out a series of portraits of celebrities, with a sketch of their career attached, has bothered me out of my life for something to go with my portrait, and to escape the abominable bad taste of some of the notices, I have done that."

pre-Boswellian epoch: the time before Boswell. James Boswell (1740–1795) wrote the famous *Life of Samuel Johnson*. Mr. Leslie Stephen declares that this book "became the first specimen of a new literary type." "It is a full-length portrait of a man's domestic life with enough picturesque detail to enable us to see him through the eyes of private friendship. . . ." A number of biographers since Boswell have imitated his method; and Leslie Stephen believes that "we owe it in some degree to his example that we have such delightful books as Lockhart's *Life of Scott* or Mr. Trevelyan's *Life of Macaulay*."

"Bene qui latuit, bene vixit": from Ovid. He who has kept himself well hidden, has lived well.

PAGE 4

Prince George of Cambridge : the grandson of King George III, second Duke of Cambridge, and Commander-in-chief of the British Army.

Mr. Herbert Spencer (1820–1903): a celebrated English philosopher and powerful advocate of the doctrine of evolution. Spencer is regarded as one of the most profound thinkers of modern times. He was one of Huxley's closest friends.

PAGE 5

in partibus infidelium : in the domain of the unbelievers.

PAGE 6

"sweet south upon a bed of violets." Cf. *Twelfth Night*, Act I, sc. I, l. 5.

> O, it came o'er my ear like the sweet sound
> That breathes upon a bank of violets,
> Stealing and giving odour.

For the reading "sweet south" instead of "sweet sound," see Rolfe's edition of *Twelfth Night*.

PAGE 7

"Lehrjahre" : apprenticeship.