vertical circle with it, while for the minimum both stars must be at the same altitude. M. Lœwy then finds that the greatest variation of refraction will be obtained with an angle of 30° for the double mirror, but as with this there would be (for the latitude of Paris) a minimum interval of 6h. 35m. between the two epochs of observation, he prefers to take an angle of 45° for the double mirror, sacrificing only 15″ in the effect of refraction, while reducing the interval between the observations to 4h. 44m. This is the minimum value of the interval found by selecting the pair of stars so that their common zenith distance at the second epoch is equal to the angle of the double mirror, or half the angular distance between the two stars.

The geometrical conditions thus found by M. Lœwy to give the maximum effect in the minimum interval of time between the observations may be somewhat modified in practice, provided the angular distance between the stars does not differ by more than a few minutes from twice the angle of the double mirror. M. Lœwy has thus been able to find some twenty pairs of bright stars suitable for the determination of refraction by this method. In its practical form the method consists in the measurement of the angular distance between a pair of stars 90° apart when one of the stars is near the horizon and the other near the zenith, and again when both the stars are at about the same altitude. It is not necessary that at the former epoch the low star should be very near the horizon, for, as M. Lœwy points out, observations may be advantageously continued till the altitude is nearly 20°, and thus the constant of refraction may be determined from observations which are practically unaffected by any uncertainty in the law of refraction.

It will readily be understood that the observation of the low star may be made either when it is rising or when it is setting. In the latter case the observation of the stars at equal altitude would precede that for which one of the stars is setting. By combining the observations of two pairs of stars chosen so that the first pair is rising when the effect of refraction on the second is a minimum, and that the first pair is at the minimum when the second pair is setting, the influence of any change in the angle of the double mirror will be eliminated by taking the mean of the two determinations, while the difference of these will give four times the change of angle in the interval, thus affording a precise determination of any such change, if it exists.

Various other methods are proposed by M. Lœwy for determining the refraction at any altitude without assuming its law of variation. These methods, however, appear to involve practical difficulties, as they either assume the absence of irregular variations in the refraction at an altitude of 10°, or require the construction of several double mirrors with different angles. They may be considered as supplementing the first method; and they are of interest as giving a direct measure of refraction independently of any theory.

The practical determination of the constants of aberration and refraction by the new method is being carried out by M. Lœwy and M. P. Puiseux with the equatorial *coudé* of the Paris Observatory, and the series of observations made during the past twelve months confirms in the most satisfactory manner the theoretical conclusions. M. Lœwy finds that the variations of the distances are really free from systematic errors, and he considers that the constant of refraction will be more accurately determined from a few nights' observations with his new method than from years of meridian observations.

In conclusion, I can only allude in the briefest terms to the other important researches for which astronomers are indebted to M. Lœwy. The following is a summary of the other new methods of instrumental research which M. Lœwy has devised in the last few years:—

(1) A method for determining the flexure of transit-circles at various zenith distances by means of an optical apparatus inserted in the central cube. This has been used to find the flexure of two transit-circles at the Paris Observatory, the absolute values of the flexure for the two ends of the telescope and for the axis being independently determined.

(2) A method for obtaining the latitude without making use of the declinations of fundamental stars.

(3) A general method for determining right ascensions without relying on assumed right ascensions of polar stars.

(4) A method for finding on each night the absolute declinations of stars without the necessity for observations of polar stars at upper and lower transit.

(5) Methods for determining directly the two co-ordinates of polar stars without a previous investigation of the instrumental errors.

All these methods except the first are based on the observation of close circumpolar stars in R.A. and N.P.D. out of the meridian at various points of the circles described by them. Conjugate observations either of a single star or of a pair of stars having the same N.P.D. are made with a transit-circle, having a field of view of 2°, at equal intervals (about two hours) before and after meridian passage or before and after passage over the hour-circle of 6h. east or west. The special methods of observation are developed in a series of communications to the French Académie des Sciences made in the years 1883 and 1885, and during the last two years M. Rénan has applied these new methods to a determination of the latitude of the Paris Observatory based on eighty very accurate results.

The account which I have given of M. Lœwy's inventions and researches is necessarily very imperfect, and I have had to pass over many points of interest in the application of his methods. But I trust that the summary I have made will at any rate suffice to show the very high importance of M. Lœwy's labours, and that they fully deserve the recognition which is to-day given to them, whether we have regard to the originality of the methods or to the value of the results which are to be obtained from them.

STRUCTURE, ORIGIN, AND DISTRIBUTION OF CORAL REEFS AND ISLANDS.[1]

THE picturesque beauty of the coral atoll, seated 'mid a waste of troubled waters, with its circlet of living green, its quiet, placid lagoon, and its marvellous submarine zoological gardens, has long been celebrated in the descriptions of voyagers to tropical seas. The attempt to arrive at a correct explanation of the general and characteristic form and features of these reefs and islands has, for an equally long period of time, exercised the ingenuity of thoughtful men.

Coral reefs are the most gigantic and remarkable organic accumulations on the face of the earth. They are met with in certain tropical regions, and are huge masses of carbonate of lime, secreted from ocean waters by myriads of marine organisms. While the great bulk of the reef consists of dead corals, skeletons, and shells, the outer surface is clothed with a living mantle of plants and animals. This is especially the case on the outer and seaward face of the reef, where there are, at all times, myriads upon myriads of outstretched and hungry mouths, and not the least interesting questions connected with a coral reef are those relating to how these hungry mouths are satisfied.

It is to the power of these organisms of secreting carbonate of lime from sea-water—building up and out generation after generation on their dead selves—that the coral reef owes its origin. So wonderful and unique is the result, that combination for a definite end has sometimes been attributed to these reef-builders.

There is, however, another process ever at work in the ocean, in a sense antagonistic to that of secretion of carbonate of lime by organisms, which has much to do in fashioning the more characteristic features of coral reefs. This is the solution of all dead carbonate of lime shells, skeletons, and calcareous *débris*, wherever these are exposed to the action of sea-water. As soon as life loses its hold on the coral structures, and wherever these dead carbonate of lime remains are unprotected by rapid accumulation or crystalline depositions, they are silently, surely, and steadily removed in solution. This appears to be one of the best established oceanographical facts, and any theories concerning the general economy of the ocean which fail to take account of this universal agency are most likely to be at fault. We know something about the rate of solution, probably more than we do about the rate of growth and secretion of carbonate of lime by the coral Polyps. It has been shown that the rate of solution varies with temperature, with pressure, and with the amount of carbonic acid present in the water. It is on the play of these two opposing forces—the one vital and the other chemical—and their varying activity in different regions and under different circumstances, that we rely for the explanation of many oceanographical phenomena, especially many of those connected with oceanic deposits and coral reefs. In some regions there may be more growth, secretion, and deposition of shell and coral materials than solution

[1] Lecture delivered by Dr. John Murray at the Royal Institution on Friday, March 16, 1888. Recently revised by the Author.

by sea-water, and then there results the formation of coral reefs and vast calcareous deposits at the bottom of the ocean. There may be an almost exact balance between these processes. And again, there may be more solution than secretion, as, for instance, in the red clay areas, which occupy the deepest parts of the ocean, and in some coral-reef lagoons.

What is the nature of the foundations of these coral islands, surrounded as they sometimes are by an ocean miles in depth? Why have some elongated reefs no lagoons? Why have most of the lagoons of the smaller atolls been filled up? Why is the circle of land or reef in the perfect atolls only, at most, a few hundred yards in diameter? What is the origin of the lagoon? What relation exists between the depth of the lagoon, its area, and the depth of the water beyond the outer reef? How has the dry land of these islands been formed, provided with a soil, a fauna and a flora? These appear to be the chief questions that demand an answer from any theory of coral island formation.

These coral formations are essentially structures belonging to the great oceans and ocean basins. They are dots of land within the oceanic areas that might be compared or contrasted with the small salt lakes which are scattered over the surface of the continental lands. A rapid survey of some of the more general phenomena of the great oceans may, then, lead to a better appreciation of the problems connected with coral reefs.

The great ocean basins occupy over two-thirds of the earth's surface, and have a mean depth of over two miles. The central portions of these basins, called the abysmal regions, occupy about one-half of the earth's surface, and have a mean depression below the general level of the continents of over three miles. The abysmal regions are vast undulating plains, sometimes rising to less than two miles from the surface of the sea, and again sinking to four and five miles beneath it. Volcanic cones rise singly or in clusters from these great submerged plains. When they shoot above the level of the sea they form single islands, like Ascension and St. Paul's Rocks, or groups, like the Azores, the Sandwich, the Fiji, and the Society Islands. As might have been expected, there are many more of these cones hidden beneath the waves than rise above them. When the *Challenger* sounded along the west coast of Africa, there was no suspicion that between her stations she was sailing over submerged cones. Since then, however, the soundings of telegraph ships have correctly mapped out no less than seven of these peaks between the latitude of Lisbon and the Island of Teneriffe. The depths on the summits of these vary from 12 to 500 fathoms. On one of them, at 400 fathoms, two species of coral (*Lophohelia prolifera* and *Amphihelia oculata*) were growing luxuriantly. Throughout the ocean basins about 300 such submarine cones, rising from great depths up to within depths of from 500 to 10 fathoms from the surface, are already known, or indicated by soundings.

All the physical agencies at work above the lower limit of wave action tend to wear away and level down these cones, and thus to form banks. Graham's Island, thrown up in the Mediterranean in 1831, was 200 feet in height and three miles in circumference, and was washed away in a year or two. The bank left on the spot, at first very shallow, has now 24 feet of water over it. Instances similar to this historical example must often have happened in the great ocean basins. Again, the same agencies produce wide banks around volcanic islands by washing away and spreading out the materials of the softer rocks. Such banks, with depths of less than 60 fathoms, are found extending many miles seawards around some volcanic islands.

On the other hand, all the deeply submerged summits are continually being built up to the lower limit of wave action by the accumulation of the remains of animals which live on them and by the fall of shells upon them from the surface waters. In the Solomon Islands, Dr. Brougham Guppy has shown that there are upraised coral islands with central volcanic cones covered with thick layers of marine deposits; Christmas Island, in the Indian Ocean, is another instance, and similar deposits must now be forming over hundreds of submerged mountains. In this way are foundations prepared for the true reef-building species, which only flourish in the shallower depths.

The bulk of the water of the ocean has a very low temperature; it is ice-cold at the bottom, even under the equator, but on the surface within the tropics there is a relatively thin film of warm water, with a temperature of from 70° to 84° F. This film of warm water is much deeper towards the western parts of the Atlantic and Pacific than it is in the eastern, the reason for this being that the trade winds, which blow continually from the east, carry all the warm surface water to the westward, and draw up cold water from beneath along the western shores of Africa and America to supply the place of that driven westward at the surface. Consequently, there is, at times, a very low temperature, and a great annual range of temperature, along these western shores. This is more clearly shown by the temperatures at 50 and 100 fathoms than by those at the surface. There are no coral reefs along the western shores of Africa and South America, a circumstance evidently connected with the low temperature, wide range, and, more directly, with the food supply, consequent on these conditions. It appears to be a confirmation of this view that, on the eastern shores of Africa, about Cape Guardafui, from off which the south-west monsoon blows for several months in the year, cold water is also drawn to the surface, and there, likewise, are no coral reefs, though they flourish to the north and south of this region.

Coral reefs flourish in mid-ocean and along the eastern shores of the continents, or wherever the coasts are bathed by the warmest and purest currents of water coming directly from the open sea. If we except Bermuda and one or two other outlying reefs, where the temperature may occasionally fall to 66° or 64° F., it may be said that reefs are never found where the surface temperature of the water, at any time of the year, sinks below 70° F., and where the annual range is greater than 12° F. In typical coral reef regions, however, the temperature is higher and the range much less.

The food supply of the coral reef is derived from pelagic oceanic organisms, which exist in the greatest variety and abundance in the surface and sub-surface waters of the ocean. These consist of myriads of Algæ, Rhizopods, Infusorians, Medusæ, Annelids, Molluscs, Crustaceans, Ascidians, and fishes. A very large number of these creatures, within the tropics, secrete carbonate of lime from the ocean to form their shells and skeletons, which, falling to the bottom after death, form the vast oceanic deposits known as Pteropod and Globigerina oozes. In falling to the bottom, they carry down some of the organic matter that composed their living bodies, and thus are the animals which live on the floor of the ocean chiefly supplied with food. Here it may be remarked, incidentally, that the abundance of life at depths of even over two miles is very great. Our small dredges sometimes bring up over sixty species and hundreds of specimens in one haul—of invertebrates and fishes, exclusive of the Protozoa. The pelagic organisms above mentioned oscillate from the surface down to about 80 or 100 fathoms, probably that stratum of the ocean affected by sunlight, and they apparently descend further in regions where the stratum of warm water has a greater depth. Many of the forms rise to the surface in the evening and during calms, and sink again in sunlight and during stormy weather. It is in the evening and when it is calm that this swarming life is most vividly forced on the attention by gorgeous phosphorescent displays. The lime-secreting organisms, like Coccospheres and Rhabdospheres, Foraminifera, Pteropods, and other Molluscs, are much more abundant, both in species and individuals, in the warmest and saltest waters than elsewhere. I have estimated, from tow-net experiments, that at least 16 tons of carbonate of lime, in the form of these shells, exist in a mass of the ocean, in coral-reef regions, one mile square by 100 fathoms in depth. If we take this estimate, which I consider much below the reality, and suppose one-sixteenth of these organisms to die and fall to the bottom each day, then they would take between 400 and 500 years to form a deposit one inch in thickness. I give this calculation more to indicate a method than to give even the roughest approximation to a rate of accumulation of deposits. The experiments were too few to warrant any definite deductions.

The great oceanic currents, moving westward at the rate of several miles an hour, bear these shoals of pelagic organisms on to the face of the reef, where millions of greedy mouths are ready and eager to receive them. The corals and other organisms situated on the outer and windward side of the reef receive the first and best supply; they are thus endowed with a greater amount of energy, and grow faster and more luxuriantly there than on other portions of the reef. The depth at which there is the most constant supply of this food is several fathoms beneath the surface, and there, too, the corals are found in most vigorous growth. It is only a relatively small quantity of this pelagic food that enters the lagoon, the corals that there struggle on in patches being largely supplied with the means of existence from the larvæ of reef-building animals.

So many observations were made during the *Challenger* Expedition on the pelagic fauna inside and outside reefs that there is little, if any, doubt in my mind that the food supply is a most important factor in relation to the growth of corals in the different portions of a reef. Actual observations were made on the feeding of corals at a good many places, as well as numerous observations on the stomach contents. These observations have been confirmed by Alexander Agassiz.

It is as yet impossible to state in what form the lime, which is secreted as carbonate in such enormous quantities by marine organisms exists in the ocean.

Dana, in "Coral and Coral Islands," considers it "unnecessary to inquire whether the lime in sea-water exists as carbonate or sulphate, or whether chloride of calcium takes the place of these. The powers of life may take from the element present whatever results the function of the animal requires."

In connection with this question an interesting series of experiments are being conducted at the Scottish Marine Station, Granton, which go far to prove that the above hypothesis is correct.

The following table shows the average composition of sea-water salts, the acids and bases being combined in the way usually adopted by chemists—

Average Composition of Sea-Salt.

Chloride of sodium	77·758
Chloride of magnesium	10·878
Sulphate of magnesium	4·737
Sulphate of lime	3·600
Sulphate of potash	2·465
Bromide of magnesium	0·217
Carbonate of lime	0·345
	100·000

In the actual ocean water there are probably traces of every known element, and it is impossible to say what is the precise amount of the respective chlorides, sulphates, and carbonates present. Theoretically, every base may be combined with every acid, and the whole solution must be in a continual state of flux as to its internal composition. While the quantity of sea-salts in a given volume of water varies with position, yet it has been shown by hundreds of analyses that the actual ratio of acids and bases—that is, the ratio of the constituents of sea-salts—is constant in waters from all regions and depths, with one very significant exception—that of lime—which is present in slightly greater proportion in deep water.

The total amount of *calcium* in a cubic mile of sea-water is estimated at nearly 2,000,000 tons. The amount of the same element present in a cubic mile of river-water is nearly 150,000 tons. At the rate at which rivers carry down water from the land it is estimated that it would take 680,000 years to pour into the ocean an amount of calcium equal to that now held by the ocean in solution.

The amount of calcium existing in the 40,000,000 square miles of the typical calcareous deposits of the ocean exceeds, however, that at present held in solution if we merely take them to have an average thickness of 30 feet, and from this calculation we might say that, if the secretion and solution of lime in the other regions of the ocean be exactly balanced, and the calcium in the ocean remain always constant, those calcareous deposits of the thickness indicated would require between 600,000 and 700,000 years to accumulate. There is good evidence, however, that the rate of accumulation is much more rapid in some positions.

The lime thus carried down to the sea is originally derived from the decomposition of anhydrous minerals, and comes from the land in the form of carbonate, phosphate, and sulphate of lime—the carbonate being in the greatest abundance in river-water. On the other hand, the sulphate of lime very greatly predominates in sea-water, the carbonates being present in small quantity. We are not in a position to say whether or not the coral Polyps take the whole of the material for their skeletons from the carbonates, as is generally believed, or indeed to say what changes take place during the progress of secretion by organisms.

In the greatest depths of the Pacific coral seas there is striking evidence of the solvent power of ocean water. Our dredges bring up from a depth of three or four miles over a hundred ear-bones of whales and remnants of the dense Ziphioid beaks, but all the larger and more areolar bones of these immense animals have been almost entirely removed by solution. In a single haul there may also be many hundreds of sharks' teeth, some of them larger than the fossil *Carcharodon* teeth, but all that remains of them is the hard dentine. None of the numerous calcareous surface shells reach the bottom, although they are quite as abundant over the red clay areas as over those shallower areas, where they form Globigerina and Pteropod deposits. In consequence of the small amount of detrital material reaching these abysmal areas distant from continents, cosmic metallic spherules, manganese nodules, highly altered volcanic fragments, and zeolitic minerals, are there found in great numbers. Almost all these things are found occasionally in the other regions of the ocean's bed, but their presence is generally masked by the accumulation of other matters. In some regions Radiolarian and Diatom remains are found in the greatest depths, and they too are subject to the solvent power of sea-water, but to a much less extent than carbonate of lime shells.

As we ascend to shallower waters, a few fragments of the thicker-shelled specimens are met with at first; with lesser depths the carbonate of lime shells increase in number, until in the shallower deposits the remains of Pteropods, Heteropods, and the most delicate larval shells are present in the deposit at the bottom. This gradation in the appearance of the shells can be well seen in a series of soundings at different depths around a volcanic cone, such as has been described as forming the base of a coral atoll. There is no known way of accounting for this vertical distribution of these dead shells except by admitting that they have been dissolved away in sinking through the deeper strata of water, or shortly after reaching the bottom; indeed, an examination of the shells themselves almost shows the process in operation. It is rare to find any trace of fish-bones in deposits other than the otoliths.

These considerations, as well as numerous experiments in the laboratory, show that everywhere in the ocean dead or amorphous carbonate of lime structures quickly disappear wherever they are exposed to the action of sea-water, and in investigating the evolution of the general features of coral reefs it is as necessary to take cognizance of this fact as of the secretion of carbonate of lime by organisms. At the same time, too much stress cannot be laid upon the fact that carbonate of lime, although markedly soluble in sea-water in the amorphous form in which it exists in connection with (organic) life, becomes practically insoluble when after the death of the secreting animal it assumes the crystalline state.

In a paper read before the Royal Society of Edinburgh, embodying some of the results of his investigations on the solubility of carbonate of lime under different forms in sea-water, Mr. Irvine remarks, "It is due to this molecular change that coral deposits, shells, and calcareous plants are able to accumulate in the ocean, ultimately to form beds of limestone rocks."

The first stage, then, in the history of a coral island is the preparation of a suitable foundation on the submerged volcanic cones, or along the shores of a volcanic island, or the borders of a continent. In the case of the atoll the cone may have been reduced below the level of the sea by the waves and atmospheric influences, or built up to the lower limit of breaker action by the vast accumulation of organisms on its summit.

A time comes, however, should the peak be situated in a region where the temperature is sufficiently high, and the surface currents contain a suitable quality of food, that the reef-builders fix themselves on the bank. The massive structure which they secrete from ocean water enables them to build up and maintain their position in the very face of ocean currents, of breakers, of the overwhelming and outrageous sea.[1]

"Coral" with the sailor or marine surveyor is usually any carbonate of lime shell or skeleton or their broken-down parts. "Coral" is used by the naturalist in a much more restricted sense: he limits the term to animals classed as Madrepores, Hydrocorallines, and Alcyonarians. The animals belonging to the first two of these orders comprise those included under the vague term of reef corals. Besides these, however, very many other classes of animals contribute to the building up of coral

[1] Dr. Brougham Guppy says, "History can afford us no clue to the first appearance or the age of reefs; yet in the myths of the Pacific Islanders we find that the savage inhabitants of these regions regard the history of a coral atoll as commencing with the submerged shoal, which through the agency of God-like heroes is brought up by their fish-hooks to the surface."—Paper, Vict. Inst.

reefs and islands—such are Foraminifera, Sponges, Polyzoa, Annelids, Echinoderms, and Calcareous Algæ. The relative proportions of these different organisms in a reef vary with the region, with the depth, and with the temperature, but members of what are known under the term of reef corals appear always to predominate.

The animals of the true reef-building species resemble the common sea-anemones in structure and size; the individual Polyps may vary from the eighth of an inch in diameter to over a foot. Some of the structures built by colonies may exceed 20 feet in diameter.

There may be great variety in the appearance of submerged reefs as they rise from banks of a different nature, form, and extent, as, indeed, was pointed out long ago by Chamisso. There may be differences due also to the kinds and abundance of deep-sea animals living on such banks, as well as differences due to currents, temperature, and other meteorological conditions.

From the very first the plantations situated on the outer edge will have the advantage, from the more abundant supply of food and the absence of sand in the water, which last more or less injuriously affects those placed towards the interior. Chamisso attributed the existence of the lagoon to the more vigorous growth of the peripherally situated corals of a reef, as compared with those placed towards the middle, and in this he was to a large extent right, but the symmetrical form of the completed atoll is chiefly due to the solution of the dead carbonate of lime structures. The Great Chagos Bank illustrates the irregular way in which such a large bank of coral plantations approaches the surface. When these, however, reach the surface, they assume slowly a more regular outline, those on the outer edge coalesce, and ultimately form a complete ring of coral reef, and the lagoon becomes gradually cleared of its coral patches or islands, for, as the atoll becomes more perfect, the conditions of life within the lagoon become less and less favourable, and a larger quantity of dead coral is removed in solution.

The coral atoll varies greatly in size and form: it is usually more or less circular, horse-shoe shaped, and may be one or over fifty miles in diameter. The breakers spend their fury on the outer edge, and produce what is known as the broad shore platform; but within, trees descend to the very shore of the lagoon, where there is quiet water, and a ship may often enter on the lee side of the atoll and find safe anchorage.

In this connection it is important to bear in mind the relation which exists between the periphery and the superficial area of the lagoon in atolls of different sizes. If the coral plantations which rise from the top of a submerged mountain have an area of one square mile, then on reaching the surface of the waves there will be a shallow depression in the centre owing to the more rapid growth of the outer edge. Such an atoll will have, if it be a square, four miles of outer reef for the supply of coral sand and other *débris*, and these being washed and blown into the one square mile of shallow lagoon it is likely to become filled up, the result being a small island with dry lagoon, in which may be found deposits of sulphate of lime, magnesian and phosphatic rocks, and guano—all these testifying to the great age of the island and absence of subsidence in the region. It is only atolls with a diameter of less than two miles that thus become filled up. In other and larger plantations, rising from a more extensive bank, the conditions are very different. In this larger atoll—say four miles square—there is now only one mile of outer reef to each square mile of lagoon, instead of four miles of outer reef to the one square mile of lagoon in the smaller atoll. Only one-fourth of the detrital matter and food enters the larger lagoon, from the outside, per square mile of lagoon, and hence there is proportionately less living coral, the solvent agencies predominate, and the lagoon is widened and deepened. Growing seawards on the outer face and dissolving away in the lagoon, the whole expands after the manner of a fairy ring, and the ribbon of reef or land can never in consequence increase beyond a half or three-quarters of a mile in width, it being usually much less. I have recently made a very careful comparison of the latest Admiralty Survey of the lagoon of Diego Garcia with the one made many years ago, and the result appears to me to indicate that the area of the lagoon has considerably increased in the interval, and the average depth is a little greater than formerly, although shallower in some places.

Atolls may occur far away from any other land, but it more frequently happens that they are arranged in linear groups, in this respect resembling volcanic islands. Extensive banks may be crowded with small atolls, like the Northern Maldives; or a bank may be occupied by one great and perfect atoll twenty to forty miles in diameter, like some of the Southern Maldives and the Paumotus. In some instances the large atolls appear to have resulted from the growth and coalescence of the smaller marginal atolls; especially does this seem to have been the case with the large Southern Maldives.

The outer slopes vary greatly in different reefs, and in different parts of the same reef. When there is deep water beyond, the reef very often extends out with a gentle slope to a depth of 25 to 40 fathoms, and is studded with living coral, the bosses and knobs becoming larger in the deeper water farthest from the reef, where there are great overhanging cliffs, which eventually fall away by their own weight, and form a talus on which the reef may proceed further outwards. Occasionally there is a very steep descent almost at once from the outer edge. Thus, the deeper the water beyond, the more slowly will the reef extend seawards. In reefs with a very gentle slope outside, the corals are frequently overhanging at depths of 6 or 7 fathoms, for in these instances the lower part of the sea-face of the reef is rendered unsuitable for vigorous growth, in consequence of the sand which is carried in by waves coming over the comparatively shallow depths outside; in these cases, lines of growing corals, or a submerged barrier, are sometimes met with in deep water some distance seawards from the edge of the reef.

As has been stated, the lagoon in many of the smallest atolls has been filled up, but this never appears to happen in atolls with a diameter of over two miles unless there be distinct evidence of upheaval. In perfectly-formed atolls—that is, those in which the reefs are nearly continuous throughout—the deepest water is found towards the centre of the lagoon, and there is a relation between this depth and the depth of water beyond the outside reefs. In North and South Minerva reefs, in the South Pacific, where the outside depths are very great, there are depths down to 17 fathoms in the lagoons, which are apparently clear of coral heads. Here we may suppose that the central parts of the lagoon have for a long time been exposed to the solvent action of sea-water, owing to the slow lateral growth of the reef as a whole. In the same regions the Elizabeth and Middleton reefs, which are about the same size, have only 4 or 5 fathoms within the lagoons, and the depths outside the reefs are, at the distance of a mile, mostly within the 100-fathom line, and sometimes less than 50 fathoms. There are also many coral heads within the lagoons. Here we may suppose the atolls to be more recent, and to have extended more rapidly than in the case of the Minerva reefs. If the depths beyond the reefs be taken into consideration, then there is usually a direct relation between the depth of the lagoon and its diameter. The greatest depths, even in the largest atolls, do not exceed 50, or at most 60, fathoms; they are usually much less. In atolls which are deeply submerged, or have not yet reached the surface, which have wide and deep openings into lagoon-like spaces, this relation may not exist. In these instances the secretion and deposition of carbonate of lime may be in excess of solution in all parts of the lagoon. It is only when the atoll reaches the surface, becomes more perfect, and its lagoon waters consequently less favourable to growth, that the solution of the dead corals and calcareous *débris* exceeds any secretion and deposition that may take place throughout the whole extent of the lagoon; it is then widened and deepened, and formed into a more or less perfect cup-like depression, unless the lagoon be of small size and is filled up.

The whole of a coral reef is permeated with sea-water like a sponge; as this water is but slowly changed in the interior parts, it becomes saturated, and a deposition of crystalline carbonate of lime frequently takes place in the interstices of the corals and coral *débris*. In consequence of the solution of coral *débris* and the re-deposited lime occupying less space, large cavities are formed, and this process often results in local depressions in some islands, as, for instance, in Bermuda. At many points on a reef where evaporation takes place there is a deposition of amorphous carbonate of lime cementing the whole reef materials into a compact conglomerate-like rock.

The fragments of the various organisms broken off from the outer edge during gales or storms are piled up on the upper surface of the reef, and eventually ground into sand, the result being the formation of a sandy cay or shoal at some distance back from the outer edge of the reef—the first stage in the formation of dry land.

The fragments of pumice thrown up into the ocean during far-distant submarine eruptions, or washed down from volcanic lands, are at all times to be found floating about on the surface of the sea, and these, being cast up on the newly-formed islet, produce, by their disintegration, the clayey materials for the formation of a soil—the red earth of coral islands. Just within the shore platform these pumice fragments are found in a fresh condition, but as the lagoon is approached they disappear, the soil becomes deeper, and the most luxuriant vegetation and largest trees are found close to the edge of the inner waters. The land is seldom continuous around the atoll; it occurs usually in patches. The water passes over the shallow spaces between the islets and through the deeper lagoon entrances, these last being kept open by the strong sand-bearing currents which pass at each tide.

The few species of plants and animals which inhabit these coral islands have been drifted to the new island like the pumice, or carried, many of them maybe, by birds; lastly, savage and civilized man finds there a home.

There is no essential difference between the reefs forming fringing and barrier reefs, and those which are known as atolls. In the former case, the corals have commenced to grow close to the shore, and as they grow outward, a small boat-passage, and then a ship-channel, is carved out between the reef and the shore by tidal scour and the solvent action of the water on the dead parts of the reef: thus, the fringing reef may be converted into a barrier reef; or the barrier may be formed directly by the upward growth of the corals at some distance from the shore. In some instances the corals find a suitable foundation on the banks that surround islands and front continental lands, it may be, at a great distance from the coast, and when they reach the surface they form a distant barrier, which proceeds seawards, ultimately on a talus made up of materials torn from its seaward face.

If the foregoing considerations be just and tenable, then it would appear that all the characteristic features of coral reefs can be produced, alike in stationary areas or in areas of slow elevation and subsidence, by processes continually at work in the ocean at the present time. Slow elevation or subsidence would only modify in a minor way a typical coral atoll or barrier reef, but subsidence in past times cannot be regarded as the cause of the leading characteristics of coral reefs. There are abundant evidences of elevation in coral-reef regions in recent times, but no direct evidence of subsidence. If it has been shown that atoll and barrier reefs can be formed without subsidence, then it is most unlikely that their presence in any way indicates regions of the earth's surface where there have been wide, general, and slow depressions.

According to Mr. Darwin's theory, which has been almost universally accepted during the past half-century, the corals commence to grow close to the shore of an island or continent: as the land slowly sinks, the corals meanwhile grow upwards to the surface of the sea, and a water space—the lagoon channel—is formed between the shore of the island and the encircling reef, the fringing being thus converted into a barrier reef. Eventually, the central island sinks altogether from sight, and the barrier reef is converted into an atoll, the lagoon marking the place where the volcanic or other land once existed. Encircling reefs and atolls are represented as becoming smaller and smaller as the sinking goes on, and the final stage of the atoll is a small coral islet, less than two miles in diameter, with the lagoon filled up and covered with deposits of sea-salts and guano.

It is at once evident that the views now advocated are in almost all respects the reverse of those demanded by Mr. Darwin's theory.

The recent deep-sea investigations do not appear in any way to support the view that large or small islands once filled the spaces now occupied by the lagoon waters, and that the reefs show approximately the position of the shores of a subsided island. The structure of the upraised coral islands, so far as yet examined, appears to lend no support to the Darwinian theory of formation. When we remember that the great growing surface of existing reefs is the seaward face from the sea surface down to 20 or 40 fathoms, that large quantities of coral *débris* must be annually removed from lagoons in suspension and solution, that reefs expand laterally and remain always but a few hundred yards in width, that the lagoons of finished atolls are deepest in the centre, and are relatively shallow compared with the depth of the outer reefs, then it seems impossible, with our present knowledge, to admit that atolls or barrier reefs have ever been developed after the manner indicated by Mr. Darwin' simple and beautiful theory of coral reefs.

DARWIN VERSUS LAMARCK.[1]

AFTER a brief sketch of the life of Lamarck (1744–1829), his theory was stated in his own words as follows:—

"(1) In every animal which has not arrived at maturity, the increased and continued employment of any organ strengthens that organ gradually, develops it, enlarges it, and gives it a power proportional to the duration of its employment: on the other hand, the continued disuse of any organ gradually weakens it, deteriorates it, progressively diminishes its faculties, and finally causes it to disappear.

"(2) Every feature which, under natural conditions, individuals have gained or lost by the action of circumstances to which their race has been for some time exposed—as, for instance, the results of excessive use or disuse of an organ—is preserved in reproduction and transmitted to the offspring, provided that the acquired changes were present in both parents."

The small changes thus produced and transmitted from generation to generation are increased in successive generations by the action of the same causes which originated them, and thus in long periods of time the form and structure of the descendants of an ancestral organism may be completely changed as compared with the form and structure of the ancestor.

Given sufficient time, these small changes can have produced man and the higher animals from simple primitive protoplasmic animalcules.

Prof. Lankester then pointed out the truth of the first law of Lamarck, but mentioned the preliminary objections to Lamarck's theory, which had prevented its acceptance by the naturalists of the first half of this century. He then briefly epitomized Darwin's theory as follows:—

(1) All plants and animals produce offspring which resemble their parents on the whole (heredity); these offspring, however, exhibit also new and individual features differing from those of their parents (congenital variations).

(2) In Nature there is a severe struggle for existence. Only one pair out of the many thousands often produced by a pair of plants or animals survive to maturity, and in their turn produce offspring.

(3) The survivors are those whose congenital variations have enabled them to gain advantage over their fellows.

(4) The surviving forms *may* be almost exactly like their parents, but often a departure from the parental form must be an advantage, however small. Such departure, or variation, when IN-BORN OR CONGENITAL, not only enables its possessor to survive and produce offspring, but is handed on by heredity to that offspring.

(5) A successful congenital variation is intensified in the new generation bred from parents in both of which it had congenitally appeared.

(6) By this process of natural selection of advantageous congenital variations, operating in countless millions of successive generations, the transformation of simple into more elaborate forms of life has been effected.

The real difference between Lamarck's and Darwin's theories was then explained. Congenital variation is an admitted and demonstrable fact; transmission of congenital variations is also an admitted and demonstrable fact. Change of structure acquired during life—as stated by Lamarck—is also a fact, though very limited. But the transmission of these latter changes to offspring is NOT PROVED EXPERIMENTALLY; all experiment tends to prove that they cannot be transmitted. Semper's book on this subject was cited as a failure in the attempt to prove such transmission.

The causes of congenital variations were next discussed, and the "stirring up" of the germ-plasma by the process of fertilization was pointed to as the chief.

Very minute congenital variations can be useful, and, therefore, selected; but congenital variations are not necessarily minute.

The subject of correlated variations was next mentioned, and their great importance pointed out. A mechanical model was used to explain this matter: it represented an antelope in which when the neck is made to elongate the legs simultaneously lengthen, whilst the horns disappear and the tail shortens.

The lecturer then gave examples of the successful explanation

[1] Abstract of a Lecture delivered at the London Institution, Finsbury Circus, on February 14, 1889, by Prof. Ray Lankester, LL.D., F.R.S.