PLATE I.

Phyllastraea tubitex; a, animal, partly expanded.

CORALS

AND

CORAL ISLANDS.

BY

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Third Edition,

WITH VARIOUS EMENDATIONS, LARGE ADDITIONS, THREE NEW MAPS, AND FOUR NEW COLORED PLATES.

"We wandered where the dreamy palm
Murmured above the sleeping wave;
And, through the waters clear and calm,
Looked down into the coral cave."

J. C. P., *U. S. N. Expl. Expd.*

NEW YORK:
DODD, MEAD, AND COMPANY,
753 AND 755 BROADWAY.

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John Wilson and Son, Cambridge.

PREFACE TO THE THIRD EDITION.

THIS third edition of the "Corals and Coral Islands" contains a full discussion of the views and arguments which have recently been brought forward in opposition to the theory of coral reefs proposed by Darwin and explained in the following pages. Besides this, changes and additions have been made in all parts of the work in order to bring it up to date of publication. Moreover, four new maps have been introduced: one, of the Central Pacific; the second, of the large coral-reef region of the Louisiade Archipelago, in the southwest Pacific; the third, a new map of the Florida and Bahama coral-reef banks, from the charts of the United States Hydrographic Department; and the fourth, a copy of part of the Hawaiian Government map of the vicinity of Honolulu, showing the coral reefs off the shores, and the positions of the many artesian borings on this border of Oahu that are throwing light on the thickness of the shore reef.

The work has its value enhanced also by four new colored plates, one representing Actinias of the Pacific, and the others living corals, selected from the author's Atlas of his Exploring Expedition Report on Zoöphytes.

JAMES D. DANA.

NEW HAVEN, CT.,
February 12, 1890.

PREFACE TO THE SECOND EDITION.

In the preparation of this work for a second edition, a few emendations have been made, and new facts introduced from recent publications on the subject. Among the latter, an account is given of the arrangements by MM. Le Clerc and De Benazé, on Tahiti, for marking, in the future, the rate of growth of the Dolphin Shoal or reef.

The Preface to the first edition alludes to some points in which the author differs from Mr. Darwin. The reader will find some additional remarks on these differences in the *American Journal of Science* for October, 1874, called out by the discussion of the subject in the new edition of Mr. Darwin's "Coral Reefs."

New Haven, Conn., *October* 1, 1874.

PREFACE.

THE object in view in the preparation of this work has been to present a popular account of "Corals and Coral Islands," without a sacrifice of scientific precision, or, on the main topic, of fulness. Dry details and technicalities have been avoided so far as was compatible with this restriction, explanations in simple form have been freely added, and numerous illustrations introduced, in order that the subject may have its natural attractiveness to both classes of readers.

I have opened the volume with a chapter on "Corals and Coral makers," describing, under it, the forms and structure of polyps; how they live and grow and hold their own in a world of enemies; how coral-making species secrete their coral; how they multiply, and develop their large clusters, spreading leaves and branching forms, so much like those among plants; and in what seas they thrive, and under what conditions produce the coral plantations.

All this is prefatory to the following part of the volume on Coral Reefs and Islands, which comprises a description of the features and structure of these reef-formations, an account of their mode of accumulation and increase, and a discussion of the origin of the included channels and lagoons, and of the distribution of reefs, together with a review of the facts with reference to their geological bearing.

The observations forming the basis of the work were made in the course of the cruise of the Wilkes Exploring Expedition, around the world, during the four years from 1838 to 1842. The results then obtained are published in my Report on Zoöphytes, which treats at length of Corals and Coral Animals, and in a chapter on Coral Reefs and Islands forming part of my Geological Report.

The opportunities for investigations in this department afforded by the Expedition, were large. We visited a number of the coral islands of the Paumotu Archipelago, to the north of east from Tahiti; also, some of the Society, Navigator, and Friendly Islands, all remarkable for their coral reefs; the Feejee Group, one of the grandest regions of growing corals in the world, where we spent three months; several islands north of the Navigator and Feejee Groups, including the Gilbert or Kingsmill Group; the Sooloo sea, between Borneo and Mindanao, abounding in reefs; and, finally, Singapore, another East India reef-region.

Most agreeable are the memories of events, scenes and labors, connected with the cruise:—of companions in travel, both naval and scientific; of the living things of the sea, gathered each morning by the ship's side, and made the study of the day, foul weather or fair; of coral islands with their groves, and beautiful life, above and within the waters; of exuberant forests, on the mountain islands of the Pacific, where the tree-fern expands its cluster of large and graceful fronds in rivalry with the palm, and eager vines or creepers intertwine and festoon the trees, and weave for them hangings of new foliage and flowers; of lofty precipices, richly draped, even the sternest fronts made to smile and be glad as delights the gay tropics, and alive with waterfalls, gliding, leaping, or plunging, on their way down from the giddy heights, and, as they go, playing out and in amid the foliage; of gorges explored, mountains and volcanic cones climbed, and a burning crater penetrated a thousand feet down to its boiling depths; and, finally,—beyond all these,—of man emerging from the depths of barbarism through christian self-denying, divinely-aided, effort, and churches and school-houses standing as central objects of interest and influence in a native village.

On the other hand, there were occasional events not so agreeable.

Even the beauty of natural objects had, at times, a dark back-ground. When, for example, after a day among the corals, we came, the next morning, upon a group of Feejee savages with human bones to their mouths, finishing off the cannibal feast of the night; and as thoughtless of any impropriety as if the roast were of wild game taken the day before. In fact, so it was.

Other regions gave us some harsh scenes. One—that of our vessel, in a tempest, fast drifting toward the rocks of Southern Fuegia, and finding anchorage under Noir Island, but not the hoped-for shelter from either winds or waves; the sea at the time dashing up the black cliffs two and three hundred feet, and shrouding in foam the high rocky islets, half-obscured, that stood about us; the cables dragging and clanking over the bottom; one breaking; then another, the storm still raging; finally, after the third day, near midnight, the last of the four cables giving way, amid a deluge of waters over the careering vessel from the breakers astern, and an instant of waiting among all on board for the final crash; then, that instant hardly passed, the loud calm command of the

Captain, the spring of the men to the yard-arms, and soon the ship again on the dark, stormy sea, with labyrinths of islands, and the Fuegian cliffs to leeward; but, the wind losing somewhat of its violence and slightly veering, the ship making a bare escape as the morning dawned with brighter skies.

And still another scene, more than two years later, on a beautiful Sunday, in the summer of 1841, when, after a cruise of some months through the tropics, we were expecting soon to land on the shores of the Columbia; of the vessel suddenly stopped on the grinding sands; there, as the waves passed, rising and falling with heavy blows on the fatal bar that made the timbers to quiver and creak; and thus helpless through a long night, the waters gaining in spite of the pumps; — morning come, the old craft, that had been a home for three eventful years, deserted, the boats carrying us, empty handed, to "Cape Disappointment" — a name that tells of other vessels here deceived and wrecked; and, twenty hours later, the old "Peacock" gone, her upper decks swept off by the waves, the hulk buried in the sands.

But these were only incidents of a few hours in a long and always delightful cruise. If this work gives pleasure to any, it will but prolong in the world the enjoyments of the "Exploring Expedition."

In explanation of some allusions in the following pages, I may here state with regard to the Exploring Expedition, that Captain (now Admiral) Charles Wilkes, U. S. N., the Commander of the Expedition, was in charge of the Sloop-of-war Vincennes; Capt. Wm. L. Hudson, U. S. N., of the Sloop-of-war Peacock; Capt. A. K. Long, U. S. N., of the Storeship Relief (the vessel which encountered the dangers in the Cape Horn sea, above related); and Lieut. Commandant C. Ringgold, of the Brig Porpoise; and that my associates in the "Scientific Corps" were Dr. CHARLES PICKERING, J. P. COUTHOUY, and TITIAN R. PEALE, Zoölogists; WM. RICH and J. D. BRECKENRIDGE, Botanists; HORATIO HALE, Philologist; JOSEPH DRAYTON and A. T. AGATE, Artists.

Our cruise led us partly along the course followed by Mr. CHARLES DARWIN during the years 1831 to 1836, in the Voyage of the Beagle, under Captain FITZROY; and, where it diverged from his route, it took us over scenes, similar to his, of coral and volcanic islands. Soon after reaching Sydney, Australia, in 1839, a brief statement was found in the papers of Mr. Darwin's theory with respect to the origin of the atoll and barrier forms of reefs. The paragraph threw a flood of light over the subject, and called forth feelings of peculiar satisfaction, and of gratefulness to Mr. Darwin, which still come up afresh whenever the subject of coral islands is mentioned. The Gambier Islands, in the Paumotus, which gave him the key to the theory, I had not seen; but on reaching the Feejees, six months later, in 1840, I found there similar facts on a still grander scale and of more diversified character, so that I was afterward enabled to speak of his theory as established with more positiveness than he himself, in his philosophic caution, had been ready to adopt. His work on Coral Reefs appeared in 1842, when my report on the subject was already in manuscript. It showed that the conclusions on other points, which we had independently reached, were for the most part the same. The principal points of difference relate to the reason for the absence of corals from some coasts, and the evidence therefrom as to changes of level, and the distribution of the oceanic regions of elevation and subsidence—topics which a wide range of travel over the Pacific brought directly and constantly to my attention.

In the preparation of the present work my former chapter on Coral Reefs and Islands has been greatly extended by the addition of facts from numerous sources. The authorities cited from are stated in the course of the volume, and need not here be re-mentioned. I have occasion, however, for special acknowledgments to our excellent Yale Zoölogist, Professor A. E. Verrill, who now stands first in the country in the department of Zoöphytes. Through his recent memoirs on the subject, and also by his personal advice, I have been greatly aided in acquainting myself with the present state of the science:—my own special labors in this branch of zoölogy having ended in 1850, when both the Reports, referred to above, had been published, and the last of my Expedition departments—that of the Crustacea—forced my studies in another direction.

The illustrations of the following pages have been drawn mainly from my Expedition Reports. Those not my own are from the works or memoirs of Gosse, Möbius, Verrill, Pourtales, L. Agassiz, A. Agassiz, Smitt, Edwards and Haime, Wilkes, and Hartt. In addition, the volume is indebted for a few cuts to the beautifully illustrated popular works, "Le Monde du Mer" and "La Vie et les Mœurs des Animaux;" but nearly half of these were engraved from my plates. The sources of all the figures are given in the List of Illustrations.

James D. Dana.

New Haven, Conn., *February* 12, 1872.

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LIST OF ILLUSTRATIONS.

The following list contains a statement of the original sources of the illustrations through the volume. By "Author's Atlas" is to be understood the Atlas of his Report on Zoöphytes. The figures are of natural size, except when otherwise stated. The new figures included have been made by Mr. Lockwood Sanford, a New Haven wood-engraver of most of the wood-cuts in this volume.

I. PLATES.

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CORALS AND CORAL ISLANDS.

CHAPTER I.

CORALS AND CORAL MAKERS.

A SINGULAR degree of obscurity has possessed the popular mind with regard to the growth of corals and coral reefs, in consequence of the readiness with which speculations have been supplied and accepted in place of facts; and to the present day the subject is seldom mentioned without the qualifying adjective *mysterious* expressed or understood. Some writers, rejecting the idea which science had reached, that reefs of rocks could be due in any way to "animalcules," have talked of electrical forces, the first and last appeal of ignorance. One author, not many years since, made the fishes of the sea the masons, and in his natural wisdom supposed that they worked with their teeth in building up the great reef. Many of those who have discoursed most poetically on zoöphytes have imagined that the polyps were mechanical workers, heaping up the piles of coral rock by their united labors; and science is hardly yet rid of such terms as polypary, polypidom, which imply that each coral is the constructed hive or house of a swarm of polyps, like the honey-comb of the bee, or the hillock of a colony of ants.

Science, while it penetrates deeply the system of things about us, sees everywhere, in the dim limits of vision, the word mystery. Surely there is no reason why the simplest of organisms should bear the impress most strongly. If we are astonished that so great deeds should proceed from the little and low, it is because we fail to appreciate that little things, even the least of living or physical existences in nature, are, under God, expressions throughout of comprehensive laws, laws that govern alike the small and the great.

It is not more surprising, nor a matter of more difficult comprehension, that a polyp should form structures of stone (carbonate of lime) called coral, than that the quadruped should form its bones, or the mollusk its shell. The processes are similar, and so the result. In each case it is a simple animal secretion; a secretion of stony matter from the aliment which the animal receives, produced by the parts of the animal fitted for this secreting process; and in each, carbonate of lime is a constituent, or one of the constituents, of the secretion.

This power of secretion is then one of the *first* and most common of those that belong to living tissues; and though differing in different organs according to their end or function, it is all one process, both in its nature and cause, whether in the Animalcule or Man. It belongs eminently to the lowest kinds of life. These are the best stone-makers; for in their simplicity of structure they may be almost all stone and still carry on the processes of nutrition and growth. Throughout geological time they were the agents appointed to produce the material of limestones, and also to make even the flint and many of the siliceous deposits of the earth's formations.

Coral is never, therefore, the handiwork of the many-armed polyps; for it is no more a result of labor than bone-making in ourselves. And again, it is not a collection of cells into which the coral animals may withdraw for concealment any more than the skeleton of a dog is its house or cell; for every part of the coral—or corallum as it is now called in science—of a polyp, in most reef-making species, is enclosed more or less completely within the polyp, where it was formed by the secreting process.

It is not, perhaps, within the sphere of science to criticise the poet. Yet we may say in this place, in view of the frequent use of the lines even by scientific men, that more error in the same compass could scarcely be found than in the part of Montgomery's "Pelican Island" relating to coral formations. The poetry of this excellent author is good, but the facts nearly all errors—if literature allows of such an incongruity. There is no "toil," no "skill," no "dwelling," no "sepulchre" in the coral plantation any more than in a flower-garden; and as little are the coral polyps shapeless worms that "writhe and shrink their tortuous bodies to grotesque dimensions."

The poet oversteps his license, and besides degrades his subject, when downright false to nature.

Coral is made by organisms of four very different kinds. These are: *First*, POLYPS, the most important of coral-making animals, the principal source of the coral reefs of the world.

Second, Animals related to the little Hydra of fresh waters, and called HYDROIDS (a division under the Acalephs), which, as Agassiz has shown, form the very common and often large corals called Millepores.

Third, The lowest tribe of Mollusks, called BRYOZOANS, which produce delicate corals, sometimes branching and moss-like (whence the name from the Greek for *moss animal*), and at other times in broad plates, thick masses, and thin incrustations. Although of small importance as reef-makers at the present time, in a former age of the world—the Paleozoic—they so abounded over the sea bottom that some beds of limestone are half composed of them.

Fourth, Algæ or sea-weeds, some kinds of which would hardly be distinguished from corals, except that they have no cells or pores.

I. POLYPS.

A good idea of a polyp may be had from comparison with the garden aster; for the likeness to many of them in external form as well as delicacy of coloring is singularly close. The aster consists of a tinted disk bordered with one or more series of petals. And, in exact analogy, the polyp flower, in its most common form, has a disk fringed around with petal-like organs called tentacles. Below the disk, in contrast with the slender pedicel in the ordinary plant, there is a stout cylindrical pedicel or body, often as broad as the disk itself, and sometimes not much longer, which contains the stomach and internal cavity of the polyp; and the mouth, which opens into the stomach, is at the centre of the disk. Here then the flower-animal and the garden-flower diverge in character, the difference being required by the different modes of nutrition and other characteristics in the two kingdoms of nature. The coral polyp is as much an animal as a cat or a dog.

The figures of the frontispiece, and others on pages 23, 24, 26, sustain well the description here given, and afford some idea also of the diversity of form among them.

The prominent subdivisions of polyps here recognized are the following:

I. Actinoid Polyps.—Related to the Actinia, or Sea-anemone, in tentacles and interior structure, and having, as in

PLATE II.

1.

2

1.Phymactis veratra; 2, P. clematis.

them, the number of tentacles and interior septa a multiple of *six*. The name *Actinia* is from the Greek for *ray*.

II. Cyathophylloid Polyps.—Like the Actinoids in tentacles and interior structure, except that the number of tentacles and interior septa is a multiple of *four*. Ludwig and De Pourtales state that the number in the earliest young state is *six*, and that therefore the fundamental ratio is the same as in the Actinoids; and that they pass from this ratio by developments of tentacles and septa more rapidly on one side than the opposite, and in such a manner that the number becomes after the first stage a multiple of four. The Cyathophylloid polyps hence combine this characteristic of the Actinoids with one feature of the Alcyonoids. The Cyathophylloids were the earliest of polyps, and the most abundant species in Paleozoic time.

III. Alcyonoid Polyps.—Having eight fringed tentacles, and other characters mentioned beyond; as the Gorgoniæ and Alcyonia.

I. ACTINOID POLYPS.

The highest of Actinoid Polyps are those of the Actinia tribe—the species that secrete no coral to clog vital action and prevent all locomotion. The details of structure may be best described from the Actinia or Sea-anemone, and afterward the distinguishing characters of the coral-making polyps may be mentioned. In external aspect and in internal characters all are essentially identical.

1. NON-CORAL-MAKING POLYPS.

As the colored figures on Plate II., and also the following, show, the external parts of an Actinia are — a subcylindrical body—a disk at top—one or more circular series of tentacles making a border to the disk—a mouth, a merely fleshy, toothless opening, at the centre of the disk, sometimes at the summit of a conical prominence—a basal disk for attachment. The upper extremity is called the *actinal* end, since it bears the tentacles or rays, and the lower or base, the *abactinal.*

Sea-anemones vary greatly in color, and in the distribution of their tints. This is finely illustrated on the first four plates of the Author's Atlas of Zoöphytes. Two figures of Plate I. are reproduced on the accompanying Plate II.: one, *Phymactis clematis*, from Valparaiso, and the other, *Phymactis veratra*, from Wollongong, New South Wales. Another variety of *P. clematis* has a pink disk, wine-red tentacles, and the body reddish with dots of dark green. The *P. florida*, from the coast of Peru, one variety of which is shown on the second plate of the Atlas, has blue tentacles and a paler disk; another has a bluish green disk with purplish tentacles and the papillæ of the body dark sap-green on a pale reddish ground; and another is green throughout.

While often brilliantly colored, especially in the tropics, other Actiniæ are nearly colorless. This was the case with that represented in the following cut, a species from Long Island Sound near the New Haven Light-house, figured some twenty years since by the author, but left undescribed. The body in this species had a delicate texture throughout, its walls being so transparent that the organs within could be seen through them. It was exceedingly flexible and passed through various shapes, imitating vases of many forms, wine glasses, goblets, etc. It was generally very slow in its changes, and sometimes continued in the same vase-attitude for a whole day.

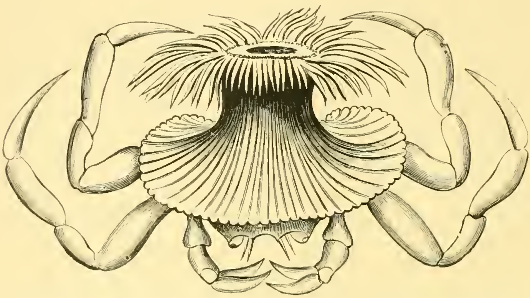
Actiniæ vary immensely in size,—from an eighth of an inch and smaller in the diameter of the disk to over a foot,—though commonly between half an inch and three inches. One species from the Paumotu Coral Archipelago in the

PARACTIS RAPIFORMIS, EDW.

Pacific, a colored figure of which is given in the Atlas of the Author's Report on Zoöphytes (Plate III.), had a diameter across its disk of *fourteen* inches; and it was also one of the most beautiful in those seas, having multitudes of tentacles with carmine tips and yellowish bases, around the open centre, gathered into a number of large groups or lobes.

With rare exceptions, Actiniæ live attached to stones, shells, or the sea bottom, or are buried at base in the sand or mud. The attached species have the power of locomotion, through the muscles of the base, but only with extreme slowness. The loose stones on a sea-shore near low tide level often have Actiniæ fixed to their under surface. A very few species swim or float at large in the ocean.

Now and then an Actinia puts itself on the back of a crab, and thus secures rapid locomotion, but only at the will of the crab, which may at times give it some hard rubs:—a



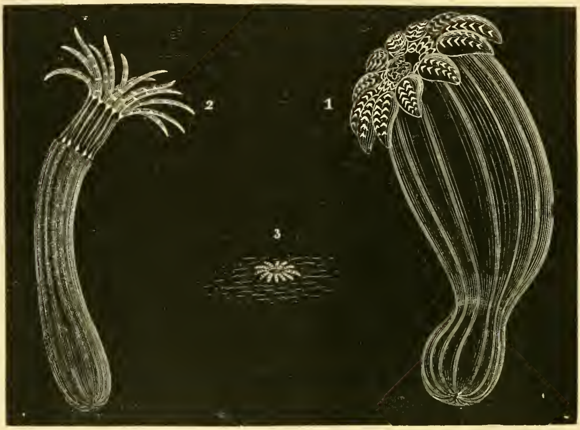
CANCRISOCIA EXPANSA ST., ON THE BACK OF DORIPPE FACCHINO.

kind of association styled *commensalism* by Van Beneden, as the two in a sense live at the same table, without preying one upon the other. In the above example, from the China seas, the Actinia has mounted a Dorippe. The figure is from the Proceedings of the Essex Institute, where an account of it is published by Prof. Verrill; the specimen was collected by the zoölogist, Dr. W. Stimpson. As Prof. Verrill states, the Dorippe carries, for its protection when young, a small shell over its back, which it holds in this position by means of its two reversed pairs of hind legs. The Actinia appears to have fixed itself, when young, to the shell, and afterward, by its growth, spread over the back of the crab, taking the place of the shell.

This case of commensalism, like most others, is not a mere chance association of species; for the two always go together, the Actinia, according to Dr. Stimpson, never being seen except upon the crab's back, and the crab never without its Actinia. The fact shows an instinctive liking on the part of the Actinia for a Dorippe courser, and for the roving life thus afforded it. And the crab is undoubtedly conscious that he is carrying his fortress about with him. It is not a solitary case; for there are many others of Actiniæ attaching themselves to locomotives—to the claws or backs of crabs, or to shells in possession of soldier crabs, or to a Medusa; and frequently each Actinia has its special favorite, proving an inherited instinctive preference for rapid change of place, and for just that kind of change, or range of conditions, which the preferred commensal provides. Prof. Verrill has an interesting article on this subject, with especial reference to crustaceans, in the third volume of the American Naturalist.

Species living in sand are often unattached; and then the base is rounded or tapering, and sometimes balloon-shaped; some of them are long and almost worm-like, and even burrow like worms.

The following are figures of three species: one, figure 3, exhibiting simply the tentacles and disk of the Actinia, the only parts visible above the sand; the others showing the whole body removed from the sand, and consequently a little out of shape. They are from Gosse's "British Sea-Anemones," in which they are given with the natural colors. Figure 1 represents the *Peachia hastata* of Gosse, a beautiful species having twelve large tentacles; fig. 2, the *Edwardsia callimorpha* G.; fig. 3, *Halocampa chrysanthellum* G. Most of these sand-dwellers bury themselves like the Halocampa, and often hide all the disk but the mouth. The Edwardsia is peculiar in having, above the hollow bladder-like basal portion, a firm opaque exterior to the body, making for it a kind of case or jacket, into which the upper extremity, which is soft and delicate in texture, may be retracted. The thickening of the epidermis in this middle portion is produced through the entangling of disintegrated cells and minute for-

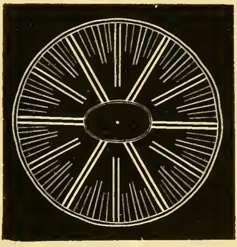


1. PEACHIA HASTATA, G.; 2. EDWARDSIA CALLIMORPHA, G.; 3. HALOCAMPA CHRYSANTHELLUM, G.

eign particles, sometimes in part spores of Confervæ, by means of the mucus of the surface; and if the layer is removed, as it may be, the skin will again become covered. This species, like others of the genus, lives buried to its neck in the sand, that is, with the soft upper extremity protruding If disturbed, the head is suddenly drawn in, together with more or less of the following jacketed part of the body.

The warty prominences on some warty species have the power of clinging by suction to a surface, and such Actiniæ often cover their sides thus with bits of shell or of other substances at hand. Where there are no warts the contracted exterior skin, reticularly corrugated, occasionally becomes a surface of suction-warts, as in many Sagartiæ.

The *internal structure* of the Actinia is radiate like the external, and more profoundly and constantly so. The mouth, a fleshy toothless opening in the disk, opens directly into a stomach, which descends usually about a third of the way to the base of the body; its sides are closed together unless it be in use. The general cavity of the body around and below the stomach is divided radiately by fleshy partitions, or septa, into narrow compartments; the larger of these septa



connect the stomach to the sides of the animal, and, besides holding it in place, serve to pull it open or distend it for the reception of food. The above figure represents in a general way a horizontal section of the body through the stomach, and shows the position of the radiating septa and the intermediate compartments. It presents to view the fact that these are in pairs, and another fact that the number of pairs of partitions in the ordinary Actinoid polyps is regularly some multiple of six, although other numbers occur during the successive developments that take place in the growth of a polyp, and are occasionally persistent in the adult state. There are six pairs in the first series; *six* in the second; *twelve* in the third; *twenty-four* in the fourth; *forty-eight* in the fifth, and so on.

The compartment between the two septa of each pair opens at top into the interior of a tentacle, and thus the cavity in each tentacle has its special corresponding compartment below. This tentacular compartment is properly, as first recognized by Prof. Verrill, the *ambulacral*, since each corresponds in position and function to an ambulacral or tentacle-bearing section in the Echinoderms and other Radiate animals.

Although polyps are true Radiates, they have something of the antero-posterior (or head-and-tail) polarity, with also the right-and-left, which is eminently characteristic of the animal type. This is manifested in the occurrence in some polyps of a ray on the disk different in color from the general surface: of one tentacle larger than the others, and sometimes peculiar in color; of two opposite septa in a calicle or polyp-cell larger than the others, and sometimes meeting so as to divide the cell into halves. The first of these marks the author has observed in a Zoanthid, as mentioned in his Report on Zoöphytes at page 419, and represented on plate 30:. and the last is very strongly developed in the cells of many Pocilloporæ (ib. p. 523). Gosse and many other authors have drawn attention to the one large tentacle, and the fact that it lies in the direction of the line of the mouth. Prof. H. James Clark, in his Mind in Nature, states that the order in which the fleshy septa and the tentacles in an Actinia are developed has direct reference to the right and left sides of the body, and that there is only one plane in which the body can be divided into two halves, and this is that corresponding with the longer diameter of the stomach, or the direction of the mouth. Mr. A. Agassiz has shown that in Actiniæ of the genus Arachnactis, the new septa and tentacles are developed either side of the one chief or anterior tentacle; and Prof. Verrill, that in Zoanthids, they are formed principally either side of this anterior tentacle and also of the opposite or posterior one, and much less rapidly, if at all, along the sides intermediate. This chief-tentacle marks properly the true front or anterior side of the polyp. A fore-and-aft structure is also very strongly marked in some of the ancient cyathophylloid corals, and hence it belonged to the type from early Paleozoic time.

The way leading out from the Radiate structure is thus manifested by these flower-like polyps. In fact perfect circular series in organs or parts do not belong to any living organism, not even to the true flower; for growth is fundamentally spiral in its progress, and there must be always an advance end to the spiral of growth; all apparent circles are only disguised spirals.

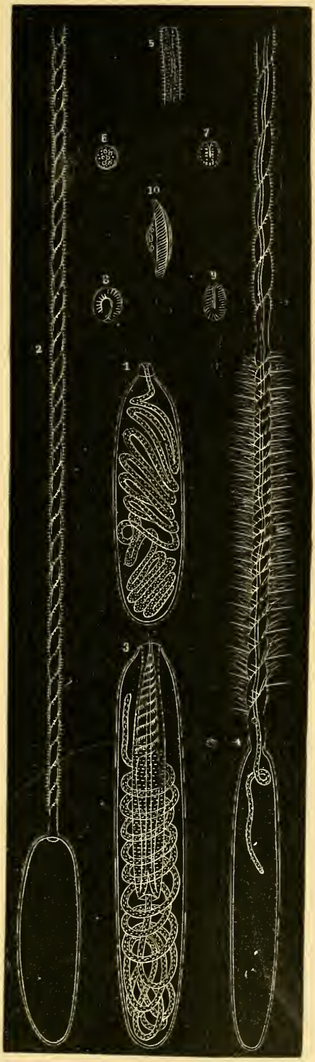
The walls of the body contain two sets of muscles, a circular and a longitudinal, the latter becoming radial in the disk and base. Similar muscles exist also in the tentacles, and corresponding muscles in the fleshy partitions or septa of the internal cavity.

By means of these muscles an Actinia, whenever disturbed, contracts at once its body; and most species make of themselves a spheroidal or conoidal lump, showing neither disk nor tentacles. One example of this contracted state is presented on the frontispiece in figure 3*a*. After a brief period of quiet the polyp commonly reassumes its full expansion. The expansion depends on an injection of the structure with salt water, which is taken in mainly by the mouth. As the whole body is thus filled and injected, the flower slowly opens out, and shows its petal-like tentacles. On contraction the water is suddenly expelled through the mouth, and by pores in the sides of the polyps, and at the extremity of the tentacles, and the tentacles disappear, along with the disk, beneath the adjoining sides of the body which are drawn or rolled in over them.

The Actinia appears, at first thought, to be well prepared for securing its prey through its numerous tentacles. But these are generally too short for prehension. Yet the disk often aids them by rolling over the captured animal, and pushing it down into the stomach. At the same time, the mouth and stomach are both very extensile, so that an Actinia may swallow an animal nearly as large as itself; it gradually stretches the margins of the mouth over the mollusk or crab, until the whole is enclosed and passed into the digestive sac; and when digestion is complete, the shell and any other refuse matters are easily got rid of by reversing the process.

But the Actinia owes nearly all its power of attack to its concealed weapons, which are carried by myriads. These are what Agassiz has called *lasso-cells*, because the little cell-shaped sheath contains a very long slender tubular thread coiled up, which can be darted out instantly when needed. As first observed by Agassiz, the tubular lasso escapes from the cell by turning itself inside out, the extremity showing itself last, and this is usually done "with lightning-like rapidity." Then follows the poison. The lasso-cells (called often *nettling cells*, and by Gosse *cnidæ*, and *thread capsules*) are usually less than a two-hundredth of an inch in length; but they are thickly crowded in the larger part of the skin or walls of the tentacles, and about the mouth; also in the walls of the stomach, and within the visceral cavity in white cords hanging in folds from the edge of the septa. Thus the polyp is armed inside and out. The mollusk or crab that has the ill luck to fall, or be thrown by the waves, on the surface of the pretty flower is at once pierced and poisoned by the minute lassos, and is rendered incapable of resistance.

The following figures, by Dr. Karl Mobius, of Hamburg, illustrate admirably these organs. The views are magnified



LASSO-CELLS.

700 diameters. Figure 1 represents one of the lasso-cells of the Actinia, *Corynactis viridis*, with its lasso coiled up within, its actual length is about a 350th of an inch. Figure 2 is the same with the lasso out, though less than half of the long thread is shown. Figure 3 is the lasso-cell of the polyps of a European coral, the *Caryophyllia Smithii.* It differs from figure 1 in having the basal part of the lasso within the cell or sheath strait and stout; it is this part which makes the first portion of the extended lasso. A view of part of the latter is represented in figure 4, and of the extremity of the same in figure 5. The lasso-cells in the above species are from a 240th to a 360th of an inch in length. In the *Metridium marginatum*, an American Actinia occurring along the coast of the United States, north of New York, the length of one of the lasso-cells, according to Dr. Leidy, was about a 400th of an inch, and the character of the extended lasso was much like that of figure 4. The lower part of the lasso, for a length 1½ times or more longer than the cell or sheath, is usually thickened, and sometimes slenderly spindle-shaped, while the rest is an even slender thread; and the thickened part and sometimes all the rest, as above shown, is spirally wound by a slender line, sometimes elevated, set with short hairs or bristles. The thread-like portion may be wanting or very short. The lasso is often twenty times as long as the cell or sheath, and occasionally forty times; but if the thread-like part is absent, only one and a half to two times.

A lasso-cell once used is afterward worthless; for the tube cannot be returned to the sheath. But those thus expended are not missed, as the polyp has indefinite supplies of such weapons, and also ready means of refurnishing itself.

Figures 6, 7, 8, 9, 10, on the preceding page, illustrate different stages in the development of a lasso-cell (fig. 10) out of a common spherical cell, as made out by Dr. Mobius in his careful microscopic investigations. The Actinia affording the results was the *Urticina crassicornis*, found in both European and American seas. The actual size of the cell represented in figure 6 is about a 5,000th of an inch. In fig. 7 the lasso-cell has already taken form but is folded on itself; in 8, there is a second infolding; 9 shows a return to a single fold, and further progress in the forming cell; and 10, the straightened lasso-cell. Thus the work of replenishing, throughout the body wherever lassos are used, is always going on.

The radiating partitions or septa in the internal cavity of the polyp have along the outer free edge what looks like a slender white cord attached to it by a much convoluted or mesentery-like membrane; and this cord contains vast numbers of lasso-cells radiately arranged. These white cords through the multiplied plaitings of the mesenteric membrane have great length; and they sometimes extend up through the stomach and pass out of the mouth; or they are extended in loops through the walls wherever they may happen to be torn. There are often also bunches of somewhat similar white cords full of lasso-cells appended to the septa, which are extended from the body through some natural orifices near the base of the Actinia (especially those of the Sargartia family). Gosse calls these cords *Acontia*. They extend out usually two or three inches, and sometimes six inches, and thereby widen much the stinging range of an Actinia, both for the purposes of defence and attack.

Gosse, in his "British Sea-Anemones," gives the results of some experiments with regard to the action of these lasso-cells (*cnidæ*), from which a few paragraphs may be here cited.

"It has long been known, that a very slight contact with the tentacles of a polyp is sufficient to produce, in any minute animal so touched, torpor and speedy death. Since the discovery of these *cnidæ* (lasso-cells) the fatal power has been supposed to be lodged in them. Baker, a century ago, in speaking of the Hydra, suggested that "there must be something eminently poisonous in its grasp;" and this suspicion received confirmation from the circumstance that the *Entomostraca* which are *enveloped in a shelly covering* frequently escape unhurt after having been seized. The stinging power possessed by many Medusæ, which is sufficiently intense to be formidable even to man, has been reasonably attributed to the same organs, which the microscope shows to be accumulated by millions in their tissues.

"Though I cannot reduce this presumption to actual certainty, I have made some experiments, which leave no reasonable doubt on the subject. First—I have proved that the *ecthoræum* (tubular thread of the lasso-cell) when shot out, has the power of penetrating, and does actually penetrate, the tissues of even higher animals. Several years ago, I was examining one of the purple *acontia* of *Adamsia palliata;* no pressure had been used, but a considerable number of *cnidæ* had been spontaneously dislodged. It happened that I had just before been looking at the sucker-foot of an Asterina, which remained still attached to the glass of the aquatic box, by means of its terminal disk. The cilia of the *acontium* had, in their rowing action, brought it into contact with the sucker, round which it then continued slowly to revolve. The result I presently discovered to be, that a considerable number of the *cnidæ* had shot their *ecthoræa* into the flesh of the sucking disk of the Echinoderm, and were seen sticking all round its edge, the wires (lassos) being embedded in its substance even up to the very capsules, like so many pins stuck around a toilet pincushion.

"To test this power of penetration still farther, as well as to try whether it is brought into exercise on the contact of a foreign body with the living Anemone, I instituted the following experiment. With a razor I took shavings of the cuticle from the callous part of my own foot. One of these shavings I presented to the tentacles of a fully expanded *Tealia crassicornis* (*Urticina crassicornis* of Europe and America). After contact, and momentary adhesion, I withdrew the cuticle, and examined it under a power of 600 diameters. I found, as I had expected, *cnidæ* standing up endwise, the wires in every case shot into the substance. They were not numerous—in a space of .01 inch square, I counted about a dozen. * * *

"These examples prove that the slightest contact with the proper organs of the Anemone is sufficient to provoke the discharge of the *cnidæ;* and that even the densest condition of the human skin offers no impediment to the penetration of the *ecthoræa.*

"As to the injection of a poison, it is indubitable that pain, and in some cases death, ensues even to vertebrate animals from momentary contact with the capsuliferous organs of the Zoöphyta. * * * I have elsewhere recorded an instance in which a little fish, swimming about in health and vigor, died in a few minutes with great agony through the momentary contact of its lip with one of the emitted *acontia* of *Sagartia parasitica.* It is worthy of observation, that, in this case, the fish carried away a portion of the acontium sticking to its lip; the force with which it adhered being so great, that the integrity of the tissues yielded first. The acontium severed, rather than let go its hold.

"Now, in the experiments which I have detailed above, we have seen that this adhesion is effected by the actual impenetration of the foreign body by a multitude of the *ecthoræa,* whose barbs resist withdrawal. So that we can with certainty associate the sudden and violent death of the little fish with the intromission of barbed *ecthoræa*."

The following observation by J. P. Couthouy, from the author's Report on Zoöphytes (p. 128), if it is beyond question, shows power even in the Actinia's presence. "Having a number of Monodontas (a genus of univalve Mollusca allied to our Trochi) too much crowded in a large jar of water, I took out half-a-dozen, and placed them in a jar with an Actinia (*Anthea flagellifera*). On looking at them about three hours after, I found that, instead of climbing like the others to the top of the water, they remained just where they had fallen, closely withdrawn into their shells. Supposing them to be dead, they were taken out, when they directly began to emerge; and when returned to the jar with the other Monodontas, they were in less than five minutes clustered round its mouth. On placing them again in the jar with the Actinia, though kept there for two hours, they did not once show themselves out of the shell. Once more placing them along with the other shells, they exhibited their former signs of life and activity. The experiment was repeated several times with a large Littorina, with the same result, evincing fear of the Actinia on the part of the Mollusks."

Gosse states the following fish story, which is much to the point. Speaking of the *Anthea cereus*, or Opelet, a British species, he says (p. 168): "I one day saw an amusing example of its power of passive resistance. A beautiful little specimen of the variety *alabastrina*, which had been sent to me by Mr. Gatehouse, I had occasion to remove from one tank to another. There was a half-grown Bullhead (*Cottus bubalis*) at the bottom, which had been in captivity rather more than a fortnight. As he had not been fed during that time, I presume he was somewhat sharp-set. He marked the Anthea falling, and before it could reach the bottom, opened his cavern of a mouth and sucked in the *bonne bouche.* It was not to his taste, however, for as instantly he shot it out again. Not discouraged, he returned to the attack, and once more sucked it in, but with no better success; for, after a moment's rolling of the morsel around his mouth, out it shot once more; and now the Bullhead, acknowledging his master, turned tail, and darted into a hole on the opposite side of the tank in manifest discomfiture."

He adds: "But if you, my gentle reader, be disposed for exploits in gastronomy, do not be alarmed at the Bullhead's failure: only take the precaution to "cook your hare." Risso calls this species "*edulis*," and says of it,—"*On le mange en friture*," and I can say, "*probatum est.*" No squeamishness of stomach prevents our volatile friends, the French, from appreciating its excellence; for the dish called *Rastegna*, which is a great favorite in Provence, is mainly prepared from *Anthea cereus.* I would not dare to say that an Opelet is as good as an Omelet; but *chacun à son goût*—try for yourselves. The dish is readily achieved."

The stomach, although without a proper sphincter muscle at its inner extremity, appears to be closed below during the process of digestion. When digestion is complete, the refuse from the food is pushed out through the mouth, the only external opening to the alimentary cavity, and the digested material passes downward, into the interior cavity; and there, mixed with sea-water from without, it is distributed through all the interior cavities of the polyp for its nutrition. The polyp has no circulating fluid but the results of digestion mixed with salt water, no blood-vessels but the vacuities among the tissues, and no passage-way for excrements excepting the mouth and the pores of the body that serve for the escape of water on the contraction of the animal.

Actiniæ have usually no gills or *branchiæ* for the aeration of the blood, the whole surface of the body being ordinarily sufficiently soft and delicate to serve in this function. Some species live half buried in the sand, and, as this in large species would prevent the skin of the sides from aiding in respiration, there are sometimes very much lobed and crimpled organs, attached to, or alongside of, the tentacles, which give the animal-flower much greater beauty, and at the same time increase the extent of surface for the purposes of æration; they are set down as branchial by Prof. Verrill.

In one tribe of polyps closely related to the Actiniæ, the Zoanthids, in which the outer skin is usually somewhat corriaceous, or is filled with grains of sand, there are narrow gills arranged vertically, one either side of the larger radiating septa, figures of which are given in the author's Zoöphyte Atlas.

As to *senses*, Actiniæ, or the best of them, are not quite as low as was once supposed. For, besides the general sense of feeling, some of them have a series of eyes, placed like a necklace around the body, just outside of the tentacles. The yellow prominences in this position on the larger figures in the frontispiece are these eyes. They have crystalline lenses, and a short optic nerve. Yet Actiniæ are not known to have a proper nervous system: their optic nerves, where they exist, are apparently isolated, and not connected with a nervous ring such as exists in the higher Radiate animals.

Reproduction is carried forward both by ova and by buds, though the latter method is mostly confined to the coral-making polyps.

The ovarian and spermatic functions belong to the radiating septa in the interior cavity of the Actinia, and to the part of a septum, mesenteric in character, at or near the outer margin. They have the aspect of a pulpy mass, or look like clusters of ovules. The ova have no chance for escape except through the stomach and mouth. They are covered with vibratile cilia, and rove about free for a while. As the development of the embryo goes forward, a depression begins at one end, which deepens and becomes a stomach, with the entrance to it as a mouth. Concurrently, septa grow out from the inner wall, and a few tentacles commence to rise around the mouth. Not unfrequently, the young has already some of its tentacles before it leaves the parent. There is at first but a single row of tentacles; the number increases with the size until the full adult limit is reached, the newer series being successively the outer.

In the budding process, which is of rare occurrence, Actiniæ grow young ones on their sides near the margin of the base. A protuberance begins to rise and soon shows a mouth, and then becomes surrounded by tentacles; and, thus begun, the new Actinia continues to grow, usually until its tentacles have doubled their number, when finally it separates from the parent, an independent animal. At times, as Prof. H. James Clark has observed, small pieces of the base of an Actinia separate by a natural process before a trace of a tentacle has appeared, and in this case "they do not at first show any signs of activity, but on the contrary, remain for a long time in a quiet state, having the appearance of artificially separated pieces, seeming to be undergoing, as in the latter, a recuperative process after the shock of a separation." After a while they commence to develop and grow into perfect individuals. Prof. Verrill mentions the case of an Actinia from Puget's Sound (the *Epiactis prolifera*, V.) which had three rows of young individuals attached to it around the middle of its body; but whether the young Actiniæ were produced by budding from this part of the body, or whether they had colonized there after being produced in the ordinary way, he was unable to determine. In all cases the young ultimately separate from the parent.

These polyps have also the faculty of reproducing lost parts; and to such an extent that a mere fragment, if it be from the lower part and include a portion of the base, will reproduce all the rest of the Actinia, even to the disk, tentacles and stomach. Thus the mere forcible tearing of an Actinia from the rock to which it is attached may result in starting a crop of new Actiniæ.

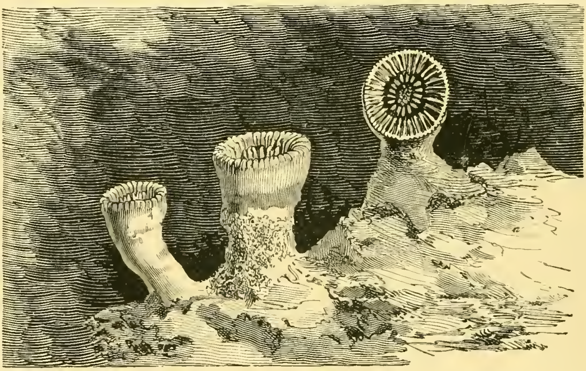
Although Actiniæ have no internal coral secretions, they sometimes make a thickened epidermic plate at the base, and also in a few cases around a part of the body. This is however not a result simply of an epidermic secretion, but arises from an exudation of mucus from the surface, and the entangling thereby of minute particles of foreign or dead matters. A case of the kind, in an Edwardsia where the body is thus encased, is mentioned and explained on page 25.

The above are the more prominent characters of the Actinia tribe of polyps. The special features distinguishing them from the coral-making polyps are the following: (1), They are simple animals, or, if they bud, the buds early separate from the parent; (2), They have a muscular base; (3), They are generally capable, more or less perfectly, of locomotion on the base by means of its muscles; (4), They sometimes possess rudimentary eyes; (5), They have no internal coral secretions. Each of these characters is evidence of the superior grade of this division of Polyps.

II. CORAL-MAKING ACTINOID POLYPS.

Of the form, tentacles, mouth, stomach, fleshy septa, lasso-cells, food, digestion and respiration of the coral-making polyps here included, nothing need here be said, these characters being the same as in the Actiniæ. Their more striking peculiarities depend on the secretion of coral, making them fixed species, and involving an absence of the base; and, in the case of the majority of the species, on the extent to which they multiply by buds, in imitation of species in the vegetable kingdom.

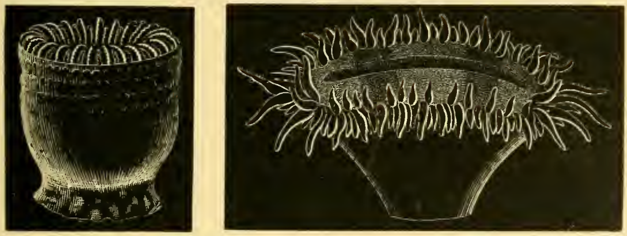
The coral skeleton which the secretions of polyps form is called the *corallum*. These secretions take place among the tis-



CARYOPHYLLIA CYATHUS.

sues of the sides and lower part of the polyp, but never in the disk or stomach, as this would interfere with the functions of these organs. In the above sketches of a simple coral, from the Mediterranean, the upper extremity is a depression, or *calicle*, enclosed by a series of radiating calcareous (coral) *septa.* Each of these septa is secreted between a pair of the radiating fleshy partitions, or septa, of the polyp (see figure p. 27); and thus the radiate structure of ordinary corals is nothing but an expression of the internally radiate structure of the polyp. When alive, the top, and usually the sides, of the coral were concealed by the outer skin of the polyp, including, above, the disk and tentacles; and into the depression or calicle at top, descended the stomach.

Whether these radiating septa of the coral are secreted from the surfaces of the fleshy septa, or from a prolongation inward of the membrane forming the walls of the internal cavity, has not been directly ascertained. The latter view is sustained by Prof. Verrill, on the ground that the coral septa contain fibres of animal tissue. The secretion does not always commence at the central plane of a septum, for the septa are sometimes hollow within, just as the surface spines of some species (*e. g.*, *Echinopora reflexa*) are hollow. The



THECOCYATHUS CYLINDRACEUS, POURT.; FLABELLUM SPHENISCUS, D.

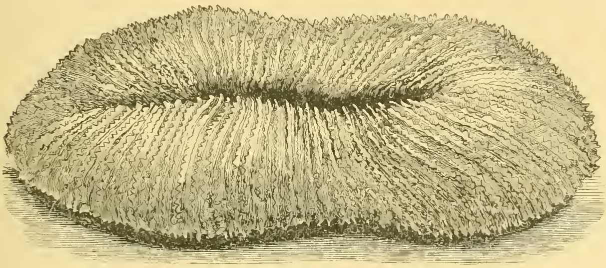
exterior surface of the corallum, that is, the part outside of the calicles, is often ribbed, and the ribs are ordinarily only an outer extension of the interior septa; so that surface spines are in fact but the outer margins of septa.

The first of the preceding figures exhibits another of the forms of these simple corals. It is described by Pourtales from specimens collected by him at a depth of 100 to 200 fathoms off the Florida reef. The actual size was one-third that of the figure. The second figure represents a living species.

The bottom of the *calicle*, or polyp-cell, in the corallum is sometimes made simply by the meeting of the radiating septa; occasionally by the same, with the addition of a point or *columella* at the centre; often by a twisting together of this part of the radiated septa. Very often, also, it is a mere porous mass. Sometimes there is a circle of prominent points about the centre, as seen in the figure of a Caryophyllia on page 42, which are the extremities of narrow vertical strips (called *pali*) lying in the planes of the septa. Similar points exist in the Thecocyathus on the preceding page, though not in sight in the figure.

In many cases the bottom is quite solid; and this may be so either (1), because the coral secretions fill up all the pores as the polyp increases in age, and thus make the interior of the corallum solid or nearly so; or (2), because there are formed periodically, as the polyp grows upward, solid horizontal plates across the bottom, so that beneath, in the interior of the corallum, there is a series of plates or tables with spaces between. The Pocilloporæ, among recent corals (p. 70), and the Favosites among ancient, are examples. Increasing solidity with the increasing age of the polyps is also produced at times by additions to the exterior of a corallum. In many species, the skin, over part or all of the exterior, gradually disappears or dies away and leaves the corallum bare, while all is living within; and, in such cases, the skin, before disappearing, often adds a layer of stony material to the exterior, giving greater firmness to the whole. An example is shown in the figure on p. 42. In such a case, there is no skin or animal tissue over the outside of the corallum, excepting at its upper extremity, above this calcareous coating.

Another form of a corallum, the secretion of a single polyp, is illustrated in the following figure of a species of the Fungia family, so-called in allusion to a resemblance to the mushroom. The long mouth occupied a considerable part of the longitudinal central line. From the line at the centre.

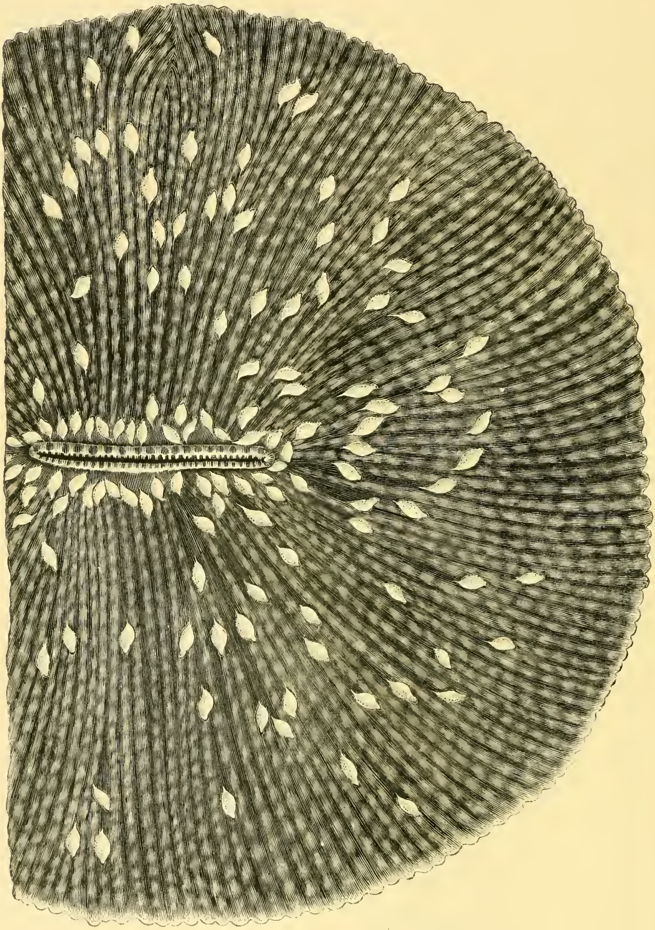


CTENACTIS ECHINATA, AG.

there is the same radiated arrangement of calcareous septa as in the preceding species, though the animal differs greatly in its extreme shortness in proportion to the breadth. The corals of this group are also peculiar in having the radiated upper surface flat, or nearly so, instead of concave. The figure is a fourth the natural size. These corals, of the genus Fungia, often exceed a foot in length; and thus coral animals are sometimes as large as the largest of Actiniæ.

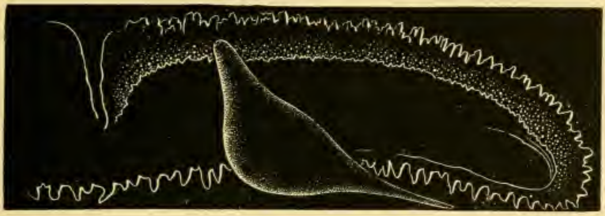
Another species of this genus, the *Fungia lacera* V. (formerly *Fungia echinata* D., from the Feejees), is represented as it appears when living (excepting a part left off to suit the page) in the following figure. The coral in the perfect state of the animal, is wholly concealed, though often showing the points of the teeth of the septa in consequence of the skin being broken.

An enlarged view of one of the tentacles is given on the



FUNGIA LACERA, D. (V.)

opposite page. They are very small, compared with the size of the polyp; and this is true of all the living Fungiæ studied by the author. It is plain that the power of such tentacles must reside wholly in their lasso-cells.



TENTACLE OF FUNGIA LACERA, ENLARGED.

The tentacles are scattered over the disk, instead of being in regular circles. Nevertheless, there is a regular order of development, as stated on page 27; a fact which shows that the apparent irregularity is a consequence of the unusual size of the polyp and the consequent larger number of the radiating lamellæ and polyps.

The Fungiæ, unlike most corals, are not fixed animals except in the young state. They are common in coral-reef seas, lying over the sandy or rocky bottom between the other corals.

Other varieties of corals and coral animals are illustrated in the figures on the following pages. They represent *compound groups*, in which great numbers of polyps are connected in a single zoöphyte—a result, in part, of the process of budding already alluded to, and partly of different modes of growth connected therewith.

This budding is very similar to the budding process in vegetation. One common method is the same that is occasionally met with in Actiniæ, the description of which is briefly given on page 40. The bud commences as a slight prominence on the side of the parent. The prominence enlarges, a mouth opens, a circle of tentacles grows out around it, and increase continues till the young finally equals the parent in size. Since in these species the young does not separate from the parent, this budding produces a compound group; and the process often continues until in some instances thousands, or hundreds of thousands, have proceeded from a single germ, and the colony has increased to a large size, sometimes many feet, or even yards, in breadth or height Such is the species of Dendrophyllia represented in the figure on page 51, and the Madrepora figured on page 50; in both of which, and in all such coral zoöphytes, each stellate cavity or prominence over the surface corresponds to a separate one of the united polyps.

The compound mass produced by budding—which consists of the united polyps with the corallum as their united secretion—was called in the Author's Report, a Zoöphyte, it being truly animal in nature, though under a plant-like form through the plant-like process of budding. But the word to many minds conveys the idea that the species is something *between* a plant and an animal, which is totally false; and besides, it is often used distinctively for the division of animals including the sponges. As a substitute the term *Zoöthome* may be employed, derived from the Greek ζωον, *animal*, and θωμος, a *heap*—a term applicable also to compound groups in other classes, as, for example, those of Rhizopods, Bryozoans and Ascidians. The term zoöphyte, where employed beyond, signifies a zoöthome formed of united polyps, or a *polyp-zoöthome.* The coral of the zoöthome being the *corallum*, that of each polyp in the compound corallum may be called a *corallet*—the term *calicle*, formerly used by the author for the same, being now restricted to the polyp-cell.

It is obvious that the connection of the polyps in all compound groups must be of the most intimate kind. The several polyps have separate mouths and tentacles, and separate stomachs; but beyond this there is no individual property. They coalesce, or are one, by intervening tissues; and there is a free circulation of fluids through the many pores or lacunes. The zoöthome is like a living sheet of animal matter, fed and nourished by numerous mouths and as many stomachs.

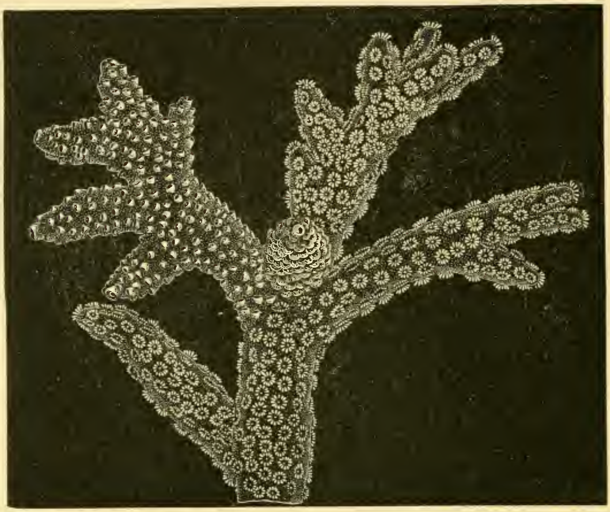
Polyps thus clustered, constitute the greater part of the flowering zoöphytes of coral reefs. Only a few are simple animals, like the Caryophyllia figured on page 42, or the Thecocyathus, page 43, or the Fungia, page 46.

This kind of budding may take place from the sides of the polyp at different heights; either (1), from the base, as in the Actinia mentioned on page 40, when it is *basal;* or (2), above the base, when it is called *lateral;* or (3), at the upper margin outside of the tentacles, when it is called *marginal* or *superior;* or (4), from the disk inside of the tentacles.

Sometimes a shoot grows out from one point only of the base of a polyp, like the stoloniferous stem from a strawberry plant, and at short intervals gives off buds; and thus makes a linear zoöphyte with a row above of flower-animals. In other cases, the base spreads in all directions and buds at the edge, or in the upper surface near the edge, and so makes an incrusting plate, consisting of a multitude of polyps.

If the germ polyp, or that from which the compound zoöphyte proceeds, has the property of growing upward beyond the adult height—which the existence of coral renders a possibility, and even to an indefinite degree—various other forms may result.

Sometimes the first polyp gives out buds from its sides, and continues so to do while it grows upward; and thus a rising stem is formed with one parent polyp at the extremity of the stem, and a terminal corallet to the corallum, or to each branch of it. This is the case in the genus *Madrepora*, a

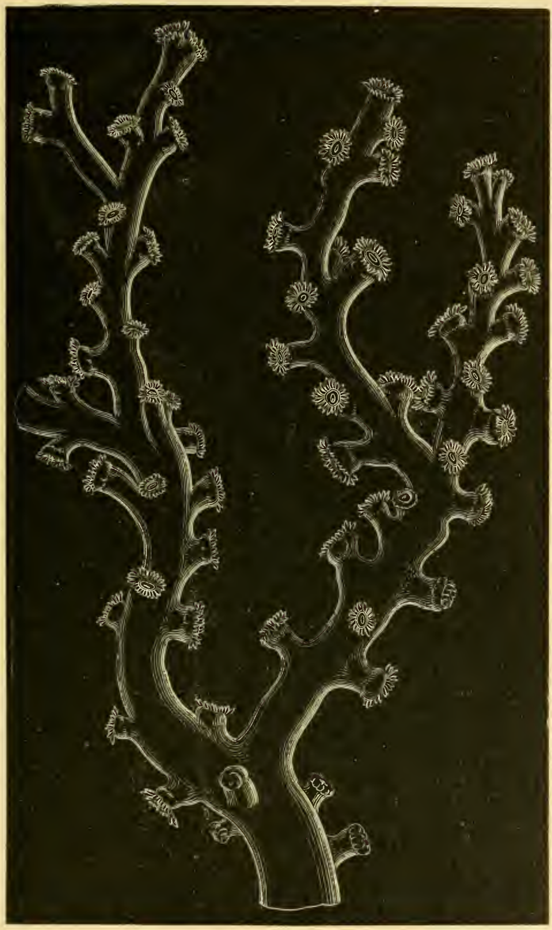


MADREPORA ASPERA, D.

species of which is here represented. Each branch in the living state had at its extremity the parent polyp of the branch, or that whose budding made the other polyps of the branch. In such species, a new lateral branch is commenced by one, among the many polyps over the surface of a branch, beginning to grow and bud. Thus branch after branch is added, and the little tree produced.

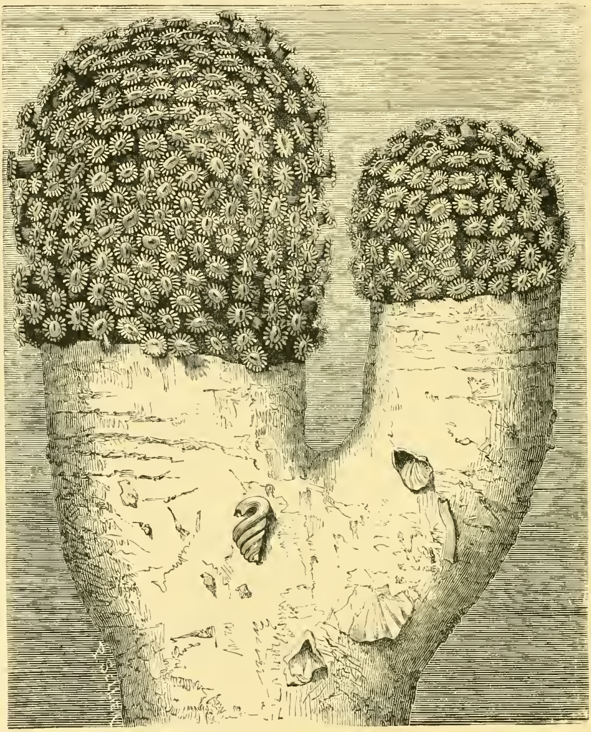
Another kind of coral, growing and budding in the same manner, is represented on page 51. It is a species of Dendrophyllia, from the Feejees—a genus often presenting tree-like forms, as the name implies.

In other cases, budding goes on until a cluster of some size is formed, and then the older or marginal polyps of the cluster



DENDROPHYLLIA NIGRESCENS, D.

cease budding while the rest continue the process; in this way a stem rises, with the budding cluster of polyps at its summit, and the more aged, or non-budding polyps, about its sides ; and the breadth of the stem depends on the size of the budding

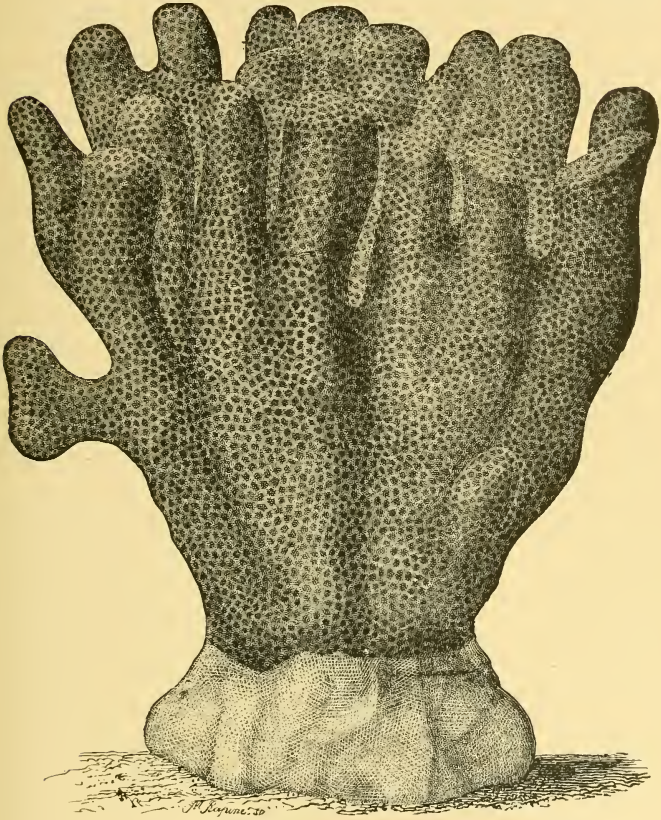


GONIOPORA COLUMNA, D.

cluster. Above a case of this kind is represented, in which the stem is a large column.

The polyps, in this beautiful Pacific species, as seen, stand up prominently over the coral when expanded, which is due to the fact that only the lower parts of the polyp secrete coral, as a moment's consideration will make apparent.

In other cases, the budding cluster is small, and hence



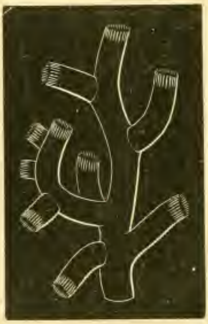
PORITES MORDAX, D.

makes small branches, as in the annexed figure of a species of Porites, from the Feejees. The cells in this genus are very small and nearly or quite superficial, as the figure shows.

New branches are made in such species by a forking of an old one. The budding cluster enlarges as it grows, and, when it is just beginning to pass the regular or normal size for the species, a subdivision of the budding cluster commences at the extremity of the branch. It is a process of spontaneous fission of a branch or stem. In this way the forking in the coral of the figure on page 52 was produced, and also the branching in that on page 53.

Sometimes, again, the budding cluster is a linear series; and then a coral with erect, flattened or lamellar branches is made.

Again, sometimes each branch of the corallum is only the corallet of a single polyp; and new branches are added by the budding of new polyps from its sides, each to lengthen out into a new branchlet. In this manner the coral here figured,



CLADOCORA ARBUSCULA, LES.

a common species of the West Indies, and also that of fig. 1 on Plate IV., a *Caulastræa*, from the Feejee group, were formed.

When the budding is not confined to any particular polyp, or cluster of polyps, but takes place universally through the growing mass, the coral formed is more or less nearly hemispherical; and often the process goes on with such extreme

PLATE IV

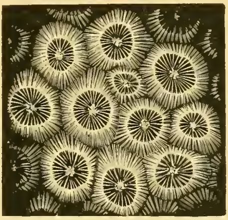
1.

3.

2.

1. Caulastraea furcata; 2. Tridacophyllia pæonia;
3. Mæandrina tenuis.

regularity that these hemispheres are perfectly symmetrical, even when enlarged to a diameter of ten or fifteen feet. A portion of the surface of one of these massive species, called *Orbicella cavernosa*, from the West Indies, is represented in the annexed figure. In the growth of these hemispheres, the enlargement takes place in the spaces between the polyps; and



ORBICELLA CAVERNOSA.

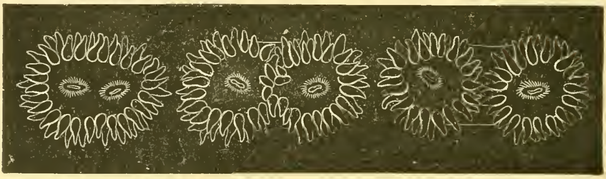
whenever these spaces begin to exceed the width usual to the species, a new mouth opens, commencing a new polyp; and thus the growth of the mass involves multiplication by buds. The small calicle near the centre of the figure is from one of the new interstitial buds.

Species of Porites also grow into hemispheres and rude hillock-like forms, through the same method of budding, and some of the masses in the tropical Pacific have a diameter of even twenty feet. Myriads of living polyps are combined in a single such mass, for each is but a fifteenth or a twentieth of an inch in diameter.

Often there is a lateral growth of the polyp and thereby of the zoöphyte without much upward growth; and spreading leaves are thus made, and bowl-like shapes. Where there is lateral budding, the leaves have generally an edge of young polyps from the new buds that are there opening, as in the

Gemmipores, and some foliaceous Madrepores. Where there is superior budding, and sometimes in the case of inferior, the new polyps appear some distance from the edge, the growing margin spreading on in advance of the buds that open in it, as in the Echinopores, the Phyllastræa represented on Plate I. (frontispiece), and also in the Merulina of Plate VI., figure 1 (facing page 82).

Besides the method of budding explained in the above remarks, there is also a kind of superior budding called *spontaneous fission*, which consists in a spontaneous subdivision of a polyp, by which two are made out of one. In such cases the disk of the polyp has not a distinct limit of growth, as in the above, but tends to enlarge indefinitely; and when there is a beginning of an increase beyond the proper adult size, a new mouth opens in the disk, a short distance from the old one, and at the same time its edges extend downward and make a new stomach beneath it; finally tentacles are developed between the two mouths, and then each polyp separates with its part of the old tentacles as illustrated in the following figure. It is not,

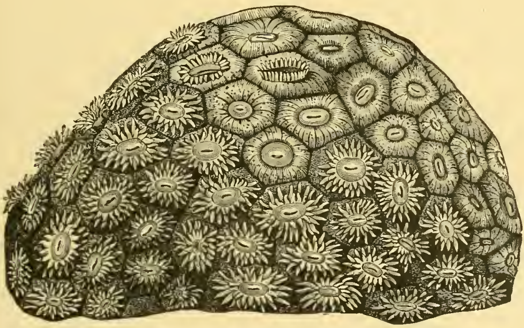


SPONTANEOUS FISSION IN POLYPS.

as is seen, a subdivision strictly into halves, as one carries off the old mouth and stomach. The figure to the left represents a polyp of the Astræa tribe, with already two mouths, through a commencement of the process of subdivision. In the next figure there are tentacles between the two mouths, so that each mouth has its own circle; and in the third, the separation has gone so far as to complete the circles and make two independent polyps. This dividing one's self in two, for the sake of an increase of population, is the process called spontaneous fission or fissiparity.

This mode of budding does not belong exclusively to coral polyps, for it has been observed among a few Actiniæ. Gosse describes its occurrence in a British species, the *Anthea cereus*, in which it results in two distinct animals. He says "the fission begins at the margin of the disk, and gradually extends downward until the separation is complete, when each moiety soon closes and forms a perfect animal." The same author alludes to the occurrence of double-disked individuals of the genera Actinoloba, and Actinia as illustrating the process without a separation of the spontaneously developed pair.

This spontaneous fission is the common kind of budding in the large Astræa tribe.



ASTRÆA PALLIDA, D.

The preceding figure represents a species of living coral of the Astræa family, from the Feejees, the *Astræa pallida* D.

which grew, and multiplied its polyps as it grew, by this method. In such species some of the disks of the polyps will be found to have two mouths. This is the first step in the process In others, the two mouths will be found to be partly divided from one another by new-formed tentacles; and finally each will have its own circle complete and all else in polyp perfection.

Many of the Astræa hemispheres of the Pacific, grown by this method, have a diameter of ten to fifteen feet.

In other Astræa-like species, this spontaneous fission ends in a complete separation of the two polyps formed; and consequently in a forking of an old branch. The figure of a Caulastræa, on Plate IV. (figure 1), illustrates this mode of branching. In the left hand polyp there are already two mouths, and the work of subdivision is consequently begun; while in those to the right, which have a single mouth, the subdivision has just been completed, and also the forking of the old branch. Thus spontaneous fission goes forward, and branches accordingly multiply. By this method some of the most magnificent clumps of coral zoöphytes found in tropical seas have been, and are being, developed each from a single germ. Many of them have the perfect hemispherical symmetry of the solid Astræas.

Sometimes, when a new mouth forms in an enlarging disk, there is not at once a separation of the two, but the disk continues to enlarge in one direction and another, and then another mouth opens, and so on until a string of mouths exists in one elongated disk; and finally, a separation occurs, but only to commence or carry forward another long series. In this way the corals with mæandrine furrows are made, some kinds of which are popularly called Brain coral, and pertain to the Mæandrina family (figure on page 65). The same may take place in the ramose corals, and so make flat branches, each with a long sinuous line of polyp mouths at top. In all such species the tentacles stand in a line either side of the line of mouths as represented in figure 3 on Plate IV., between pages 54 and 55.

By the simple methods here explained all of the various forms of Actinoid zoöphytes have been produced; and, equally so, those of the Alcyonoids described beyond. The tree, shrub, clusters of coral leaves, hemispheres, and coral net-work require for the explanation of their origin only the few principles which have been mentioned. The germ-polyp, growing upward and more or less outward, and budding as it grows, makes thus the rising stem — that of the Madrepore or Dendrophyllia, with its summit polyp (figures p. 50, 51), or that of the Porites, with its terminal budding clusters (p. 53); or the rising, massive dome of the Astræa and Mæandrina (pp. 57, 65), in case budding is symmetrical in all directions; or, if growth in the germ-polyp is upward exclusively, it forms a rising stem bearing at top the single polyp that originated it, or crowded clusters of such stems branching variously and having each branch surmounted with its one polyp (figure p. 54); or, if there is lateral growth and but little of upward, it produces leaf-like forms and graceful groups or clusters of leaves, vases, and other shapes; or, if the germ-polyp is capable of lateral growth alone, the results are simple lines of polyps creeping over the supporting rock, like the creeping stolons of a plant, or else encrusting plates, spreading outward like a lichen.

In the descriptions of corals the following terms have the significations annexed. Those already mentioned are here repeated to bring them all together.

Zoöthome. — The compound animal mass produced by budding.

Corallum. — The coral either of the compound mass, or of the solitary polyp.

Corallet (In Latin, corallulum). — The coral of a single polyp in a compound corallum.

Calicle. — The polyp cell in the top of a corallet, or of a solitary corallum, within the walls of the cells; it is sometimes flat at top, that is, without the usual depression.

Septa. — The radiated plates of the cell or calicle.

Dissepiments. — Small cross plates between adjoining septa, approximately horizontal; sometimes wanting.

Synapticulæ.— Calcareous bars extending across the interseptal spaces, or *loculi*, and so uniting the surfaces of adjoining septa.

Tabulæ. — Horizontal plates dividing the interior of a cell into a series of chambers, as in the ancient Favosites, and in the Pocilliporæ.

Tabulate. — Having tabulæ. The Tabulatæ include the Favosites and some other ancient corals.

Columella. — The prominent axis of a corallet projecting at the centre of a calicle. It is generally absent.

Costæ. — The vertical ridges over the exterior of some corals; they usually correspond to the septæ, and are an external extension of them; but in other cases they are opposite the intermediate chambers, or are interseptal *loculi*, as they are often called.

Cœnenchyma. — The common mass of the corallum between its different polyp cells or corallets, as in the Madreporæ, Gemmiporæ, and Dendrophylliæ.

Epitheca. — The coral layer sometimes deposited over the exterior of the corallum during the life of the polyp by the outer skin before it dries away, as explained on page 44.

Peritheca. — The epitheca of a compound group or zoöthome (fig. p. 71).

Exotheca. — The portion of the corallum outside of the walls of cells in many coralla of the Astræa family, and some others, in which the polyps of the mass are properly in contact, and there is consequently no true cœnenchyma.

Endotheca. — The portion of the corallum inside of the walls of the cell.

We may now state briefly the characteristics of the grander divisions of the Actinoid polyps, several of which have been illustrated in the preceding figures.

The tribes adopted are those recognized by Prof. Verrill, and have the limits he has assigned to them. The classification diverges from his system in uniting the non-coral-making and coral-making species into one grand division, that of the Actinoids (on the ground of the close resemblance of the polyps), and also in separating from the latter the Cyathophylloid corals, for the reasons mentioned on page 21. Some of the figures of corals on former pages are here repeated in order to present together those of like relations.

1. *Species without internal Coral Secretions.* ACTINARIA of Verrill.

1. The *Actinia tribe*, or ACTINACEA, secrete no coral internally, and moreover have a muscular base, with some degree of locomotion by means of it. The Actiniæ of the frontispiece, and of pages 23, 24, 26, are examples.

2. The *Zoanthus tribe*, or ZOANTHACEA. The species here included are like the Actiniæ in secreting no coral. But while they have a base, it is not muscular, and they are never capable of locomotion. The polyps have a thick or somewhat leathery exterior, and, as already observed (p. 39), have gills, or branchiæ. Some of the species are solitary polyps; but generally they form compound masses or zoöthomes, by budding; sometimes making simple lines of polyps over a supporting surface; at other times incrusting plates, or irregular masses. The following figure (from Verrill) represents a species found in American seas off the coast of New Jersey, in deep water, and also in Massachusetts Bay, which has a habit of fixing on a shell for its support and of always taking one containing a soldier crab. The shell finally becomes dissolved away—how, it is not known, by

the growing Zoanthid; but the crab holds on to its house although at the expense of transporting wherever it goes a

EPIZOANTHUS AMERICANUS, V., WITH EUPAGURUS PUBESCENS, ST.

colony of flowering polyps. The polyps are but partly expanded in figure 1, and wholly so in figure 2.

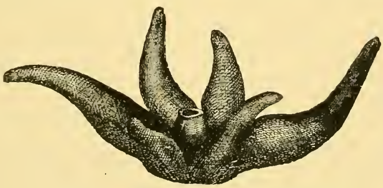
The animals of the Zoanthus tribe have broad, radiated disks, with an edging of short tentacles, in one or more rows. Although not secreting coral, the mucus of the surface in some of the species entangles the sand that falls on it, and thus gives a degree of firmness to the mass of the zoöphyte.

3. The *Antipathus tribe*, or ANTIPATHACEA. In this tribe the polyps never have locomotion, and, so far as known, always produce compound groups by budding. These groups have the forms of delicate shrubs and long twigs; and some of them are three feet or more in height. The branches consist of a horny axis, usually spiny or hispid over its surface, surrounded by an animal coating, which is made up of united polyps. An example is shown in the following figure of a living species from the Feejees. A view of one of the polyps, much enlarged, is given in the following figure. Its tentacles are closely like those of the Actinia. The height of the entire shrub, collected by the author, was three feet, and the trunk at base was half an inch thick. The polyps had a brownish-yellow color, not particularly beautiful, and the tentacles were in general, as

in another species described by the author, rather awkwardly

ANTIPATHES ARBOREA, D.

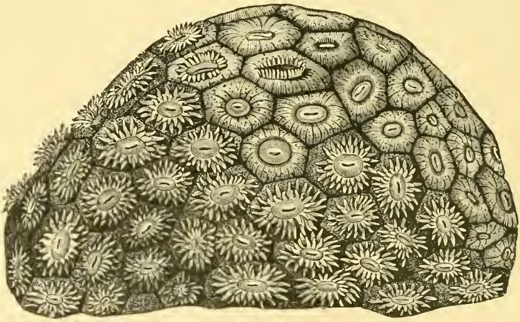
handled by the polyp. The number is commonly *six*; but in one genus, Gerardia, it is as great as *twenty-four*.



POLYP OF A. ARBOREA, MUCH ENLARGED.

2. *Polyps having internal calcareous secretions.* MADREPORARIA of VERRILL (*the Cyathophylloid species excluded*). HEXACORALLA of some authors.

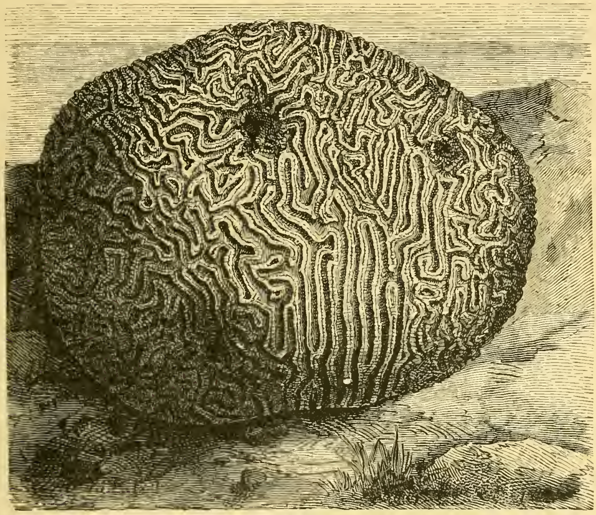
4. *Astræa tribe*, or ASTRÆACEA.—In this tribe the polyp-cells or calicles are distinctly lamello-radiate within, and generally so outside. Moreover, budding is always by division of the disks, or spontaneous fission. The figure of the Caulastræa, on page 58, illustrates one section of this family, that in which each branch of the corallum is made by a single polyp, and branching is by furcation through spontaneous fission. In other related genera, as Mussa, the polyps sometimes have a diameter of two inches, being as large as ordinary Actiniæ.



ASTRÆA PALLIDA, D.

The *Astræa pallida* is a good representative of the massive Astræas. The color of the polyps in this species is quite pale, the disks being bluish-gray, and the tentacles whitish. In others, the tentacles are emerald-green, or deep purple, or of other shades.

Another range of forms is represented by the following figure of one of the Meandrine corals, already referred to as often called "Brain coral." In the figure, the coral is reduced one-half lineally. The difference between its mode of formation and that of an Astræa, has been stated on page 59. This species is common at the Bermudas, where it grows to a diameter of three feet. It is also found in the West Indies. The ridges in this species are double, and hence the name *Diploria*,

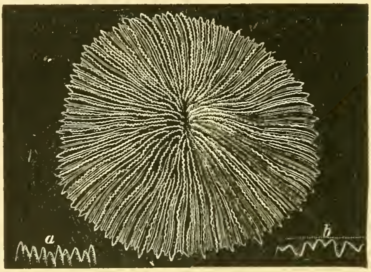


DIPLORIA CEREBRIFORMIS, E. AND H. $\times \frac{1}{2}$

from the Greek for *double*. A view of part of a living specimen of a related species is shown on Plate IV. A common large West India species of Brain coral is called *Mæandrina labyrinthica*.

Still other forms of the Astræa tribe are foliaceous, or such as would result if the growing margin of an Astræa, or of a Mæandrina, were to spread out into folia instead of thickening upward in the ordinary way. The groups of gracefully curving leaves are sometimes very large and symmetrical, as in the Tridacophyllia, Plate IV., and Merulina, Plate VI.

2. *Fungia tribe*, or FUNGIACEA.— The general character of the simple species of this tribe is mentioned on page 45, and the character of the living Fungia, with its tentacles, is shown in the figure of a Feejee species on page 46. Large, compound groups, both massive and foliaceous, are formed by budding, and the budding is always superior. There are no margins to the disk in this tribe, and in the corallum of the compound kinds no wall or partition between the adjacent stars, and no walls to adjoining polyps, or only imperfect ones. The polyps consequently coalesce throughout by their disks. The simple Fungiæ are attached when young,



FUNGIA DANÆ, E. & H., REDUCED TO ONE-SIXTH LINEALLY; *a*, *b*, TEETH OF UPPER AND LOWER MARGINS OF SEPTUM, NATURAL SIZE.

and then would hardly be distinguished from a simple or solitary species of the Astræa tribe.

3. *Oculina tribe*, or OCULINACEA.—These species occur either simple or compound, and the latter are often branched, massive, or encrusting, never thin, foliaceous. Budding is either superior, lateral, or basal; never by spontaneous fission. The coralla are remarkable for the solid walls and lamellæ of the cells; and often for having the cœnenchyma nearly or

quite solid. Transverse septa between the lamellæ are sometimes wanting. The calicles are usually striated externally but seldom dentate. The polyps, moreover, are small; and very commonly they stand prominent above the corallum when expanded. The Orbicella, figured on page 55, is an example of one of the massive Astræa-like forms, constituting the Orbicella family, or *Orbicellidæ*, in the Oculina tribe.

The Caryophyllia here figured is one of the solitary species

CARYOPHYLLIA SMITHII, STOKES.

of the tribe found in European Seas, and on the coast of Great Britain. The figure is from Gosse's British Actinology. It also grows much longer in proportion to the breadth. The figure to the right is of one unexpanded. One of its lasso-cells, in different states, is shown in figures 3, 4, 5, on page 31.

The corallum of a related species, *Caryophyllia cyathus*, is given on page 42. The walls and septa are remarkably solid. The *Caryophyllia flavus* has been found not only in the Mediterranean, but also as far north as the British Isles, and in the Florida Straits.

Another example of this tribe, as defined by Prof. Verrill, is the species of Astrangia occurring alive along the southern shores of New England, and on the coast of New Jersey. Specimens are not uncommon in the vicinity of New Haven, on the rocks by the Light-House, and at other places in Long Island Sound, and when alive it is an exceedingly beautiful object. The accompanying figures of the animal are from the drawings made to illustrate a yet unpublished memoir by Prof. Agassiz. They are copied from the "Sea-Side Studies" of Mrs. Agassiz and Alexander Agassiz. In fig. *c*, the polyps are of the natural size, while fig. *a* represents one of them enlarged. The polyps, as is observed, stand very prominent above the cells of the corallum, because only the bases of them secrete coral; and the buds, which open between the calicles, are hence *lateral* buds; the coral has much resemblance to that of an Orbicella, in which budding is margin-

ASTRANGIA DANÆ, AG.

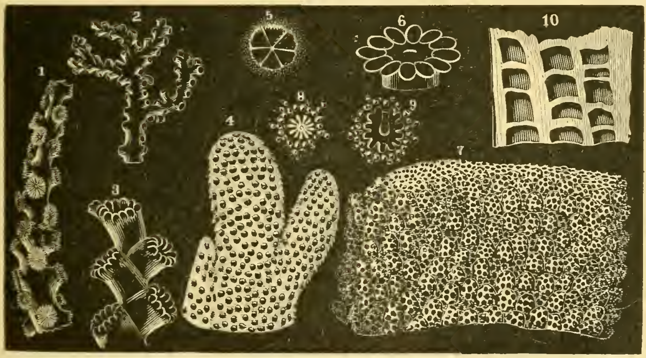
al. The tentacles have minute warty prominences over them, which are full of lasso-cells, each about a 500th of an inch in length, or about two-thirds larger than those of the *white cords* that edge the internal septa. The corallum, though massive, is somewhat irregularly lobed above, and grows to a diameter of two or three inches. It is covered with stars an eighth of an inch to a sixth across (fig. *b*), which are usually crowded together, the intervening wall being very thin and solid. The author alluded to the crowd of stars in the name Pleiadia, which he proposed for the genus in his Report on Zoophytes (p. 722).

The genus Cladocora, containing slenderly branching ramose zoöphytes, is closely related in its polyps, according to Prof. Verrill, to the Astrangiæ, and belongs to that family Its cylindrical stems are gathered into crowded clumps. The *C. arbuscula* is figured on page 54.

PHYLLANGIA AMERICANA, E. & H.

A West India species of another genus of the group, the *Phyllangia Americana*, is represented in the annexed figure.

In the following cut, figure 1 represents the extremity of a branch of an Oculina, the *O. varicosa*, of the family *Oculinidæ.*



CORALS OF THE OCULINA TRIBE.

The species of this genus grow in clumps of round branches, and have very solid coralla, so white and firm when bleached as to go by the popular name of "white coral," and to be sometimes polished for beads and other such ornamental purposes.

Figure 2 is a branch of a beautiful little coral called *Stylaster erubescens* Pourt., and 3, a portion of the same enlarged. It has the firmness, and something of the habit of an Oculina, but is rather like a miniature Oculina, its calicles never exceeding a twentieth of an inch in breadth. The *Stylasteridæ* have been shown, however, to be Hydrocorallinæ, like the Millepores (page 103).

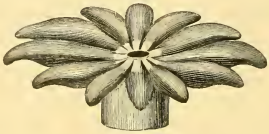
Figure 4, in the same cut, represents a portion of a branch of the *Stylophora Danæ* E. and H. The corals of the genus are remarkable for their small, crowded calicles, and for the very distinct six-rayed star in each calicle (as shown magnified in figure 5), and usually have a prominent point or columella at the centre of the star. The polyp of a Feejee species, *S. mordax*, is represented in figure 6. The name of the family, *Stylophoridæ* (signifying style-bearer), alludes to this columella. The corals grow in regular hemispherical clumps consisting of flattened or rounded branches, and are sometimes a foot or more across.

In another family under this tribe, the *Pocilliporidæ*, very common in coral-reef seas, the cells of the corallum are always very small and crowded, as shown in figure 7. The corals are branching, and in Pocillipora, the surface is often irregular and warty, the little prominences, like the rest, being covered with polyp cells; while in Seriatopora, the branches are slender, even, and pointed. The corallum in both is very firm and solid. In the larger part of them the number of tentacles is only twelve, and formerly they were referred on this account to the Madrepore tribe; a few have as many as twenty-four tentacles.

The Pocilliporæ form hemispherical clumps like the Stylophoræ; and the branches vary from the flattened and broad form shown in figure 7 (which represents the upper part of a branch of the *P. grandis* D.), to irregularly cylindrical branches, looking rough on account of the very short branchlets. The cells are usually stellate, as in figure 8, from *P. elongata* D., and often one of the septa, and sometimes two opposite ones, extend to a columella at the centre, as illustrated in figure 9, from *P. plicata* D.; dividing the cell into halves. The cell in the interior of the corallum is crossed by thin plates or tables, as shown in figure 10, and hence they have been called *tabulate* corals. Agassiz, after the discovery of the Hydroid character of the animals of the Millepore corals, whose cells also are tabulate, referred the Pocilliporæ to the same Hydroid type. But the recent study of the polyps has shown that they are true polyps; and Prof. Verrill remarks on the resemblance of the tentacles to those of the Oculinæ. The stellate character of the calicle also proves that the animals must be polyps.

Madrepore tribe, or MADREPORACEA.—In this tribe the coralla, even to the walls of the corallets, are remarkable for being porous, and the radiating lamellæ of the polyp-cells are narrow, often perforated or imperfectly developed, and frequently mere points. The coralla are either branched, massive, or foliaceous. Budding is lateral, and in the branching species there is either a parent polyp, as in Madrepora and Dendrophyllia, or a terminal budding cluster. This peculiarity has been already illustrated in the figure of *Madrepora aspera*, on page 50. On the following page there is an outline sketch of another species, the *Madrepora formosa* D., common in the Feejees, and also in the East Indies. The two species here mentioned give a good idea of the ordinary character of the Madrepore corals. One of the polyps of the *Mad-*

repora cribripora D., a species collected in the Feejees, is represented much enlarged in the accompanying figure. The nat-



POLYP OF M. CRIBRIPORA, D.

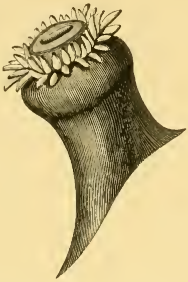
ural size of the expanded polyp in this genus is generally from an eighth to a twelfth of an inch across the star. The disk of the polyp is quite small, and the number of tentacles is always twelve. The most common color of the polyps is green, while that of the general surface between is ordinarily a pale or a dark umber. In many species of Madrepora the branches spread out laterally from a central or lateral trunk, and coalesce together into a complete net-work, having the form of a shallow vase; and the interior of the vase is filled with multitudes of short, cylindrical coral stems, rising from the reticulating branches, which, when alive, have literally the aspect of sprigs of flowers in the vase.

In certain kinds, closely related to Madreporæ, the calicles are reduced to points, or spiniform or angular prominences, or fail altogether, and there are sometimes rounded prominences between the cells; these degraded Madrepores belong to the genus Montipora (Manopora of the Author's Report).

The genus Dendrophyllia is also referred to the Madrepore tribe. The budding, as already explained, is of the same kind as in the Madrepores. But the tentacles exceed twelve. One of the polyps of *D. nigrescens* D., enlarged, is shown in the figure, on page 75. This Pacific species grows to a height of at least three feet, and is peculiar in having a very

MADREPORA FORMOSA.

dark blackish green or almost black color, while the polyps have the tentacles nearly colorless, and the disk has a circle of emerald green around the mouth. *Dendrophyllia arborea* is the name of a common species of this genus found in deep



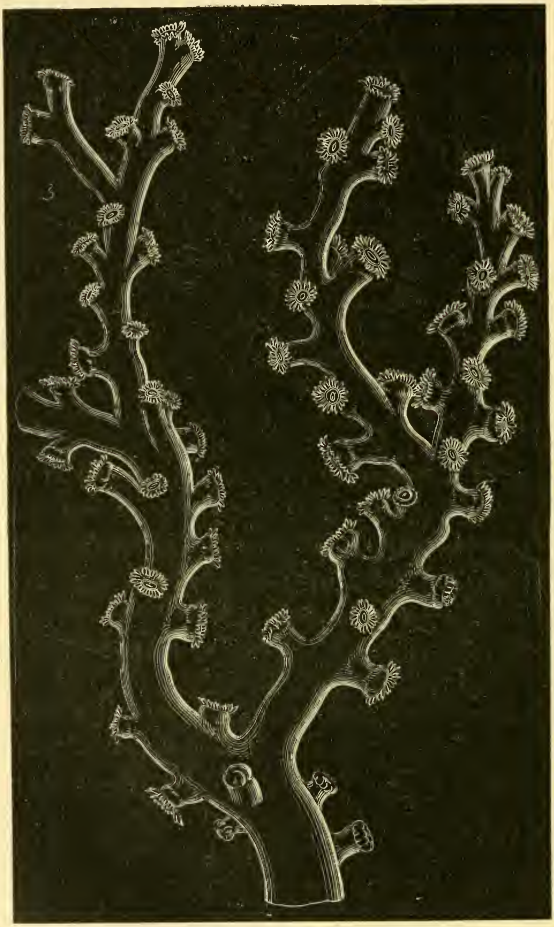
POLYP OF DENDROPHYLLIA NIGRESCENS.

water in the Mediterranean; it is equally large with the preceding, and somewhat similar in its mode of branching, but a little stouter. It has also been found in the Atlantic about the Azores. Another common Mediterranean species is the *D. cornigera.* It is sparingly branched, and has very long and stout corallets, sometimes as long and large as the finger.

The genus Gemmipora contains porous corals, of foliaceous, bowl-like, and massive forms, covered by prominent cylindrical, porous calicles, and having many short tentacles to the polyps, usually in a single circle.

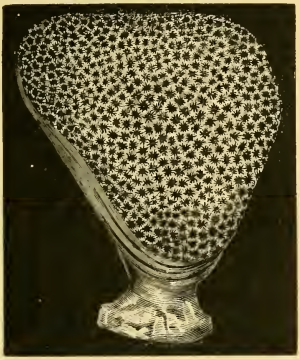
Here belongs also the large *Porites* family (Poritidæ), the corals of which are very porous, and sometimes almost spongy, and whose polyp-cells are exceedingly shallow, and usually only imperfectly radiated.

One of the genera in this family is Alveopora. It contains the lightest of known corals, the texture being exceedingly porous, and the walls of the cells, which are continued reg-



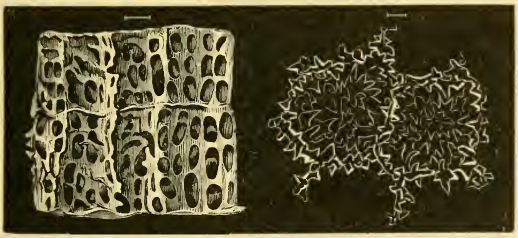
DENDROPHYLLIA NIGRESCENS, D.

ularly through the corallum, are like delicate lace-work. As stated long since by the author, "they are intermediate in character between the Montiporæ and the Favosites group"—as shown by the texture and the horizontal partitions across the



ALVEOPORA VERRILLIANA, D.

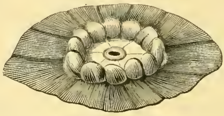
cells, giving them the "tabulate" character of the ancient Favosites, as represented by the author in the annexed figure



VERTICAL SECTION OF CORALLUM, AND UPPER VIEW OF CALICLES, ENLARGED, OF ALVEOPORA SPONGIOSA, D.

exhibiting a section of the corallum of a Feejee species. On account of this tabulate structure, the genus was referred by the author to the Favosites family. A related species, of unknown locality, has been made the type of a new genus, called *Favositipora*, by Mr. W. S. Kent, on the ground of its tabulate character (Ann. Mag. Nat. Hist., 1870), thus confirming, though overlooking, the author's conclusions.

In the genus Porites, the corals are frequently branching, as in the *Porites mordax* D., sometimes more slenderly, but oftener less so, and at times massive and monticulose in form. Another species of Porites is represented on the following page, with one of the branches fully expanded, but the others in outline; a polyp, much enlarged, having twelve tentacles as



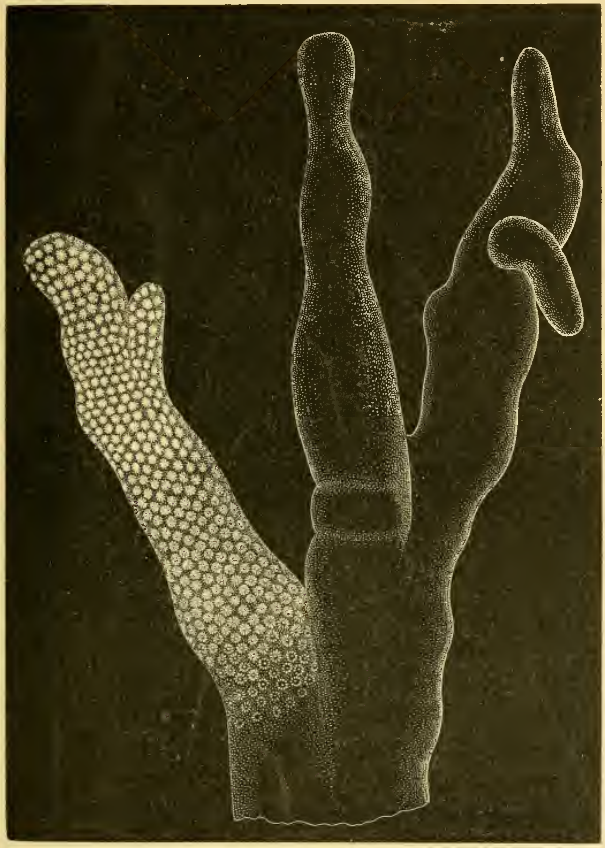
POLYP OF PORITES LEVIS.

in the Madreporæ, is shown in the following figure. The cells of the corallum are superficial, and hence the name of the species, *Porites levis*.

Another form, different in the size and character of its polyps, is exemplified in the genus Goniopora. In the species figured on p. 52, the color of the projecting polyps was lilac or pale purple, and the number of tentacles eighteen to twenty-four, yet all were in a single series. The columns grow to a height of two feet or more, with only the summits for two or three inches alive. The dead portion is usually encrusted with nullipores, sponges, serpulæ and various shells, which protect the very porous corallum within from wear and solution by the moving waters.

3. Cyathophylloids, *or* Rugosa. Tetracoralla.

It is not necessary to dwell here at length upon the ancient Cyathophylloids. The corals have a close resemblance to those of the Astræa tribe in general aspect, varieties of form, and range of size; the methods of multiplication by buds were the same that are now known in the Oculina tribe. Some of the larger kinds of simple corals, such as those of the genera Zaphrentis and Heliophyllum, had at times a diameter of



PORITES LEVIS, D.

three or four inches, so that the breadth of the polyp flower was probably at least six inches. Hemispherical masses of solid corals attained, in some species, a diameter of several feet. No doubt the colors, among the coral polyps and other life of the ancient seas, were as brilliant as now exist.

Nature's economist here puts the question—Why all this beauty when there were no eyes to enjoy it? But beauty exists because, "in the beginning," "the Spirit of God moved upon the face of the waters;" and man finds delight therein inasmuch as he bears the image of his Maker.

A single recent species has been obtained by Mr. L. F. de Pourtales, in dredging at a depth of 324 fathoms, near the Florida reef, which may be a Cyathophylloid, although it has been supposed that the species of the tribe have been extinct since the middle of the Mesozoic era. It was half an inch high and broad, and the polyp-cell had eight septa—*a multiple of four*, as in the true Cyathophylloids. The discoverer has named it *Haplophyllia paradoxa.* But he observes that it may after all be only an abnormal Actinoid.

III. ALCYONOID POLYPS.

The name *Alcyonium*, given to some of the species of this group, is derived from Alcyone, the fabled daughter of Neptune. It is sometimes written with an initial H, in conformity with the aspirate of the Greek word; but Latin authors usually omitted the H, and this has been good enough authority for Linnæus and the majority of later writers.

The Alcyonoids include some of the gayest and most delicate of coral shrubs. Almost all are flexible, and wave with the motion of the waters. They contribute but little to the material of coral reefs, but add largely to the beauties of the coral landscape. Not only are the polyps of handsome tints, but the whole shrub is usually of a brilliant orange, yellow, scarlet, crimson or purple shade. Dun colors also occur, as ash-gray, and dark brown, and almost black. Some kinds, the Sponggodiæ, are too flexible to stand erect, and they hang from the coral ledges, or in the coral caves, in gorgeous clusters of scarlet, yellow, and crimson colors.

The species of this order spread from the tropics through the colder seas of the globe, and occur at various depths, down to thousands of feet.

The two following are the most striking external peculiarities of the polyps: the number of tentacles is always eight; and these tentacles are always fringed with papillæ, though the papillæ are sometimes mere warts. Some of the various forms of the polyps are shown in the figures on the following pages.

But besides these characteristics, there is also the following: the existence of only eight internal septa, and these septa *not in pairs;* consequently, the interior is divided into only eight compartments (octants), and with each a tentacle is connected. Hence in the Alcyonoids, as Prof. Verrill has observed, the areas externally, and the compartments within, are all *ambulacral*, or tentacular, which makes a wide distinction between them and the Actinoids (p. 28) in which only the alternate are tentacular.

The solid secretions of these polyps are of two kinds: Either (1), internal and calcareous; or (2), epidermic, from the base of the polyp. The latter make an axis to the stem or branch, which is either horney (like that in Antipathus, p. 62) or calcareous. A few species have no solid secretions.

All the species are incapable of locomotion on the base; yet there are some that sometimes occur floating in the open ocean.

The three following divisions of the Alcyonoids are those now generally recognized:

1. The *Alcyonium tribe* or ALCYONACEA.—One of the forms under this tribe is represented in the annexed figure. It is from the Feejees (like most of the zoöphytes figured by the author), and in the living state the polyps had the middle portion of the tentacles pale brown, with the fringe deep brown. In another more beautiful species of the genus, from the same region, the *Xenia florida* D. (made *Xenia Danæ* by Verrill, as it proved to be distinct from Lamarck's species to

XENIA ELONGATA, D.

which the author referred it), the polyps are as large, but shorter, and the color is a shade of lilac. These species differ from the larger part of the Alcyonia in having the polyps not retractile; the tentacles fold together, if the zoöphyte is disturbed, but cannot hide themselves.

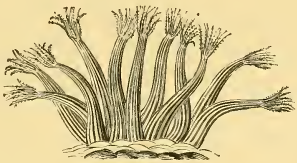
The following figure represents another related species

PLATE VI.

1. 1a, Merulina regalis; 2. 2a, Telesto trichostemma.

obtained by Dr. W. Stimpson, near Hong Kong, and called by its discoverer *Anthelia lineata;* the polyps are but partly expanded.

Other Alcyonoids are much branched, with the branches thick and finger-like, and soft or flexible, and the polyps small and wholly retractile into the mass. The branches, bare of polyps, are usually of some dull pale color, and on account of this fact some of these Alcyonia go by the common name of *dead-men's fingers.*



ANTHELIA LINEATA, ST.

The above kinds secrete granules or spicules of carbonate of lime in the tissues, and are harsher or softer in texture according to the proportion of these granules.

Some species form branching tubes, rising from an incrusting base, which are rather firm owing to the calcareous spicules present. Such species are referred to the genus Telesto—one of which, from Hong Kong, from the collection made by Dr. Stimpson, is here figured (from Verrill). The second figure shows the form of the expanded polyps.

Another species of Telesto, *T. trichostemma,* is represented colored, as in life, in figures 1, 2*a,* on Plate VI. It encrusts the dead axis of a branching Antipathes. The polyp is remarkable for its size and beauty.

In one family of this tribe the polyps form red calcareous tubes; sometimes a slender, creeping tube, with polyps at intervals, as in a species referred by the author to the genus

Aulopora; but generally vertical tubes, grouped into large red masses, called, popularly, *Organ-pipe coral.* A portion of one of the latter—*Tubipora syringa D.*—is represented in the

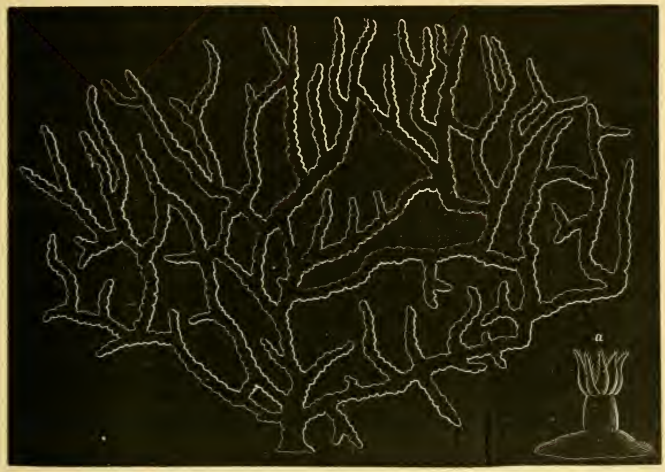
TELESTO RAMICULOSA, V.

first of the following figures, with its expanded polyps; and a polyp from the group much enlarged in the second figure. The papillæ of the fringe are arranged closely together in a

1, 2. TUBIPORA SYRINGA, D.; 3. T. FIMBRIATA, D.

plane, so that it is not at first apparent that there is a fringe. The third figure represents, enlarged, the polyp of another Feejee species, the *Tubipora fimbriata* D. Such coral masses are sometimes a foot or more in diameter, and the living zoöphyte, with its lilac or purple polyps fully expanded, looks much like a large cluster of flowers from a lilac bush. The tubes are united by cross plates at intervals.

2. *Gorgonia tribe*, or Gorgonacea.—The following figure represents a species of this tribe from the Kingsmill or Gilbert



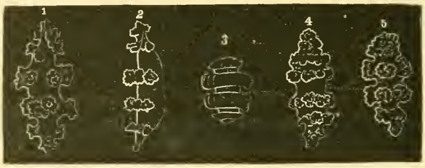
GORGONIA FLEXUOSA, D.

Islands. It is one of the net-like or reticulated species, the reticulation being a result of the coalescence of the branchlets. The general color of the species was crimson; but when alive and expanded it was covered throughout with yellowish polyps of the form in figure *a*, though much smaller, the natural size not exceeding a twelfth of an inch. The common sea-fan of the West Indies, *Gorgonia flabellum*, is much more finely reticulated, the meshes of the net-work being ordinarily not over a fourth of an inch in breadth; while the fan often grows to a height and breadth of a yard.

Other species of the Gorgonia family are like clusters of slender twigs, and others like many-branched shrubs or miniature trees.

The exterior of the stem or branch in a Gorgonia is a layer of united polyps, with minute calcareous spicules distributed through the tissues and giving the layer some firmness. It is like a bark to the axis of the stem or branch, and may be peeled off without difficulty, and hence is often called the *cortex.* The outer surface of the dried cortex is often smooth, or nearly so; but sometimes covered with small prominences. Over it there may be seen numerous oblong points (one to each of the prominences if there are any; each of these is the spot where a polyp opened out its tentacles when the zoöphyte was alive.

Kölliker and others have shown that genera, and sometimes species, of the Gorgonacea, may be distinguished by the



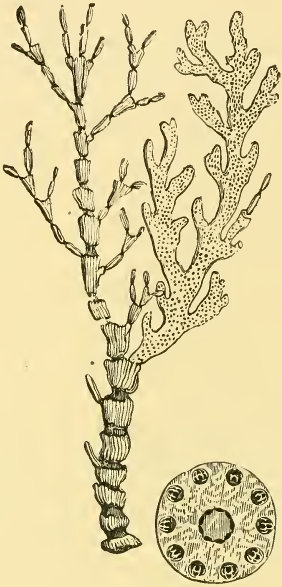
SPICULES OF GORGONIÆ, MUCH ENLARGED.

forms of the calcareous spicules. Some of these knobby spicules are represented in the annexed cut, from figures published by Prof. Verrill. The most common forms are those of figures 1, 4, 5; they occur, with small differences, in the genera Gorgonia, Eugorgia, Leptogorgia, etc. Figure 1 is from the *Leptogorgia eximia* V. Figure 2, in which one side is smooth (from the *Gorgonia quercifolia* V), is characteristic of the genus Gorgonia, but occurs in the species along with forms much like fig. 1. The forms represented in figures 3, 4, 5, are all from *Eugorgia aurantiaca* V., the peculiar kind shown in fig. 3 occurring with the other more common form, in species of this genus. In species of Plexaurella many of the spicules are beautiful crosses of various fancy shapes. In Eunicellæ the cortex is covered with an outside layer, in which the spicules are club-shaped, though ornately so, and have the smaller end pointed inward. These spicules afford valuable distinguishing characters also in all Alcyonoids.

The spicules are often brilliantly colored, and sometimes variously so in the same individual. Yellow, crimson, scarlet and purple are common colors, and they occur both of dark and pale shades. Viewed under a compound microscope by transmitted light, a group of these spicules from some species, part bright yellow and part crimson, or of some other tints, produces an exceedingly beautiful effect. It gives still greater interest to this subject that all Gorgoniæ owe the various colors they present to the colors of their spicules.

Spicules are usually wholly internal, or they only come to the surface so as to make the exterior slightly harsh. But in other cases, as in the genus Muricæa, they project and give a somewhat bristly look to the coral.

The calcareous spicules are internal secretions, like those of ordinary coral, and the constitution is the same,—mere carbonate of lime. But the secretion of the axis of the branches is *epidermic*, from the inner surface of the cortex, as in the Antipathus before described (p. 62). In the ordinary Alcyonoids that make no horny axis, the stolons, or budding stem or mass, creeps or spreads over the supporting body. But in these Gorgoniæ, the budding cluster, which would make a stolon if there were no horny secretions, has the form of a tube about a horny axis; and as this tube elongates and secretes the axis within, it gives out buds externally; thus the branch rises. New branches commence at intervals over the sides of the rising stem or branch through the starting of new

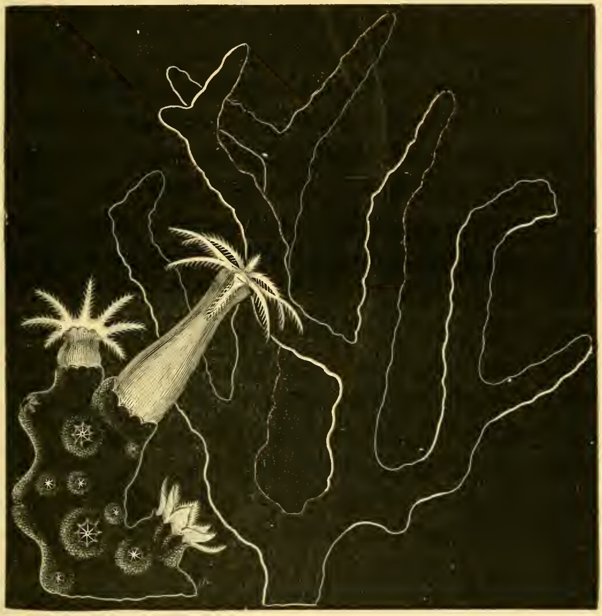


ISIS HIPPURIS, LINN.

budding centres, and so, finally, the Gorgonia zoöphyte is completed.

In a few species, the axis is partly or wholly calcareous. In the Isis family, it is made up of a series of nodes and internodes. The former, in the genus Isis, are white, calcareous, furrowed or fluted pieces; and the latter are smaller and horn-like in nature, as illustrated in the preceding figures. In the branching stem here figured, the main stem and the branch on the left are simply the axis, bare of the polyp-layer or cortex; while the branch on the right, with the surface dotted, has the cortex complete, and the dots are the sites of the contracted polyps. The circular figure below is a transverse section of the stem enlarged, showing the cavities occupied by the retracted polyps.

In the genus Melitæa, and some others related, the inter-



CORALLIUM RUBRUM.

nodes are porous and somewhat cork-like or suberose instead of horny. The species of this group are often bright-colored and much branched, and resemble, in aspect, ordinary Gorgoniæ; but they are very brittle, breaking easily at the internodes.

In the *Corallidæ*, the axis is wholly calcareous, and firm and solid throughout, with usually a red color, varying from crimson to rose-red. Here belongs the *Corallium rubrum*, or precious coral. The polyp-crust or cortex, which covers the red axis or coral, is thin, and contains comparatively few calcareous spicules, and consequently it readily disappears when the dried specimens are handled. In an uninjured state, the polyp centres may be distinguished over it by a faint six-rayed star. A branch from a specimen obtained by the author at Naples, is represented, of natural size, in the cut on page 89. The polyps, as the enlarged view, by Lacaze Duthiers, shows, are similar to those of other Alcyonoids—the tentacles being eight in number and fringed. The figure represents the extremity of a branch, magnified about four times lineally, with one polyp fully expanded, two partly, and the rest unexpanded. In the living Corallium, they open out thickly over the branches, and make it an exceedingly beautiful object. The coral grows in branching forms, spreading its branches nearly in a plane; and sometimes the little shrub is over a foot in height. The author just mentioned states that, among the polyps, those of the same branch are often all of one sex alone, and that, besides males and females, there are a few that combine both sexes. The red calcareous axis consists really of united spicules.

The precious coral is gathered from the rocky bottom of the borders of the Mediterranean, or its islands, and most abundantly at depths of 25 to 50 feet, though occurring also even down to 1,000 feet. There are important fisheries on the coast of southern Italy; of the island of Ponza, off the Gulf of Gaeta; of Sicily, especially at Trapani, its western extremity; of Corsica and Sardinia, in the straits of Bonifacio; of Algeria, south of Sardinia, near Bona, Oran, and other places, which in 1853 afforded 80,000 pounds of coral; and on the coast of Marseilles. The rose-colored is the most highly valued, because the rarest.

Another species of Corallium was obtained by the author at the Sandwich Islands (Atlas of Zoöphytes, plate 60); but, while probably from the seas of that region, its precise locality is not known.

3. *Pennatula tribe*, or PENNATULACEA. These are com-

COPHOBELEMNON CLAVATUM, V., AND VERETILLUM STIMPSONI, V.

pound Alcyonoids, that, instead of being attached to rocks or some firm support, have the base or lower extremity free from polyps and buried in the sand or mud of the sea-bottom, or else live a floating life in the ocean. Their forms are very various.

In the Veretillum family (Veretillidæ) they are stout and short club-shaped. One of the species from Hong Kong, is shown in the figure on the left, with its polyps fully expanded, and the small figure represents one of the polyps enlarged. The third figure represents a polyp of another species, from Hong Kong, a true Veretillum, enlarged three diameters; the specimens, obtained by Dr. Stimpson, and described by Prof. Verrill, were six to eight inches in length, and, where thickest, were three inches or more in diameter.

A common Mediterranean species is the *Veretillum cynomorium;* and it has been recently found, of a length of ten inches, in the depths of the Atlantic off the coast of Spain. Mr. W. S. Kent observes, with regard to its polyps and their phosphorescent qualities, as follows:

"Nothing can exceed the beauty of the elegant opaline polyps of this zoöphyte when fully expanded, and clustered like flowers on their orange-colored stalk; a beauty, however, almost equalled by night, when, on the slightest irritation, the whole colony glows from one extremity to the other with undulating waves of pale green phosphoric light. A large bucketful of these Alcyonaria was experimentally stirred up one dark evening, and the brilliant luminosity evolved produced a spectacle too brilliant for words to describe. The supporting stem appeared always to be the chief seat of these phosphorescent properties, and from thence the scintillations travelled onward to the bodies of the polyps themselves. Some of the specimens of this magnificent zoöphyte measured as much as ten inches from the proximal to the distal extremity of the supporting stalk, while the individual polyps, when fully exserted, protruded upward of an inch and a half from this inflated stalk, and measured as much as an inch in the diameter of their expanded tentacular discs."

In several genera of the Pennatula tribe there are two kinds of polyps over the surface, and this was the case with the *Veretillum Stimpsoni*, as observed by Prof. Verrill. Between the large and well-developed polyps, there were multitudes of small wart-like prominences, each of which proved to be a polyp, but very small and imperfectly developed, having only two lamellæ in the interior instead of the usual eight, and without distinct tentacles, or the ordinary nettling cords within.

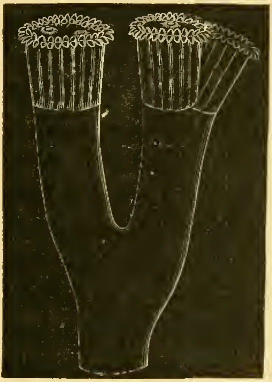
Among the other forms of Zoöphytes in the Pennatula tribe are those having a stout axis. with branches either side, arranged regularly in plume-like style (the Pennatulidæ); or a very slender stem and very short lateral polyp-bearing pinnules or processes along it (the Virgularidæ); or a thin reniform shape (Renillidæ). Others differ from the preceding in having the polyps not retractile; and some of these have a slender stem and the polyps arranged along one side of it (the Pavonaridæ); and still others a terminal cluster of polyps (the Umbellularidæ).

The most of the species secrete a slender, horny axis, and have slender calcareous spicules among the tissues, somewhat like those of the Gorgonidæ. By the thickened base of the stem these species anchor the corallum in the mud. Many species occur in the deep seas, some at depths of two thousand fathoms. Moreover, they are brilliantly phosphorescent; and Moseley says that the depths may be in places lighted by patches of these species and "possibly the animals with eyes congregate around these sources of light."

The *Heliporæ* are peculiar among the Alcyonoids in having a solid compound corallum, of rather large size; and they are alone among corals in having a blue color within. The corallum consists of slender tubes with intervening cellular cœnenchyma; and as the tubes are crossed by tabulæ, though distantly, Heliopora has been referred to the Tabulatæ, and also to the Milleporids. It was shown to belong here by Moseley of the Challenger Expedition. The eight tentacles are pinnately fringed as in other Alcyonoids, and are wholly retractile by introversion. *Heliolites*, a Paleozoic genus, is supposed to be related to Heliopora. The most common species of Heliopora is the *H. cærulea* of the East Indies.

IV. LIFE AND DEATH IN CONCURRENT PROGRESS IN CORAL ZOÖPHYTES.

The large, massive forms of stony corals would not exist, and the tree-shaped and other kinds would be of diminutive size, were it not for the fact that, in the living zoöphyte, death and life are going on together, *pari passu*. This condition of growth is favored by the coral secretions; for these give a chance for the polyp to mount upward on the coral, as it lengthens it by secretions at the top. But, to be successful in this ascending process, either the polyp must have the power of indefinite elongation, or it must desert the lower part of the corallum as growth goes forward; and this last is what happens. In some instances, a polyp, but a fourth of an inch long, or even shorter, is finally found at the top of a stem many inches in height. The following figure represents a case of this kind; for all is dead coral, excepting less than an inch at the extremity of each branch. The tissues that once filled the cells of the rest of the corallum have dried away, as increase went on above. Another example is shown on page 54, in which the living part had a length of one eighth of an inch. The Goniopora, on page 52, is still another example of the process; but here the living part combines a great number of polyps: these are growing and budding with all the exuberance of life, while below, the old polyps gradually disappear, and even their cells become superficial and fade out. Trees of Madrepores may also have their limits—all below a certain distance from the summit being dead; and this distance will differ for different species. But this is not a limit to the existence of the zoöthome, even



CAULASTRÆA FURCATA, D.

though a slender tree or shrub, or of its flourishing state; for the dead coral below is firm rock itself, often stronger than ordinary limestone or marble, and serves as an ever-rising basement for the still expanding and rising zoöphyte.

But this death is not in progress alone at the base of the column or branch. Generally the *whole interior* of a corallum is dead, a result of the same process with that just explained. Thus, a Madrepora, although the branch may be an inch in diameter, is alive only to the depth of a line or two, the growing polyps of the surface having progressively died at the lower or inner extremity as they increased outward.

The large domes of Astræas, which have been stated to attain sometimes a diameter of ten or fifteen feet, and are alive over the whole surface, owing to a symmetrical and unlimited mode of budding, are nothing but lifeless coral throughout the interior. Could the living portion be separated, it would form a hemispherical shell of polyps, in most species about half an inch thick. In some Porites of the same size, the whole mass is lifeless, excepting the exterior for a sixth of an inch in depth.

With such a mode of increase, there is no necessary limit to the growth of zoöphytes. The rising column may increase upward indefinitely, until it reaches the surface of the sea, and then death will ensue simply from exposure, and not from any failure in its powers of life. The huge domes may enlarge till the exposure just mentioned causes the death of the summit, and leaves only the sides to grow, and these may still widen, it may be indefinitely. Moreover, it is evident that if the land supporting the coral domes and trees were gradually sinking, the upward increase might go on without limit.

In the following of death after life "æquo pede," there is obedience to the universal law. And yet the polyps, through this ever yielding a little by piecemeal, seem to get the better of the law, and in some instances secure for themselves almost perpetual youth, or at least a very great age. Of the polyps over an Astræa hemisphere, none ever die as long as the dome is in a condition of growth; and the first budding individual, or at least its mouth and stomach, is among the tens of thousands that constitute the living exterior of the dome of fifteen feet diameter. In the Madrepore, the terminal parent-polyp of a branch grows on without being reached by the death-warrant that takes off at last the commoners about the base of the tree; it keeps growing and budding, and the tree thus continues its increase.

The death of the polyps about the base of a coral tree would expose it, seemingly, to immediate wear from the waters around it, especially as the texture is usually porous. But nature is not without an expedient to prevent to some extent this catastrophe.

In the first place, there is often a *peritheca* over the dead corallum—that is, an outer impervious layer of carbonate of lime, secreted by the lower edge of the series of dying polyps, a fact in the *Goniopora columna* figured on page 52. Then, further, the dead surface becomes the resting-place of numberless small encrusting species of corals, besides Nullipores, Serpulas, and some Mollusks. In many instances, the lichen-like Nullipore grows at the same rate with the rate of death in the zoöphyte, and keeps itself up to the very limit of the living part. The dead trunk of the forest becomes covered with lichens and fungi, or in tropical climes, with other foliage and flowers; so among the coral productions of the sea, there are forms of life which replace the dying polyp. The process of wear is frequently thus prevented.

The older polyps, before death, often increase their coral secretions also within, filling the pores as the tissues occupying them dwindle, and thus render the corallum nearly solid; and this is another means by which the trees of coral growth, though of slender form, are increased in strength and endurance.

The facility with which polyps repair a wound, aids in carrying forward the results above described. The breaking of a branch is no serious injury to a zoöphyte. There is often some degree of sensibility apparent throughout a clump even when of considerable size, and the shock, therefore, may occasion the polyps to close. But, in an hour, or perhaps much less time, their tentacles will again have expanded; and such as were torn by the fracture will be in the process of complete restoration to their former size and powers. The fragment broken off, dropping in a favorable place, would become the germ of another coral plant, its base cementing by means of new coral secretions to the rock on which it might rest; or, if still in contact with any part of the parent tree, it would be reunited and continue to grow as before. The coral zoöphyte may be levelled by transported masses swept over it by the waves; yet, like the trodden sod, it sprouts again, and continues to grow and flourish as before. The sod, however, has roots which are still unhurt; while the zoöphyte, which may be dead at base, has a root—a source or centre of life—in every polyp that blossoms over its surface. Each animal might live and grow if separated from the rest, and would ultimately produce a mature zoöphyte.

V. COMPOSITION OF CORAL.

Ordinary corals have a hardness a little above that of common limestone or marble. The ringing sound given, when coral is struck with a hammer, indicates this superior hardness. It is possible that it may be owing to the carbonate of lime being in the state of aragonite, whose hardness exceeds a little that of ordinary carbonate of lime or calcite. It is a common error of old date to suppose that coral when first removed from the water is soft, and afterward hardens on exposure. For, in fact, there is scarcely an appreciable difference; the live coral may have a slimy feel in the fingers; but if washed clean of the animal matter, it is found to be quite firm. The waters with which it is penetrated may contain a trace of lime in solution, which evaporates on drying, and adds slightly to the strength of the coral; but the change is hardly appreciable. A branched Madrepore rings on being struck when first collected; and a blow in any part puts in hazard every branch throughout it, on account of its elasticity and brittleness. The specific gravity of coral varies from 2·5 to 2·8 : 2·523 was the average from fifteen specimens examined by Prof. Silliman.

Chemically, the common reef-corals, of which the branching Madrepora and the massive Astræas are good examples, consist almost wholly of carbonate of lime, the same ingredient which constitutes ordinary limestone. In 100 parts, 95 to 98 parts are of this constituent; of the remainder, there are 1½ to 4 parts of organic matter, and some earthy ingredients amounting usually to less than 1 per cent. These earthy ingredients are phosphate of lime, with sometimes a trace of silica. A trace of fluorine also has been observed.

S. P. Sharples found the following constitution for the species below named (*Am. Jour. Sci.*, III., i. 168).

	CARBONATE OF LIME.	PHOSPHATE OF LIME.	WATER AND ORGANIC MATTERS.
Oculina arbuscula, N. Car.	95.37	0.84	3.79
Manicina areolata, Florida	96.54	0.50	2.96
Agaricia agaricites	97.73	0.53	1.64
Siderastræa radians	97.30	0.28	2.42
Madrepora cervicornis	98.07	0.32	1.93
Madrepora palmata	97.19	0.78	2.81

Forchhammer found 2·1 per cent. of magnesia in Corallium rubrum, and 6·36 in Isis hippuris.

The sea-water, and the ordinary food of the polyps, are evidently the sources from which the ingredients of coral are obtained. The same powers of elaboration which exist in other animals belong to polyps; for this function, as has been remarked, is the lowest attribute of vitality. Neither is it at all necessary 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 make from the elements present whatever results the functions of the animal require.

The proportion of lime salts which occurs in the water of the ocean is about $\frac{1}{24}$ to $\frac{1}{36}$ of all the ingredients in solution. The lime is mainly in the state of sulphate. Bischof states that the proportion of salts of all kinds in sea-water averages 3·527 per cent.; and in 100 parts of this, 75·79 are chloride of sodium, 9·16 chloride of magnesium, 3·66 chloride of potassium, 1·18 bromide of sodium, 4·62 sulphate of lime or gypsum, and 5·597 sulphate of magnesia, = 100. This corresponds to about 16$\frac{1}{3}$ parts of sulphate of lime to 10,000 of water.

Fluorine has also been detected in sea-water; so that all the ingredients of coral are actually contained in the waters of the ocean.

It has been common to attribute the origin of the lime of corals to the existence of carbonic-acid springs in the vicinity of coral islands. But it is an objection to such a hypothesis, that, in the first place, the facts do not require it; and, in the second, there is no foundation for it. The islands have been supposed to rest on volcanic summits, thus making one hypothesis the basis of another. Carbonic-acid springs are by no means a universal attendant on volcanic action. The Pacific affords no one fact in support of such an opinion. There are none on Hawaii, where are the most active fires in Polynesia; and the many explorations of the Society and Navigator Islands have brought none to light. Some of the largest reefs of the Pacific, those of Australia and New Caledonia, occur where there is no evidence of former volcanic action.

The currents of the Pacific are constantly bearing new supplies of water over the growing coral beds, and the whole ocean is thus engaged in contributing to their nutriment. Fish, mollusks, and zoöphytes are thus provided with earthy ingredients for their calcareous secretions, if their food fails of giving the necessary amount; and, by means of the powers of animal life, bones, shells, and corals alike are formed.

The origin of the lime in solution throughout the ocean is an inquiry foreign to our present subject. It is sufficient here to show that this lime, whatever its source, is adequate to explain all the results under consideration.

II. HYDROIDS.

The annexed sketch represents a Hydra as it often occurs attached to the under surface of a floating leaf—that of a species of Lemna. The animal is seldom over half an inch

HYDRA.

long. It has the form of a polyp, with long slender tentacles; and, besides these tentacles with their lasso-cells, it has no special organs except a mouth and a tubular stomach. Like the fabled Hydra, if its head be cut off another will grow out; and any fragment will, in the course of a short time, become a perfect Hydra, supplying head, or tail, or whatever is wanting: and hence the name given to the genus by Linnæus.

The Hydroids were long considered polyps. But they have been found to give origin, with few exceptions, to *Medusæ*, or jelly-fishes, and it is now proved that they are only an intermediate stage in the development of Medusæ, between the embryo state and that of the adult or Medusa state. The Millepores afford, therefore, examples of coral-making by species of the class of Acalephs. Many of these Medusæ and their Hydroids will be found illustrated in the admirable work of Alexander and Mrs. L. Agassiz entitled "Sea-Side Studies," — an excellent companion for all who take pleasure in sea-shore rambles.

The Hydra is the type of a large group of species. It buds, but the buds drop off soon, and hence its compound groups are always small, and usually it is single. But other kinds multiply by buds that are persistent, and almost indefinitely so; and they thus make membranous coralla of considerable size and often of much beauty.

The species here figured, *Hydrallmania falcata* (formerly called *Plumularia falcata*), is one of them. Along the branches there are minute cells, each of which was the seat of one of the little Hydra-like animals (in this not a fourth of a line long) having usually short tentacles spread out star-like. Other kinds are simple branching threads, and sometimes the cells are goblet-shaped and terminal. The Tubulariæ grow in tufts of thread-like tubes, and have a star-shaped flower at top often half an inch in diameter, with a proboscis-like mouth at the centre. In Coryne, a closely-related genus, the tentacles are shorter, and somewhat scattered about the club-shaped or prosbosciform head of the stem, so that the animal at top is far from star-shaped or graceful in form.

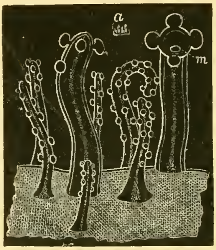
To the animal of the Coryne, that of the very common, and often large, corals, called Millepores, is closely related, as first detected by Agassiz on one of his cruises to the reefs of Florida. The coral-making Hydroids have been named *Hydroco-*

HYDRALLMANIA FALCATA.

rallinæ. The group includes also, as Moseley first showed, the Stylasteridæ mentioned on page 70 and other related species.

The corals of the Milleporæ are solid and stony, as much so as any in coral seas. They have generally a smooth surface, and are always without any prominent calicles, there being only very minute rounded punctures over the surface, from which the animals show themselves. The cells in the corallum are divided parallel to the surface, but irregularly, by very thin plates or tables, approaching in this character the Pocilliporæ and Favosites.

Each coral is a group or colony of Hydroids in the Hydriform state. Agassiz observes that the animals of Millepora are very slow in expanding themselves. When expanded, they have no resemblance to true polyps; there is simply a fleshy

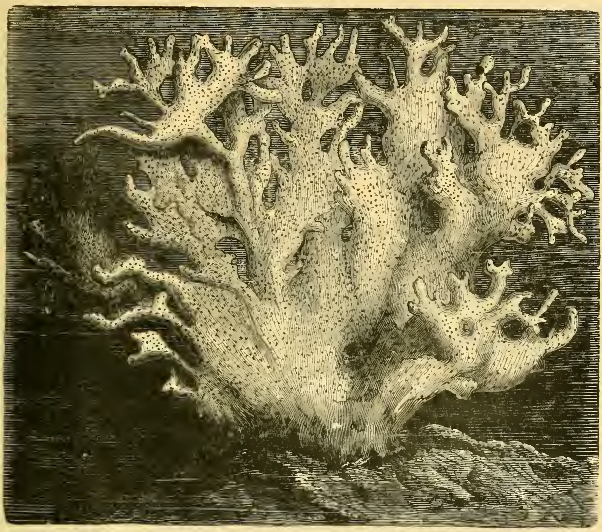


ANIMALS OF MILLEPORA ALCICORNIS, MUCH ENLARGED.

tube with a mouth at top and a few small rounded prominences in place of tentacles, four of them sometimes largest. The preceding figure, from Agassiz, shows, much enlarged, a portion of a branch of the *Millepora alcicornis* with the animals expanded; and the small figure *a*, near the top of the cut, gives the natural size of the same. But it has been further observed by Moseley that in the Millepores the animals have two forms: one is the tentacle-like kind here figured, and the other shorter and mouth-bearing; and the former are sometimes arranged around the latter in more or less perfectly circular groups, called "cyclosystems."

In the Stylasteridæ, the cyclosystems occupy usually stellate cells which stand out prominently along the branches, and look much like the calicles of an Oculina (Figs. 2, 3, p. 69).

S. P. Sharples found the coral of *M. alcicornis* to consist of 97·46 per cent of carbonate of lime, 0·27 of phosphate of lime, and 2·54 of water and organic matters. The Millepores contribute largely to the material of coral reefs.



MILLEPORA ALCICORNIS, LINN.

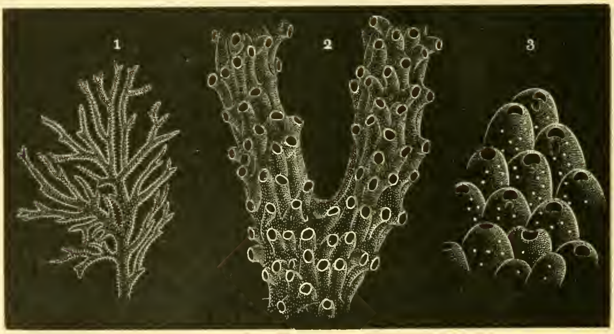
The ancient corals of the Chætetes family may be Hydrocorallinæ, as suggested by Agassiz, but more probably were Bryozoan.

III. BRYOZOANS.

The Bryozoans are very small animals, and look much like Hydroids. Although belonging to the sub-kingdom of Mollusks, they are externally polyp-like, having a circle or ellipse of slender tentacles around the mouth. But, in internal structure, and all of the animal below the head, they are Mollusks. They form delicate corals, membranous or calcareous, made up of minute, cabin-like cells, which are either very thin crusts on sea-weeds, rocks, or other supports, or slender moss-like tufts, or graceful groups of thin, curving plates, or net-like fronds; and sometimes thread-like lines, or open reticulations.

Occasionally they make large, massive corals, from the growing of plate over plate.

The first of the following figures, represents one of the delicately branching species, of natural size; and the second, a portion of the same, much enlarged. The latter figure shows that the branches are made up of minute cells. From each cell, when alive, the bryozoum extends a circlet of tentacles, less than a line in diameter.



1, 2, HORNERA LICHENOIDES; 3, DISCOPORA SKENEI, SMITT.

The encrusting kinds are common in all seas. The crust of cells they make is often thinner than paper. A portion of such a crust is represented, enlarged, in figure 3. When expanded, the surface is covered over with the delicate flower-like bryozoa. A low magnifying power is necessary to observe them distinctly. The animals, unlike true polyps and the Hydroids, have two extremities to the alimentary canal, and in this, and other points, they are Molluscan in type.

The cells of a group never have connection with a common tube, as in the Hydroids; on the contrary, each little Bryozoum, in the compound group or zoöthome, is wholly independent of the rest in its alimentary canal.

Bryozoans occur in all seas and at all depths; and in early Paleozoic time they contributed largely to the making of limestone strata.

IV. NULLIPORES.

The more important species of the Vegetable Kingdom that afford stony material for coral reefs are called Nullipores. They are true Algæ or sea-weeds, although so completely stony and solid that nothing in their aspect is plant-like. They form thick, or thin, stony incrustations over surfaces of dead corals, or coral rock, occasionally knobby or branching, and often spreading lichen-like.

They have the aspect of ordinary coral, especially the Millepores, but may be distinguished from these species by their having no cells, not even any of the pin-punctures of those species.

Besides the more stony kinds, there are delicate species, often jointed, called *Corallines*, which secrete only a little lime in their tissues, and have a more plant-like look. Even these grow so abundantly on some coasts, that, when broken up and accumulated along the shore by the sea, they may make thick calcareous deposits. Agassiz has described such beds as having considerable extent in the Florida seas.

V. THE REEF-FORMING CORALS AND THE CAUSES INFLUENCING THEIR GROWTH AND DISTRIBUTION.

I. DISTRIBUTION IN LATITUDE.

Reef-forming species are the warm-water corals of the globe. A general survey of the facts connected with the temperature of the ocean in coral-reef seas appears to sustain the conclusion that they are confined to waters which, through even the coldest winter month, have a mean temperature not below 68° F. Under the equator, the surface waters in the hotter part of the ocean have the temperature of 85° F. in the Pacific, and 83° F. in the Atlantic. The range from 68° F. to 85° F. is, therefore, not too great for reef-making species.

An isothermal line, crossing the ocean where this winter-temperature of the sea is experienced, one north of the equator, and another south, bending in its course toward or from the equator wherever the marine currents change its position, will include all the growing reefs of the world; and the area of waters may be properly called the *coral-reef seas.*

This isothermal boundary line, the *isocryme* (or cold-water line) of 68° F., extends, through mid-ocean, near the parallel of 28°; but in the vicinity of the continents it varies greatly from this, as explained beyond in the course of remarks on the geographical distribution of reefs. It is to be observed that the temperature of 68° F. is a temporary extreme—not that under which the polyps will flourish. Except for a short period, the waters near the limits of the coral seas are much warmer; the mean for the year is about 73½° F. in the North Pacific, and 70° F. in the South; from which it may be inferred that the summer mean would be as high at least as 78° and 74° F.

Over the sea thus limited coral reefs grow luxuriantly, yet in greatest profusion and widest variety through its hotter portions. Drawing the isocryme of 74° F. (that is, the isotherm for 74° F. as the mean for the coldest month) around the globe, the coral-reef seas are divided, both north and south of the equator, into two regions, a *torrid*, and a *subtorrid*, as they are named by the author (see Chart beyond, from the Author's Report on Crustacea); and these correspond, as seen below, to a marked difference in the corals which they grow.

Further, the torrid region should be divided, as the distribution of corals show, into a *warmer* and a *cooler* torrid, the isocryme separating the two being probably that of 78°.

But, before considering the facts connected with the geographical distribution of existing coral-reef species, it is important to have a correct apprehension of what are these reef species as distinct from those of colder and deeper seas.

The coral-reef species of corals are the following.—

1. In the Astræa tribe (Astræacea), all the many known species.

2. In the Fungia tribe (Fungacea), almost all known species, the only exceptions at present known being two free species found much below coral-reef depths, in the Florida seas, by C. F. de Pourtales, one of them, at a depth of 450 fathoms.

3. In the Oculina tribe (Oculinacea), all of the Orbicellids; part of the Oculinids and Stylasterids; some of the Caryophyllids, Astrangids and Stylophorids; all of the Pocilloporids.

4. In the Madrepora tribe (Madreporacea), all of the Madreporids and Poritids; many of the Dendrophyllia family or Eupsammids.

5. Among Alcyonoids, numerous species of the Alcyonium and Gorgonia tribes, and some of the Pennatulacea.

6. Among Hydroids, the Millepores and Stylasterids.

7. Among Algæ, many Nullipores and Corallines.

The corals of *colder* waters, either outside of the coral-reef seas, or at considerable depths within them, comprise, accordingly, the following:—

1. A very few Fungids.

2. Some of the Oculinids; many of the Astrangids and Caryophyllids; a few Stylophorids.

3. Many of the Eupsammids.

4. Some of the Gorgonia and Pennatula tribes, and a few of the Alcyonium tribe.

5. Milleporids of the genus Pliobothrus; many Stylasterids.

A large proportion of the cold water species are solitary polyps.

Through the *torrid* region, in the central and western Pacific, that is, within 15° to 18° of the equator, where the temperature of the surface is never below 74°F. for any month of the year, all the prominent genera of reef-forming species are abundantly represented—those of the Astræacea, Fungacea, Oculinacea, Madreporacea, Alcyonoids, Millepores and Nullipores. The Feejee seas afford magnificent examples of these torrid region productions. Astræas and Mæandrinas grow there in their fullest perfection; Madrepores add flowering shrubbery of many kinds, besides large vases and spreading folia; some of these folia over six feet in expanse. Mussæ and related species produce clumps of larger flowers; Merulinæ, Echinoporæ, Gemmiporæ and Montiporæ form groups of gracefully infolded or spreading leaves; Pavoniæ, Pocilliporæ, Seriatoporæ and Porites branching tufts of a great variety of forms; Tubipores and Xeniæ, beds or masses of the most delicately-tinted pinks; Sponggodiæ, large pendant clusters of orange and crimson; and Fungiæ display their broad disks in the spaces among the other kinds. Many of the species may be gathered from the shallow pools about the reefs.

But with a native canoe, and a Feejee to paddle and dive, the scenes in the deeper waters may not only be enjoyed, but boat-loads of the beautiful corals be easily secured.

The Hawaian Islands, in the north Pacific, between the latitudes 19° and 22°, are outside of the torrid zone of oceanic temperature, in the *subtorrid*, and the corals are consequently less luxuriant and much fewer in species. There are no Madrepores, and but few of the Astræa and Fungia tribes; while there is a profusion of corals of the hardier genera, Porites and Pocillipora.

The genera of corals occurring in the East Indies and Red Sea are mainly the same as in the Central Pacific; and the same also occur on the coast of Zanzibar.

At the eastern of the Pacific coral islands, the Paumotus, which are within the limits of the torrid region, the variety of species and genera is large, but less so than to the westward. Special facts respecting this sea have not been obtained. The author's observations were confined to the groups of islands farther west, the department of corals having been in the hands of another during the earlier part of the cruise of the Government Expedition with which he was connected.

The Gulf of Panama and the neighboring seas, north to the extremity of the California peninsula and south to Guayaquil, lie within the *torrid* region; but in the cooler part of it. The species have throughout a Pacific character, and nothing of the West Indian; but they are few in number, and are much restricted in genera. There are none, yet known, of the Astræacea, and no Madrepores. Prof. Verrill, through the study of collections made by F. H. Bradley and others, has observed that there are, near Panama, a few species of Porites and Dendrophylliæ, a Stephanaria (near Pavonia), two species of Pocilliporæ, two of Pavoniæ, one of them very large and named

P. gigantea V., several Astrangids, and a few other small species, besides a large variety under the Gorgonia tribe. At La Paz, on the California peninsula at the entrance to the Gulf, occur a small but beautiful Fungia (*F. elegans* V.), three Porites, a Dendrophyllia, a Pocillipora, some Astrangids, and many fine Gorgoniæ. The character of the species is that of the *cooler torrid* region, rather than that of the warmer torrid.

Owing to the cold oceanic currents of the eastern border of the Pacific—one of which, that up the South American coast, is so strong and chilling as to push the southern isocryme of 68°, the coral-sea boundary, nearly to the Galapagos, and north of the equator—the coral-reef sea, just east of Panama, is narrowed to 20°, which is 36° less of width than it has in mid ocean; and this suggests that these currents, by their temperature, as well as by *their usual westward direction*, have proved an obstacle to the transfer of mid-ocean species to the Panama coast.

In the West Indies the reefs lie within the limits of the isocryme of 74° F., or the torrid region; and yet the variety of species and genera is very small compared with the same in the central Pacific. The region contains some large Madrepores, the *M. palmata*, a spreading foliaceous species that forms clumps two yards in diameter; *M. cervicornis*, a stout, sparsely-branched tree-like species, which attains a height of fifteen feet; *M. prolifera*, a handsome shrub-like species, of rather crowded branches; besides others; and these are marks of the existence of the *warmer torrid* region; yet the sea has not as high a temperature as the hottest part of the Pacific. The species of the Astræa tribe are few in number, and among the largest kinds are the Mæandrinæ (the Diploria being here included). None of the free Fungidæ are known excepting the two species in deep water, and none of the Pavoniæ among the compound species; but the massive Siderinæ (Siderastrææ) are common, and the foliaceous Agariciæ and Mycedia. Of the Oculina tribe, species of Oculina, Cladocora and Astrangia are relatively more numerous than in the central Pacific; but there are none of the Pocilliporids, which are common both in the torrid and subtorrid regions of the Pacific. Millepores are very common. Gorgoniæ, are of many species.

Prof. Verrill observes that not a single West Indian coral occurs on the Panama coast, although, on the opposite coast, at Aspinwall, there are found nearly all the reef-building species of Florida, viz.: *Porites astræoides* Lmk., *P. clavaria* Lmk., *Madrepora palmata* L., *M. cervicornis* L., *M. prolifera* L., *Mæandrina clivosa* V., *M. labyrinthica*, *M. sinuosa* Les., with other species of Mæandrina, *Manicina areolata* Ehr., *Siderastræa* (*Siderina*) *radiata* V., *S. galaxea* Bl., *Agaricia agaricites*, *Orbicella cavernosa* V., *O. annularis* D. Moreover no West Indian species is known to be identical with any from the Pacific or Indian ocean.

The reefs of the Brazilian coast south of Cape Roque lie in the subtorrid region of oceanic temperature, or between the isocrymes of 74° and 68°. The reef corals extend as far south as Cape Frio, according to Prof. C. F. Hartt. The species, as determined by Prof. Verrill, from Prof. Hartt's collections, resemble the West Indian. All species of Madrepora, Mæandrina, Diploria, Manicina, Oculina, genera eminently characteristic of the West Indies, appear to be wanting, while the most important reef-making genera are *Favia*, *Acanthastræa*, *Orbicella*, *Siderastræa*, *Porites*, and *Millepora*, and also, of less importance, *Mussa* and some others. A few species, viz.: *Siderastræa stellata* V., *Orbicella aperta* V., *Astræa gravida* V., and *Porites solida* V., are very close to West Indian species; and *Millepora alcicornis* is an identical species, though different in variety.

The Bermudas are in the North Atlantic subtorrid region, in the range of the Gulf Stream. The few reef-making species that occur there are all West Indian. The principal among them are: *Isophyllia dipsacea*, *I. rigida*, *Astræa ananas*, *Diploria cerebriformis*, *D. Stokesi*, *Mæandrina labyrinthica*, *M. strigosa*, *Orbicella cavernosa*, *Oculina diffusa*, *Oculina varicosa*, *Oculina pallens*, *Oculina Valenciennesii*, *O. speciosa*, *Siderastræa radians*, *Mycedium fragile*, *Porites clavaria*, *P. astræoides*, *Millepora alcicornis*; and the common West India Alcyonoids, *Gorgonia flabellum*, *Plexaura crassa* Lx., *Pl. flexuosa* Lx., *Pl. homomalla* Lx., *Pterogorgia Americana* Ehr., *Pt. acerosa* Ehr.

The facts presented are sufficient to show that temperature has much to do with the distribution of reef-corals in latitude, while proving also that regional peculiarities exist that are not thus accounted for.

II. DISTRIBUTION IN DEPTH.

Quoy and Gaymard were the first authors who ascertained that reef-forming corals were confined to small depths, contrary to the account of Foster and the early navigators. The mistake of previous voyagers was a natural one, for coral reefs were proved to stand in an unfathomable ocean; yet it was from the first a mere opinion, as the fact of corals growing at such depths had never been ascertained. The few species which are met with in deep waters appear to be sparsely scattered, and nowhere form accumulations or beds.

The above-mentioned authors, who explored the Pacific in the Uranie under D'Urville (and afterward also in the Astrolabe), concluded from their observations that five or six fathoms (30 or 36 feet) limited their downward distribution.

Ehrenberg, by his observations on the reefs of the Red Sea, confirmed the observations of Quoy and Gaymard; he concluded that living corals do not occur beyond six fathoms. Mr. Stutchbury, after a visit to some of the Paumotus and Tahiti, remarks, in Volume I. of the West of England Journal, that the living clumps do not rise from a greater depth than 16 or 17 fathoms.

Mr. Darwin, who traversed the Pacific with Captain Fitzroy, R. N., gives 20 fathoms as not too great a range.

In his soundings off the fringing reefs of Mauritius, in the Indian ocean, on the leeward side of the island, he observed especially two large species of Madrepores, and two of Astræa; and a *Millepora* down to fifteen fathoms, with also, in the deeper parts, Seriatopora; between fifteen and twenty fathoms a bottom mostly of sand, but partly covered with the Seriatopora, with a fragment of one of the Madrepores at twenty fathoms. He states that Capt. Moresby, in his survey of the Maldives and Chagos group, found, at seven or eight fathoms, great masses of living coral; at ten fathoms, the same in groups with patches of white sand between; and, at a little greater depth, a smooth steep slope without any living coral; and further, on the Padua Bank, the northern part of the Laccadive group, which had a depth of twenty-five to thirty-five fathoms, he saw only dead coral, while on other banks in the same group.ten or twelve fathoms under water, there was growing coral.

In the Red Sea, however, according to Capt. Moresby and Lient. Wellstead, there are, to the north, large beds of living corals at a depth of twenty-five fathoms, and the anchors were often entangled by them; and he attributes this depth, so much greater than reported by Ehrenberg, to the peculiar purity, or freedom from sediment, of the waters at that place. Kotzebue states that in some lagoons of the Marshall group he observed living corals at a depth of twenty-five fathoms, or one hundred and fifty feet.

Prof. Agassiz observes that about the Florida reefs, the reef-building corals do not extend below 10 fathoms. Mr. L. F. de Pourtales states that he found species of Oculina and Cladocora off the Florida reefs living to a depth of 15 fathoms.

It thus appears that all recent investigators since Quoy and Gaymard have agreed in assigning a comparatively small depth to growing corals. The observations on this point, made during the cruise of the Wilkes Exploring Expedition, tend to confirm this opinion.

The conclusion is borne out by the fact that soundings in the course of the various and extensive surveys afford no evidence of growing coral beyond twenty fathoms. Where the depth was fifteen fathoms, coral sand and fragments were almost uniformly reported. Among the Feejee Islands, the extent of coral-reef grounds surveyed was many hundreds of square miles, besides the harbors more carefully examined. The reefs of the Navigator Islands were also sounded out, with others at the Society Group, besides numerous coral islands; and through all these regions no evidence was obtained of corals living at a greater depth than fifteen or twenty fathoms. Within the reefs west of Viti Lebu and Vanua Lebu, the anchor of the Peacock was dropped sixty times in water from twelve to twenty four fathoms deep, and in no case struck among growing corals; it usually sunk into a muddy or sandy bottom. Patches of reef were encountered at times, but they were at a less depth than twelve fathoms. By means of a drag, occasionally dropped in the same channels, some fleshy Alcyonia and a few Hydroids were brought up, but no reef-forming species.

Outside of the reef of Upolu, corals were seen by the writer growing in twelve fathoms. Lieutenant Emmons brought up with a boat-anchor a large Dendrophyllia from a depth of fourteen and a half fathoms at the Feejees; and this species was afterward found near the surface. But Dendrophyllia, it may be remembered, is one of the deep-water genera.

These facts, it may be said, are only negative, as the sounding-lead, especially in the manner it is thrown in surveys, would fail of giving decisive results. The character of a growing coral bed is so strongly marked in its uneven surface, its deep holes and many entangling stems, to the vexation of the surveyor, that in general the danger of mistake is small. But allowing uncertainty as great as supposed, there can be little doubt as to the general fact after so numerous observations over so extended regions of reefs.

The depth of the water in harbors and about shores where there is no coral, confirms the view here presented. At Upolu, the depth of the harbors varies generally from twelve to twenty fathoms. On the south side of this island, off Falealili, one hundred yards from the rocky shores, Lieutenant Perry found bare rocks in eighteen and nineteen fathoms, with no evidence of coral. There is no cause here which will explain the absence of coral, except the depth of water; for corals and coral reefs abound on most other parts of Upolu. Below Falelatai, of the same island, an equal depth was found, with no coral. Off the east cape of Falifa harbor, on the north side of Upolu, Lieutenant Emmons found no coral, although the depth was but eighteen fathoms. About the outer capes of Fungasa harbor, Tutuila, there was no coral, with a depth of fifteen to twenty fathoms; and a line of soundings across from cape to cape, afforded a bottom of sand and shells, in fifteen to twenty-one and a half fathoms. About the capes of Oafonu harbor, on the same island, there was no coral, with a depth of fifteen fathoms.

Similar results were obtained about all the islands surveyed, as the charts satisfactorily show. There is hence little room to doubt that *twenty-five fathoms*, or 150 feet, may be received as the limit in depth of flourishing banks of reef corals.

It may however be much less, possibly not over half this, on the colder border of the coral-reef seas, as, for example, at the Hawaian Islands and the atolls northwest of that group. It is natural that regions so little favorable for corals on account of the temperature should differ in this respect from those in the warmer tropics.

It may be here remarked, that soundings with reference to this subject are liable to be incorrectly reported, by persons who have not particularly studied living zoöphytes. It is of the utmost importance, in order that an observation supposed to prove the occurrence of living coral should be of any value, that fragments should be brought up for examination, in order that it may be unequivocally determined whether the corals are living or not. Dead corals may make impressions on a lead as perfectly as living ones.

As to the origin of this narrow limit in depth, temperature may be one cause through the colder parts of the coral seas, it having been proved to be predominant with regard to distribution of life throughout the extent of the ocean. Yet it is not the only cause. The range of temperature 85° to 74° gives sufficient heat for the development of the greater part of coral-reef species; and yet the temperature at the 100 foot plane in the middle Pacific is mostly above 74°. The chief cause of limitation in depth is the diminished light, as pointed out by Prof. T. Fuchs.[1]

[1] Verh. k. k. geologischen Reichsanstalt, 1882, and Ann. Mag. N. H. Jan. 1883.

III. LOCAL CAUSES INFLUENCING DISTRIBUTION.

Coral making species generally require pure ocean water, and they especially abound in the broad inner channels among the reefs, within the large lagoons, and in the shallow waters outside of the breakers. It is therefore an assertion wide from the fact that only small corals grow in the lagoons and channels, though true of lagoons and channels of small size, or of such parts of the larger channels as immediately adjoin the mouths of freshwater streams.

There are undoubtedly species especially fitted for the open ocean; but as peculiar conveniences are required for the collection of zoöphytes outside of the line of breakers, we have not the facts necessary for an exact list of such species. From the very abundant masses of Astræas, Mæandrinas, Porites, and Madrepores thrown up by the waves on the exposed reefs, it was evident that these genera were well represented in the outer seas. In the Paumotus, the single individuals of Porites lying upon the shores were at times six or eight feet in diameter. Around the Duke of York's Island the bottom was observed to be covered with small branching and foliaceous Montipores, as delicate as any of the species in more protected waters.

Species of the same genera grow in the face of the breakers, and some are identical with those that occur also in deeper waters. Numerous Astræas, Mæandrinas and Madrepores grow at the outer edge of the reefs where the waves come tumbling in with their full force. There are also many Millepores and some Porites and Pocillipores in the same places. But the weaker Montipores, excepting incrusting species, are found in stiller waters either deep or shallow.

Again, the same genera occur in the shallow waters of the reef inside of the breakers. Astræas, Mæandrinas and Pocillipores are not uncommon, though requiring pure waters. There are also Madrepores, some growing even in impure waters. One species was the only coral observed in the lagoon of Honden Island (Paumotus), all others having disappeared, owing to its imperfect connection with the sea. Upon the reefs enclosing the harbor of Rewa (Viti Lebu), where a large river. three hundred yards wide empties, which during freshets enables vessels at anchor two and a half miles off its mouth to dip up fresh water alongside, there is a single porous species of Madrepora (M. cribripora), growing here and there in patches over a surface of dead coral rock or sand. In similar places about other regions, species of Porites are most common. In many instances, the living Porites were seen standing six inches above low tide, where they were exposed to sunshine and to rains; and associated with them in such exposed situations, there were usually great numbers of Alcyonia and Xeniæ. The Siderinæ endure well exposure to the air.

The exposure of six inches above low tide, where the tide is six feet, as in the Feejees, is of much shorter duration than in the Paumotus, where the tide is less than half this amount; and consequently the height of growing coral, as compared with low-tide level, varies with the height of the tides.

Porites also occur in the impure waters adjoining the shores; and the massive species in such places commonly spread out into flat disks, the top having died from the deposition of sediment upon it.

The effects of sediment on growing zoöphytes are strongly marked, and may be often perceived when a mingling of fresh water alone produces little influence. We have mentioned that the Porites are reduced to flattened masses by the lodgment of sediment. The same takes place with the hemispheres of Astræa; and it is not uncommon that in this way large areas at top are deprived of life. The other portions still live unaffected by the injury thus sustained. Even the Fungiæ, which are broad simple species, are occasionally destroyed over a part of the disk through the same cause, and yet the rest remains alive. It is natural, therefore, that wherever streams or currents are moving or transporting sediment, there no corals grow; and for the same reason we find few living zoöphytes upon sandy or muddy shores.

The small lagoons, when shut out from the influx of the sea, are often rendered too salt for growing zoöphytes, in consequence of evaporation,—a condition of the lagoon of Enderby's Island.

They also are liable to become highly heated by the sun, which likewise would lead to their depopulation.

Coral zoöphytes sometimes suffer injury from being near large fleshy Alcyonia, whose crowded drooping branches lying over against them, destroy the polyps and mar the growing mass. Again, the dead parts of a zoöphyte, though in very many cases protected by incrusting nullipores, shells, bryozoans, etc., as already explained, in others is weakened by boring shells and sponges. Agassiz states, in his paper on the Florida Reefs (Coast Survey Report for 1851): "Innumerable boring animals establish themselves in the lifeless stem, piercing holes in all directions into its interior, like so many augurs, dissolving its solid connection with the ground, and even penetrating far into the living portion of these compact communities. The number of these boring animals is quite incredible, and they belong to different families of the animal kingdom; among the most active and powerful we would mention the date-fish or Lithodomus, several Saxicavæ, Petricolæ, Arcæ, and many worms, of which the Serpula is the largest and most destructive, inasmuch as it extends constantly through the living part of the coral stems, especially in the Mæandrina. On the loose basis of a Mæandrina, measuring less than two feet in diameter, we have counted not less than fifty holes of the date-fish—some large enough to admit a finger—besides hundreds of small ones made by worms. But however efficient these boring animals may be in preparing the coral stems for decay, there is yet another agent, perhaps still more destructive. We allude to the minute boring-sponges, which penetrate them in all directions, until they appear at last completely rotten through."

On the other hand Serpulas and certain kinds of barnacles (of the genus Creusia, etc.) penetrate living corals without injury to them. They attach themselves when young to the surface of the coral, and finally become imbedded by the increase of the zoöphyte, without producing any defacement of the surface, or affecting its growth. Many of these Serpulas grow with the same rapidity as the zoöphyte, and finally produce a long tube, which penetrates deep within the coral mass; and, when alive, they expand a large and brilliant circle or spiral of delicate rays, making a gorgeous display among the coral polyps. Instinct seems to guide these animals in selecting those corals which correspond with themselves in rate of growth; and there is in general a resemblance between the markings of a Creusia and the character of the radiations of the Astræa it inhabits.

In recapitulation, the three most influential causes of the exclusion of reef-forming corals from coasts are the following:

I. The too low temperature of the waters along shores.

II. The too great depth of the waters.

III. The proximity of the mouths of rivers, on account of which sediment is distributed along the coast adjoining and over the sea bottom.

IV. RATE OF GROWTH OF CORALS.

The rate of growth of coral is a subject but little understood. We do not refer here to the progress of a reef in formation, which is another question complicated by many co-operating causes; but simply to the rapidity with which particular living species increase in size. There is no doubt that the rate is different for different species. It is moreover probable that it corresponds with the rate of growth of other allied polyps that do not secrete lime. The rate of growth of Actiniæ might give us an approximation to the rate of growth in coral animals of like size and general character; for the additional function of secreting lime would not necessarily retard the maturing of the polyp; and from the rate of growth of the same animals in the young state, we might perhaps draw some inferences as to the rate in polyps of corresponding size. But no satisfactory observations on this point have yet been made.

Although the rapidity is undoubtedly far less than was formerly reported, the following facts from different sources seem to show that the rate is greater than has been of late believed. Mr. Darwin, citing from a manuscript by Dr. Allan, of Forres, some experiments made on the east coast of Madagascar, states that, in December, 1830, twenty corals were weighed, and then placed by him apart on a sandbank, in three feet water (low tide), and in the July following, each had nearly reached the surface and was quite immovable; and some had grown over the others. Mr. Darwin mentions also a statement made to him by Lieut Wellstead, that "in the Persian

Gulf a ship had her copper bottom encrusted in the course of twenty months, with a layer of coral two feet thick,—evidently to be accepted hesitatingly. He also speaks of a channel in the lagoon of Keeling atoll having been stopped up in less than ten years; and of the natives of the Maldives finding it necessary occasionally to root out, as they express it, coral knolls from their harbors.

Mr. Stutchbury describes a specimen consisting of a species of oyster whose age could not be over two years, encrusted by an Agaricia weighing two pounds nine ounces; but he does not state whether the shell was that of a living oyster or not.

Dr. D. F. Weinland states that on Hayti, in a small coral basin between the town of Corail and the island Caymites, never disturbed by vessels on account of the small depth of water, he observed several branches of the *Madrepora cervicornis* projecting above the surface of the water from three to five inches, all of which, down to the water level, were dead, as a result evidently of exposure to the air. This was in the month of June. He adds that all along the north shore of Hayti, the water level is from four to six feet higher in the winter season than during summer; and suggests that the growth of three to five inches, above referred to, might have been made during the three winter months.

Duchassaing (in L'Institut, 1846, p. 117) observes that in two months some large individuals of *Madrepora prolifera* which he broke away, were restored to their original size. More definite and valuable is the observation of Mr. L. F. de Pourtales, that a specimen of *Mæandrina labyrinthica*, measuring a foot in diameter, and four inches thick in the most convex part, was taken from a block of concrete at Fort Jefferson, Tortugas, which had been in the water only twenty years. Again, Major E. B. Hunt mentions, in the *American Journal of Science* for 1863, the fact of the growth of a Mæandrina at Key West, Florida, to a radius of six inches in twelve years, showing an average upward increase in this hemispherical coral of half an inch a year, if, as is evidently implied, this radius was a vertical radius. Major Hunt deposited specimens of corals of his collection near Fort Taylor, Key West, in the Yale College Museum, and three of these are labelled by him as having grown to their present size between the years 1846 and 1860, or in fourteen years. Two are specimens of *Oculina diffusa;* one is a clump four inches high and eight broad; and the other has about the same height. The weight of the first of these clumps is forty-four ounces. The rate of four inches in fourteen years would be equal to about $3\frac{1}{2}$ twelfths of an inch a year in height, or three and one-seventh ounces a year of solid coral. The other specimen is of the *Mœandrina clivosa* V.; it has a height of two and a quarter inches and a breadth of seven and a half inches. This is equivalent to about a sixth of an inch of upward growth in fourteen years. The specimen weighs about eighteen ounces. It is not certain that with either of these specimens the germs commenced to grow the first year of this interval, and hence there is much doubt with regard to these calculations.

The following observations are from a paper read by Prof. Verrill before the Boston Society of Natural History in 1862. The wreck of a vessel, supposed to have been the British frigate Severn, lost in 1793 near "Silver Bay," off Turk's Islands, is covered with growing corals. It lies (according to the journal of Mr. J. A. Whipple, by whom specimens were collected in 1857) in about four fathoms of water. One of the specimens was a mass of the species *Orbicella annularis*, shaped somewhat like a hat; it is attached to the top of a bell and spreads outward on all sides. The thickness of the coral at the centre is about eight inches, and the breadth fifteen. Another specimen consisted of an olive jar and glass decanters cemented together by a mass, of like size, of the same species of coral. The interval since the wrecking of the vessel, to 1857, was sixty-four years, and if the corals commenced their growth immediately after the wreck the increase of this species of coral is very slow.

The journal of Mr. Whipple, in the library of the same society, contains the records of his observations on the spot, and the efforts made to remove the corals in order to examine the wreck. The following are a few extracts made from it by Prof. Verrill:

April 21, 1857.—Moored our boat over the remains of a large wreck, * * its depth being from three to ten fathoms. I made the first descent in the armor. I found the bottom very uneven and covered with the remains of a man-of-war, what appeared to be the bow lying in a gulch, with the shanks of three large anchors, the palm of only one of which projected out of the coral rock.

April 22.—Made a second descent and commenced examining in six fathoms of water on what appeared to be midships. All astern of this is thick branching coral (Madrepora), and it must have made very fast, the branches being twelve inches in diameter and sixteen feet in height. To look among it from the bottom reminds one of a thick forest of a heavy growth of timber. * * * This branched coral appears to grow where there is but very little iron, as I could see no guns or shot around its roots. Commenced examining the cannon with hammer and chisel. * * * Near these cannon, which must have been near the forward part of the ship, I commenced to work on a clear space between the cannon. After breaking three inches of coral crust I found the collar bone of a man, a brass regulating screw belonging to a quadrant, and some large lead bullets. * * * The magazine must be under the branch-coral, which has been sixty-four years growing. * * *

Here we have a height of *sixteen feet* in a Madrepora attained in *sixty-four years*, or at the rate of three inches a year. Observations of Prof. Joseph Le Conte on Madrepora growths at the Tortugas in 1851 (American Journal of Science, 1875) lead to a rate of $3\frac{1}{2}$ inches a year.

Observations on the rate of growth of different species might easily be made by those residing in coral seas, either in the manner adopted by Mr. Allan (placing the specimens on a platform which could be raised for examination from time to time—say every five years), or by placing marks upon particular species where they are immovably fixed to the bottom. By inserting slender glass pins a certain distance from the summit of a Madrepore, its growth might be accurately measured from month to month. Two such pins in the surface of an Astræa, would in the same manner, by the enlarging distance between, show the rate of increase in the circumference of the hemisphere; or if four were placed so as to enclose an area, and the number of polyps counted, the numerical increase of polyps resulting from budding, might be ascertained. If specimens are selected, as done by Mr. Allan, it is important that they should be placed where other corals are growing in luxuriance, so as to be sure that there are no deleterious influences to retard growth. It is to be hoped that some of the foreign residents at the Sandwich, Society, Samoan or Feejee Islands will take this subject in hand. There are also many parts of the West Indies where these investigations might be conveniently made.

CHAPTER II.

STRUCTURE OF CORAL REEFS AND ISLANDS.

Coral reefs and coral islands are structures of the same kind under somewhat different conditions. They are made in the same seas, by the same means; in fact, a coral island has in all cases been a coral reef through a large part of its history, and is so still over much of its area. The terms however are not synonymous. *Coral islands* are reefs that stand isolated in the ocean, away from other lands, whether now raised only to the water's edge and half submerged, or covered with vegetation; while the term *coral reef*, although used for reefs of coral in general, is more especially applied to those which occur along the shores of high islands and continents. There are peculiarities in each making it convenient to describe them separately.

I. CORAL REEFS.

1. GENERAL FEATURES.

Coral reefs are banks of coral rock built upon the sea-bottom about the shores of tropical lands. In the Pacific, these lands, with the exception of New Caledonia and others of large size to the westward, are islands of volcanic or igneous rocks. and they often rise to mountain heights. The coral reefs which skirt their shores are ordinarily wholly submerged at high tide; but, at the ebb, they commonly present to view a broad, flat, bare surface of rock, just above the water level, strongly contrasting with the steep slopes of the encircled island.

Nearing in a vessel a coral-bound coast, the first sign of the reef, when the tide is well in, is a line of heavy breakers, perhaps miles in length, off a great distance from the land. On closer view, some spots of bare reef may be distinguished as the waves retreat for another plunge; but the next moment all again is an interminable line of careering waters. Happy for the cruiser in untried reef-regions, if the surging waves continue to mark the line of reef; for a treacherous quiet sometimes intervenes, which seems to be evidence of deep waters ahead, and the unsuspecting craft dashes onward ; but soon it is grinding over the coral masses, then thumping heavily at short intervals, and, in a few moments more, is landed helpless on the coral reef. The heavier billows as they roll by a vessel in such a plight—the author's experience attesting—have a way of lifting it and then letting it drop with all its weight against the bottom, and hence, unless prompt escape is in some way secured, the assaulting waves gain speedy possession, and soon after make complete the work of destruction. At low tide the breakers often cease, or nearly so. But the reef for the most part, is then in full view, and, with a good lookout aloft, favorable winds, and plenty of daylight, navigation is comparatively safe.

Some idea of the features of a tropical island thus bordered, may be derived from the following sketch. The reef to the right is observed to fringe the shore, making a simple broad platform, as an extension, apparently, of the dry land. To the left there is the same coral platform at the surface, but it is divided by a channel into an inner and an outer reef—a *fringing* and a *barrier* reef, as these two parts are called. At a single place the sea is faced by a cliff; and here, owing to the boldness of the shores and depth of waters, the reef is wanting. The barrier reef at one point has a passage through it, which is an opening to a harbor; and many such harbors exist about coral-girt islands.

HIGH ISLAND WITH BARRIER AND FRINGING REEFS.

While some islands have only narrow fringing reefs, others are almost or quite surrounded by the distant barrier, which stands off like an artificial mole to protect the land from an encroaching ocean. The barrier is occasionally ten or fifteen miles from the land, and encloses not only one, but at times several, high islands. From reefs of this large size, there are all possible variations down to the simple fringing platform.

The inner channel is sometimes barely deep enough at low tide for canoes, or for long distances may be wanting entirely. Then again, it is a narrow intricate passage, obstructed by knolls or patches of coral, rendering the navigation dangerous. Again, it is for miles in length an open sea, in which ships find room to beat against a head wind with a depth of ten, twenty, or even thirty fathoms. Yet hidden reefs make caution necessary. Patches of growing corals, from a few square feet to many square miles in extent, are met with over the broad area enclosed by these distant barriers.

These varieties of form and position are well exemplified in a single group of islands—the Feejees; and the reader is referred to the chart of this Archipelago at the close of this volume.

Near the middle of the chart is the island *Goro;* its shores, excepting the western, are bordered by a fringing reef. The island *Angau*, south of Goro, is encircled by a coral breakwater, which on the southern and western sides runs far from the shores, and is a proper barrier reef, while on the eastern side, the same reef is attached to the coast and is a fringing reef. From these examples we perceive the close relation of barrier and fringing reefs. While a reef is sometimes quite encircling, in other instances it is interrupted, or wholly wanting, along certain shores; and occasionally it may be confined to a single point of an island.

Above Angau lies *Nairai;* although a smaller island than Angau, the barrier reef is of greater extent, and stretches off far from the shores. To the eastward of Nairai are *Vatu Rera*, *Chichia*, and *Naiau*, other examples of islands fringed around with narrow reefs. *Lakemba*, a little more to the southward, is also encircled with coral; but on the east side the reef is a distant barrier. In *Aiva*, immediately south of Lakemba, the same structure is exemplified; but the coral ring is singularly large for the little spots of land it encloses. The *Argo Reef*, east of Lakemba, is a still larger barrier, encircling two points of rock called Bacon's Isles. It is actually a large lagoon island, twenty miles long, with some coral islets in the lagoon, and two of basaltic constitution, of which the largest is only a mile in diameter. Aiva and Lakemba are in fact other lagoon islands, in which the rocky islands of the interior bear a larger proportion to the whole area. The same view is further illustrated by comparing the Argo reef with Nairai, Angau, or Moala: these cases differ only in the greater or less distance of the reef from the shores and the extent of the enclosed land.

Passing to the large islands *Vanua Levu* and *Viti Levu*, we observe the same peculiarities illustrated on a much grander scale. Along the southern shores of Viti Levu, the coral reef lies close against the coast; and the same is seen on the east side and north extremity of Vanua Levu. But on the west side of these islands, this reef stretches far off from the land, and in some parts is even twenty-five miles distant, with a broad sea within. This sea, however, is obstructed by reefs, and along the shores there are proper fringing reefs.

The forms of encircling reefs depend evidently to a great extent on that of the land they enclose. That this is the case even in the Argo reef, and such other examples as offer now but a single rock above the surface of the enclosed lagoon, we shall endeavor to make apparent, if not already so, when the cause of the forms of coral islands is under discussion. Yet it is also evident that this correspondence is not exact, for many parts of the shores, and sometimes more than half the coasts, may be exposed to the sea, while other portions are protected by a wide barrier.

In recapitulation, we remark, that reefs around islands may be (1) entirely encircling; or they may be (2) confined to a larger or a smaller portion of the coast, either continuous or interrupted; they may (3) constitute throughout a distant barrier; or (4) the reef may be fringing in one part and a barrier in another; or (5) it may be fringing alone: the barrier may be (6) at a great distance from the shores, with a wide sea within, or (7) it may so unite to the fringing reef that the channel between will hardly float a canoe. These points are sustained by all reef regions.

It is to be noted that the fringing and barrier reefs here pointed out are not the whole of the coral reef; they are only the portions that have been built up to the water's level. Between them, and also outside of all, there are the submerged

LOUISIADE ARCHIPELAGO.

coral banks which are continuous with the higher portions, and all together make up the coral reef-ground of an island.

A wide difference in the extent of reef-grounds, follows from the above-mentioned facts. On some coasts there are only scattered groups of corals, or rising knolls, or mere points of emerged coral rock; but again, as for example, west of the two large Feejee Islands, there may be three thousand square miles of continuous reef-ground, occupied with coral patches and intermediate channels or seas. The enclosing barrier off Vanua Levu alone is more than one hundred miles long. The Exploring Isles, in the eastern part of the Feejee group, have a barrier eighty miles in circuit. New Caledonia has a reef along its whole western shores, a distance of two hundred and fifty miles, and it extends one hundred and fifty miles farther north, adding this much to the length of the island. The great Australian barrier forms a broken line, twelve hundred and fifty miles in length, lying off the coast from the Northern Cape to the tropical circle.

In the Louisiade Archipelago, Plate VII., the area within the great reef, one hundred and twenty-five miles long, is five sixths water, with depths of ten to two hundred feet; and the westernmost island is an atoll.

In the further description of reef-grounds, we note:

1. *Outer reefs*, or reefs formed from the growth of corals exposed to the open seas. Of this character are all proper barrier reefs, and such fringing reefs as are unprotected by a barrier.

2. *Inner reefs*, or reefs formed in quiet water between a barrier and the shores of an island.

3. *Channels*, or *seas within barriers*, which may receive detritus either from the reefs, or from the shores, or from both of these sources combined

4. *Beach* and *Drift formations*, produced by coral accumulations on the shores through the action of the sea and winds.

The outer and inner reefs, channels, and beaches, act each their part in producing the coral formations in progress about islands.

II. OUTER REEFS.

The barrier and other outer reefs are always submerged at high tide, except where elevated at surface by accumulations of beach sands. The level is generally that of about one third tide. The coral rock is built up by the agencies at work to this level, and hence the existence of the broad platform-like top of the barrier. The surface is however not even, for there are many pools of water over it, even at the lowest tides, especially toward its outer limits, where corals of various kinds are growing luxuriantly, with fit associates of shells, star-fishes, echini, holothurias with their large flower-bearing heads, sponges, corallines and sea-weeds, making scenes of rare beauty. The growing corals are, however, most abundant along the outer margin of the reef, and in the adjoining shallow seas. Here they grow in profusion ; but yet the eager lover of coral landscapes will be often disappointed by finding among the crowded plantations, extensive areas of coral sand.

The outer margin of the reef receives the plunging waves, and under this action, and the consequent unequal growth of the corals, the outline is very irregular, being often deeply cut into, and hence having sometimes long channels that give entrance to the surging tide, and to the currents that flow back in preparation for the next breaker. From it, seaward, the depth of water usually sinks off rapidly from three to six fathoms, and then falls away more gradually for many rods, or it may be some hundreds of yards ; over the bottom in these shallow waters are spread out the coral plantations, down to a depth of 80 to 150 feet. Finally there is a rather abrupt descent to depths beyond the reach of an ordinary sounding-lead. The great difference in the rapidity with which the water deepens depends chiefly on the varied character of submarine slopes. Shallow waters may extend out for miles, especially off the prominent points or angles ; but it is more common to meet with the opposite extreme—great depths within a few hundred feet.

The outer reef or coral platform is generally a little the highest at its seaward margin, owing partly to the growth of ordinary corals and other species on this part, and also to the accumulations which naturally would there be piled up by the waves and become cemented. This part is therefore first laid bare by the retreating tide ; and though a tempting place for a ramble, it is often a dangerous place on account of the heavy breakers. There is not only greater height, but often also a remarkably smooth surface to the reef-rock, looking as if water-worn, and frequently a blotching of the rock with various shades of pink and purple. These colors and the smoothness, as observed by Chamisso, are due to incrusting Nullipores ; and to the same calcareous sea-weeds, as Darwin first observed, is often owing the increased height. The material of the incrusting plant is more solid than ordinary coral, for it is without a pore ; and layer is added to layer until it has considerable thickness. It is thus an important protection to the reef against the wash of the waters.

Darwin states that on Keeling Island, the Nullipore bed has a thickness of two or three feet and a breadth of twenty feet. Nullipores are abundant on the Paumotu reefs. Still, they are not essential to the formation or protection of an outer reef, and are not always present; the outer margin is higher than the rest of the reef when they are absent.

The Nullipores are not alone on this outer edge, for there are always sprigs of Madrepores, small Astræas, and some other corals, lodged in the cavities, with many Echini, star-fishes and sea-anemones, besides barnacles and serpulas; and fish of many colors dart in and out of the numerous recesses.

Outer reefs are far more liable than the inner to become covered with accumulations of coral fragments and sand through the force and inward movement of the waves. The débris gathered up by the waters finds a lodgment some distance back from the margin—it may be one or two hundred feet, or as many yards, and gradually increases, until in many instances dry land is formed, and an islet covered with vegetation appears. Such effects are confined chiefly to the reef on the sides open to the prevailing wind, and the final result, a green islet, is not of common occurrence. But occasionally, the reef for miles has become changed from the coral bank, bare at low or middle tide, to habitable land, and makes literally, as at Bolabola, a green belt to the island of volcanic rocks and lofty hills within. The causes and the result are much the same as in a coral island, and the steps in the process are more particularly described beyond where treating of atolls.

The rock of the outer reef, wherever broken, exhibits usually a compact texture. In some parts it consists of coral fragments, rounded or angular, of quite large size, firmly cemented. Other portions are a finer coral breccia or conglomerate. Still others, more common, are solid white limestones, as impalpable and homogeneous in texture as the old limestones of our continents. There are also other regions where the corals in the rock retain the original position of growth. But the rock in general consists of the débris of the coral fields, consolidated by a calcareous cement; and the great abundance of the finer variety of rock indicates that much of it has originated from coral sand or mud. Wherever broken, it usually presents the character here described, a texture indicating a detrital or conglomeritic origin. Such a reef-rock is formed in the midst of the waves; and to this fact it owes many of its peculiarities. Reef-rocks made of corals in the position of growth are formed about the outer reefs wherever the corals grow undisturbed.

Besides corals, the shells of the seas contribute to it, and it sometimes contains them as fossils, along with bones of fishes, exuvia of crabs, spines and fragments of Echini, Orbitolites (disk-shaped foraminifers), the tubes of Serpulæ or sea-worms, and other remains of organic life inhabiting reef-grounds.

III. FORMATIONS IN THE SEA OUTSIDE OF THE BARRIER REEFS.

While barrier reefs are mostly made up of coarse coral material, owing to the rough action of the waves, the region immediately outside of the breakers, where of much width, is, to a depth of 50 to 150 feet, one of growing patches of coral and extended surfaces of coral sands.

Isolated islets of reef-rock are not however of common occurrence in the middle Pacific, though occurring in large groups like the Feejees. They are most likely to occur where there are great regions of shallow water extending outward from the barrier, and where the tides are not heavy or there is partial protection from them. In some seas, such isolated patches are shaped somewhat like a great mushroom—having a narrow trunk or column below, supporting a broad shelf of reef above. Mr. J. A. Whipple, in his Journal, referred to on page 126, figures and describes one of these "coral heads" standing in water fifty feet deep, near Turks Island. Its trunk, which made up two thirds of its height (or of the fifty feet), was only fifteen feet in diameter along its upper half; and it supported above a great tabular mass one hundred feet in diameter, whose top was bare at low tide. The tide at this place is but two feet, and this is favorable to the preservation of such top-heavy structures. In many places, he says, these tops have joined together, leaving arches between them; and in some parts of the reef-region such united coral-heads cover acres in extent, being joined together above and supported by their pillars. A case is reported of a whale having gone through one of these under passages after being struck with a harpoon. Mr. Whipple also states that there are cavernous recesses in some of these heads, some that are 200 to 300 feet across; and "when there is a heavy swell on, the water is one entire sheet of white foam, caused by its being forced through them and the air entering as the heavy sea recedes from them."

THE LIXO CORAL REEF, ABROLHOS.

Professor C. F. Hartt, in his "Geology, etc., of Brazil" (1870), describes very similar coral-heads in his account of the reefs of the Abrolhos, and represents a scene of coral-head tops in a sketch, of which the preceding is a copy. Professor Hartt speaks of it as giving simply a general view of the region without any attempt at accuracy of position. The patches of reef in the view are of this coral-head kind, though not all as slenderly supported as that above described. A vessel is represented passing through a passage between two of them. Prof. Hartt, after describing the fringing reefs of the Abrolhos, gives the following account of the outside coral formations (p. 199). "Corals grow over the bottom in small patches, *in the open sea*, and, without spreading much, often rise to a height of forty or fifty or more feet, like towers, and sometimes attain the level of low water, forming what are called on the Brazilian coast *chapeirões* (signifying *big hats*). At the top these are usually very irregular, and sometimes spread out like mushrooms, or, as the fishermen say, like umbrellas. Some of these chapeirões are only a few feet in diameter. A few miles to the eastward of the Abrolhos is an area, with a length of nine to ten and in some places a breadth of four miles, over which these structures grow abundantly, forming the well known Parcel dos Abrolhos, on which so many vessels have been wrecked." "Among these chapeirões I measured a depth of sixteen to twenty metres, and once, while becalmed, I found twenty metres alongside of one and three metres on top. They are rarely laid bare by the tide. They do not coalesce here to form large reefs as they do to the west of the islands. * * * Sometimes vessels striking heavily on small chapeirões, break them off and escape without injury, as has been remarked by Mouchez. At other times a vessel may run upon one and stick fast by the middle of the keel, to the amazement of the captain, who finds deep water all around, the vessel being perched on the chapeirões like a weather-cock on the top of a tower."

"In the northern part of the Parcel the chapeirões so closely unite as to form an immense reef, which has grown upward to a level a little above low water, and is quite uncovered at low tide." "The northeastern part of the reef is called the Recife do Lixo, that is, Reef of the *lixo*, a shark-like ray which is furnished with large crushing teeth and frequents the reef in search of shell-fish."

The rock of the submerged coral-heads is but a loose aggregation of corals in the position of growth, except probably, in their lower portion, where the open spaces may be filled with sand and fragments and all cemented together.

The deposits of sand or coral mud over the bottom of the seas outside of barrier reefs are sometimes of great extent. These sands are the fine detritus which the return flow of the breaker bears seaward; and, in still deeper water, the deposits should be mainly of the finest calcareous sand or mud—fit material for impalpable compact limestones. The waters outside of the reef, especially when moved by heavy tidal currents or storms, are often milky with the coral sand; and while the coarser sand is dropped near the shores, the finer may be carried for miles and distributed far out to sea. As Major Hunt, in his observations on the Florida Reefs remarks, this "white water" is one of the signs of proximity to a coral reef. After storms, the white coral material subsides and the waters become clear again.

Mr. Jukes, who made special examinations of the Australian reef region, and others in that vicinity, in H. M. S. Fly, states that in the deeper waters outside of the great barrier, "and in all the neighboring East India seas, from Torres Straits, north of Australia, to the Straits of Malacca, wherever the bottom was brought up by the lead, it proved to be a very fine-grained, impalpable, pale olive-green mud, wholly soluble in dilute hydrochloric acid, and therefore essentially carbonate of lime. The substance, when dried, looked much like chalk, excepting in its greener tinge. How far this calcareous matter may be due to foraminifers, rather than corals, is not known."

Since the tidal waves on any coast that is gradually shallowing have a landward propelling power, the coral sands are mostly gathered about the reef, and generally are not to any great extent lost in the depths of the ocean. The great oceanic currents, like that of the Gulf stream, might bear away the lighter material for long distances, if it swept with full strength over the shore reefs; but it is generally true that such currents are little felt close in shore. Notwithstanding the proximity of the Florida reefs, and the strength of the Gulf stream in the channel between the Keys and Florida, the adjoining sea-bottom consists mainly of common mud, with relics of deep water life, and only sparingly of coral débris. According to Mr. L. F. de Pourtales, between twelve fathoms and one hundred, in the Florida channel, outside of the reef, coral fragments occur, but are rare; dead specimens of Cladocora and Oculina occur to a depth of about 50 fathoms. But on the other side of the channel, "along the Salt Key Bank, dead corals were dredged up in 315 fathoms; but this is at the foot of a very steep slope washed by the edge of the Gulf stream; which is much better defined here than on the Florida side." The bottom, in the Florida channel, of 100 fathoms, is a rocky plateau, and outside of 200 fathoms, a mud full of foraminifers, *Globigerina mud*, as it is called from the species characterizing it; and yet this channel is situated beneath the Gulf stream and close by the Florida reefs. The facts seem to show that in most regions the reefs contribute little calcareous matter to the deep ocean. This may be otherwise over the bottom, of comparatively little depth, of a great Archipelago like that of the East Indies.

IV. INNER REEFS.

In the still waters of the inner channels or lagoons, when of large extent, we find corals growing in their greatest perfection, and the richest views are presented to the explorer of coral scenery. There are many regions—in the Feejees, examples are common—where a remote barrier encloses as pure a sea as the ocean beyond; and the greatest agitation is only such as the wind may excite on a narrow lake or channel. This condition gives rise to some important peculiarities of structure in the inner reefs, in which the inner margin of the barrier reef participates.

In the general appearance of the surface, the inner generally much resemble the outer reefs. They are nearly flat, and, though mostly bare of life, and much covered with coral sand, there are seldom any large accumulations of coral débris. The margin is generally less abrupt; yet there is every variety of slope, from the gradually inclined bed of corals to the bluff declivity with its clinging clumps. In different parts, there are many portions still under water at the lowest tides; and here (as well as upon the outer banks) fine fishing sport is afforded the natives, who wade out at ebb tide with spears, pronged sticks, and nets, to supply themselves with food. The lover of the marvellous may find abundant gratification by joining in such a ramble; for besides living corals, there are myriads of other beings which science alone has named, of various beautiful forms and colors, as becomes the inhabitants of a coral world.

Between the large reefs, which spread a broad surface, at the water's edge, of lifeless coral rock, sometimes of great extent, there are other patches, still submerged, that are covered with growing corals throughout. They are of different elevations under the water's surface; and though at times but a few yards in breadth, there is often alongside of them a depth of many fathoms. The mushroom shape described above is common among them; and a ship striking one with her keel may crush it and glide on. More frequently, they are at bottom like the solid reef above described, and the contest is more likely to be fatal to the vessel than to the coral patch. In a passage between two reefs near Tongatabu, called the Astrolabe channel, the sloop-of-war Vincennes ran on a coral patch, which had been laid down as a reef. It stopped the ship for a moment, but broke away under her; and in the survey of the passage afterward, says Captain Wilkes, "no shoal was found in the place where the ship had struck, and we had the satisfaction of knowing that we had destroyed it without injury to the vessel." Corals grow over these patches, as in the shallow waters about other reefs; and, as elsewhere, there are deep cavities among the congregated corals, in which a lead will sometimes sink to a depth of many feet, or even fathoms. These holes about growing reefs often give much annoyance to the boat which may venture to anchor upon them; and in many an instance diving is found to be the only resource left for freeing the foul anchor.

The margins of the reefs in and about the inner channels are often luxuriant with magnificent corals quite to the edge, so that while the reef is elsewhere solid rock to its very top, here at the margin it is alive and may be said literally to be growing.

The rock of the inner reefs seldom consists of rolled or broken fragments of coral like a large part of that of the outer reef. It is often made of dead corals, standing to a great extent as they grew; yet it is generally compact and firm in texture. The cavities among the branches and masses gradually become filled with coral sand, and the whole is finally cemented and so made solid. At Tongatabu and among the Feejee Islands, reefs thus formed of corals standing in their growing positions are common. Though now mere dead rock, and exceedingly firm and compact, the limits of the several constituent coral masses may be distinctly made out. Some individual specimens of Porites in the rock of the inner reef of Tongatabu are twenty-five feet in diameter; and Astræas and Mæandrinas, both there and in the Feejees, measure twelve to fifteen feet. These corals, when growing beneath the water, form, as has been stated, solid hemispheres, or rounded hillocks; but on reaching the surface, the top dies, and enlargement takes place only on the sides; and in this manner the hemisphere is finally changed to a broad cylinder with a flat top. This was the condition of the Astræas and Porites in the reef-rock referred to. Such a platform looks like a Cyclopean pavement, except that the calcareous cementing material, filling in between the huge masses, is more solid than in any work of art: it even exceeds in compactness the corals themselves. Other portions of reefs consist of *branching* corals, with the intervals filled in by sand and small fragments; for even in the stiller waters fragments are to some extent produced. A rock of this kind is often used for buildings and for walls on the island of Oahu. It consists mainly of Porites, and in many parts is still cavernous, or but imperfectly cemented.

There is also to be found about inner reefs, over large areas, the solid white limestone already described, showing internally no evidence of its coral origin, and containing rarely a shell or other imbedded fossil. It is a result of the consolidation of the fine coral sand or mud that is made and accumulated through the action of the light waves that work over the inner reefs. It has been said that large regions of barren sands or mud occur among the patches of growing corals, and these would give origin to this compact limestone.

The formation of the inner reefs goes on at a less rapid rate than that of the outer, because the process depends on the growth of the corals with comparatively little aid from the action of the waves. Moreover, as is explained more particularly in another place, impure or fresh waters and currents often operate to destroy the living corals or retard their progress.

Owing to the last mentioned cause, the inner reefs are not usually joined directly to the beach. They stand off a little, separated by an interval of shallow water. At Mathuata, in the Feejees, however, the reef extends quite up; and it is the more remarkable as the coast is flat, the site of a Feejee village, and a mile or two back stands a high bluff. On an island off this part of Vanua Lebu there is another example of this fact, and many more might be cited. In such cases, however, there is evidence that the shores upon which the corals grew were bare rocks, instead of moving beach-sands.

From these descriptions it appears that the main distinction between the inner and outer reefs consists in the less fragmentary character of the rock in the former case, the less frequent accumulations of débris on their upper surface, and the more varied features and slopes of the margin. Moreover, the Nullipores, which seem to flourish best in the breakers, are here but sparingly met with.

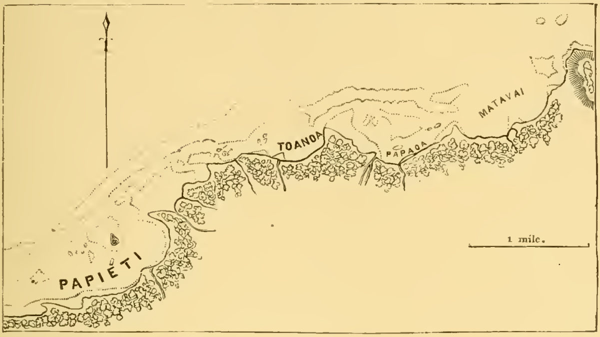
The variety of coral zoöphytes is also greater in the stiller waters, when these have great breadth, and there are species peculiar to the different regions.

V. CHANNELS AMONG REEFS.

To complete this review of the general appearance and constitution of reef formations, it remains to add some particulars respecting the channels which intervene between coral patches, or separate them from the shores of an island, and also to describe the coral accumulations forming beaches.

The reef of Australia has been instanced as affording an example of one of the larger reef-channels, varying from twenty to sixty miles in width, and as many fathoms in depth. Its average distance from the land is twenty to thirty miles, and the ordinary depth ten to twenty-five fathoms; but toward the southern end, where the channel is widest, the depth exceeds sixty fathoms. "The new Caledonia barrier reefs, 400 miles in length," says Darwin, "seldom approach within eight miles of the shore." The reefs west of the large Feejee Islands are another remarkable example, the reef-grounds being in some parts twenty-five miles wide, and the waters within the barrier, where sounded, twelve to forty fathoms in depth. The barrier in this instance may be from a few hundred yards to half a mile in width; and some of the inner patches are of the same extent; but by far the larger part of the reef-ground is covered with deep waters, mostly blue like the ocean, and as clear and pure. In the course of the cruise of the Wilkes Exploring Expedition, the sloop of war Peacock sailed along the west coast of both Viti Lebu and Vanua Lebu, within the inner reefs, a distance exceeding two hundred miles.

The island of Tahiti, on its northern side, presents a good illustration of a narrow channel, and at the same time one that exhibits the usual broken or interrupted character of reefs. This is seen in the following cut, in which the reefs, both fringing and barrier, are the parts enclosed by dotted lines. The outer reef extends half to two-thirds of a mile from the shore. Within it, between Papieti and Matavai, there is an irregular ship channel, varying from three to



CORAL REEFS OFF THE NORTH SHORE OF TAHITI.

twenty fathoms in depth. Occasionally it enlarges into harbors; and in other parts it is very intricate, though throughout navigable by large vessels. The island of Upolu, of the Samoan Group, is bordered by a reef nearly a mile wide on part of its northern shore; but the waters within are too shallow for a canoe at low tide; and therefore, notwithstanding its extent, the reef is rather a fringing than a barrier reef. Within the green belt that encircles Bolabola (p. 138) there is a large and deep channel navigable by ships.

Beneath these channels lies, in general, the coral rock of the reef-region—the inferior part of the great reef formation whose upper portions constitute the so-called barrier and fringing reefs. The rock would necessarily resemble that of the inner reefs already described; but there should be a larger proportion of the white compact limestone made from the fine coral sands carried off from the higher reefs by the currents.

Yet the bottoms of these channels are not always made up of calcareous or coral sands and fragments; for the volcanic or basaltic lands they adjoin are a source of ordinary mud; and the river courses of the land and the tidal currents of the sea will often determine the nature of the bottom, or may cause in it alternate variations.

At Upolu the white coral sands of the reefs (or in more general terms the reef débris), forms the bottom. In some places this coral material had the consistence of mud, and it was seldom observed to be covered with coarse material; there were some small patches of coral over it, and here and there a growing mass of Porites. The fresh waters of the shores do not flow over these wide reefs, as there is no proper inner channel, and there is consequently no shore detritus mingled with the reef débris.

At Tahiti, the sounding lead, where dropped in the channels, usually brought up sand, shells, and fragments of coral. At Tongatabu, the bottom where the Peacock anchored was a grayish blue calcareous mud, appearing as plastic as common clay; it consisted solely of comminuted corals and shells, with coloring matter probably from vegetable and animal decomposition.

But to the west of the larger Feejee islands, in the channels near the land, soundings commonly indicated a bottom of mud made from the material of the rocks of the mountains, and the same was frequently brought up with our dredges. On the north side of Vanua Lebu, a stream had so filled with its detritus the wide channel into which it empties, that for a mile the depth is but two to three fathoms, although elsewhere the depth is mostly from twelve to twenty fathoms; and at least half a dozen square miles of land had been added to the shores from this source. Though due principally to shore material, the reefs have probably added somewhat to these accumulations; yet little coral sand could be detected in the mud by the eye, and the proportion is certainly very small. In many places where the ships of the Wilkes Exploring Expedition anchored, having the reef not more than five hundred yards from the ship, the material of the bottom was wholly mud from the land, as much so as if there were no corals or shells within many miles.

When the materials from both sources, the shore and the reef, are mingled, the proportion will necessarily depend on the proximity to the mouths of streams, the breadth of the inner waters or channels, and the direction and force of the currents. These tidal currents often have great strength, and are much modified and increased in force at certain places, or diminished in others, by the position of the reef with reference to the land. Sweeping on, they carry off the coral débris from some regions to others distant; and again they bear along and distribute only the shore detritus. It is thus seen that the same region may differ widely in its adjacent parts, and seemingly afford evidence in one place that there is no coral near, and in another no high land, although either is within a few rods, or even close alongside.

The extent of the land in proportion to the reef will have an obvious effect upon the character of the channel or lagoon depositions. When the island stands, like one of Bacon's isles in the Feejees, as a mere point of rock in a wide sea enclosed by a distant barrier, the streams of the land are small and their detritus quite limited in amount. In such a case, the reef, and the growing patches scattered over the lagoon, are the sources of nearly all the material that is accumulated upon the bottom.

The bottom between the inner reefs within the great Australian barrier, according to Jukes, as brought up by the dredge from depths of fifteen to twenty fathoms, often resembles the unconsolidated mass of a shelly or coralline limestone. At other times it consisted very largely of the small disk-shaped foraminifers called Orbitolites, closely allied in form and nature to the Nummulites of the Tertiary; and they seemed in some places to make up the whole sand of the beaches, both of the coral islets and of the neighboring Australian shores.

The facts show that the rock formed in such channels may be of all the kinds that occur in reef regions—coral and shell conglomerates, compact impalpable limestones, limestones full of Orbitolites, or containing, as well, remains of other species of the seas, and also rocks made of the clay, mud, sand or pebbles of the mountains or high lands adjoining.

VI. BEACH SAND-ROCK.

Besides the ordinary coral rock, there are also beach formations made of coral sands, worn shells, etc., thrown up by the tides and waves. Their mode of formation is like that of any sea-beach. The material is mostly like common sand in fineness, but often much coarser. When the beach is fronted by a distant barrier to shield it from the force of the waves, the material is usually sand and small pebbles; but if the reef is narrow, so that the sea breaks over it with full force, it may consist even of cobble stones, as on any other shore, and include also huge masses of coral rock.

These deposits become cemented by being alternately moistened and dried, through the action of the recurring tides and the wash of the sea on the shores. The waters take up some carbonate of lime, and this is deposited and hardens among the particles on the evaporation of the moisture at the retreat of the tides. In some places the grains are loosely coherent, and seem to be united only by the few points in contact; and with a little care the calcareous coating which caused the union may be distinctly traced out. In other cases, the sand has been consolidated into a solid limestone rock, the interstices having been filled till a compact mass was formed. Generally even the most solid varieties show evidence of a sand origin, and in this they differ from the reef rock. The pebbly beds produce a pudding stone of coral.

In most localities the rock is an oölite or oölitic limestone. The grains become coated by the agglutinating carbonate of lime, and each enlarges thus into a minute sphere—a spherical concretion; and the aggregation of these concretions makes the oölite. The grains are usually much smaller than the roe of most fishes, a resemblance which is alluded to in the name, from the Greek ωον, *egg*.

These beach deposits consist of regular layers, commonly from a few inches to a foot in thickness, and are generally consolidated up to a line a little above high-tide mark. In all instances observed, the layers dip at an angle of six to eight degrees down the beach. This dip is nothing but the slope of the beach itself, and arises from the circumstance that the sands are deposited by the incoming waves, or tides, on such a sloping surface. Tutuila and Upolu, in the Navigator Group, and Oahu in the Hawaiian, afford many examples of these beach formations. At certain localities the beach sand-rock has been washed away after it was formed; and occasionally large masses or slabs have been uplifted by the sea and thrown high up on the beach.

Deposits of the same kind sometimes include detritus from the hills. Black basaltic pebbles are thus cemented by the white calcareous material, producing a rock of very singular appearance. Near Diamond Hill, on Oahu, is a good locality for observing the steps in its formation. Many of the pebbles of the beach are covered with a thin incrustation of carbonate of lime, appearing as if they had been dipped in milk, and others are actually cemented, yet so weakly that the fingers easily break them apart.

The lime in solution in waters washing over these coral shores is also at times deposited in the cavities or seams of the volcanic rocks; thus the cavities of a lava or basalt become filled with white calcareous kernels, and the cellular lava is changed into an amygdaloid. In large cavities, or caverns, it often forms stalactites or stalagmitic incrustations. Similar facts are stated by Mr. Darwin as observed on the shores of Ascension; and many interesting particulars are given respecting calcareous incrustations on coasts in his work on Volcanic Islands, some of which are cited beyond. They were observed by the writer upon Madeira, in St. Jago, one of the Cape Verds, as well as among the volcanic islands of the Pacific.

Jukes speaks of the oölitic character of the beach sand-rock about islets connected with the Australian barrier, and states "that the fact that the rock was not consolidated under water was proved by nests of turtles' eggs being found imbedded in it, these evidently having been deposited by the animal when the sand was above water and still loose and incoherent."

VII. DRIFT SAND-ROCK.

Still another kind of beach formation is going on in some regions through the agency of the winds in connection with the sea. It occurs only on the windward side of islands when the reefs are narrow, and proceeds from the drifting of the sand into hillocks or ridges by the winds.

The drifts resemble ordinary sand-drifts, and are often quite extensive. On Oahu, they occur at intervals around the eastern shores, from the northern cape to Diamond Point, which forms the south cape of the island,—the part exposed to the trades; and they are in some places twenty to forty feet in height. They are most remarkable on the north cape, a prominent point exposed to the winds that blow occasionally from the westward, as well as to the regular trades. They also occur on Kauai, another of the Hawaian Islands. But at Upolu (Samoa), where the protecting reefs are broad, the author met with no instance worthy of mention.

These sand-banks, through the agency of infiltrating waters, fresh or salt, become cemented into a sand-rock, more or less friable, which is frequently oölite. The rock consists of thin layers or laminæ, which are very distinct, and indicate, generally, every successive drift of sand which puffs of wind had added in the course of its formation: and where a heavier gale had blown off the top of a drift, and new accumulations again completed it, the whole history is distinctly displayed.

On northern Oahu, the elevated bluffs of coral-made limestone near Kahuku Point, eighty feet or so high above the sea-level, have a top of drift-sand rock, characteristic in its structure, resting on a much thicker coral-reef rock made up in part of large corals, some of them in the position of growth. Views of the bluffs showing the division between the two formations are given in the author's notes on Oahu, in his work on "Volcanoes and the Hawaiian Islands."

The thickness and extent of drift-sand deposits depends on the character of the wind, the agent that makes them. Winds from one direction add a little to the height of a beach; from two or more, by sweeping off sands for contributions from a wider range of surface, make the height often forty feet or more; and in a region subject to violent tempests or cyclones, like those of the Bahamas and the Bermudas, they raise hills to a height of one or more hundred feet, that are sometimes one or two miles broad, and may make banks that are many miles in width.

About cavities over the surface, the rock is usually very compact to a depth of half an inch or more, almost horny in texture, owing to the infiltration of lime from the waters often occupying them; but this is an exceptional variety of the rock.

Oölitic beds appear to be confined to the superficial formations of a reef, that is, to the beach and wind-drift accumulations. No example has come under the notice of the author of oölite constituting the foundation rock of a reef or island. It is possible that such beds might in some cases be the basement rocks to a considerable depth below; for a reef-island might subside so much more slowly than coral formations grow and accumulate, that a succession of beach-made beds would be produced even to a great thickness. Yet the probability is that the subsidence would sink the surface beneath the water, and put an end to beach and wind-drift work. The beach slope of 6° to 8° is an almost constant mark of beach-made beds.

VIII. THICKNESS OF REEFS.

We have considered in the preceding pages the peculiarities of form and structure characterizing the reef formations bordering islands and continents, and their influence upon the enclosed land. Could we raise one of these coral-bound islands from the waves, we should find that the reefs stand upon the submarine slopes, like massy structures of artificial masonry; some forming a broad flat platform or shelf ranging around the land, and others encircling it like vast ramparts, perhaps a hundred miles or more in circuit. The reefs that were near the water-line of the coast would be seen to have stood in the shallowest water, while the outer ramparts rested on the more deeply submerged slopes. Indeed, it is obvious that with a given slope to the declivity of the land, the thickness of the reef resting upon it may be directly determined, as it would be twice as great two hundred feet from the shore as at one hundred feet. The only difficulty, therefore, in correctly determining the depth or thickness of any given reef, arises from the uncertainty with regard to the submarine slope of the land. It is, however, admitted as the result of extensive observation, that in general these slopes correspond nearly with those of the land above water. Mr. Darwin has thus estimated the thickness of the reefs of the Gambier Group (p. 265) and some other Pacific islands, and he arrives at the conclusion, as his figures indicate, that some coral reefs, at their outer limits, are at least *two thousand feet* in thickness.

The mountain slopes of the islands of the Pacific, except when increased by degrading agents, do not exceed in angle twelve or fourteen degrees, and they are often but half this amount. The slopes of Mauna Kea and Mauna Loa, island of Hawaii, do not average over eight degrees. On the north side of Upolu, where the reefs are wide, the inclination is from three to six degrees. Throughout the Pacific, the *steeper* slopes of the mountains are due to agencies which cannot be shown to have affected the submarine slopes, excepting in cases of disruption of islands by forces below.

Assuming *eight* degrees as the mean inclination, we should have for the depth of reef (or water), one mile from the shore, 740 feet; or assuming *five* degrees, 460 feet. Adopting the first estimate, the Gambier Group would give for the outer reef a thickness of at least 1,750 feet; or with the second, 1,150 feet. The island of Tahiti (taking the north side for data) would give in the same manner 250 feet by the last estimate, which we judge to be most correct; Upolu, by the same estimate, 440 feet. The deduction for Upolu, may be too large: taking three degrees as the inclination, it gives 260 for the thickness at the outer margin. The results are sufficiently accurate to satisfy us of the great thickness of many barrier reefs.

These calculations, however, are liable to error from many sources. Very different results might generally be obtained from different sides of the same island; and the same group often contains islands without reefs, and others with reefs one or even several miles from the shores. But since we may show that the absence of a reef, or its limited extent, may be traced to some causes restricting or modifying its formation, it is obvious that the error would probably be on the side of too low an estimate.

Adjacent to the larger islands, such as those of Vanua Levu, and Australia, the error might be of the opposite kind; for the slopes of the land are of a more complex or irregular character than on the smaller islands. In the latter, they may be shown to belong generally to a single elevation of igneous origin, or,at the most, to two or three combined; while, in the former, they may pertain to different ranges of hills or mountains. For correct results in any instance, the land and its declivities should be carefully studied beforehand, and the system in its inclinations determined by observation. With regard to Tahiti and Upolu, information bearing upon this point was obtained, and the above conclusions may be received with much confidence. Many of the Feejee reefs, on the same principle, cannot be less than 2,000 feet in thickness.

IX. A GOOD WORD FOR CORAL REEFS.

All coral-bound coasts, and especially those of islands in mid ocean, derive great benefit from their reefs. The wide coral banks and the enclosed channels greatly enlarge the limits tributary to the lands they encircle. Besides being barriers against the ocean, they are dykes to detain the detritus of the hills. They stop the waters of the streams, and cause it to drop the silt they were bearing off, and thus secure its addition to the land. They prevent, therefore, the waste which is constantly going on about islands without such barriers; for the ocean not only encroaches upon the unprotected shores of small islands, but carries off much of whatever the streams empty into it. The delta of Rewa, on Viti Lebu, resulting from the detritus accumulations of a large river, covers nearly sixty square miles. This is an extreme case in the Pacific, as few islands are so large, and consequently rivers of such magnitude are not common. But there is rarely a coral-girt island which has not at least some narrow plains from this source; and upon them the villages of the natives are usually situated. Around Tahiti these plains are from half a mile to two or three miles in width, and the cocoa-nut and bread fruit groves are mostly confined to them.

The reefs also provide extensive fishing-grounds for the natives, and afford abundant fish, their main reliance in the way of animal food. They also supply large interior waters for practice in navigation and for safe communication between distant settlements. And the effect is evident in the spirit of maritime enterprise which characterizes the islanders; for these circumstances have favored the construction of large sail-canoes in which they venture beyond their own land, and often undertake voyages hundreds of miles in length. Communication between the Friendly Islanders and the Feejees has long been kept up by means of these large rudely-rigged sail-canoes.

Instead of a rock-bound coast, harborless and thinly habitable, like St. Helena, in the tropics, and nearly all extra-tropical islands, the shores of these reef-bound lands are blooming to the very edge, and wide plains are spread out with bread fruit and other tropical productions. Harbors, safe for scores of vessels, are also opened by the same means; and some islands number a dozen, when the unprotected shores would hardly have afforded a single good anchorage. Jukes remarks that the sea within the great Australian barrier is "one great natural harbor;" and this harbor is as long as from the extremity of Florida to Newfoundland.

Coral-reefs are sometimes viewed as only traps to surprise and wreck the unwary mariner; but whoever has visited the dreary prison-house, St. Helena, will have some appreciation of the benefits derived from the growing zoöphytes.

But in addition to these general benefits, there are also contributions from the larger reef regions to the commerce of the world. Besides pearls, there is the *biche de mar* (called also, *bêche de mer*, *sea-ginseng*, and in China, *tripang*), thousands of hundred-weight of which annually enter the Chinese market from the reef-regions of the East Indies, Australia, and the seas to the north, including the Feejee Archipelago. This favorite material for Chinese dishes, either stews or soups, etc., is *dried holothuria*—large slug-like animals, called often *sea slugs*, and also *sea cucumbers*, from their form in the contracted state. They are not slugs, but are most nearly related to the echinus, though having a thick flexible skin, while the echinus has for its exterior a firm shell, armed about with spines. The largest are only nine or ten inches long when contracted; but they lengthen out sometimes to two feet or more. They live just under the sand in the shallow waters, with the head projecting and bearing a beautiful feathery rosette or flower which is branchial in nature. To fit them for exportation, the holothuria, of which half a dozen different kinds are taken, are slit open, boiled, and then dried, in which last state they look like "smoked sausages. Dr. S. Wells Williams says, in his "Middle Kingdom," that "when soaked in water, the material resembles pork rind, and is like that in taste when stewed." They are brought to China by the Malays from Macassar, and elsewhere. There are also large drying-houses at the Feejees, and ships from America make their occasional visits to collect them, with the aid of the Feejees, and to dry and load up for China. The term *biche de mar*, and also the French form of it, *bêche de mer*, are corruptions of the Portuguese *bicho do mar*, which means *sea-worm* or *sea-slug*.

II. STRUCTURE OF CORAL ISLANDS.

I. FORMS AND GENERAL FEATURES.

Coral islands resemble the reefs just described, except that a lake or lagoon is encircled instead of a mountainous island. A narrow rim of coral reef, generally but a few hundred yards wide, stretches around the enclosed waters. In some parts the reef is so low that the waves are still dashing over it into the lagoon; in others it is verdant with the rich foliage of the tropics. The coral-made land, when highest, is seldom more than ten or twelve feet above high tide.

When first seen from the deck of a vessel, only a series of dark points is descried just above the horizon. Shortly after the points enlarge into the plumed tops of cocoa-nut trees, and a line of green, interrupted at intervals, is traced along the water's surface. Approaching still nearer, the lake and its belt of verdure are spread out before the eye, and a scene of more interest can scarcely be imagined. The surf, beating loud and heavy along the margin of the reef, presents a strange contrast to the prospect beyond,—the white coral beach, the massy foliage of the grove, and the embosomed lake with its tiny islets. The color of the lagoon water is often as blue as the ocean, although but ten or twenty fathoms deep; yet shades of green and yellow are intermingled, where patches of sand or coral-knolls are near the surface; and the green is a delicate apple-shade, quite unlike the ordinary muddy tint of shallow waters.

CORAL ISLAND, OR ATOLL.

The belt of verdure, though sometimes continuous around the lagoon, is usually broken into islets separated by varying intervals of bare reef; and through one or more of these intervals, a ship-channel often exists opening into the lagoon. The larger coral islands are thus a string of islets along a line of reef.

These lagoon islands are called *atolls*, a word of Maldive origin. The king of the Maldives bears the high sounding title of "Ibrahim Sultan, King of the thirteen Atollons and twelve thousand Isles (see page 189); which Capt. W. F. W. Owen, R. N., says is no exaggeration.

In the larger atolls, the waters within look like the ocean, and are similarly roughened by the wind, though not to the same extent. Standing on the north shore of the Raraka lagoon and looking southwest, nothing is seen but blue waters. Far in the distance to the right, and also to the left, a few faint dots are observed; and as the eye sweeps around in either direction, these dots gradually enlarge and pass into lines of verdure, and finally, distinct groves near the observer. At Dean's Island, another of the Paumotus, and at some of the Carolines, the resemblance to the ocean is still more striking. The lagoon is in fact but a fragment of the ocean cut off by more or less perfect walls of coral reef-rock; and the reef is here and there surmounted by verdure, forming a series of islets.

In many of the smaller coral islands, the lagoon has lost its ocean character, and become a shallow lake, and the green islets of the margin have coalesced in some instances into a continuous line of foliage. Traces may perhaps be still detected of the passage, or passages, over which the sea once communicated with the internal waters, though mostly concealed by the trees and shrubbery which have spread around and completed the belt of verdure. The coral island is now in its most finished state; the lake rests quietly within its circle of palms, hardly ruffled by the storms that madden the surrounding ocean.

From the islands with small lagoons, there is every variety in gradation down to those in which there is no trace of a lagoon. These simple banks of coral are the smallest of coral islands. In all the larger islands the windward side is the highest; and sometimes it is wooded and habitable throughout when the leeward reef is bare. The entrances to the lagoons are accordingly on the leeward side.

A single group of islands, the Gilbert or Kingsmill, affords good examples of the principal varieties. It is at once seen from these examples that atolls are *not annular*. In the southernmost, Tapateuea, the form is very narrow, the length being thirty-three miles, with the width of the southern portion scarcely exceeding six miles, and that of the northern more than one-half less. The emerged land is confined to one side, the eastern or windward, and consists of a series of islets upon the eastern line of coral reef. The western side is for the most part several feet under water, and there is hardly a proper lagoon. Sailing by the island, to windward, the patches of verdure, thus strung together, seem to rise out of a long white line of breakers, the sea surging violently against the unseen coral reef upon which they rest.

Nonouti, the next island north, is about twenty miles long by eight broad. The rim of land, though in fewer islets, is similar to that of Tapateuea in being confined to the reef fronting northeast. The reef of the opposite side, though bare of vegetation, stands near low-tide level, and the whole encloses a large lagoon.

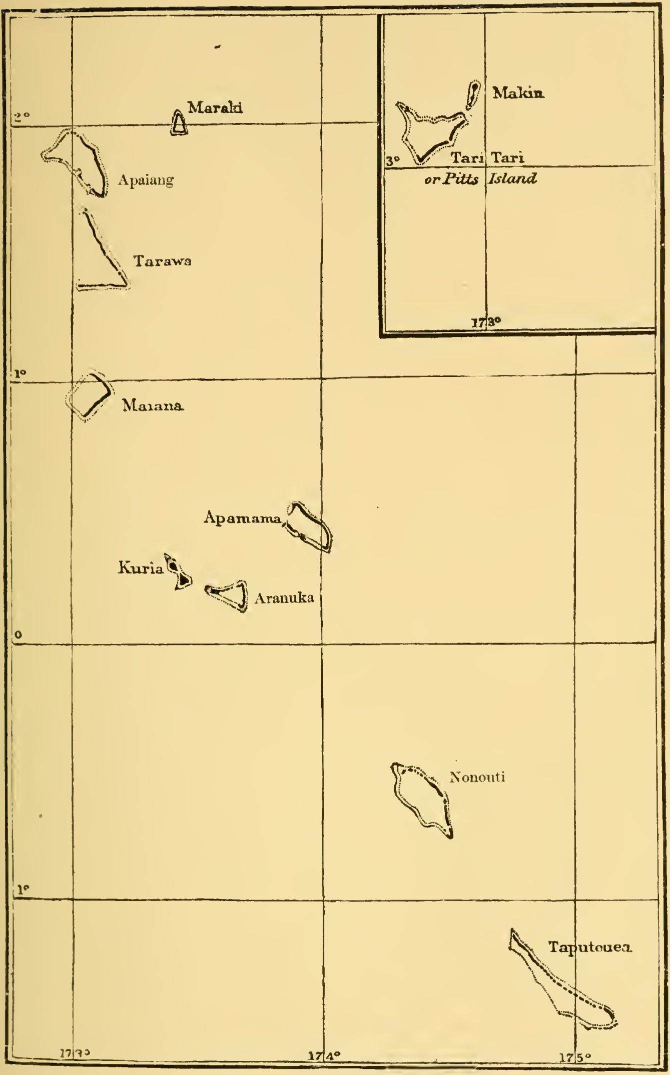
Aranuka and Apamama, though smaller than Nonouti, have the same general character. Aranuka is triangular in shape, and has an islet on the western point or cape, which is quite prominent. Apamama differs from either of the preceding in having two narrow ship entrances to the lagoon, one through the northwestern reef, and another through the southwestern.

Kuria is a remarkable double island, without a proper lagoon. It consists of two neighboring groves, each about a square mile in extent, on adjacent patches of reef.

Maiana is quite regularly quadrangular, with an uninterrupted range of land on two of the four sides, and an exposed reef constituting the other two.

Tarawa consists of two sides of a triangle. The western

Plate VIII.



GILBERT OR KINGSMILL ISLANDS

reef is wanting, and the sea and lagoon have unbroken communication. In place of it, there are two to ten fathoms of water, and a bottom of coral sand. Small vessels may sail in almost anywhere on this side to good anchorage, and there is a passage for ships of the largest size. The depth within is greater than on the bar, and these inner waters obviously correspond to the lagoon of other islands.

Apaiang has much resemblance to Apamama in its forest border and lagoon. Moreover, there is a ship entrance through the southwestern reef.

Marakei is one of the prettiest coral islands of the Pacific. The line of vegetation is unbroken. In a view from the masthead it lies like a garland thrown upon the waters; the unpracticed eye scarcely perceives the variation from a circular form, however great it may be. The grove is partially interrupted at one point, where there are indications of a former passage through the reef.

Tari-tari, lying to the north of Apia, is a large triangular atoll. It is wooded almost continuously on the side facing southeast, and has a few spots of verdure on the southwest, with three entrances to the extensive lagoon. The northern side is a naked reef throughout, scarcely apparent from a ship's deck, except by the long line of breakers. Makin, just north of Tari-tari, is a mere patch of coral reef without a lagoon.

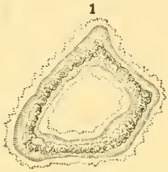
Tapateuea is also called *Drummond's Island;* Nonouti is *Sydenham;* Aranuka is *Henderville,* and Apamama is *Hopper Island.*

We add a few more descriptions of Pacific islands, with figures reduced from the maps of the Wilkes Expedition to a scale of four-tenths of an inch to a mile.

Taiara and Henuake (figs. 1 and 2) are two small belts of foliage, somewhat similar to Maraki.

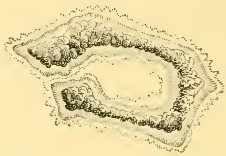
Swain's and Jarvis's Islands (figs. 3 and 4), are of still smaller size, and have no lagoon. The former is densely covered with foliage, while the surface of the latter is sandy. Both islands are a little depressed about the centre, a fact indicating that there was formerly a lagoon.

1



TAIARA.

2



HENUAKE, OR HONDEN.

Fakaafo, or Bowditch (fig. 5), 200 miles north of the Navigator Islands, is the type of a large part of coral islands. The bank of reef has only here and there emerged from the

3

JARVIS'S ISLAND.

4

SWAIN'S ISLAND.

5

FAKAAFO, OR BOWDITCH'S ISLAND.

waves and become verdant; in other portions the reef is of the usual height,—that is, near low-tide level,—excepting a few spots elevated a little by the accumulation of sand.

The Paumotu Archipelago, the crowded cluster of coral islands east and northeast of Tahiti, is a most instructive study for the reader; and a map of these islands by the Wilkes Exploring Expedition, inserted in the Narrative of the Expedition, and also in the Hydrographical Atlas, will well repay close examination. Sailing among these islands, over eighty in number,—only four of which are over twelve feet high exclusive of the vegetation,—two or three are almost constantly in sight from the mast-head.

The small amount of habitable land on these reef-islands is one of their most peculiar features. Nearly the whole surface is water; and the land around the lagoon is but a narrow rim, the greater part of which is usually under water at high tide. This fact will be rendered more apparent from the following table, containing a statement of the sizes and areas of several islands, with the amount of habitable land. The measures are given in geographical miles.

	LENGTH.	GREATEST BREADTH.	AREA IN SQ. MILES.	HABITABLE PARTS IN SQ. MILES.
Carlshoff, Paumotus,	27	13	200	10
Wolchonsky, "	15	3	40	3
Raraka, "	15	10	90	8
Manhii, "	14	6½	50	9
Nairsa or Deans, Paumotus,	50	19	1000	16
Fakaafo, Union Group,	7½	4½	20	2½
Duke of Clarence, "	8½	5½	27	2
Tapateuea, Kingsmills,	33	6	60	6
Tarawa, "	20	10	130	8
Nonouti, "	22	9	125	7
Tari-tari, "	18	11	110	4

The ten islands here enumerated have an aggregate area of 1,852 square miles, while the amount of actual dry habitable land is but seventy-six miles, or less than one twenty-fourth. In the Caroline Archipelago the proportion of land is still smaller. Menchikoff atoll covers an area of 500 square miles, and includes hardly six square miles of wooded land. In the Marshall Islands the dry land is not over one-hundredth of the whole surface; while in the Pescadores the proportion of land to the whole area is about as 1 to 200.

The distribution of the land upon the reef is obvious from the sketches already given. It is seen, as long since remarked.

MENCHICOFF ATOLL.
1-20 *of an inch to a mile.*

that the windward side is, in general, the highest. It is also apparent that there are not only great irregularities of form, but that on one side the reef may at times be wholly wanting or deeply submerged.

In many islands there is a ship-entrance through the reef, sometimes six or eight fathoms deep, to the lagoons, where good anchorage may be had; but the larger part have only shallow passages, or none at all. In the Paumotus, out of the twenty-eight visited by the Expedition, not one-half were found to have navigable entrances. In the Carolines, where the islands are large and not so much wooded, entrances are of more common occurrence. About half of the Kingsmill Islands afford a good entrance and safe anchorage. Through these openings in the reefs, there is usually a rapid outward current, especially during the ebbing tide. At Depeyster Island, it was found to run at the rate of two and a half miles an hour. It was as rapid at Raraka, in the Paumotus, and, as Capt. Wilkes remarks, it was difficult to pull a boat against it into the lagoon.

II. SOUNDINGS ABOUT CORAL ISLANDS.

The water around coral islands deepens as rapidly and in much the same way as off the reefs about high islands. The atoll usually seems to stand as if stilted up in a fathomless sea. The soundings of the Expedition afford some interesting results.

Seven miles east of Clermont Tonnerre, the lead ran out to 1,145 fathoms (6,870 feet), without reaching bottom. Within three quarters of a mile of the southern point of this island, the lead, at another throw, after running out for a while, brought up an instant at 350 fathoms, and then dropped off again and descended to 600 fathoms without reaching bottom. On the lead, which appeared bruised, a small piece of white coral was found, and another of red; but no evidence of *living* zoöphytes. On the east side of the island, three hundred feet from the reef, a bottom of coral sand was found in 90 fathoms; at one hundred and eighty feet, the same kind of bottom in 85 fathoms.

Off the southeast side of Ahii (another of the Paumotus), about a cable's length from the shore, the lead, after descending 150 fathoms, struck a ledge of rock, and then fell off and finally brought up at a depth of 300 fathoms.

Two miles east of Serle's Island, no bottom was found at 600 fathoms.

A mile and a half south of the larger Disappointment Island, there was no bottom at 550 fathoms.

Near the eastern end of Metia, an island nearly north of Tahiti, no bottom was found with a line of 150 fathoms; and, a mile distant, no bottom was reached at 600 fathoms.

In general, for one to five hundred yards from the margin of the shore reef, the water slowly deepens, and then there is an abrupt descent at an angle of 40 or 50 degrees. The results of earlier voyagers correspond with this statement.

Beechey, whose observations on soundings are the fullest hitherto published, states many facts of great interest. At Carysfort Island, he found the depth, 60 yards from the surf line, 5 fathoms; 80 yards, 13 fathoms; 120 yards, 18 fathoms; 200 yards, 24 fathoms; and immediately beyond, no bottom with 35 fathoms. At Henderson's Island, soundings continued out 250 yards, where the depth was 25 fathoms, and then terminated abruptly. Off Whitsunday, 500 feet out, there was no bottom at 1,500 feet.

Darwin states other facts bearing upon this subject, of which we may cite the following: At Heawandoo Pholo (one of the Maldives), Lieutenant Powell found 50 or 60 fathoms close to the edge of the reef. One hundred fathoms from the mouth of the lagoon of Diego Garcia, Captain Moresby found no bottom with 150 fathoms. At Egmont Island, 50 fathoms from the reef, soundings were struck in 150 fathoms. At Cardoo Atoll, only 60 yards from the reef, no bottom was obtained with a line of 200 fathoms. Off Keeling Island, 2,200 yards from the breakers, Captain Fitzroy found no bottom at 1,200 fathoms. Mr. Darwin also states that, at a depth between five and six hundred fathoms, the line was partly cut as if it had rubbed against a projecting ledge of rock; and deduces from the fact "the probable existence of submarine cliffs."

Plate IX

CENTRAL PACIFIC
BATHYMETRIC MAP
1000 fath.
2000 fath.
3000 fath.
RALICK
CHAIN
RATACK
CHAIN
GILBERT
ISLANDS
ELLICE
ISLANDS
PHŒNIX GROUP
UNION GROUP
Hudson
Sophia
Strathmore Shoal
Howland
Baker
A
A

In the Phœnix Group (Plate IX.), depths of 3,000 to 3,300 fathoms occur, and 3,000 half way between Sydney's and Birnie's, sixty miles apart; to the southwest of Enderbury's slopes of 1 : 6 and 1 : 3 exist, and to the northeast, of 1 : 1·5 and 1 : 4. Off Swain's Island, slopes of 1 : 7 and 1 : 13 were obtained; and off Danger Island (same Plate), 660 fathoms within half a mile southwest of the reef, and 985 fathoms one mile east, giving slopes of 1 : 1 and 1 : 0·75.

Off the Bahamas, for 400 miles, depths of 2,500 to 3,000 fathoms occur within twenty miles of the reefs, and at one point 2,336 fathoms within two miles, a pitch down of 1 : 0·75. South of central Cuba a depth of 3,428 fathoms exists within twenty miles of the Grand Cayman reef, and 3,010 fathoms within fifteen miles of Swan Island reef.

There are examples also of less abrupt slopes. Northwest of the Hawaian Group, Captain Lisiansky, who commanded the Russian ship Neva in a voyage round the world in the years 1860–61, at the island bearing his name found shallow water for a distance of six or seven miles; the water deepened to ten or eleven fathoms the first mile, fifteen the second, and at the last throw of the lead there were still but twenty-five fathoms. Christmas Island affords on its western side another example of gradually deepening waters. Yet these shallow waters terminate finally in a rapid declivity of forty or fifty degrees.

Off the prominent angles of an atoll, soundings generally continue much beyond the distance elsewhere, as was first observed by Beechey. At Washington Island, mostly abrupt in its shores, there is a bank, according to the surveys of the Expedition, extending from the east point to a distance of half a mile, and another on the west extending to a distance of nearly two miles. At Kuria, one of the Kingsmills, soundings continue for three miles from the north extremity, along a bank stretching off from this point to the north-northwest.

III. STRUCTURE OF CORAL ISLANDS.

The descriptions of reefs and their islets already given apply with equal force to coral islands. By transferring here the statements respecting the former, we should have a nearly complete account of the latter. The same causes, with scarcely an exception, are at work:—the growing of coral zoöphytes, and the action of the waves, of oceanic currents, and of the winds. This resemblance will be rendered more apparent by a review of their characters. The description will be found to be a simple recapitulation of a former paragraph.

The reef of the coral atoll, as it lies at the surface still uncovered with vegetation, is a platform of coral rock, usually two to four hundred yards wide, and situated so low as to be swept by the waves at high tide. The outer edge, directly exposed to the surf, is generally broken into points and jagged indentations, along which the waters of the resurging wave drive with great force. Though in the midst of the breakers, the edge stands a few inches, and sometimes a foot, above other parts of the platform; the incrusting *Nullipores* cover it with varied tints, and afford protection from the abrading action of the waves. There are usually three to five fathoms water near the margin; and below, over the bottom, which gradually deepens outward, beds of corals are growing profusely among extensive patches of coral sand and fragments. Generally the barren areas much exceed those flourishing with zoöphytes, and not unfrequently the clusters are scattered like tufts of vegetation in a sandy plain. The growing corals extend up the sloping edge of the reef, nearly to low-tide level. For ten to twenty yards from the margin, the reef is usually very cavernous or pierced with holes or sinuous recesses, a hiding-place for crabs and shrimps, or a retreat for the echini, asterias, sea-anemones and mollusks; and over this portion of the platform, the gigantic Tridacna, sometimes over two feet long, and 500 pounds in weight, is often found lying more than half buried in the solid rock, with barely room to gape a little its ponderous shell, and expose to the waters a gorgeously colored mantle. Further in are occasional pools and basins, alive with all that lives in these strange coral seas.

The reef-rock, when broken, shows commonly its detritus origin. Parts are of compact homogeneous texture, a solid white limestone, without a piece of coral distinguishable, and rarely an imbedded shell. But generally the rock is a breccia or conglomerate, made up of corals cemented into a compact mass, and the fragments of which it consists are sometimes many cubic feet in size.

It is apparent that we are describing a second time an *outer* reef. Without dwelling further upon its characters, we may pass to the features of the reef when raised above the waters and covered with vegetation.

Sections of coral islands and their lagoons have been given by Captain Beechey and Mr. Darwin. We add another, by way of illustration, although little may be presented that is novel after the excellent descriptions of these authors. Sketches of several of these islands, showing the general relation of the rim of land to the reef and the lagoon within, are given in the maps of islands on pages 165, 168. The following sketch represents a section of the rim of land from the sea on one side (the left), to the lagoon on the other. In the view, the part *m a* represents the shallow sea bordering an island, and abruptly deepening one to six hundred feet from the line of breakers. In these shallow waters are the growing corals; yet, as before stated, a large part is often barren sand or coral rock, especially where the depth is over fifty feet.

SECTION OF THE RIM OF AN ATOLL.

From *a* to *b* is the shore platform or reef-rock, nearly at low-tide level, with the margin (*a*) slightly elevated, and usually much incrusted at top with Nullipores. From the platform there is a rise, by a steep beach (*b c*), of six or eight feet, to the wooded part of the coral belt represented between *c* and *d*. From *d* to *e* there is a gently sloping beach bordering the lagoon. Beyond *e*, the waters of the lagoon at first deepen gradually, and then fall off more or less abruptly.

In the Paumotus, the shore platform, the steep beach, and the more gently sloping shore of the lagoon are almost constant characteristics.

The width of the whole rim of land, when the island gives no evidence of late elevation, varies from three hundred yards to one-third of a mile, excepting certain prominent points, more exposed to the united action of winds and waves and often from opposite directions, which occasionally exceed half a mile.

The *shore platform* is from one to three hundred feet in width, and has the general features of a half-submerged outer reef. Its peculiarities arise solely from the accumulations which have changed the reef into an island. Much of it is commonly bare at low tide, although there are places where it is always covered with a few inches or a foot of water; and the elevated edge, the only part exposed, often seems like an embankment preventing the water from running off. The tides, as they rise, cover it with water throughout, and bear over it coral fragments and sand, comminuted shells and other animal remains, to add them to the beach. The heavier seas transport larger fragments; and at the foot of the beach there is often a deposit of blocks of coral, or coral rock, a cubic foot or so in size, which low tide commonly leaves standing in a few inches of water. On moving these masses, which generally rest on their projecting angles and have an open space beneath, the waters at once become alive with fish, shrimps, and crabs, escaping from their disturbed shelter; and beneath, appear various Actiniæ or living flowers, the spiny echini and sluggish biche-de-mar, while swarms of shells, having a soldier crab for their tenant, walk off with unusual life and stateliness. Moreover, delicate corallines, Ascidiæ and sponges tint with lively shades of red, green and pink, the under surface of the block of coral which had formed the roof of the little grotto.

Besides the deep channels cutting into the margin of the reef and giving it a broken outline, there are in some instances long fissures intersecting its surface. On Aratica (Carlshoff), and Ahii (Peacock Island), they extended along for a fourth to half a mile, generally running nearly parallel with the shore, and at top were from a fourth to half an inch wide. These fissures are not essential features of the reef. They are probably a result of a subterranean movement or shaking.

The *beach* consists of coral pebbles or sand, with some worn shells, and occasionally the exuviæ of crabs and bones of fishes. Owing to its whiteness, and the contrast it affords to the massy verdure above, it is a remarkable feature in the distant view of these islands, and often seemed like an artificial wall or embankment running parallel with the shores. On Clermont Tonnerre, the first of these islands visited by us, the natives seen from shipboard, standing spear in hand along the top of the beach, were believed by some to be keeping patrol on the ramparts of a kind of fortification. This deception arose from the dazzling whiteness of the coral sand, in consequence of which, the slope of the beach was not distinguished in the distant view.

The *emerged land* beyond the beach, in its earliest stage, when barely raised above the tides, appears like a vast field of ruins. Angular masses of coral rock, varying in dimensions from one to a hundred cubic feet, lie piled together in the utmost confusion; and they are so blackened by exposure, or from incrusting lichens, as to resemble the clinkers of Mauna Loa; moreover, they ring like metal under the hammer. Such regions may be traversed by leaping from block to block, with the risk of falling into the many recesses among the huge masses. On breaking an edge from the black masses, the usual white color of coral is at once apparent. Some of the blocks, measuring five or six feet in each of their dimensions, were portions of single individual corals; while others had the usual conglomerate character of the reef-rock, or, in other words, were fragments torn by the waves from the reef-rock.

In the next stage, coral sand has found lodgment among the blocks; and although so scantily supplied as hardly to be detected without close attention, some seeds have taken root, and vines, purslane, and a few shrubs have begun to grow, relieving the scene, by their green leaves, of much of its desolate aspect.

Both of these stages are illustrated on the greater part of coral islands.

In the last stage, the island stands six to ten feet out of water. The surface consists of coral sand, more or less discolored by vegetable or animal decomposition. Scattered among the trees, stand, still uncovered, many of the larger blocks of coral, with their usual rough angular features and blackened surface. There is but little depth of coral soil, although the land may appear buried in the richest foliage. In fact, the soil is scarcely any thing but coral sand. It is seldom discolored beyond four or five inches, and but little of it to this extent; there is no proper vegetable mould, but only a mixture of darker particles with the white grains of coral sand. It is often rather a coral gravel, and below a foot or two, it is usually cemented together into a more or less compact coral sand-rock.

One singular feature of the shore platform, occasionally observed, remains to be mentioned. Huge masses of reef-rock are sometimes found upon it, some of which lie loose upon the reef, while others are firmly imbedded in it below, and so cemented to it as to appear to be actually a part of the platform rock. Sketches of two of these masses are here given.

1 2

BLOCKS OF CORAL ROCK ON THE SHORE PLATFORM.

Figure 1 represents a mass on the island of Waterland (one of the Paumotus), six feet high and about five in diameter; it was solid with the reef-rock below, as though a part of it, and, about two feet above its base, it had been so nearly worn off by the waters as to have become irregularly top-shaped. Another mass, similarly attached to the reef at base, observed on Kawehe (Vincennes Island), was six feet high above low-water level, and seven feet in its longest diameter

Below, it had been worn like the one just described, though to a less extent. Another similar mass was eight feet high. Figure 2 represents a block six feet high and ten feet in its longest diameter, seen on Waterland; it was unattached below, and lay with one end raised on a smaller block. On Aratica (Carlshoff), others were observed. One loose mass like the last was eight feet high and fifteen feet in diameter, and contained at least a *thousand cubic feet.* Raraka also afforded examples of these attached and unattached blocks, some standing with their tops six feet above high-water mark.

These masses are similar in character to many met with among the fields of blocks just described, and differ only in having been left on the platform instead of transported over it. Some of them are near the margin of the reef, while others are quite at its inner limit. The second mass alluded to above, on Kawehe, was a solid conglomerate, consisting of large fragments of Astræas and Madrepores, and contained some imbedded shells, among which an Ostræa and a Cypræa were noticed. This is their usual character. The other two were parts of large individual corals (Porites); but there was evidence in the direction of the cells that they did not stand as they grew; on the contrary, they had been upthrown, and were afterward cemented with the material of the rock beneath them, probably at the time this rock itself was consolidated. Below some of the loose masses the platform was at times six inches higher than on either side of the mass, owing to the protection from wear given to the surface beneath it. These blocks are always extremely rough and uneven, like those of the emerging land beyond; and the angular features are partly owing, in both cases, to solution from rains and from the dashes of sea-water to which, with every tide, they are exposed.

It should be distinctly understood that these masses here described were found isolated, and only at considerable intervals. In no instance were they observed clustered. The loose blocks and those cemented below had the same general character, and must have been placed where they were by the same cause, though it may have been at different periods.

Such blocks are of course not confined to coral island reefs, but belong to barrier reefs generally.

Jukes says, "I once landed close to the edge of the Australian barrier on the south side of the Blackwood channel, in south latitude 11° 45′, on a *continuous mass of Porites which was at least twenty feet across*, and it seemed to pass downwards into the mass of the reef below water without any disconnection. It was worn into pinnacles above, so that two or three of us could stand in the different hollows without seeing each other; and it was one of a line of such masses that attracted our attention for a distance of three miles."

The *shore of the lagoon* is generally low and gently inclined, yet in the larger islands, in which the waters of the lagoon are much disturbed by the winds, there is usually a beach resembling that on the seaward side, though of less extent. A platform of reef-rock at the same elevation as the shore platform sometimes extends out into the lagoon; but it is more common to find it a little submerged and covered for the most part with growing corals; and in either case, the bank terminates outward in an abrupt descent, of a few yards or fathoms, to a lower area of growing corals, or a bottom of sand. Still more commonly, we meet with a sandy bottom gradually deepening from the shores without growing coral. These three varieties of condition are generally found in the same lagoon, characterizing its different parts. The lower area of growing corals slopes outward, and ceases where the depth is 10 to 12 fathoms or sooner; from this there is another descent to the depth which prevails over the lagoon. On some small lagoons the shore is a thick plastic mud, either white or brownish, and forms a low flat which is very gently sloping. On Henuake, these mud deposits are quite extensive, and of a white color. At Enderbury's Island, another having a shallow lagoon, the mud was so deep and thick that there was some difficulty in reaching the waters of the lagoon; the foot sunk in eight or ten inches and was not extricated without some difficulty. It looked like a dirty brownish clay. This mud is nothing but comminuted coral, so fine as to be almost impalpable.

The *lagoons* of the smaller islands are usually very shallow; and in some, merely a dry bed remains, indicating the former existence of water. Instances of the latter kind are met with only in islands less than three miles in diameter; and those with shallow lagoons are seldom much larger. These shallow waters, when direct communication with the sea is cut off, become, in some instances, very salt by evaporation, and contain no growing coral, with few signs of life of any kind; and in other cases, they are made too fresh for marine life through the rains. At Enderbury's Island the water was not only extremely saline, but the shores of the lagoon were in some places incrusted with salt. But when there is an open channel, or the tides gain access over a bare reef, corals continue to grow, and a considerable portion of the lagoon may be obstructed by them. At Henuake, the sea is shut out except at high water, and there were consequently but few species of corals, and those of small size. At Ahii (Peacock's Island), there was a small entrance to the lagoon, and though comparatively shallow, corals were growing over a large part of it.

In the larger islands, the lagoons contain but small reefs compared with their whole extent; the greater part is an open sea, with deep waters and a sandy or muddy bottom. There are instances, as at the southern Maldives, of a depth of 50 and 60 fathoms. From 20 to 35 fathoms is the usual depth in the Paumotus. This was the result of Captain Beechey's investigations; and those of the Expedition, though few, correspond. It is however probable that deeper soundings would be found in the large island of Nairsa (Dean's). In Gilbert's Group, southeast of the Carolines, the depth, where examined by the Expedition, varied from 2 to 35 fathoms. Mr. Darwin found the latter depth at Keeling Island. Chamisso found 25 to 35 fathoms at the Marshall Islands.

The bottom of these large lagoons is very nearly uniform, varying but little except from the occasional abrupt shallowings produced by growing patches of reef. Soundings bring up sand, pebbles, shells, and coral mud; and the last mentioned material appears to be quite common, even in lagoons of considerable size. It has the same character as above described. The bluish clay-like mud of the harbor of Tongatabu may be classed with these deposits. Darwin describes this mud as occurring at the Maldives, and at Keeling Island (op. cit. p. 26); Kotzebue mentions it as common at the Marshall atolls, and Lieutenant Nelson observed it at the Bermudas. It appears, therefore, that the finer coral material of the shores prevails throughout the depths of the lagoon. The growing reefs within the lagoons are in the condition of the *inner* reefs about high islands. The corals grow but little disturbed by the waves, and the reef-rock often contains them in the position of growth. At Taputeouea (Kingsmill's or Gilbert's Group), reefs very similar to those of the Feejees occur; they contain similar large Astræas ten to twelve feet in diameter, which once were growing where they stand, but are now a part of the solid lifeless rock.

Beach formations of coral sand-rock are common on the coral islands, and they present the same features in every respect as those described. They were observed among the Paumotus, on Raraka, Honden, Kawehe, and other islands. The stratified character is always distinct, and the layers slope toward the water at the usual small angle, amounting to 5–7 degrees bordering the lagoon, and 6–8 degrees on the seashore side of the land. Agassiz gives the same angle for the seaward slope of similar deposits at Key West. The rock is largely a fine oölite. They often occupy a breadth of thirty to fifty yards, appearing like a series of outcrops; yet they are frequently covered by the sands of the steep part of the beach. The rock is a fine or coarse sand-rock, or oölite, or coral pudding-stone, and consists of beach materials. Occasionally it is compact, and resembles common limestone, excepting in its whiter color; but generally its sand origin is apparent. Deposits of sand and fragments of corals and shells cover *the top* of a reef-bank underneath what there is of soil; and they are horizontal instead of having the dip of the beach.

In borings by Lieutenant Johnson, of the Wilkes Exploring Expedition, on Aratica or Carlshoff's Island, in the Paumotus, ten or eleven feet were passed through easily, and then there was a sudden transition from this softer rock (probably the beach sand-rock), to the solid reef-rock.

The *drift sand-rock* was not met with by the author on any of the coral islands visited. The time for exploration on these islands allowed by the Expedition was too short for thorough work. It has been stated that the more exposed points toward the trades, especially the northeastern and southwestern, are commonly a little higher than other parts; and it is altogether probable that some of the sand heaps there formed will prove on examination to afford examples of this variety of coral-rock. Such situations are identical with those on Oahu, where they occur on so remarkable a scale.

In the Atlantic, on the Bermudas and Bahamas, and Florida reefs, the drift-sand accumulations often have heights of forty to one hundred feet and sometimes of one hundred and fifty to two hundred and fifty feet. They make the dry land or islands and cays of these regions as described beyond.

Although in these descriptions of atolls, some points have been dwelt upon more at length than in the description of barrier reefs, still it will be observed that the former have no essential peculiarities of structure apart from such as necessarily arise from the absence of high rocky lands. The encircling atoll reef corresponds with the outer reefs that enclose high islands; and the green islands and the beach formations, in the two cases, originate in the same manner.

The lagoons, moreover, are similar in character and position to the inner channels within barrier reefs; they receive coral material only from the action of degrading agents, because no other source of detritus but the reefs is at hand. The accumulations going on within them are, therefore, wholly of coral. The reefs within the lagoons correspond very exactly in mode of growth and other characters to the *inner* reefs under the lee of a barrier.

IV. NOTICES OF SOME CORAL ISLANDS.

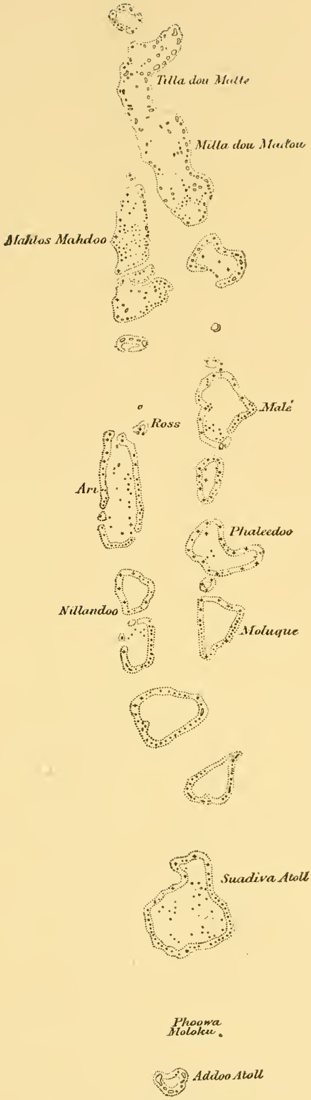
The preceding descriptions represent the general character of atolls, but are more especially drawn from the Paumotus. There are some peculiarities in other seas, to which we may briefly allude.

Among the scattered coral islands north of the Samoan

Group, the shore platform is seldom as extensive as at the Paumotus. It rarely exceeds fifty yards in width, and is cut up by passages often reaching almost to the beach. In some places the platform is broken into islets. Enderbury's Island is one of the number to which this description applies. The beach is eleven or twelve feet high. For the first eight feet it slopes very regularly at an angle of thirty to thirty-five degrees, and consists of sand, coarse pebbles, or rounded stones of coral, with some shells; and there is the usual beach conglomerate near the water's edge. After this first slope, it is horizontal for eighty to two hundred feet, and then there is a gradual rise of three to four feet. Over this portion there are large slabs of the beach conglomerate, along with masses from the reef-rock, and some thick plates of a huge foliaceous Madrepora; and these slabs, many of which are six feet square, lie inclining quite regularly against one another, as if they had been taken up and laid there by hand. They incline in the same direction with the slope of the beach. The large Madrepora alluded to has the mode of growth of the *Madrepora palmata;* and probably the entire zoöphyte extended over an area twelve or fifteen feet in diameter. The fragments are three to four inches thick, and thirty square feet in surface.

As a key to the explanation of the peculiarities here observed, it may be remarked that the tides in the Paumotus are two to three feet, and about Enderby's Island five to six feet in height.

Maldive Archipelago.—The Maldives have been often appealed to in illustration of coral structures. They are particularly described by Mr. Darwin from information communicated to him by Captain Moresby, and from the charts of this officer and Lieutenant Powell. A paper on the northern Maldives, by Captain Moresby, is contained in the Journal of the

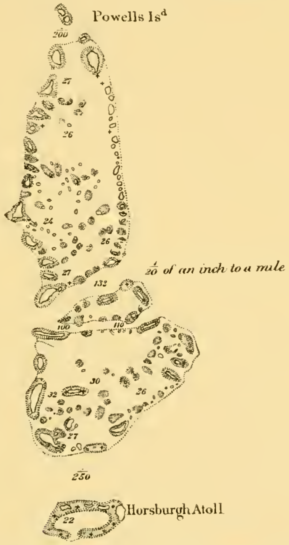


MALDIVE ARCHIPELAGO.

One inch to 60 miles.

Royal Geographical Society, vol. v., p. 398; and another on this group by J. J. Horsburgh, and W. F. W. Owen, in the the same journal, vol. ii., pp. 72 and 81. As stated by Mr. Darwin, the archipelago has a length of 470 miles, with an average breadth of 50 miles; and it consists for the most of its length of two parallel lines of atolls. The large atoll at the north end has a length of 88 miles, while Suadiva, one of the southernmost, is 44 miles long from north to south, and 34 miles across.

The point of special interest in their structure is the occurrence of atolls or annular reefs within the larger atolls.



MAHLOS MAHDOO ATOLL, WITH HORSBURGH ATOLL.

Scale 1-20 *of an inch to a mile.*

The islets of the lagoon and those of the encircling reef, are in many instances annular reefs, each with its own little lake. Gems within gems are here clustered together.

This feature is well exhibited in the Mahlos Mahdoo atoll, an enlarged map of which, from Darwin's work, is here inserted. The atoll consists of three main atoll-shaped portions; but in each of these, the border is made up in part of atolls. Many of the subordinate atolls of the border are "three, and some even five miles in diameter, while those within the lagoon are usually smaller, few being more than two miles across, and the greater number less than one. The depth of the little lagoons within these small annular reefs is generally from five to seven fathoms, but occasionally more; and in Ari atoll, many of the central ones are twelve, and some even more than twelve fathoms deep. These subordinate atolls rise abruptly from the platform or bank on which they stand, with their outer margin bordered by living corals." "The small atolls of the border, even where most perfect and standing farthest apart, generally have their longest axis directed in the line which the reef would have held if the atoll had been bounded by an ordinary wall." (Darwin, on Coral Reefs, pp. 33, 34.)

The Maldives are among the largest atoll reefs known; and they are intersected by many large open channels; and Mr. Darwin observes, that the interior atolls occur only near these channels, where the sea has free access. We may view each large island in the archipelago as a sub-archipelago of itself. Although thus singular in their features, they illustrate no new principles with regard to reef-formations.

Mr. Darwin thus remarks (Op. cit. pp. 33, 34),—"I can in fact point out no essential difference between these little ring-formed reefs (which, however, are larger, and contain deeper lagoons than many true atolls that stand in the open sea), and the most perfectly characterized atolls, excepting that the ring-formed reefs are based on a shallow foundation instead of on the floor of the open sea, and that instead of being scattered irregularly, they are grouped closely together."—"It appears from the charts on a large scale, that the ring-like structure is contingent on the marginal channels or breaches being wide, and, consequently, on the whole interior of the atoll being freely exposed to the waters of the open sea. When the channels are narrow, or few in number, although the lagoon be of great size and depth (as in Suadiva), there are no ring-formed reefs; where the channels are somewhat broader, the marginal portions of reef, and especially those close to the larger channels, are ring-formed, but the central ones are not so: where they are broadest, almost every reef throughout the atoll is more or less perfectly ring-formed. Although their presence is thus contingent on the openness of the marginal channels, the theory of their formation, as we

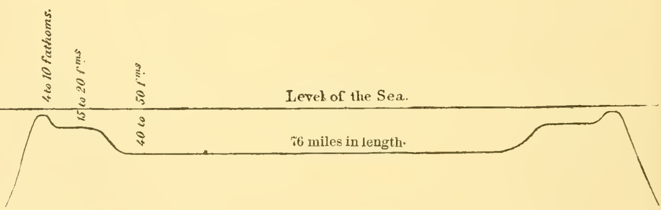
GREAT CHAGOS BANK.

shall hereafter see, is included in that of the parent atolls, of which they form the separate portions."

The Great Chagos Bank. This bank lies about ten degrees south of the Maldives, and is ninety miles long and seventy in its greatest breadth. It is a part of the Chagos Group, in which there are some true atolls, some bare atoll-reefs, and others, like the Great Chagos Bank, that are quite submerged, or nearly so. Its rim is mostly from four to ten fathoms under water.

Mr. Darwin confirms the opinion of Captain Moresby, that this bank has the character of a lagoon reef, resembling one of the Maldives; and he states, on the evidence of extensive soundings, that, if raised to the surface, it would actually become a coral island, with a lagoon forty fathoms deep. He says that, in the words of Captain Moresby, it is in truth "nothing more than a half-drowned atoll."

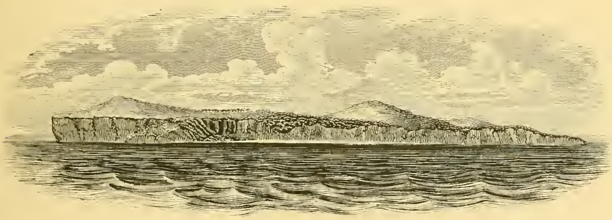
The form of the bank, its margin of shoals, and a line of soundings across it, giving the depth of the central or lagoon portion, are shown in the map on p. 191, from Darwin, and for which, as well as for other information about the



EAST AND WEST SECTION ACROSS THE GREAT CHAGOS BANK.

bank, he gives credit to Captain Moresby. The cross section is still further illustrated in the annexed cut. The whole length of the section (or width of the bank in the line of the soundings) is seventy-six miles. From the outer rim of the submerged atoll, there is a drop off to a deeper level, which is mostly fifteen to eighteen fathoms below the surface; and then to the bottom of what was once the lagoon, now for the most part forty to fifty fathoms under water, though having its shoals that are five to ten fathoms submerged. All points in the map that are shaded, have a depth of less than ten fathoms; the only emerged parts are three or four spots on the western margin, as indicated on the map above. The bottom over the interior is muddy; on the flat bordering it, 15 to 20 fathoms deep, there is coral sand with "a very little live coral; the outer rim is coral rock with scarcely any live coral;" while the shoals or knolls of the interior are "covered with luxuriantly-growing corals." Darwin states also that the rim is steep on both sides, and outward slopes abruptly to unfathomable depths; at a distance of less than half a mile from one part no bottom was found with 190 fathoms; and off another point, at a somewhat greater distance, there was none with 210 fathoms. For other similar facts see page .

Metia and other elevated Coral Islands.—Metia, or Aurora Island, is one of the western Paumotus. It is a small island about four miles by two and a half in width, and two hundred and fifty feet in height; and it consists throughout



METIA, OR AURORA ISLAND

of coral limestone. Approached from the northeast, its high vertical cliffs looked as if basaltic, resembling somewhat the

Palisades on the Hudson. This appearance of a vertical structure was afterward traced to vertical furrowings by the waters dripping down its front, and the consequent formation of stalagmitic incrustations. Deep caverns were also seen.

The cliff, though vertical in some parts, is roughly sloping in others, and on the west side, the surface of the island gradually declines to the sea.

The rock is a white and solid limestone, seldom presenting any traces of its coral origin. In some few layers there were disseminated corals, looking like imbedded fossils, along with beautiful casts of shells; but for the most part it was as compact as any ancient limestone, and as uniform in texture. Occasionally there were disseminated spots of crystallized calcite.

The caverns contain coarse stalactites, some of which are six feet in diameter; and interesting specimens were obtained containing recent land shells that had been enclosed by a calcareous film while hibernating.

It is probable that more extensive caverns would have been found had there been more than a few hours for the examination of the island. The Rev. Mr. Williams, in his work on Missionary Enterprises in the Pacific, gives very interesting descriptions of caverns in the *elevated* coral rock of Atiu, one of the Hervey Group. In one, he wandered two hours, without finding a termination to its windings, passing through chambers with "fretwork ceilings of stalagmite and stalactite columns, which, 'mid the darkness, sparkled brilliantly with the reflected torch-light." This author remarks, "that while the madrepores, the brain and every other species of coral are full of little cells, these islands (including those resembling Atiu), appear to be *solid masses of compact limestone, in which nothing like a cell can be detected.*"

Beechey, in his description of Henderson Island, another of this character, speaks of the rock as *compact, and having the fracture of a secondary limestone.*

The surface of Metia is singularly rough, owing to erosion by the rains. The paths that cross it wind through narrow passages among ragged needles and ridges of rock as high as the head, the peaks and narrow defiles forming a miniature model of the grandest Alpine scenery. There is but little soil, yet the island is covered with trees and shrubbery.

The shores at the first elevation of the island, must have been worn away to a large extent by the sea; and the cliff and some isolated pinnacles of coral rock still standing on the coast are evidence of the degradation. But at present there is a wide shore-platform of coral reef, two hundred or two hundred and fifty feet wide, resembling that of the low coral islands, and having growing coral, as usual, about its margin and in the shallow depths beyond.

In the face of the cliff there are two horizontal lines, along which cavities or caverns are most frequent, which consequently give an appearance of stratification to the rock, dividing it into three nearly equal layers.

We might continue this account of coral reefs and islands, by particular descriptions of others in the Pacific. But the similarity among them is so great, and their peculiarities are already so fully detailed, that this would amount only to a succession of repetitions. The characters of a few, briefly stated, will suffice in this place. The first eight mentioned beyond are small islands situated within ten degrees of the equator; Birnie's, Enderbury's, and Hull's belonging to the Phœnix Group, and Oatafu and Fakaafo to the Union Group. Their positions are shown on Plate VIII. The remainder are a few islands of the Paumotu Archipelago, in latitudes 12°

to 21° S. Several of them are guano islands, as described on pages 318 to 324.

Birnie's. — Lat. 3° 35′ S. Long. 171° 30′ W. Four-fifths of a mile by one-third, trending northwest. No lagoon. A sandy flat about ten feet high, except near the north-northeast extremity, where it is about twelve feet. To the south-southwest the submerged reef extends out nearly a mile, over which the sea breaks. In passing it, distinguished no vegetation except the low purslane and some trailing plants.

Enderbury's. — 3° 8′ S. 171° 15′ W. 4 miles by 1 mile nearly, trending N. N. W., and S. S. E.; form trapezoidal or nearly rectangular. Little vegetation on any part, and but few trees. The lagoon very shallow, and containing no growing coral; its shores of coral mud, allowing the foot to sink in eight or ten inches, and covered in places with saline incrustations. Shore platform one hundred feet or less in width, and surface inclined outward at a very small angle; covered with three or four feet of water at high tide, and with few corals or shells; beyond this, falls off four to six feet, and then the bottom inclines for one hundred yards or more. The beach very high and regular; rises eight feet at an inclination of thirty to thirty-five degrees; then horizontal for eighty to two hundred, after which another rise of three or four feet. It consists of pebbles and fine sand, but above of slabs and blocks of coral rock and of the beach sand-rock, those of the latter nearly rectangular and flat. This beach sand-rock occurs in layers from ten to twenty inches thick along the shore, and is inclined from five to seven degrees seaward. Some portions are very compact, and ring under the hammer, while others enclose fragments of different sizes to a foot or more in diameter. Large trunks of transported trees lay upon the island, one of which was forty feet long and four in diameter. The shore platform was much intersected by channels.

Captain Hudson obtained soundings half a mile off in two hundred fathoms; the lead struck upon a sandy bottom, but was indented by coral.

Hull's Island. — Lat. 4° 20′ S. Long. 171° 15′ W. Trends northeast and southwest. Well wooded nearly all round; but on leeward side the forest in patches, with breaks of bare coral. Lagoon narrow, without entrance. Width of island from sea to lagoon, one hundred to four hundred yards: width greatest at south end. Beach ten feet high. The soil of the island consisted of coral fragments and sand. Shore platform fifty to eighty feet wide; five or six feet of water over it at high tide. Cut up very irregularly by channels three to eight or ten feet wide. Observed small corals growing on the bottom outside of the platform. Shores of lagoon shallow for fifty yards, and consisting of coral sand. Beyond this a slope covered with growing corals; the corals rather tender species of Madrepores. In the interior of the lagoon many knolls and large patches of coral.

Swain's. — (Fig. 3, page 168.) Lat. 11° 10′ S. Long. 170° 52′ W. $1\frac{1}{4}$ miles by $\frac{2}{3}$; shape nearly rectangular; trends east and west. No lagoon, but the centre a little lower than the sides. Surface covered with shrubbery and large trees, among the latter many cocoanuts; the centre more sparsely wooded. Height fifteen to eighteen feet, excepting on the middle of the western side, where the surface is covered with loose fragments of coral of small size; there appears to have been a former entrance to the lagoon at this place. Shore reef, or platform, one hundred yards in average width, and one hundred and fifty yards at the place where we landed. Beach high, ten to twelve feet. At lower part of beach, for a height of two to three feet, the coral reef-rock was exposed, indicating an elevation of the island. For three or four feet above this, layers of the beach sand-rock were often in view, consisting of coral pebbles firmly cemented, and having the usual dip of seven or eight degrees seaward; in many places it was concealed by the beach sands and pebbles. There was no growing coral on the platform, excepting Nullipores. The outer margin of this platform was very uneven, and much intersected by channels, though less so than at Enderbury's Island. Great numbers of Birgi (large Crustacea) were burrowing over the island, some of which were six inches in breadth.

Oatafu or *Duke of York's.* — 8° 38′ S. 172° 27′ W. Form oblong, trending northwest. Length 3¾ miles; breadth 2 miles. Circuit 9½ miles, and about one-half wooded in patches. Southwest reef mostly bare. A lagoon, but without entrance except for canoes at high tide, on leeward side. Island ten feet high. Shore platform narrow, and intersected by channels. Shores lined by reef-rock, two or three feet out of water, indicating an elevation of the island. This reef-rock consists of various corals firmly cemented. Within the lagoon, knolls of coral, but none near the shore on the leeward side.

Fakaafo or *Bowditch's.* — 9° 20′ S. 171° 5′ W. 6¾ miles by 4. Shape nearly triangular. Circuit seventeen miles, about six of which are wooded in several patches, separated by long bare intervals. A large lagoon, but no ship entrance. Height of island, fifteen feet. Width to the lagoon, one hundred to two hundred yards. Soil of the island coral sand, speckled black with results of vegetable decomposition. Shore platform narrow. At outer edge a depth of three fathoms, and from thence gradually deepens, and abounds in corals for fifty yards, when it deepens abruptly. Coral reef-rock elevated three or four feet, indicating an elevation of the island. Lagoon shallow, with some growing coral, but none near the shore. Some corals growing on the platform, near its margin, mostly small Madrepores, Astræas, Nullipores. Fragments of pumice were found among the natives, which had floated to the island (see fig. 5, page 168).

Washington Island. — Lat. 4° 41′ N. Long. 160° 15′ W. 3 miles by 1¼, trending east and west. It is a dense cocoanut grove with luxuriant shrubbery. No lagoon. The shore platform is rather narrow. A point of submerged reef, one and a half miles long, stretches out from the southwest end. Did not land on account of bad weather.

Otuhu, Paumotu Archipelago. — 14° 5′ S. 141° 30′ W. 1½ miles by ⅔, trending north and south. No lagoon. Wooded.

Margaret, Paumotu Archipelago. — 20° 42′ S. 143° 4′ W. Diameter one mile, nearly circular. A small shallow lagoon with no entrance. Northeast side alone wooded, and in two patches.

Teku or *Four Crowns,* Paumotu Archipelago. — 20° 28′ S. 143° 18′ W. Diameter 1½ miles, nearly circular. A small lagoon with no entrance. Southwestern reef bare; five patches of forest on the other part.

Honden or *Henuake,* Paumotu Archipelago. — Size 3½ miles by 2 miles. Oblong, five-sided; trending west-northwest. A small, shallow lagoon, communicating with the sea only at high tide, on the west side. There are two other entrances which are seldom if ever covered with water, and appeared merely as dry beds of coral rock. Height of the island twelve feet; lowest on the south side. Belt of verdure complete, and consisting of large forest trees, with the Pandanus and other species, but no cocoanuts; its breadth half a mile, and in some parts three-fourths. Among the trees large masses of coral rock often exposed to view, and the surface in many parts very rough. It seemed surprising at all these islands that there should be so luxuriant a growth of trees and shrubbery over so rocky a surface. Shores of the lagoon nearly flat. On one side there was a large area of extremely fine coral sand and mud, which extended a long distance into the lagoon. Elsewhere about the centre of the island the reef-rock was bare, and contained numerous shells of Tridacnæ. A few small Madrepores still growing in the lagoon. Beach on the sea-shore side eight feet high. In lower part of beach several layers of white limestone (the beach sand-rock), formed of coral fragments or sand, shells, etc., much of which was very compact. The layers inclined toward the sea at an angle of about six degrees. Shore platform as elsewhere in this archipelago.

The facts above stated are evidence of a slight elevation, probably not exceeding three feet (see fig. 5, page 168).

Taiara, or *King's*, Paumotu Archipelago. — 15° 42′ S. 144° 46′ W. $2\frac{2}{3}$ miles by $1\frac{3}{4}$, trending northwest. Has a small lagoon with no entrance. Reef almost continuously wooded around, somewhat broken into patches.

Ahii, or *Peacock's Island*, Paumotu Archipelago. — 14° 30′ S. 146° 20′ W. 13 miles by 6, trending N. E. by E. Shape irregularly oblong. A large lagoon, having an entrance for small vessels on the west. Reef wooded throughout nearly its whole circuit. Lagoon shallow, and much obstructed by growing coral, the latter giving the water over it a clear light green color. Platform, or outer coral shelf of the island, about two hundred and fifty feet wide; under water except at the lowest tides. Margin highest, and covered with Nullipore incrustations, which give it a variety of delicate shades of color, mostly reddish, of peach-blossom red, rose, scarlet. For thirty to fifty feet from the margin, very cavernous, and con taining many Tridacnæ, lying half imbedded, with the variously tinted mantle expanded when the surface is covered with water. Rock of the platform either a compact white limestone or a solid conglomerate; dead over its surface, excepting a few Madrepore tufts or Astræas near the margin in pools. In this shelf there were long fissures, extending nearly parallel with the shore, a quarter to half an inch wide at top, and continuing sometimes a fourth of a mile or more. These fissures were commonly filled with coral sand. The higher parts of the island either consisted of loose blocks of coral or were covered with some soil; the soil mostly of comminuted coral and shells, with dark particles from vegetable decomposition intermingled. On the bottom, exterior to the shore platform, observed the same corals growing as occurred in fragments upon the island; but the larger part of the bottom was without coral, or consisted only of sand.

Raraka, Paumotu Archipelago.—16° 10′ S., 145° W. 14 miles by 8, trending east and west. Shape somewhat triangular. North side nearly continuously wooded; south angle and southwest reef bare. A large lagoon with an entrance for small vessels on the north side. A rapid current flows from the entrance, which it was difficult for a boat to pull against. Shore platform, as usual, about a hundred yards wide, with the edge rather higher than the surface back; the platform mostly bare of water at low tide. Several large masses of coral and coral rock, one to four hundred cubic feet, on the platform and upon the higher parts of the island, some of which stood five and six feet above high-water mark; they were cemented to the reef-rock below, and appeared like projecting parts of the reef. Layers of beach sand-rock on the lagoon shores, as well as on the seaward side, inclined at an angle of six or seven degrees: characters as already described. Growing coral in the entrance to the lagoon, within two feet of the surface, mostly a species of Millepora (M. squarrosa). Interior of the lagoon not examined, no time being allowed for it by the Expedition. The water looked as blue as the ocean, and was much roughened by the winds.

Kawehe or *Vincennes Island*, Paumotu Archipelago, 15° 30′ S., 145° 10′ W. 13 miles by 9, trending north-northwest. Shape irregularly oval. Having a large lagoon, and mostly wooded around, least so to leeward. Between the wooded islets (as on Raraka and elsewhere), surface consisted of angular masses of coral rock (among which the Porites prevail), strewed in great numbers together; and in some parts bearing a few vines and purslane among the blocks, though scarcely any appearance of soil, or even of coral sand. In other parts, not as high, no vegetation, and surface still wet by high tide. A few large masses of coral on the shore platform, either lying loose, or firmly attached below, as already described; some of them were six feet cube, and one was raised seven feet above high-water mark. Shore platform about a hundred yards wide, rather highest at the edge, and much of its surface two to four feet under water at low tide. As elsewhere, this platform is nothing but a compact coral conglomerate or limestone, having no growing coral over it, except in some shallow pools near its outer margin, where also there are numerous holes in which crabs are concealed, with small fish and other animals of the shores. On the lagoon shore, layers of beach sand-rock, six or seven in number, dipping at an angle of seven degrees toward the lagoon, and outcropping one above the other. Similar layers on the sea-shore side

Manhii, *Wilson's* or *Waterlandt*, Paumotu Archipelago, 14° 25′ S., 146° W. 15 miles by 6, trending E. N. E. A large lagoon with a deep entrance on the west side. Shape oblong triangular.

Shore platform as usual; mostly under water at low tide. Large masses of coral here and there, standing on this reef, either cemented to it, or loose. One top-shaped mass is figured on p. 179. High water did not reach the part of it which was most worn; and this was evidently owing to the fact that the action of the swell or waves is greatest above the actual level of the tide at the time. The reef-rock is either a compact limestone, showing no traces of its composite origin, or a conglomerate. Beach, regular as usual, six to ten feet high, consisting of coral sand, and fragments of worn shells, with occasional exuviæ of crabs, remains of Echini, fish, etc. The entrance to the lagoon is deep and narrow, with vertical sides.

Aratica or *Carlshoff*, Paumotu Archipelago, 15° 30′ S., 145° 30′ W. 17 miles by 10, trending N. E. Large lagoon with a good entrance for vessels. The reef fronting south bare for nine miles; on northwest side, mostly very low, with only here and there a clump of trees; occasionally a line of wooded land for a quarter of a mile on the east side; more continuously wooded on the north. The bare parts mostly covered with blocks of coral, one to thirty cubic feet and larger, tumbled together as on the preceding. Some blocks of coral on the shore platform very large; one eight feet high and fifteen in diameter, containing at least 1,000 cubic feet.

Nairsa or *Dean's*, Paumotu Archipelago, 15° S., 148° W. 44 miles by 17, trending W. N. W. Northern shore mostly wooded; southern with only an occasional islet, connected by long lines of bare reef. In these intervals, the reef stood eight feet or so out of water, according to estimate from shipboard, and was worn into a range of columns, or excavated with caverns, so as to look very much broken, though quite regularly even in the level of the top line.

We continue these descriptions with notes on some coral reefs and islands of the Atlantic, derived from the charts of the ocean and different publications mentioned beyond.

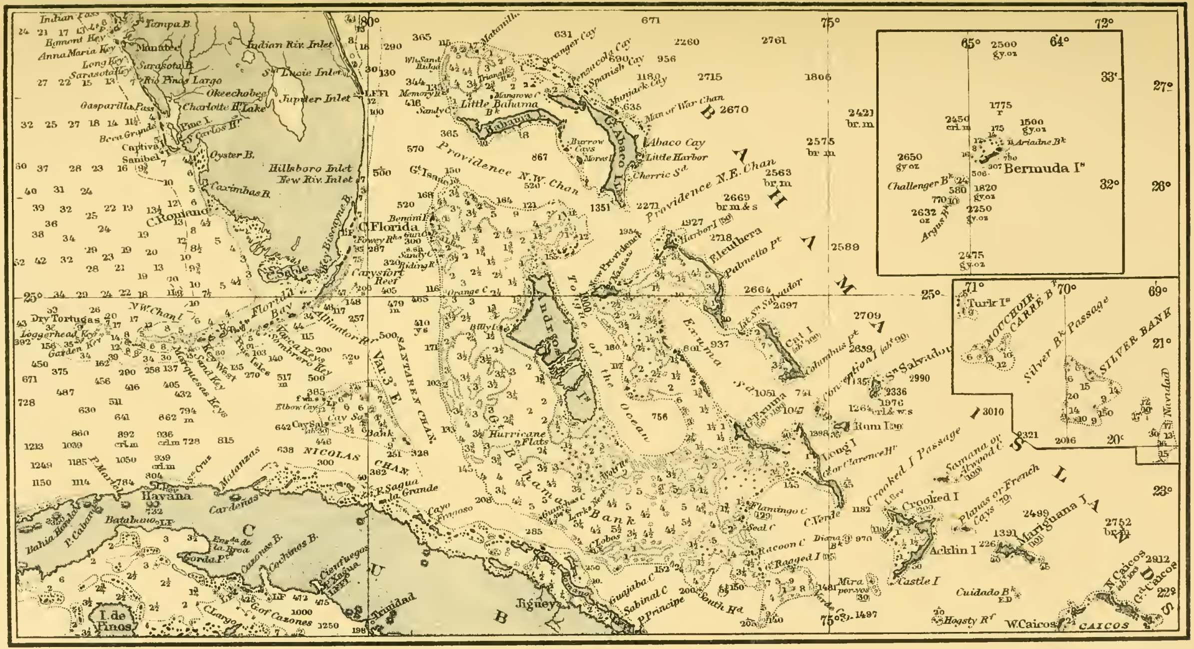
Florida Reefs. — The position of the Florida coral reefs, and of the Bahama Islands with reference to Florida and Cuba, and to one another, and the depths over and among the reefs, are shown on Plate XI., which is taken from one of the Atlantic Ocean charts of the United States Hydrographic Department.[1]

The Florida coral formations are mainly great reef-made banks. They commence on the east coast, at Cape Florida, in latitude 25° 40′ N., continue around the south extremity of the peninsula, and stretch westward to and beyond Key

[1] The chart is Sheet One of the North Atlantic Ocean, Lower Part (No. 21). It has great geological interest; for it includes all the West Indian and Gulf seas, with also the Bermudas and northern South America to the equator, and gives all soundings to date of publication. This chart and another of the Florida reefs and Bahamas on a still larger scale (No. 944) are the best sources of information as to the extent, positions, forms, general characters, and relations of the reef regions, and the distributions of islands and keys; and detailed descriptions are of little value without them.

The more important scientific accounts of the Florida reefs are the following: Prof. Louis Agassiz's Memoir, published, in part, in the Coast Survey Reports for 1851, and entire, with added illustrations of West India corals, in the Memoirs of the Museum of Comparative Zoölogy, vol. vii., 1880; M. Tuomey's paper in the American Journal of Science, 1851, 2d ser., xi.; Publications of F. de Pourtalès, in the Bulletin of the Museum of Comparative Zoölogy for 1867, 1868, 1878, and his Report on Deep-Sea Corals in the Illustrated Catalogue of the Museum, in 1871; the excellent and finely illustrated work of Mr. Alexander Agassiz, entitled the "Three Cruises of the Blake," in two volumes, 1888; besides papers by Mr. Agassiz in the Bulletin of the Museum of Comparative Zoölogy, and in the Memoirs of the American Academy, 1883, xi. Other papers are those of Prof. Joseph Le Conte, American Journal of Science for 1857, xxiii., 46, on the Agency of the Gulf Stream in the Formation of the Peninsula and Keys of Florida; and Capt. E. B. Hunt, U. S. A., ibid., 1863, xxxv., 197, on the Origin, Growth, and Chronology of the Florida Reef.

Plate XI.



THE FLORIDA REEFS AND BAHAMAS, WITH THE BERMUDA ISLANDS.

West. They are broad reef-ground flats more or less swept by the tides; the Biscayne Bay, two to eight miles wide, is on the east side of Florida, and the larger Florida Bay on the south. The width of the bank rapidly increases to the westward, becoming thirty miles off Cape Sable. No subdivision into a fringing and barrier reef is suggested by its features. "The whole tract between Cape Sable and the Keys as far as Cape Florida, at least as far as Soldier Key, is so shoal that it is inaccessible except for very small vessels." This shoal region, as Professor Agassiz's Memoir (1851) states, is literally studded with mangrove islands, either in continuous ranges of great extent, or making "innumerable small islets, so intimately interwoven and separated by so narrow and shallow channels as to be almost impenetrable." The mangrove bushes, which seem to be "striding out in the mud" in consequence of the many root-making stems that grow downward from the branches, serve to entangle the sand, sea-weed, and drift-wood that float by, and thus aid in the process of emergence. The material of the great mud-flats of the area on the bottom of the shoal water is the finest of coral sand; but it is darkened in color by the carbonaceous results of animal and vegetable decomposition, so that much of it looks like ordinary silt or mud.

Along the western side of Florida the coast-flats extend from Cape Sable northward for fifty to sixty miles, with a mean width of nearly ten miles; but the sands of the flats are partly siliceous. Outside of the bank the waters are deeper, but the bottom continues to be largely calcareous.[1] The bed of coral rock at Tampa Bay containing silicified corals has been supposed to be of recent origin; but it is

[1] The "Three Cruises of the Blake," of Mr. A. Agassiz, has, at page 286 of the first volume, a colored map of much interest illustrating the nature of the sea-bottom in the Florida region.

proved, by the observations of Dr. E. C. Stearns and Prof. A. Heilprin, to be Tertiary and probably Miocene. At Tampa Bay and along the coast south there is shell-rock, or *coquina*, in process of formation in some places. The large accumulations of worm-like tubes on this coast, which have been referred to Serpulæ, have been recently found by Mr. W. H. Dall to be the tubes of a Mollusk, — the Gastropod *Vermetus nigricans*, whose worm-like spirals are much like those of sea-worms.[1]

Along the outer borders of the great Florida Bank the waters abound in growing corals. They cover its margin, and also the bottom adjoining at depths of one to seven or eight fathoms, this being the ordinary limit of reef-forming corals in the Florida seas. Over this marginal belt of growing corals, toward its outer limit, there are many spots of half-emerged reef and some islets; and these reefs make the outer boundary of a navigable channel carrying four to seven fathoms of water. This belt of growing corals is ordinarily called the "Florida Reefs."

The islands and keys of the bank are almost wholly of wind-drift origin. The sands of the outer margin of the reef, where thrown up by the waves, have been taken up by the winds and deposited in long, high drifts a mile or so back. Key Largo, one of the eastern of the drift ridges, is thirty miles long and between one and two miles wide. Key West is near the southwestern extremity of the bank, and has the rather unusual height of fifteen feet above tide-level. East of Key West for thirty-five miles the Keys are cut into strips that trend north and south, — the Pine Islands, — owing to passages that have been kept open by the tides.

The drift-sands of the Keys are consolidated into a coral-

[1] Dall, American Journal of Science, 1887, xxxiv., 161.

sand rock, and much of it into true oölite. The manner in which this consolidation is produced is explained on page 153.

Pourtalès was the first to point out that the sand-made reef off the coast of Northern Florida continues to consist of siliceous sands quite down to Cape Florida; that abruptly at this point it becomes a coral-made reef, and is so continued southward. The facts indicate, as observed by Major E. B. Hunt in 1863, that the drifting action of currents parallel with the coast have had much to do in locating the coral-built reef as well as the banks of siliceous sands; the material supplied is the chief difference between the two, coral sands failing where growing corals fail. Major Hunt pointed out also that the current along the Florida coral reefs was a current counter to the Gulf Stream.

How far the encroachment of siliceous sediments from the north may have determined the limit of coral-growing in that direction has not been ascertained. If, as the author states in his Wilkes Expedition Report on Crustacea, the isocryme of 68° F. terminates at Cape Canaveral, it would appear that the coral seas, or those warm enough to grow corals, extend one hundred and seventy-five miles north of Cape Florida, and that the northern siliceous sands have encroached all this distance.

The limit may have been even north of Cape Canaveral; for, as the author has recently learned from Professor Verrill, corals of the genus *Oculina* have been dredged up from a rocky bottom off Charleston, South Carolina, in depths of eight to ten fathoms. There is a question, however, whether the Oculina was one of the reef-making species.

Little is seen over the flats or reefs of the true coral-reef rock, or the under-water coral limestone, which is the main material of all coral formations. It is generally concealed beneath the drift-sands of the surface. Tuomey observes that — "the greater number, if not all the Keys, rest upon a foundation of corals. At Sand Key large rugged masses of dead coral are seen bordering the Key on the windward side, and rising above low water; similar masses may be seen at Sambo Key, and at other places along the outer reef. But the Keys within this barrier present better opportunities for studying the foundation upon which they rest. At Key Vacca corals rise to a height of four feet above high water, and present not the slightest evidence of disturbance, beyond the upward movement which raised them to their present position. The rocky mass of coral along the margin of the Key is undermined by the waves, and otherwise worn into singularly rugged shapes, with sharp projecting points. Even at some distance from the water, bunches of coral project above the surface wherever the overlying sand is washed away.

"In the shallow water off many of the Keys very beautiful patches of Algæ, interspersed with living corals, are seen within six or eight inches of the surface. Off Indian and Plantation Keys dark knobs of coral are visible upon the white mud of the bottom, which render the navigation amongst these Keys dangerous. On lower Matacumba I traced the rugged coral rocks for a mile in extent; I also found them on Conch Key, as I did indeed on nearly every island that I examined, where a section could be found on the shore, from which the overlying sands were washed."

What is the actual thickness of the Florida coral-reef formation, and what it rests upon, no one knows, as no attempts to ascertain by borings have been made. The Mississippi silt makes no encroachments on the region; for it is carried westward by the tidal currents of the Gulf, and does not reach eastward to within five hundred miles of the Florida reef region.

The banks continue westward of Key West to the Marquesas Key, which is atoll-like in form and probably in origin. But it is so situated at present within the sand-made area that there are no growing corals "on its weather-side." Farther west a true atoll — that of the Tortugas — stands apart from the bank, a channel of eleven to sixteen fathoms intervening between it and the Marquesas reef. Branching corals and others are growing in abundance about it, which are the source of the coral fragments that are thrown on the beach. The bank may perhaps receive some light calcareous silt from the reefs to the eastward; but the intervening channel through which the tide sweeps must be filled before driftings from the eastward will reach effectively the Tortugas.

Whether a bend in the south end of the peninsula of Florida determined the direction of drift of the marine currents in the region, and the bend in the form of the skirting reef, or whether the direction of current drift alone gave direction to the belt of reef, is not determined by any positive facts. The east-and-west trend of Cuba favors the former of these explanations; and the position of the Tortugas leads to the conclusion that it was probably an atoll off the extremity of the Florida Bank. An artesian boring in the centre of the Tortugas with a diamond drill that would supply a large core for study, would give the facts for positive conclusions as to the nature of the basement and the depth to which it consists of coral-reef rock.

No good evidence of elevation of the Florida Bank has been reported. The height of the islands and cays is not satisfactory evidence, as it is so generally due to sand-drifts. At the same time the opinion that there had been a rise of half a dozen feet or so may be found to have much in its favor.

Region between the Florida Reefs and Cuba. — Through the labors of Pourtalès, in connection with the soundings by the Coast Survey, interesting facts have been brought to light respecting the sea between the Florida reefs and the opposite shores or reefs along Cuba and the Bahamas (see Plate XI.). A few paragraphs on the region, by Pourtalès, are cited from his memoir.[1]

"In transverse sections of the channel the greatest depth is nearest its southern or eastern shore. and in a longitudinal section the depth diminishes in passing toward the north, finding its minimum in the narrowest part between Cape Florida and the Bemini Islands, after which it increases again. In a transverse section between Key West and Havana, the greatest depth is 853 fathoms; between Sombrero Light and Elbow or Double-Headed Shot Key on the Cay Sal, or Salt Key Bank, 500 fathoms; between Carysfort reef and Orange Key on the Great Bahama Bank, 475 fathoms; and between Cape Florida and the Bemini Islands, 370 fathoms."

Pourtalès says of the bottom outside of the Florida reefs:

"Although the deep blue color of the water after passing the reef seems to indicate a very abrupt slope, there is in no part of it anything to compare with the sudden deepening on the edge of the coral reefs of the Pacific Ocean, or even of the Bahamas or the coast of Cuba. The distance from the reef to the 100-fathom line is not less than three miles, and often as much as six. In this space the bottom consists of calcareous mud, and is not particularly rich in animal life. From ninety or a hundred fathoms to two hundred and fifty or three hundred, the bottom slopes rather gently in the

[1] Museum of Comparative Zoölogy, Illustrated Catalogue, Cambridge, Mass., 1871.

shape of a rough, rocky floor, without great inequalities; this formation obtains its greatest breadth, of about eighteen miles, a little to the east of Sombrero Light, and tapers off to the west, where it ends in about the same longitude as the end of the reef; toward the east and north it approaches nearer the reef, and ends gradually between Carysfort reef and Cape Florida. This bottom, which is called the 'Pourtalès Plateau' in Professor Agassiz's report, is very rich in deep-sea corals, and most of the species described in the memoir [of Pourtalès] were dredged on this ground. Outside of the rocky bottom the Globigerina mud prevails and fills the trough of the channel.

"On the Cuba shore the bottom is rocky and the slope very abrupt, particularly for the first four or five hundred fathoms. Along the Salt Key and Bahama Banks the slope is also exceedingly abrupt, but the underlying rock is often covered with mud."

The rock of the bottom of the Pourtalès Plateau is a limestone made from the calcareous relics of the species (corals, shells, echinoderms, etc.) living at those depths; and it is still increasing, well exemplifying what limestone-making may go on below the limit of reef-making corals. Mr. A. Agassiz has a cut on page 287 of his "Cruises of the Blake" representing a specimen of the material.

The Salt Key Bank is mostly a submerged atoll-like area, seventy miles long, having emerged islets and cays along its northeastern and northern sides, or those to windward, and falling off southward to a depth of four and a half to six and a half fathoms and then steeply to depths of two hundred and fifty fathoms and beyond to those of the channel along the north side of Cuba.

Prof. L. Agassiz describes the banks and keys embraced between Double-Headed Shot Key, Salt Key, and Anguilla Key as a very instructive combination of the phenomena of building and destruction. He says: "The whole group is a flat bank covered by four or five, and occasionally six, fathoms of water, with fine sandy bottom, evidently corals reduced to oölite, the grains, which are of various sizes, from fine powder to coarse sand, mingled with broken shells, among which a few living specimens are occasionally found. The margin of the Bank is encircled on several points by rocky ridges of the most diversified appearance, and at others edged by sand-dunes. A close examination and comparison of the different Keys show that these different formations are in fact linked together, and represent various stages of the accumulation, consolidation, and cementation of the same materials. On the flat top of the bank the loose materials are pounded down to fine sand; in course of time this sand is thrown up upon the shoalest portions of the Bank, and it is curious to notice that these shoalest parts are its very edge, along which corals have formed reefs which have become the basis of the dry banks. The foundation rock, as far as tide, wind, and wave may carry the coarser materials, consists of a conglomeration of coarser oölitic grains, rounded fragments of corals, or broken shells, and even larger pieces of a variety of corals and conchs, all the species being those now found living upon the Bank, among which *Strombus gigas* is the most common; besides that, *Astræa* [*Orbicella*] *annularis, Siderastræa siderea,* and *Mæandrina mammosa* prevail. The shells of Strombus are so common that they give great solidity and hardness to the rock. The stratification is somewhat irregular, the beds slanting toward the sea at an angle of about seven degrees. Upon this foundation immense masses of Strombus, dead shells, and corals have been thrown in banks, evidently the beginning of deposits similar to those already consolidated below; but there is this difference in their formation, namely, that while the foundation rock is slightly inclined, and never rises above the level of high water, the accumulation of loose materials above water-level forms steeper banks, varying from fifteen to twenty and thirty degrees. In some localities broken shells prevail; in others, coarse and fine sand; and the ridges thus formed, evidently by the action of high waves, rise to about twelve and fifteen feet. This is evidently the foundation for the accumulation of finer sand driven by the wind over these ridges, and forming high sand-dunes, held together by a variety of plants, among which a trailing vine (*Batatas littoralis*), various grasses, and shrubs are the most conspicuous. These dunes rise to about twenty feet; on their lee side and almost to their summits grows a little palmetto. The sand of the dunes is still loose, but here and there shows a tendency to incrustation at the surface. The slope of these dunes is rather steep, sometimes over thirty degrees, and steeper to the seaward than on the landward side.

"In the interior of Salt Key there is a pool of intensely salt water, the tint of which is pinkish or flesh-colored, owing to the accumulation of a small alga. When agitated by the wind, this pool is hedged all around by foam of the purest white, arising from the frothing of the viscous water. Along the edge the accumulation of this microscopic plant forms large cakes, not unlike decaying meat, and of a very offensive odor. The foundation rock of this Key is exactly like what Gressly described as the 'facies corallien' of the Jurassic formation; while the deposit in deep water, consisting chiefly of muddy lime particles, answers to his 'facies vaseux.'

"Double-Headed Shot Key is a long, crescent-shaped ridge of rounded knolls, not unlike 'roches moutonnées,' at intervals interrupted by breaks, so that the whole looks like a dismantled wall, broken down here and there to the water's edge. The whole ridge is composed of the finest oölite, pretty regularly stratified, but here and there like torrential deposits; the stratification is more distinctly visible where the rocks have been weathered at the surface into those rugged and furrowed slopes familiarly known as 'karren' in Switzerland. It is plain that we have here the same formation as on Salt Key, only older, with more thoroughly cemented materials."

The Bahama Islands. — The Bahamas are, like the Florida reefs, great coral-made banks, having their emerged land in the form of islands and cays. These dry portions are situated mostly along the windward sides. To comprehend the relations of the Bahamas to atolls they should be compared with the Louisiade Group, Plate VII., and other broad combinations of barriers and atolls, although true barrier reefs are absent. They are more remarkable than the Florida reefs for their drift-sand accumulations, their height being sometimes two hundred to two hundred and thirty feet, though generally under one hundred feet. A large part of the banks, however, are in a lagoon condition, being covered with water at depths ordinarily of two to five fathoms, and the leeward margin is for the most part submerged.

The group extends for six hundred miles through the seas north of Cuba and Hayti, with the Florida Straits — fifty miles in mean width and three to five hundred fathoms in depth — separating them from Florida. The two great western banks are the Little Bahama, or the northwestern, one hundred and fifty miles long, and the Great Bahama Bank, to the south and east, three hundred and twenty-five miles long. The latter is shaped like a letter S, or a pothook, and occupies two thirds of the whole Bahama area. Nassau, the principal seaport of the group, is situated on the island of New Providence, at the northwest angle of the second turn in the S.

The Bahama group continues eastward, in a number of coral islands, to Turk's Island, in longitude 71° W.; but topographically and geologically it extends two degrees farther west in a line of atolls and reefs to Navidad Island. The small map to the right on Plate XI. contains Turk's Island and the reef islands east of it. Turk's Island is situated near the southeast angle of Caicos Island.

The western portion of the Bahamas is built up on the broad submarine plateau, five hundred to six hundred fathoms under water, that extends parallel with the continental coastline from off North Carolina southward. The plateau in this southern part has a breadth from east to west of about two hundred miles. More to the eastward along the Bahamas the water deepens, and at the same time the reef becomes narrower; and from the east end of the S stretches a line of independent coral islands, some of which are typical atolls.

The peculiar form of the "Great Bahama Bank" is partly due to the coalescence of separate islands with the main western portion through coral growths. It probably secured thus the addition of Long Island Bank, Eleuthera Bank, and Cat Island; and almost certainly the last of the three, Cat Island, whose connection with the part next west is made by a narrow submerged reef, fifty to seventy-five feet under water, the northern side of which pitches off at an angle of about forty-five degrees to a depth of fifty-five hundred feet.

The S-like form is dependent also on the intrusion into the area of two deep and broad tongues of the ocean, one going in from the northward, commencing with two thousand fathoms at its entrance, and having depths inside of one thousand to seven hundred and fifty fathoms; and the other, Exuma Sound, entering from the east, and having depths within of twelve hundred fathoms toward the entrance, and eight hundred near the inner extremity.

Beyond the Great Bank, eastward, the ocean's depths and the abruptness of the submarine declivities increase rapidly. Even in the New Providence Channel, east of the Little Bahama Bank, there are depths of twenty-two hundred and seventy fathoms, over thirteen thousand five hundred feet. The north shore of Eleuthera Island has nearly this depth within seven miles, or thirty-seven thousand feet, of its emerged reef; the pitch, therefore, 1:2·75. San Salvador, east of Cat Island, has a depth of fourteen thousand feet within three miles of the emerged reef, a pitch down of about 1:1·13, and a depth of sixteen thousand six hundred and forty-four feet within ten miles, the pitch 1:3; and almost eighteen thousand feet within twenty-one miles. These steep northern under-water slopes are continued along the course of the group eastward. Besides this, the channel on the *south* side of the group, which is twelve hundred to fifteen hundred feet deep against middle Cuba, is over thirteen thousand five hundred feet north of Hayti. The line of reef-islands beyond Turk's Island eastward have less emerged land than those to the westward. The last, Navidad, is mostly submerged reef, and has depths of thirteen thousand five hundred feet within fifteen miles on the east and south, and seventeen thousand five hundred within thirty-five miles to the east-northeast.

These facts as to the depths and steep submarine declivities along the coral-reef islands are as remarkable as any yet observed in the Pacific Ocean, even among its equatorial islands.

The rock of the Bahama Islands is, like that of the Florida Keys, a coral-sand rock of wind-drift origin. It is generally a poor building stone because of the numerous sand-flaws. Its weight varies from sixty-five to one hundred and forty-five pounds per cubic foot. In some of the basins or lagoon-bottoms a chalk-like deposit occurs, and nowhere so extensively as along the western coast of Andros Island. The coarser fragments of corals are never found much beyond the surf range of high tide. Captain Nelson says that "the south side of Silver Cay and the beach extending westward from Nassau afford rolled blocks, pebbles, and sand derived from the more massive corals, mixed with remains of turtles, fish, crustaceans, echinoderms, and mollusks. On the beach between Clifton Point and West Bay the shells of *Strombus gigas* more especially accompany the rolled corals. At East Point the sand is derived from corallines and nullipores; the finer sand being often in approximately spherical grains, though not so perfectly as the White Cay, and between Exuma and Long Cay. The beach near Charlotteville Point consists principally of *Lucina Pennsylvanica* in various stages of comminution. At Six Hills (Caicos Group) the mass of conch shells (*Strombus gigas*) is so great and sufficiently cemented together as to form not only rock, but an island several hundred feet in length. Along the northwest beach at Gun Cay a hard, coarse, stratified rock is formed of conch shells and others, together with coral fragments."

"A counterfeit oölite occurs near White Cay, Exuma, and elsewhere, in which the spherules have been derived apparently from the stems of corallines." On the larger islands the rocky surface of the hills is very thinly and partially covered with "red earth" mixed in varying proportions with vegetable matter. There are many large caverns in the group, and those of Long Cay and Rum Cay are described as equalling those of the Bermudas.

The Bahamas differ from ordinary atolls more in the great size of the two western banks, and the wide distribution and high heapings of the wind-drift deposits, than in any other characteristics. Some peculiarities are due also to the position of the reefs, — one end resting on a sea-border plateau and the other extending out into the deeper waters of the ocean. To the westward, a rise of three thousand feet would make one land of Florida, Cuba, and the Bahamas; but the Bahamas to the eastward would still be a line of oceanic islands. As to evidences of recent elevation nothing is positively known. The great extent and height of the drift-made dry land appears to indicate a long resting at the present level.

The Bermuda or Somers' Islands. — The Bermudas are what remains of a large atoll, as first announced by Lieutenant Nelson;[1] and this atoll is the most remote from the equator of any existing. It lies in deep seas between the parallels

[1] Transactions of the Geological Society of London, 1840, v., 103.

The following are other important publications on the structure of the Bermudas: The Reports of the Challenger Expedition of 1873 and 1876, by Sir Wyville Thomson, London, vol. i.; "The Naturalist in Bermuda," by John Matthew Jones, with a map and illustrations, London, 1859; also, by the same, "A Visitor's Guide to Bermuda;" Observations on the Bermudas, in Nature for 1872; and on the geological features of the Bermudas in the Proceedings and Transactions of the Nova Scotia Institute of Natural Science, 1867; A paper on the Bermuda Reefs by Dr. J. J. Rein, in the Senckenberg. Ber. naturforsch. Gesellschaft, 1869–70, and Verhandlung des I. deutsch. Geographentages für 1881, Berlin, 1882. There are also two valuable American contributions to the Geology of the Bermudas, one by Prof. William North Rice, of Middletown, Conn., 32 pp. 8vo, being Bulletin No. 25 of the U. S. National Museum, 1884; and a volume by A. Heilprin, of Philadelphia, entitled "The Bermuda Islands: a contribution to the Physical History and Zoölogy of the Somers' Archipelago," a handsomely illustrated work of 231 pp. 8vo, treating of the coral reefs, and also of the zoölogy, and discussing at length the coral-island problem, with conclusions favoring, like those of Professor Rice, the Darwinian theory.

32° and 32° 35′, and the meridians 64° 30′ and 65° 30′. The principal species of corals are mentioned on page 114.

The general form and position of the reef and its islets are shown on the accompanying map; and its position in the ocean and the depths of the seas, on Plate XI. The longer diameter of the elliptical area trends nearly northeast-by-east,

THE BERMUDA ISLANDS.

and is about twenty-five miles in length, while the transverse diameter is about fifteen miles. In the ocean about the Bermudas, the depth descends to twenty-five hundred fathoms and beyond. Within seventeen English miles west of the Bermuda reef there is a sounding (by the Challenger Expedition) of twenty-four hundred and fifty fathoms, giving a slope of 1:6·1; and fifteen miles east of the southern submerged (in ten fathoms) reef, one of twenty-two hundred and fifty fathoms, giving the slope 1:6. There is also a sounding of twenty-six hundred and thirty-two fathoms sixteen miles southwest of the same southern reef, giving a slope of 1:5·4. The soundings are too few for a decision as to the maximum slope.

The emerged land, about fifteen miles long, is confined to the side facing southeast, excepting a single isolated rock, or group of rocks, on the north side (between *c* and *d* on the map) called North Rock. It is broken into a hundred and fifty or more islets, and the surface is made up of hills and low basins. The highest point, Sears' Hill (E), is, according to Lieutenant Nelson, two hundred and sixty feet in elevation above the sea, and Gibbs Hill (D), the site of the lighthouse, two hundred and forty-five feet. Wreck Hill (F), near the western point of the principal island, is about one hundred and fifty feet high, and North Rock is sixteen feet high, above mean tide. H is the position of Hamilton, the seat of Government, and G, of St. George's, the other principal town. A (Castle Harbor), B (Harrington Sound), and C (Great Sound) are three encircled bays, looking as if once the lagoons of sub-atolls in a Maldive-like compound atoll. The surface, about half way between the sounds A and B, is low. Most of the land is covered with cedars where not cultivated or given over to loose sand. The last island of the southern hook is Ireland Island.

The greater part of the old atoll is still a submerged reef. But it is of the typical form, in having a large lagoon-like depression enclosed within a relatively narrow border. Its border is mostly from one to three fathoms under water at low tide, though in some parts laid bare at the ebb. It has open channels at *a*, called the Chub cut; *b*, Blue cut, shallow; *c*, N. W. Channel; *d*, N. E. Channel; *e*, Mills' Breaker Channel; *f*, the channels affording the nearest routes to Murray Anchorage and St. George's Harbor; *g*, Channel by St.

David's Head, shallow; and *h*, Hog-fish cut. The reef-grounds, inside, are encumbered with countless clumps of corals and coral-heads, one to four fathoms under water, with intervals between of five to ten fathoms; some large tracts are without corals, and these have a nearly uniform depth of seven or eight fathoms. To a vessel entering, the positions of the coral clumps are made known by the brownish or discolored water above them. The bottom, over large areas, is a calcareous clay or mud; that of Murray Anchorage, a fine chalky clay.

Serpulæ have made large accumulations over parts of the reef, as stated by Nelson. The tubes are so heaped over one another as to make rings or atoll-like elevations two feet or so high and two to twenty feet wide. Nelson calls them "Serpuline reefs." The reefs on the east and south sides are narrow, not over a fourth of a mile wide, and the waters abruptly deepen; we may consequently conclude that this southeastern side of the original land was bold and high, while off to the north and west the surface was relatively low and flat.

The rock of the surface is a calcareous sand-rock of wind-drift and beach origin like that of the Florida and Bahama reefs. Prof. Wm. N. Rice says that no true coral-reef rock is seen anywhere above the sea-level, and that the beach and wind-drift formations graduate into one another and are not easily distinguishable. The beach-made rock is in some places eight to fifteen feet above tide-level. Professor Rice says further:[1] —

"The beach-rock is, on the average, more perfectly consolidated than the drift-rock, but in this character both rocks vary widely. Drift-rock, when submerged by a subsidence

[1] Rice, Bulletin No. 25, United States National Museum, 1884, pp. 10, 11, 14, 15.

consequent to its deposition, may come to assume the degree of consolidation usually observed in beach-rock. On the south shore of the main island, near Spanish Rock, I observed strata perfectly continuous dipping toward the water, exceedingly hard at the margin of the water, but becoming considerably softer as they were traced upward and landward. Mr. Ebenezer Bell, who some years ago had charge of some works in progress on Boaz Island, informed me that he found that the rock, so soft as to crumble in one's fingers, became quite hard on immersion for a week or a fortnight in sea-water. Some of the hardest rock which I observed in Bermuda was shown by other characters to be unmistakably drift-rock. A more reliable distinction is found in the lamination, the beach-rock showing a general and uniform dip toward the water, while the drift-rock shows the high and extremely irregular dips which are characteristic of wind-blown sands. But not every section exhibits characters sufficiently marked to settle the nature of the rock, since the beach-structure admits of a considerable degree of irregularity in dip, while wind-blown sands in a long ridge or dune may have for long distances a gentle and nearly uniform dip. The indication furnished by the fossil contents of the rock is important. The beach-rock is often richly fossiliferous, containing shells and pieces of coral of considerable size. The drift-rock will, of course, ordinarily contain no relics of marine animals except fragments so small as to be blown by the wind. A high wind can, however, sweep along pieces of shell and coral larger than one would at first suppose. . . .

"While the presence of marine fossils in a sand-rock is an indication that it is a beach-rock, the drift-rock is quite apt to contain the shells of land snails. The presence of snail shells cannot, however, be regarded as a sure proof of drift-rock, since they may easily be washed down by rains from a bank or bluff above the beach and imbedded in the beach-sands.

"The usual softness of this drift-rock has made it a matter of small labor and expense to secure easy grades on most of the roads in the islands, by making deep cuts wherever they are required. These cuttings are of great interest to the geologist, from the beautiful illustration which they afford of that extreme irregularity of lamination which is characteristic of wind-drifts. Not only the country roads, but also the streets of the towns, abound in these beautiful and instructive sections. Fine exhibitions of this same structure are to be seen in the natural sections afforded by the cliffs or pinnacles of the shore."

Professor Heilprin's work on the Bermuda Islands contains three phototypes which show finely the general landscape features of the rock.

The great drift-sand hills, ridges, and flats, like those of the Bahamas, are results of the fiercer storm-winds, as stated on page 155. At the Bermudas, the ordinary westerly winds are feeble at transportation. But cyclones, as the "Sailing Directions" state, are very frequent, and "especially in the autumn;" and during the earlier and more furious half of the storm, the wind is easterly. In addition, "Bermuda squalls are sudden and violent tempests" of the winter, and in them the winds are from all directions. By comparing ordinary winds with violent tempests we may apprehend the difference at these times in the amount of force at work, and lose surprise over the differences in results. The "North Rock" is apparently the remains of drift-hills built up on the projecting northwest point of the reef-island; but the surface must have been higher than now, for their formation.

The Bahamas are still farther within the belt of Atlantic storm tracks, and in the West Indian portion, as is well shown on the Chart of Atlantic Storms by Wm. C. Redfield in Volume XXXI. of the American Journal of Science, 1837. They are situated just outside of the continental line where the tracks of many of the cyclones make the turn northward; and this is reason enough for high drift-heaps and the great width of the areas.

The Florida region feels less powerfully the influence of the storms, but their influence is sufficient for the accumulation of extensive drift-ridges and a wide spread of the sands over the bank.

The Bermudas have suffered greatly from erosion. There are no running streams, but the coral sands and the limestones made from them are easily dissolved and removed by carbonated waters; and consequently the rains, reinforced in their carbonic acid by more from vegetable or animal decomposition in the soil, have done a large part of the erosion over the surface and of that of cavern-making beneath it; while the waves have made cliffs, towers, and pinnacles, and caves too, along the coasts. The winds, moreover, have aided both.

Professor Rice confirms the earlier accounts of Lieutenant Nelson and others, and speaks of the "innumerable caves" as "ranging in size from miniature grottos — the bijoux of Nelson — to extensive caverns." One of the miniature caves had been opened at Paynter's Vale in quarrying: its horizontal diameter was about five feet, its height at middle only two; but pigmy stalagmites rose from the floor toward the slender stalactites that were pendent from the roof, and along the sides the stalactites and stalagmites were in many cases united to form little columns; and all was of most exquisite finish.

Proofs of subsidence are reported to exist in the occurrence of shoreward dips of the sand-rock into and below the water-level (Rice); in the existence of caverns submerged over fifty feet, with stalagmites rising from their floors, now far beneath the surface (Heilprin); and the fact mentioned in the Report of the Challenger Expedition, that a peat-bed, stumps of cedar, land snails (*Helix Bermudensis*), and loose masses of the drift-sand rock were found on Ireland Island at a depth below tide-level of forty feet, in the excavation for a floating dock. When these cedars were growing, the land was consequently forty-five feet or more above its present level. It is probable that at this time there was a long period of rest or cessation in the subsidence, and that during it the drift-sand formation of the island, including that of "North Rock," was chiefly made. Afterward, when the subsidence was resumed, the work of degradation began.

A comparatively recent elevation is indicated, according to Professor Rice, by the height of the beach-sand rock, fifteen feet, on part of the north side of the strip of dry land.

The origin of the "red earth"[1] making much of the soil

[1] Analysis of the coral sand of Bermuda, and mean of three analyses of the red earth, by Mr. F. A. Manning (Agricultural Report, at Bermuda in 1873, of Maj.-Gen. J. H. Lefroy).

	1. Coral sand	2. Red earth.
Carbonic acid	42.87	4.06
Lime	52.47	5.95
Magnesia	1.69	0.36
Potash	0.06	0.14
Soda	0.24	0.03
Alumina } Iron sesquioxide }	0.52	16.94
		19.58
Sulphuric acid	0.20	0.03
Chlorine	0.02	0.015
Phosphoric acid	0.08	0.70
Sand	0.05	56.60
Organic substance	3.80	15.41
	102.00	99.81

Excluding the 15·41 per cent of organic substance in the red earth, 100 parts, according to the above, contain about 23 per cent of iron oxide, 20 of alumina, and 43 of sand, besides some lime carbonate and small portions of the other ingredients enumerated.

was first explained by Sir Wyville Thomson. The limestone contains about half of one per cent of iron oxide and earthy ingredients; and these are left behind as "red earth" when the rest is dissolved away by the carbonated waters.

Another source in some regions, if not at the Bermudas, is the volcanic dust that is widely distributed by the winds, or fragments of pumice and other volcanic rocks that may have been brought by the sea and drifting logs. Pieces of pumice and augitic lava have been found on the island; and from the sands Mr. Murray obtained magnetite, chrysolite, augite, sanidin and other feldspars, mica, and perhaps quartz.

Twenty miles southwest-by-west from the Bermudas, there are two submerged banks or shoals, both reported as having a "corally and rocky bottom;" one has over it a minimum depth of twenty-four fathoms, and the other of ten fathoms. Dredging on these banks might make some interesting disclosures.

CHAPTER III.

FORMATION OF CORAL REEFS AND ISLANDS, AND CAUSES OF THEIR FEATURES.

I. FORMATION OF REEFS.

I. ORIGIN OF CORAL SANDS AND THE REEF-ROCK.

VERY erroneous ideas prevail respecting the appearance of a bed or area of growing corals. The submerged reef is often thought of as an extended mass of coral, alive uniformly over its upper surface, and as gradually enlarging upward through this living growth; and such preconceived views, when ascertained to be erroneous by observation, have sometimes led to skepticism with regard to the zoöphytic origin of the reef-rock. Nothing is wider from the truth: and this must have been inferred from the descriptions already given. Another glance at the coral plantation should be taken by the reader, before proceeding with the explanations which follow.

Coral plantation and coral field are more appropriate appellations than coral garden, and convey a juster impression of the surface of a growing reef. Like a spot of wild land, covered in some parts, even over acres, with varied shrubbery, in other parts bearing only occasional tufts of vegetation in barren plains of sand, here a clump of saplings, and there a carpet of variously-colored flowers in these barren fields—such is the coral plantation. Numerous kinds of zoöphytes grow scattered over the surface, like vegetation upon the land; there are large areas that bear nothing, and others of great extent that are thickly overgrown. There is, however, no green sward to the landscape; sand and fragments fill up the bare intervals between the flowering tufts: or, where the zoöphytes are crowded, there are deep holes among the stony stems and folia.

These fields of growing coral spread over submarine lands, such as the shores of islands and continents, where the depth is not greater than theirhabits require, just as vegetation extends itself through regions that are congenial. The germ or ovule, which, when first produced, is free, finds afterward a point of rock, or dead coral, or some support, to plant itself upon, and thence springs the tree or other forms of coral growth.

The analogy to vegetation does not stop here. It is well known that the débris of the forest, decaying leaves and stems, and animal remains, add to the soil; that in the marsh or swamp—where decaying vegetation is mostly under water, and sphagnous mosses grow luxuriantly, ever alive and flourishing at top, while dead and dying below,—accumulations of such débris are ceaselessly in progress, and deep beds of peat are formed. Similar is the history of the coral mead. Accumulations of fragments and sand from the coral zoöphytes growing over the reef-grounds, and of shells and other relics of organic life, are constantly making; and thus a bed of coral débris is formed and compacted. There is this difference, that a large part of the vegetable material consists of elements which escape as gases on decomposition, so that there is a great loss in bulk of the gathered mass; whereas coral is an enduring rock material undergoing no change except the mechanical one of comminution. The animal portion is but a mere fraction of the whole zoöphyte. The coral débris and shells fill up the intervals between the coral patches, and the cavities among the living tufts, and in this manner produce the reef deposit; and the bed is finally consolidated, while still beneath the water.

The coral zoöphyte is especially adapted for such a mode of reef-making. Were the nourishment drawn from below, as in most plants, the solidifying coral rock would soon destroy all life: instead of this, the zoöphyte is gradually dying below while growing above; and the accumulations of débris cover only the dead portions.

But on land, there is the decay of the year, and that of old age, producing vegetable débris; and storms prostrate forests. And there are corresponding effects among the groves of the sea. It has been shown that coral plantations, from which reefs proceed, do not grow in the "calm and still" depths of the ocean. They are to be found amid the waves, and usually extend little below a hundred feet, which is far within the reach of the sea's heavier commotions. To a considerable extent they grow in the very face of the tremendous breakers that strike and batter as they drive over the reefs. Here is an agent which is not without its effects. The enormous masses of uptorn rock found on many of the islands may give some idea of the force of the lifting wave; and there are examples on record, to be found in various treatises on Geology, of still more surprising effects.

During the more violent gales the bottom of the sea is said, by different authors, to be disturbed to a depth of three hundred, three hundred and fifty, or even five hundred feet, and De la Beche remarks, that when the depth is fifteen fathoms, the water is very evidently discolored by the action of the waves on the sand and mud of the bottom.

In an article on the Force of Waves, by Thomas Stevenson, of Edinburgh, published in the Transactions of the Royal

Society of Edinburgh (vol. xvi., 1845), it is stated as a deduction from two hundred and sixty-seven experiments, extending over twenty-three successive months, that the average force for Skerryvore, for five of the summer months, during the years 1843, 1844, was six hundred and eleven pounds per square foot; and for six of the winter months of the same year, it was two thousand and eighty-six pounds per square foot, or three times as great as during the summer months. During a westerly gale, at the same place, in March, 1845, a pressure of six thousand and eighty-three pounds was registered by Mr. Stevenson's dynamometer (the name of the instrument used). He mentions several remarkable instances of transported blocks.

We must, therefore, allow that some effect will be produced upon the coral groves. There will be trees prostrated by gales, as on land, fragments scattered, and fragmentary and sand accumulations commenced. Besides, masses of the heavier corals within ten to twenty feet of the surface may be uptorn, and carried along over the coral plantation, which will destroy and grind down every thing in their way. So many are the accidents of this kind to which zoöphytes appear to be exposed, that we might believe they would often be exterminated, were they not singularly tenacious of life, and ready to sprout anew on any rock where they may find quiet long enough to give themselves again a firm attachment.

But it should be observed, that the sea would have far less effect upon the slender forms characterizing many zoöphytes, among which the water finds free passage, than on the massive rock, against whose sides a large volume may drive unbroken. Moreover, much the greater part of the strength of the ocean is exerted near tide level, where it rises in breakers which plunge against the shores. Yet owing to the many nooks and recesses deep among the corals, the rapidly moving waters, during the heavier swells, must produce whirling eddies of considerable force, tending to uproot or break the coral clumps. Moreover, it is to be kept in mind that shells and echinoderms make contributions as well as corals, and that all life grows luxuriantly in the coral seas.

There is another process going on over the coral field, somewhat analogous to vegetable decay, though still very different. Zoöphytes have been described as ever dying while living. The dead portions have the surface much smoothed, or deprived of the roughening points which belong to the living coral, and the cells are sometimes half obliterated, or the delicate lamellæ worn away. This may be viewed as one source of fine coral particles; and as the process is constantly going on, it is not altogether unimportant. This material is in a fit condition to enter into solution, and it cannot be doubted that the water receives lime from this source, which is afterward yielded to the reef.

In the Alcyonia family, which includes semi-fleshy corals, and in the Gorgoniæ, the lime is often scattered through the polyps in granules; and the process of death sets these calcareous grains free, which are constantly added to the coral sands. The same process has been supposed to take place in the more common reef corals, the Madrepores and Astræas, and it is possible that this may be to some extent the case. Yet it would seem, from facts observed, that after the secretion has begun within the polyp, the secretion of lime going on takes place *against* the portions already formed and in direct union with them, and not as granules to be afterward cemented.

The *mud-like* deposits about coral reefs (pp. 142, 183, 205) have been attributed to the causes just mentioned, but without due consideration. There is an unfailing and abundant source of this kind of material in the self-triturating sands of the reefs acted upon by the moving waters. On the seaward side of coral islands, and on the shores of the larger lagoons, where the surface rises into waves of much magnitude, the finer portions are carried off, and the coarser sand remains alone to form the beaches. This making of coral sand and mud is just like that of any other kind of sand or mud. It takes place on all shores exposed to the waves, coral or not coral, and in every case the gentler the prevailing movement of the water, the finer the material on the shore. In the smaller lagoons, where the water is only rippled by the winds, or roughened for short intervals, the trituration is of the gentlest kind possible, and, moreover, the finely pulverized material remains as part of the shores. Thus the fine material of the mud must be constantly forming on all the shores, for the sands are perpetually wearing themselves out; but the particles of the fine mud, which is washed out from the beach sands, *accumulates* only in the more quiet waters some distance outside of the reef, and within the lagoons and channels, where it settles. This corresponds exactly with the facts; and every small lake or region of quiet waters over our continent, illustrates the same point.

Mr. Darwin, in discussing the origin of the finer calcareous mud, (op. cit., p. 14), supposes that it is derived in part from fishes and Holothurians; and other authors have thrown out the same suggestion. He cites as a fact, on the authority of Mr. Liesk, that certain fish browse on the living zoöphytes; and from Mr. Allan, of Forres, he learned also that Holothurians subsisted on them. The statement about the Holothurians has been set aside by observation. Small fish swarm about the branching clumps, and when disturbed, seek shelter at once among the branches, where they are safe from pursuit. The author has often witnessed this, and never saw reason to suppose that they clustered about the coral for any other purpose. It is an undoubted fact, as stated by Mr. Darwin, that fragments of coral and sand may be found in the stomachs of these animals, but this is not sufficient evidence of their browsing on the coral. Fish so carefully avoid polyps of all kinds because of their power of stinging (as illustrated on p. 37), that we should wait for further and direct evidence on this point. The conclusion deduced by him from the facts, may be justly doubted. The fish and Holothurians, though numerous, are quite inadequate for the supply; and, moreover, we have, as explained above, an abundant source of the finest coral material without such aid. Motion of particle over particle will necessarily wear to dust, even though the particles be diamonds; and this incessant grinding action about reefs accounts satisfactorily for the deposits of coral mud, however great their extent.

The coral world, as we thus perceive, is planted, like the land, with a variety of shrubs and smaller plants, and the elements and natural decay are producing gradual accumulations of material, like those of vegetation. The history of the growing reef has consequently its counterpart among the ordinary occurrences of the land about us.

The progress of the coral formation is like its commencement. The same causes continue, with similar results, and the reader might easily supply the details from the facts already presented. The production of débris will necessarily continue to go on: a part will be swept by the waves, across the patch of reef, into the lagoon or channel beyond, while other portions will fill up the spaces among the corals along its margin, or be thrown beyond the margin and lodge on its surface. The layer of dead coral rock which makes the body of the reef, has its border of growing corals, and is thus undergoing extension at its margin, both through the increase in the corals, and the débris dropped among them.

But besides the small fragments, larger masses will be thrown on the reefs by the more violent waves, and commence to raise them above the sea. The *clinker fields* of coral by this means produced, constitute the first step in the formation of dry land. Afterward, by further contributions of the coarse and fine coral material, the islets are completed, and raised as far out of the water as the waves can reach—that is, about ten feet, with a tide of three feet; and sixteen to eighteen feet with a tide of six or seven.

The Ocean is thus the architect, while the coral polyps afford the material for the structure; and, when all is ready, it sows the land with seed brought from distant shores, covering it with verdure and flowers.

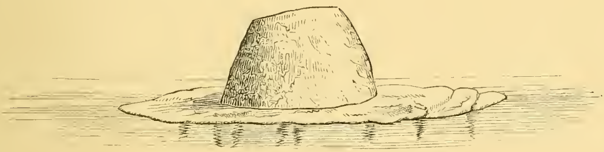
The growth of the reefs and islands around high lands is the same as here described for the atoll. The reef-rock is mainly a result of accumulations of coral and shell débris. There are reefs where the corals retain the position of growth, as has been described on a former page. But with these the débris comes in to fill up the intervening spaces or cavities, and make a compact bed for consolidation. There are other parts, especially portions of the outer reef along the line of breakers, which are formed by the gradual growth of layer upon layer of incrusting Nullipores; but such formations are of small extent, and only add to the results from other sources.

II. ORIGIN OF THE SHORE PLATFORM.

Among the peculiarities of coral islands, the *shore platform* appears to be one of the most singular, and its origin has not been rightly understood. It will be remembered that it lies but little above low-tide level, and it is often over three hundred feet in width, with a nearly flat surface throughout.

Though apparently so peculiar, the existence of this platform is due to the simple action of the sea, and is a necessary result of this action. On the shores of New South Wales, Australia, near Sydney, as observed by the author, the same structure is exemplified along the *sandstone* shores of this semi-continent, where it is continued for scores of miles. At the base of the sandstone cliff, in most places one or more hundred feet in height, there is a layer of sandstone rock, lying, like the shore platform of the coral island, near low-tide level, and from fifty to one hundred and fifty yards in width. It is continuous with the bottom layer of the cliff: the rocks which once covered it have been removed by the sea. Its outer edge is the surf-line of the coast. At low-tide it is mostly a naked flat of rock, while at high tide it is wholly under water, and the sea reaches the cliff.

New Zealand, at the Bay of Islands, affords a like fact in an argillaceous sand-rock; and there was no stratification in this case to favor the production of a horizontal surface; it



THE OLD HAT.

was a direct result from the causes at work. The shore shelf stands about five feet above low water. A small island in this bay is well named the "Old Hat," the platform encircling it, as shown in the above figure, forming a broad brim to a rude conical crown. The water, in these cases, has worn away the cliffs, leaving a broad horizontal basement above the level of low tide.

According to Professor Verrill, the same feature is exhibited on a grand scale at the island of Anticosti in the Gulf of St. Lawrence, and "Old Hats" are among the forms produced. The cliff consists of limestone, and the "shore-platform" is in many places over four hundred yards wide.

A surging wave, as it comes upon a coast, gradually rears itself on the shallowing shores; finally, the waters at top, through their greater velocity, plunge with violence upon the barrier before it. The force of the ocean's surge is therefore mostly confined to the summit waters, which add weight to superior velocity, and drive violently upon whatever obstacle is presented. The *lower* waters of the surge advance steadily but more slowly, owing to the retarding friction of the bottom; the motion they have is directly forward, and thus they act with little mechanical advantage; moreover, they gradually swell over the shores, and receive, in part, the force of the *upper* waters. The wave, after breaking, sweeps up the shore till it gradually dies away. Degradation from this source is consequently most active where the upper or plunging portion of the breaker strikes.

But, further, we observe that at low-tide the sea is comparatively quiet; it is during the influx and efflux that the surges are heaviest. The action commences after the rise, is strongest from half to three-fourths tide, and then diminishes again near high tide. Moreover, the plunging part of the wave is raised considerably above the general level of the water. From these considerations, it is apparent that the line of greatest wave-action must be above low-water level. Let us suppose a tide of three feet, in which the action would probably be strongest when the tide had risen two feet out of the three; and let the height of the advancing surge be four feet: the wave, at the time of striking, would stand, with its summit, three feet above high-tide level; and from this height would plunge obliquely downward against the rock or any obstacle before it. It is obvious that, under such circumstances, the greatest force would be felt not far from the line of high tide, or between that line and three feet above it; moreover, the rise of the waters to half or two-thirds tide affords a protection against the breaker to whatever is below this level. In regions where the tide is higher than just supposed, as six feet for example, the same height of wave would give nearly the same height to the line of wave action, as compared with high-tide level. Under the influence of heavier waves, such as are common during storms, the line of wave-action would be at a still higher elevation, as may be readily estimated by the reader.

Besides a line of *greatest* wave-action, we also distinguish a height of feeble action, — so feeble that the rock remains unremoved along and below a nearly horizontal plane which is often three hundred to four hundred yards in width. The height, as is evident from the facts stated, is some distance above low-tide level. The lower waters of the tide, besides being protective, as above explained, are *accumulative* in their ordinary action, when the material exposed to them is movable; they transport shoreward, while the upper waters are eroding, and preparing material to be carried off. The height at which these two operations balance each other will be the height, therefore, of the line of least degradation. Moreover, it should vary with the height of the tides. This height, on the eastern shores of Australia, is three feet above ordinary low tide, and at New Zealand about five feet. With regard to the height varying with the tides, we observe that in the Paumotus, where the water rises but two or three feet, the platform is seldom over four to six inches above low tide, which is proportionally less than at Australia and New Zealand, where the tide is six and eight feet. From these observations it appears that the height of least *wave-action*, as regards the degradation of a coast under ordinary seas, is situated near one-fifth tide in the Paumotus, and above half-tide at New Zealand, showing a great difference between the effect of the comparatively quiet work of the middle Pacific, and the more violent of New Zealand. Within the Bay of Islands, where the sea has not its full force, the platform, as around the "Old Hat," is but little above low-water level. The exact relation of the height of the platform to the height and force of the tides, and the force of wave-action, remains to be determined more accurately by observation. While, therefore, the height of the shore platform depends on the tides, and the degree of exposure to the waves, the breadth of it will be determined by the same causes in connection with the nature of the rock material.

On basaltic shores it is not usual to find a shore platform, as the rock scarcely undergoes any degradation, except from the most violent seas; such coasts are consequently often covered and protected by large fragments of the basaltic rocks. But on sandstone shores, if the rock is not too firm to yield sensibly under the stroke of the breakers, this gradual action keeps the platform of nearly uniform breadth. Moreover, any masses torn from the edge of the platform and thrown upon it by storm waves, or the heavier earthquake waves, may be soon destroyed by the same action, and carried off; and thus the platform may be kept nearly clean of débris, even to the base of the cliff.

In the case of the coral island, the material of the coral platform is piled up by the advancing surges, and cemented through the infiltrating waters. These surges, on reaching the edge of the shelf, break upon it with more or less force during low tide and the commencing rise; but later the waters swell over it before breaking, and thus throw a protection about the exposed rocks; and as the tide continues to rise, they sweep over the shelf, but only clear it of sand and fragments, by bearing them to the beach on which they expend their force. Where the tides are five to six feet in height, the shore platform of atolls is narrow.

The isolated blocks in the Paumotus which stand on the platform, attached to it below, are generally most worn one or two feet above high-tide level, — a fact which corresponds with the statement in a preceding paragraph with regard to the height of the greatest wave-action.

III. EFFECTS OF WINDS AND GALES.

In addition to this ordinary wave-action, there are also more violent effects from storms; and these are observed alike on the Australian shores referred to, and on those of coral islands. The waters as they move in, first draw away, and then drive on with increased velocity up the shallowing shores, or under shelving layers, and thus they easily break off great rocks from the edge of the platform, and throw them on the reef. From the observations of Mr. Stevenson, cited on a preceding page (p. 229), it appears that the force of the waves during the summer and winter months differs at Skerryvore more than 1,200 pounds to the square foot. The seasons are not as unlike in the tropical part of the Pacific. But in all seas there is a marked difference and in some stormy months increase this difference. Further, the winds work with the waves, and bear the lighter part of the beach-making sands to a higher level than can be reached by the waves, giving the beach a top of wind-drift deposition as already explained. Still more violent in action are the great earthquake-waves, which move through the very depths of the ocean.

These principles offer an explanation also of the general fact that the windward reef is the highest. The ordinary seas both on the leeward and windward sides, are sufficient for producing coral débris and building up the reef, and in this work the two sides will go on together, though at different rates of progress. We may often find no very great difference in the *width* of the leeward and windward reefs, especially as the wind for some parts of the year, has a course opposite to its usual direction. But seldom, except on the side to windward, is a sufficient force brought to bear upon the edge of the platform, to detach and uplift the larger coral blocks. The distance to which the waves may roll on without becoming too much weakened for the transportation of uptorn blocks, will determine the outline of the forming land. With proper data as to the force of the waves, the tides, and the soundings around, the extent of the shore platform might be made a subject of calculation.

The effect of a windward reef in diminishing the force of the sea, is sometimes shown in the influence of one island on another. A striking instance of this is presented by the northernmost of the Gilbert Islands (see map, on page 165.) All the islands of this group are well wooded to windward—the side fronting east. But the north and northeast sides of Tari-tari are only a bare reef, through a distance of twenty miles, although the southeast reef is a continuous line of verdure. The small island of Makin, just north of Tari-tari, is the breakwater which has protected the reef referred to from the heavier seas.

Coral island accumulations have an advantage over all other shore deposits, owing to the ready agglutination of calcareous grains, as explained on a following page. It has been stated that coral sand-rocks are forming along the beaches, while the reef-rock is consolidating in the water. A defence of rock against encroachment is thus produced, and is in continual progress. Moreover, the structure built amid the waves, will necessarily have the form and condition best fitted for withstanding their action. The atoll is, therefore, more enduring than hills of harder basaltic rocks. Reefs of zoöphytic growth but "mock the leaping billows," while other lands of the same height gradually yield to the assaults of the ocean. There are cases, however, of wear from the sea, owing to some change of condition in the island, or in the currents about it, in consequence of which, parts once built up are again carried off. Moreover, those devastating earthquake-waves which overleap the whole land, may occasion unusual degradation. Yet in ordinary seas these islands have within themselves the source of their own repair, and are secure from all serious injury.

The change of the seasons is often apparent in the distribution of the beach sands covering the prominent points of an island. At Baker's Island (near the equator, in long. 176° 23′, W.), this fact is well illustrated. J. D. Hague states (*Am. Jour. Sci.*, II., xxxiv, 237), that the shifting sands change their place twice a year. "The western shore of the island trends nearly northeast and southwest; the southern shore, east-by-north. At their junction there is a spit of sand extending out toward the southwest. During the summer, the ocean swell, like the wind, comes from the southeast, to the force of which the south side of the island is exposed, while the western side is protected. In consequence, the sands of the beach that have been accumulating during the summer on the south side, are all washed around the southwest point and are heaped up on the western side, forming a plateau along the beach two or three hundred feet wide, nearly covering the shore platform, and eight or ten feet deep. With October and November comes the winter swell from the north-northeast, which sweeps along the western shore, and from the force of which the south side is in its turn protected. Then the sand begins to travel from the western to the southern side; and, after a month or two, nothing remains of the great sand plateau but a narrow strip; while on the south side, the beach has been extended two hundred or three hundred feet. This lasts until February or March, when the operation is repeated."

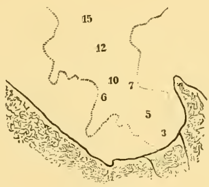
II. CAUSES MODIFYING THE FORMS AND GROWTH OF REEFS.

Coral reefs, although (1) *dependent on the configuration of the submarine lands for many of their features*, undergo various modifications of form, or condition, through the influence of extraneous causes, such as (2) *unequal exposure to the waves;* (3) *oceanic or local currents;* (4) *presence of fresh or impure waters.* In briefly treating of these topics, we may consider first, reefs around high islands, and afterward, atoll reefs. The effect of the waves on different sides of reefs has already been considered, and we pass on, therefore, at once to the influence of oceanic or local currents, and fresh or impure waters.

I. BARRIER AND FRINGING REEFS.

The *existence of harbors* about coral-bound lands, and of entrances through reefs, is largely attributable to the action of tidal or local marine currents. The presence of fresh-water streams has some effect toward the same end, but much less than has been supposed. These causes are recognized by Mr. Darwin in nearly the same manner as here: yet the views presented may be taken as those of an independent witness, as they were written out before the publication of his work.

There are usually strong tidal currents through the reef channels and openings. These currents are modified in character by the outline of the coast, and are strongest wherever there are coves or bays to receive the advancing tides. The harbor of Apia, on the north side of Upolu, affords a striking illustration of this general principle. The coast at this place



HARBOR OF APIA, UPOLU.

has an indentation 2,000 yards wide and nearly 1,000 deep, as in the accompanying sketch, reduced from the chart by the Expedition. The reef extends from either side, or cape, a mile out to sea, leaving between an entrance for ships. The harbor averages ten feet in depth, and at the entrance is fifteen feet. In this harbor there is a remarkable out-current along the bottom, which, during gales, is so strong at certain states of the tide that a ship at anchor, although a wind may be blowing directly in the harbor, will often ride with a slack cable; and in more moderate weather the vessel may tail out *against* the wind. Thus when no current but one inward is perceived at the surface, there is an undercurrent acting against the keel and bottom of the vessel, which is of sufficient strength to counteract the influence of the winds on the rigging and hull. The cause of such a current is obvious. The sea is constantly pouring water over the reefs into the harbor, and the tides are periodically adding to the accumulation; the indented shores form a narrowing space where these waters tend to pile up: escape consequently takes place along the bottom by the harbor-entrance, this being the only means of exit. There are many such cases about all the islands. In a group like the Feejees, where a number of the islands are large and the reefs very extensive, the currents are still more remarkable, and they change in direction with the tides. "Through the channels and among the inner reefs of the Australian reef-region," says Jukes, "they run sometimes with an impetuous sweep in the same direction even for two or three days together, especially after great storms have driven large quantities of water into the space between the outer edge and the land."

A current of the kind here represented will carry out much coral débris, and strew it along its course. The transported material will vary in amount from time to time, according to the force and direction of the current. It is therefore evident that the ground over which it runs must be wholly unfit for the growth of coral, since most zoöphytes are readily destroyed by depositions of earth or sand, and require, for most species, a firm basement. Or if the flow is very strong, it will scour out the channels and so keep them open. The existence of an opening through a reef may require, therefore, no other explanation; and it is obvious that harbors may generally be expected to exist wherever the character of the coast is such as to produce currents and give a fixed direction to them.

The currents, about the reef grounds west of the large Feejee Islands, aid in distributing the débris both of the land and the reefs. In some parts, the currents eddy and deposit their detritus; in others they sweep the bottom clean. Thus, under these varying conditions, there may be growing corals over the bottom in some places and not in others; and the reefs may be distributed in patches, when without such an influence we might expect a general continuity of coral reef over the whole reef-grounds.

The results from marine currents are often increased by waters from the island streams; for the coves, where harbors are most likely to be found, are also the embouchures of valleys and the streamlets they contain. The fresh waters poured in add to the amount of water, and increase the rapidity of the out-current. At Apia, Upolu, there is a stream thirty yards wide; and many other similar instances might be mentioned. These waters from the land bring down also much detritus, especially during freshets, and the depositions aid those from marine currents in keeping the bottom clear of growing coral. These are the principal means by which fresh-water streams contribute toward determining the existence of harbors; for little is due to their freshening the salt waters of the sea.

The small influence of the last-mentioned cause—the one most commonly appealed to—will be obvious, when we consider the size of the streams of the Pacific islands, and the fact that fresh water is lighter than salt, and therefore, instead of sinking, flows on over its surface. The deepest rivers are seldom over six feet, even at their mouths; and three or four feet is a more usual depth. They will have little effect, therefore, on the sea water beneath this depth, for they cannot sink below it; and corals may consequently grow even in front of a river's mouth.

Fresh-water streams, acting in all the different modes pointed out, are of little importance in harbor-making about the islands of the Pacific. The harbors, with scarcely an exception, would have existed without them. They tend, however, by the detritus which they deposit, to keep the bottom more free from growing patches of coral, and keep channels over the shore reef sufficiently deep and wide for a boat to reach the land.

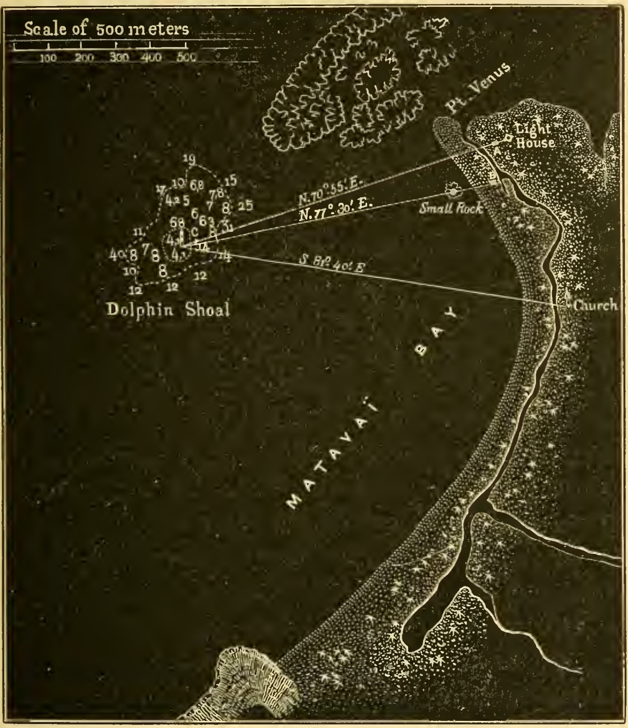
The map of the reef of North Tahiti, on page 149, and the following map of Matavai Bay on a larger scale, afford illustrations of this subject.

a. The harbor of Papieti is enclosed by a reef about three fourths of a mile from the shore. The entrance through the reef is narrow, with a depth of eleven fathoms at centre, six to seven fathoms either side, and three to five close to the reef. This fine harbor receives an unimportant streamlet, while a much larger stream empties just to the east of the east cape, *opposite which the reef is close at hand and unbroken.*

b. Toanoa is the harbor next east of Papieti. The entrance is thirty-five fathoms deep at middle, and three and a half to five fathoms near the points of the reef. There is no fresh-water stream, except a trifling rivulet.

c. Papaoa is an open expanse of water, harbor-like in character, but without any entrance; the reef is unbroken. Yet two streams empty into it.

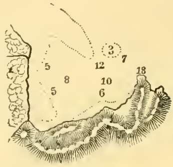
d. Off Matavai, the place next east, the reef is interrupted for about two miles. The harbor is formed by an extension of the reef off Point Venus, the east cape. There is no stream on the coast opposite this interruption in the reef, except toward Point Venus; and at the present time the waters find their principal exit east of the Point, behind a large coral reef, a quarter of a mile distant.



PART OF NORTH SHORE OF TAHITI.

It is evident that the growth of coral reefs is not much retarded about Tahiti by fresh-water streams. In fact none of these so-called rivers are over three feet in depth; and the most they can do is to produce a thin layer of brackish water over the sea within the channels.

e. The following figure of the harbor of Falifa, Upolu, represents another coral harbor, as surveyed by Lieutenant Emmons. At its head there is a stream twenty-five or thirty yards wide and three feet deep. Notwithstanding the unusual size of the river, the coral reef lies near its mouth, and projects some distance in front of it. Its surface is dead, but corals are growing upon its outer slope.



HARBOR OF FALIFA.

f. The harbor of Rewa, in the Feejees, may be again alluded to. The waters received by the bay amount to at least 500,000 cubic feet a minute. Yet there is an extensive reef enclosing the bay, lying but three miles from the shores, and with only two narrow openings for ships. The case is so remarkable that we can hardly account for the facts without supposing the river's mouth to have neared the reef by depositions of detritus since the inner parts of the reef were formed ; and there is some evidence that this was the case, though to what distance we cannot definitely state. With this admission, the facts may still surprise us ; yet they are explained on the principle that fresh water does not sink in the ocean, but is superficial, and runs on in a distinct channel ; its effect is almost wholly through hydrostatic pressure, increasing the force of the underwater currents, and through their depositions of detritus Besides these instances, there are many others in the Feejees, as will be observed on the chart at the end of this volume. Mokungai has a large harbor, without a stream of fresh water ;—so also Vakea and Direction Island.

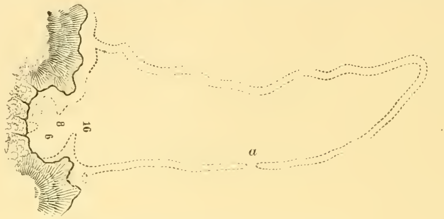
The instances brought forward are a fair example of what is to be found throughout coral seas; and they establish, beyond dispute, that while much in harbor-making should be attributed to the transported sand or earth of marine and fresh-water currents, in preventing the growth of coral, but little is due to the freshening influence of the streams of islands.

But while observing that currents have so decided an influence on the condition of harbors, we should remember another prevalent cause already remarked upon, which is perhaps more wide in its effects than those just considered. I refer to the features of the supporting land, or the character of soundings off a coast. We need not repeat here the facts, showing that many of the interruptions of reefs have thus arisen. The wide break off Matavai may be of this kind. The widening of the inner channel at Papieti, forming a space for a harbor, may be another example of it; for the reef here extends to a greater distance from the shores, as if because the waters shallowed outward more gradually off this part of the coast.

The same cause—the depth of soundings, on the principle that corals do not grow where the depth much exceeds a hundred feet—has more or less influence about all reefs in determining their configuration and the outlines of harbors. A remarkable instance of the latter is exemplified in the annexed chart of Whippey harbor, Viti Levu, reduced from the chart of the Wilkes Expedition to the scale of half an inch to the mile.

The existence of harbors should therefore be attributed, to a great extent, to the configuration of the submarine land; while currents give aid in preventing the closing of channels, and keeping open grounds for anchorage. This subject will be further illustrated in the following pages.

The permanency of coral harbors follows directly from the facts above presented They are secure against any immediate obstruction from reefs. Any growing patches within them may still grow, and the margins of the enclosing reef may gradually extend and contract their limits; yet only at an extremely slow rate. Notwithstanding such changes, the channels will remain open, and large anchorage grounds clear, as



WHIPPEY HARBOR, VITI LEVU.

long as the currents continue in action. Coral harbors are therefore nearly as secure from any new obstructions as those of our continents. The growing of a reef in an adjoining part of the coast, may in some instances diminish or alter the currents, and thus prepare the way for more important changes in the harbor; but such effects need seldom be feared, and results from them would be appreciable only after long periods, since, even in the most favorable circumstances, the growth of reefs is very slow.

When channels have a bottom of growing coral, they form an exception to the above remark; for since the coral is acted upon by no cause sufficient to prevent its growth, the reef will continue to rise slowly toward the surface.

Again, when the channels are over twenty-five fathoms in depth, they have an additional security beyond that from currents, in the fact that reef-making corals rarely grow at such a depth. The only possible way in which such channels could close, without first filling up by means of shore material, would be by the extension of the reefs from either side, till they bridge over the bottom below. But such an event is not likely to happen in any but narrow channels.

In recapitulation, the existence of passages through reefs, and the character of the coral harbors, may be attributed to the following causes:

1. The configuration and character of the submarine land;—corals not growing where the depth exceeds certain limits, or where there is no firm rocky basement for the plantation.

2. The direction and force of marine currents, with their transported detritus;—these currents having their course largely modified, if not determined, as in other regions, by the features of the land, the form of the sea-bottom, and the positions of the reefs, and being sometimes increased in force by the contributions of island streams, which add to the detritus and to the weight of accumulating waters.

3. Harbors which receive fresh-water streams, or submarine springs of fresh-water, are more apt to be clear from sunken patches; and the same causes keep open shallow passages to the shores, where there are shore reefs.

It should be remembered, that while the effects from fresh-water streams are so trifling around islands, they may be of very wide influence on the shores of the continents where the streams are large and deep, and transport much detritus. This point is illustrated beyond.

II. ATOLL REEFS.

The remarks on the preceding pages, respecting reefs around other lands, apply equally to atoll reefs. There are usually currents flowing to leeward through the lagoon, and out, over or through the leeward reef, the waves with the rising tide dashing over the windward side, and keeping up a large supply, which is greatly increased in times of storms; and this action tends to keep open a leeward channel for the passage of the water. This is the common explanation of the origin of the channels opening into lagoons. These currents are strongest when a large part of the windward reef is low, so as to permit the waves to break over it; and the coral débris they bear along will then be greatest. When a large part of the leeward reef is under water, or barely at the water's edge, the waters may escape over the whole, and on this account large reefs sometimes have no proper channels. When the land to windward becomes raised throughout above the sea, so as to form a continuous barrier which the waves cannot pass, the current is less perfectly sustained, since it is then dependent entirely upon the influx and efflux of the tides; and the leeward channels, in such a case, may gradually become closed.

The action of currents on atolls is, therefore, in every way identical with what has been explained. The absence of coves of land to give force to the waters of currents, and to direct their course, and the absence also of fresh-water streams, are the only modifying causes not present. It is readily understood, therefore, why lagoon entrances are more likely to become filled up by growing coral than the passages through barrier reefs.

Although atolls in seas of moderate tides have the stability stated on page 237, yet in those having tides of six feet or over and subject to the sweep of cyclones, they may find it difficult to stand their ground and repair losses above mean tide. But the larger reef islands may be increased in height by the more powerful agencies, as is well exemplified in the Bermuda Islands and the Bahamas.

III. RATE OF GROWTH OF REEFS.

The formation of a reef has been shown to be a very different process from the growth of a zoöphyte. Its rate of progress is a question to be settled by a consideration of many distinct causes, none of which have yet been properly measured.

a. The rapidity of the growth of zoöphytes is an element in this question of great importance, and one that should be determined by direct observation with respect to each of the species which contribute largely to reefs, both in the warmer and colder parts of coral-reef seas.

b. The character of the coral plantation under consideration should be carefully studied; for it is of the greatest consequence to know whether the clusters of zoöphytes are scattered tufts over a barren plain, or whether in crowded profusion. Compare the débris of vegetation on the semi-deserts of California with that of regions buried in foliage; equally various may be the rate of growth of coral rock in different places. An allowance should also be made for the shells and other reef relics. The amount of reef-rock formed in a given time cannot exceed, in cubic feet, the aggregate of corals and shells added by growth—that is, if there are no additions from other distant or neighboring plantations.

c. It is also necessary to examine all conditions that are connected with, or can influence, the marine or tidal currents of the region—their strength, velocity, direction, where they eddy, and where not, whether they flow over reefs that may afford débris or not. All the débris of one plantation may sometimes be swept away by currents to contribute to other patches, so that one will enlarge at the expense of others. Or, currents may carry the detritus into the channels or deeper waters around a coral patch, and leave little to aid the plantation itself in its increase and consolidation.

d. The course and extent of fresh waters from the land, and their detritus, should be ascertained.

e. The strength and height of the tides, and general force of the ocean waves, will have some influence.

Owing to the action of these causes, barrier reefs enlarge and extend more rapidly than inner reefs. The former have the full action of the sea to aid them, and are farther removed from the deleterious influences which may affect the latter.

No results with reference to this question of the rate of progress in reefs were arrived at by the author in the course of his observations in the Pacific. The general opinion, that their progress is exceedingly slow, was fully sustained. The facts with regard to the growth of zoöphytes, give some data.

Allowing that the large Madrepora of the wreck, mentioned on page 126, may grow three inches in height a year, and other Madrepores probably three to four inches, it is still not easy to deduce from it the rate of increase of the reef. In the first place, the whole Madrepore is growing over the sides of its branches, at the rate, if we may judge from the size of the trunk at base, of a tenth of an inch a year, thus increasing annually the diameter a fifth of an inch a year, which, in a large species, is a very great addition to the three inches per year at the extremities of the branches. Again, the branches of the large Madrepore of the wreck were widely spaced, those of *M. cervicornis*, having intervals of from six to eighteen inches or more between the branches.

In fact it is impossible to make any exact estimate of the amount of increase without a knowledge of the weight of the part annually added. This ascertained, it would be easy to calculate how much the added coral would, if ground up, raise the area that is covered by the Madrepora. A rough estimate gives the author an average increase to this surface of a fourth of an inch a year. But this fourth must be much reduced, if we would deduce the rate of growth of the reef; because a large part of the reef-grounds—that is, of the region of soundings receiving the coral débris—is bare of growing corals. This is the case with much the larger portion of all lagoons and channels among reefs, the bottoms of which, as already explained, are often sandy or muddy, and to a great extent so because too deep for living corals; and it is true even of the coral plantations, these including many and large barren areas. These unproductive portions of reef-grounds constitute ordinarily at least two-thirds of the whole; and making this allowance, the estimate of one-fourth of an inch a year would become one-twelfth of an inch.

Again, shells add considerably to the amount of calcareous material, perhaps one-sixth as much as the corals; but against this we may set off the porosity of the coral.

The rate of growth of the *Mæandrina clivosa*, stated on page 125, would make the rate of increase in the reef very much less rapid. The specimen—the growth of fourteen years—weighs 24 oz. avoirdupois, and has an average diameter of 7 inches. This gives for the amount of calcareous material —the specific gravity being 2·523 (p. 99)—16·45 cubic inches; which is sufficient to raise a surface seven inches in diameter to a height of 0·428 inch; and consequently the average *yearly* increase would be about 1-33d of an inch. Allowing for two-thirds of the reef-ground being unproductive in corals, the rate of increase for the whole would become 1-100th of an inch. But supposing that shells add one-fourth as much as the corals to the reef material, the rate of increase would become about 1-80th of an inch per year.

The specimen of *Oculina diffusa*, referred to on page 125, weighs 44 ounces, which is five-sixths more than that of the Mæandrina, while the average diameter of the clump is the same. The average annual increase would consequently cover a circular area of seven inches diameter 1-18th of an inch deep. And making the same allowances as above, the rate for the year for the whole reef-grounds would be 1-44th of an inch. The specimen of Mæandrina mentioned by Major Hunt, is not here made the basis of a calculation, because we have not the specimen for examination, and it is not certain that the diameter stated by him was not the horizontal diameter. For other facts see the Appendix.

These estimates from the *Mæandrina clivosa* and *Oculina diffusa* have this great source of uncertainty, that the growth of the groups may not have been begun in the first year of the fourteen. Further, the corals obtained by Major Hunt near Fort Taylor, Key West, may not have been as favorably situated for growth as those of the outer margin of the reef. Again, we have made no allowance for the carbonate of lime that is supplied by the waters by way of cement, supposing that this must come originally, for the most part, from the reef itself. Besides, we have supposed, above, all the coral reef-rock to be solid, free from open spaces; and, further, it is not considered that much of it is a coral conglomerate, in which the fragments have their original porosity.

On the other side, we have not allowed for loss of débris from the reef-grounds by transportation into the deep seas adjoining, believing the amount to be very small.

Whatever the uncertainties, it is evident that a reef increases its height or extent with extreme slowness. If the rate of upward progress is one-sixteenth of an inch a year, it would take for an addition of a single foot to its height, one hundred and ninety years, and for *five feet a thousand years.*

It is here to be considered, that the thickness of a growing reef could not exceed twenty fathoms (except by the few feet added through beach and wind-drift accumulations), even if existing for hundreds of thousands of years, unless there were at the same time a slowly progressing subsidence; so that if we know the possible rate of increase in a reef, we cannot infer from it the actual rate for any particular reef; for it may have been very much slower than that. Without a subsidence in progress, the reef would increase only its breadth.

In order to obtain direct observations on the rate of increase of reefs, a slab of rock was planted, by the order of Captain Wilkes, on Point Venus, Tahiti, and by soundings, the depth of Dolphin shoal, below the level of this slab, was carefully ascertained. By adopting this precaution, any error from change of level in the island was guarded against. The slab remains as a stationary mark for future voyagers to test the rate of increase of the shoal. Before, however, the results can be of any general value toward determining the average rate of growing reefs, it is still necessary that the growing condition of the reef should be ascertained, the species of corals upon it be identified, and the influence of the currents investigated which sweep in that direction out of Matavai Bay. See the map, page 247, and Appendix, page 417.

The depth to which the shells of Tridacnas lie imbedded in coral rock, has been supposed to afford some data for estimating the growth of reefs. But Mr. Darwin rightly argues that these mollusks have the power of sinking themselves in the rock, as they grow, by removing the lime about them. They occur in the dead rock,—generally where there are no growing corals, except rarely some small tufts. If they indicate any thing, it must be the growth of the reef-rock, and not of the corals themselves. But the shore-platform where they are found is not increasing in height; its elevation above low-tide being determined, as has been shown, by wave action (page 232). They resemble, in fact, other saxicavous mollusks, several species of which are found in the same seas, some buried in the solid masses of dead coral lying on the reef. The bed they excavate for themselves is usually so complete that only an inch or two in breadth of their ponderous shells are exposed to view. Without some means like this of securing their habitations, these mollusks would be destroyed by the waves; a tuft of byssus, however strong, which answers for some small bivalves, would be an imperfect security against the force of the sea for shells weighing one to five hundred pounds.

IV. ORIGIN OF THE BARRIER CONDITION OF REEFS, AND OF THE ATOLL FORMS OF CORAL ISLANDS.

I. OLD VIEWS.

In the review of causes modifying the forms of reefs, no reason is assigned for the most peculiar, we may say the most surprising, of all their features,—that they so frequently take a belt-like form, and enclose a wide lagoon; or, in other cases, range along, at a distance of some miles, it may be, from the land they protect, with a deep sea separating them from the shores.

This peculiar character of the coral island was naturally the wonder of early voyagers, and the source of many speculations. The instinct of the polyp was made by some the subject of special admiration; for the "helpless animacules" were supposed to have selected the very form best calculated to withstand the violence of the waves, and apparently with direct reference to the mighty forces which were to attack the rising battlements. They had thrown up a breastwork as a shelter to an extensive working ground under its lee, "where," as Flinders observes, "their infant colonies might be safely sent forth."

It has been a more popular theory that the coral structures were built upon the summits of volcanoes;—that the crater of the volcano corresponded to the lagoon, and the rim to the belt of land; that the entrance to the lagoon was over a break in the crater, a common result of an eruption. This view was apparently supported by the volcanic character of the high islands in the same seas. But since a more satisfactory explanation has been offered by Mr. Darwin, numerous objections to this hypothesis have become apparent, such as the following:

a. The volcanic cones must either have been subaerial and then have afterward sunk beneath the waters, or else they were submarine from the first. In the former case the crater would have been destroyed, with rare exceptions, during the subsidence; and in the latter there is reason to believe that a distinct crater would seldom, if ever, be formed.

b. The hypothesis, moreover, requires that the ocean's bed should have been thickly planted with craters—seventy in a single archipelago,—and that they should have been of nearly the same elevation; for if more than twenty fathoms below the surface, corals could not grow upon them. But no records warrant the supposition that such a volcanic area ever existed. The volcanoes of the Andes differ from one to ten thousand feet in altitude, and scarcely two cones throughout the world are as nearly of the same height as here supposed. Mount

Loa and Mount Kea, of Hawaii, present a remarkable instance of approximation, as they differ but two hundred feet; but the two sides of the crater of Mount Loa differ three hundred and fourteen feet in height. Mount Kea, though of volcanic character, has no large crater at top. Hualalai, the third mountain of Hawaii, is 5,440 feet lower than Mount Loa. The volcanic summit of East Maui is 10,000 feet high, and contains a large crater; but the wall of the crater on one side is 700 feet lower than the highest point of the mountain; and the bottom of the crater is 2,000 feet below the rim of the crater. Similar facts are presented by all volcanic regions.

c. It further requires that there should be craters over fifty miles in diameter, and that twenty and thirty miles should be a common size. Facts give no support to such an assumption.

d. It supposes that the high islands of the Pacific, in the vicinity of the coral islands, abound in craters; while, on the contrary, there are none, so far as is known, in the Marquesas, Gambier, or Society Group, the three which lie nearest to the Paumotus. Even this supposition fails, therefore, of giving plausibility to the crater hypothesis.

Thus at variance with facts, the theory has lost favor, and it is now seldom urged.

The question still recurs with regard to the basement of coral islands, and the origin of their lagoon character.

DARWIN'S THEORY OF THE ORIGIN OF BARRIER REEFS AND ATOLLS.

Mr. Darwin, in his voyage around the world as naturalist of the expedition of the "Beagle," under Captain Fitzroy, R. N., during the years 1832 to 1836, visited and investigated the Keeling atoll in the Indian Ocean, and the barrier and fringing reefs of Tahiti. With the facts thus gathered, he had a key to all descriptions and maps of the reefs and reef islands of the oceans, and through careful study of the resources at hand, he arrived at a comprehensive knowledge of the facts and a theory of their origin.[1] The voyage of the author in 1838 to 1842 brought the subject to his attention, and afforded him abundant illustrations of all sides of the subject and elucidations of some points which had been deemed obscure; and he believes that the collected facts place the theory on a firm basis of evidence.[2]

Darwin's theory is this: that a fringing reef skirting an ordinary island becomes changed by means of a slow subsidence and the compensating upward growth of the corals into a barrier reef; and that the barrier reef, by the continuation of the sinking until the old island has disappeared, and by the same process of growth, becomes finally an atoll.

[1] The third edition of Darwin's work, issued in 1889, contains a valuable appendix by Prof. T. G. Bonney, giving a full review of the new contributions to the subject of coral reefs, and his own views confirmatory of those of Darwin.

[2] The author, besides working among the reefs of Tahiti, the Samoan (or Navigator) Islands, and the Feejees (at this last group staying three months), was also twice at the Hawaiian Islands. In addition, he landed on and gathered facts from fifteen coral islands, — seven of these in the Paumotu Archipelago; one, Tongatabu, in the Friendly Group; two, Taputeuea and Apia, in the Gilbert Group; and five others near the equator, east of the Gilbert Group, Swain's, Fakaafo, Oatafu (Duke of York's), Hull, and Enderbury's Island.

In sustaining the theory, the fact of the subsidence requires proof, and secondly, its sufficiency for the result claimed.

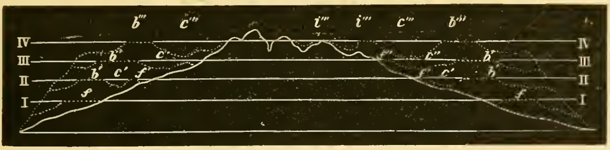
Darwin gives as evidence of the subsidence the near identity of barrier-girt islands and atolls. He compares the two, points out the fact that a slight change in the former by submergence is all that is required to convert it into an atoll, and enforces the argument by pointing to transitions between the two states.

The facts from the Feejee Archipelago illustrate the subject well. On the map, Plate XII., let the reader glance successively at the islands Goro, Angau, Nairai, Lakemba. Argo Reef, Exploring Isles, and Nanuku. It will be observed that in Goro the reef closely encircles the land upon whose submarine shores it was built up. In the island next mentioned, the reef has the same character, but is more distant from the shores, forming what has been termed a barrier reef; the name implying a difference in position, but none in mode of formation. In the last of the islands enumerated, the barrier reef includes a large sea, and the island it encloses is but a rocky peak within this sea.

If, now, the island Angau were sinking slowly, at a rate not more rapid than that of the upward growth of the reef, there would be a gradual disappearance of the land beneath the waters, while the reef might keep its level unchanged. Should the sinking go on until the land had mostly gone, the condition would be like that of the Exploring Isles, in which only a single ridge and a few isolated summits stand above the waters; and, at a stage beyond when only a single peak was left, the reef-girt island would have become a Nanuku. The subsidence of Goro, on the same principle, would produce an Angau.


CHART
OF THE
VITI GROUP
OR
FEEJEE ISLANDS
BY THE
U. S. Ex. Ex.
1840
179 Long. East of Greenwich
Chicobea I.
Korotuma I.
Nukulevu
Vanua Levu
Nateva Bay
Kambe I.
Vuna I.
Ringgold Isles
Round Island Passage
Within this Reef sunken coral patches
Yadua
Ruku Ruku Bay
Vitilevu
Goro I.
Sea of Goro
Nanuku Passage
Lakemba I.
Lakemba Passage
Oneata Passage or Channel
Moala I.
Totoia I.
Matuku I.
Kantavu I.
Mbenga I.
Vatu Leile I.
Angau I.
Nairai I.
Wakaia I.
Ovolau I.
Mokungai I.
Mango I.
Vanua Valavo I.
Exploring Isles
Tabutha I.
Chichia I.
Naitamba I.
Mali I.
Passed Midshipmans

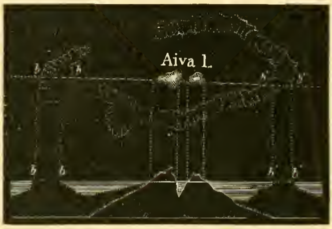
The steps in the process are illustrated in the following sections of an island and its reefs. If the water-level be at I, the island enclosed would be, like Goro, one with a simple, fringing reef *f*, *f*. Suppose a submergence to have gone on until II is the water line: — the reef growing upward may then have the surface represented by $b' f'$, $b' f'$. There is here a fringing reef (f'), and also a barrier reef (b'), with a narrow channel (c') between, such as exists on the shores of Tahiti (p. 149). Suppose a further submergence, till III is the water line: then the channel ($c'' c''$), within the barrier has become quite broad, as in the island of Nairai or Angau;



SECTION ILLUSTRATING THE ORIGIN OF BARRIER REEFS.

on one side (f''') the fringing reef remains, but on the other it has disappeared, owing, perhaps, to some change of circumstance as regards currents which retarded its growth and prevented its keeping pace with the subsidence. With the water at IV, there are two islets of rock in a wide lagoon, along with other islets ($i''' i'''$) of reef over two peaks which have disappeared. $b''' b'''$ are sections of the distant enclosing barrier, and $c''' c'''$, and other intermediate spots, of the water within. The coral reef-rock by gradual growth has attained a great thickness, and envelops nearly the whole of the former land. Nanuku, the Argo Reef, and Exploring Isles are here exemplified; for the view is a good transverse section of either of them.

The supposed similarity between these ideal sections and existing islands is fully sustained by actual comparison. The figure beyond is a map of the island of Aiva, in the Feejee Group. There are two peaks in the lagoon, precisely as above; and although we have no soundings of the waters in and about it, nor sketches of peaks, facts observed elsewhere authorize in every essential point the transverse section here given, which resembles closely, as is apparent, the preceding. The section is made through the line *b b*, *b′ b′*, of the map. It is unnecessary to add other illustrations. They may be made



MAP AND IDEAL SECTION OF AIVA ISLAND.

out from any of the eastern groups of the Feejees, the Gambier Group of the Paumotus, or Hogoleu in the Carolines.

It has been urged against the theory, that the process appealed to ought to fill the channels inside as the island sinks, and thus a plane of coral result, instead of an outside barrier reef and narrow belts within.

But the facts prove that the existence of inner passages is a necessary feature of such islands. It has been shown that the ocean acts an important part in reef-making, that the outer reefs, exposed to its action and to its pure waters, grow more rapidly than those within, which are under the influence of marine and fresh-water currents and transported detritus. It is obvious, therefore, that the former may retain themselves at the surface, when through a too rapid subsidence the inner patches would disappear. Moreover, after the barrier is once begun, it has growing corals on both its inner and outer margins, while a fringing reef grows only on one margin. Again, the detritus of the outer reefs is, to a great extent, thrown back upon itself by the sea without and the currents within, while the inner reefs contribute a large proportion of their material to the wide channels between them. These channels, it is true, are filled in part from the outer reefs, but proportionally less from them than from the inner. The extent of reef-grounds within a barrier, raised by accumulations at the same time with the reefs, is often fifty times greater than the area of the barrier itself. Owing to these causes, the rate of growth of the barrier may be at least twice more rapid than that of the inner reefs. If the barrier increases one foot in height in a century, the inner reef, according to this supposition, would increase but half a foot; and any rate of subsidence between the two mentioned, would sink the inner reefs more rapidly than they could grow, and cause them to disappear. There is therefore no objection to the theory from the existence of wide channels and open seas; on the contrary, they afford an argument in its favor.

From these remarks on the channels and seas within barrier reefs, we pass to an illustration of the origin of an atoll. The inference has probably been already made by the reader, that the same subsidence which has produced the distant barrier, if continued a step farther, would produce the lagoon island. Nanuku is actually a lagoon island, with a single mountain peak still visible; and Nuku Levu, north of it, is a lagoon island, with the last peak submerged. The Gambier group, near the Paumotus, appears to have afforded an early hint with regard to the origin of the atoll, or at least the close relations of the two. Captain Beechey, in his "Voyage in the Pacific," implies this resemblance, when he says of the Gambier group, which he surveyed, "It consists of five large islands and several small ones. *all situated in a*

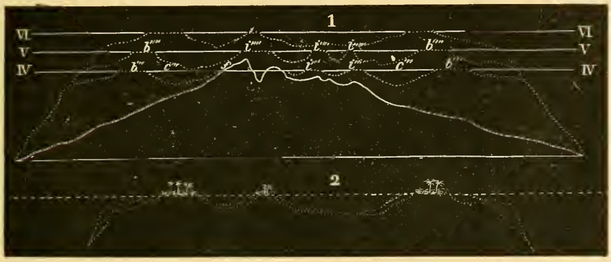
GAMBIER ISLANDS.

lagoon, formed by a reef of coral." Balbi, the geographer, as Mr. Darwin remarks, describes those barrier reefs which encircle islands of moderate size, by calling them atolls with high lands rising from their central expanse.

The manner in which a further subsidence results in producing the atoll is illustrated in the following figures. Viewing V as the water line, the land is entirely submerged; the barrier (b''' b''') then encloses a broad area of waters, or a *lagoon*, with a few island patches of reef over the peaks of the mountains. A continuation of the subsidence would probably sink beneath the waters some of the islets, because of their increasing in height less rapidly than the barrier; and this condition is represented along the upper line of the above Figure VI, subsidence having taken place to that level. The lagoon has all the characters of those of atoll reefs.

Should subsidence now diminish greatly or cease, the reefs, no longer increasing in height, would go on to widen, and the accumulations produced by the sea would commence the formation of dry land, as exhibited in figure 2. Verdure may soon after appear, and the coral island will finally be completed.

All the features of atolls harmonize completely with this view of their origin. In form they are as various and irregular as the outlines of barrier reefs. Compare Angau of the Feejees, with Tari-tari of the Gilbert Group (p. 165); Nairai or Moala with Tarawa; Nanuku with Maiana or Apamama.



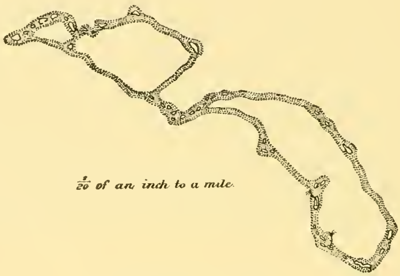
SECTION ILLUSTRATING THE ORIGIN OF ATOLLS.

The resemblance is close. In the same manner we find the many forms of lagoon reefs represented among barrier reefs.

We observe, also, that the configurations are such as would be derived from land of various shapes of outline, whether a narrow mountain ridge (as in Taputeuea, one of the Gilbert Islands), or wide areas of irregular slopes and mountain ranges. Among the groups of high islands, we observe that abrupt shores may occasion the absence of a reef on one side, as on Moala; and a like interruption is found among coral islands. Many of the passages through the reefs may be thus accounted for.

The fact that the submerged reef is often much prolonged from the capes or points of a coral island, accords well with these views. These points or capes correspond to points in the original land, and often to the line of the prominent ridge; and it is well known that such ridge lines often extend a long distance to sea, with slight inclination compared with the slopes or declivities bounding the ridge on either side.

The derivation of the forms of reef islands from a former mountain range is further sustained, according to Darwin, by the occurrence of coral islands or reefs in chains, like the peaks



MENCHICOFF ATOLL.

of such a range. He gives as an example Menchicoff atoll, of the Caroline Archipelago, which consists of three long loops or lagoon islands, united by their extremities, and which further subsidence might reduce to three islands.

Darwin, in his account of the Maldives, points out indications of a breaking up of a large atoll into several smaller atolls. The land with many summits or ranges of heights may at first have had its single enclosing reef; but as it subsided, this reef, contracting upon itself, may have encircled separately the several ranges of which the island consisted.

and thus several atoll reefs may have resulted in place of the large one; and, further, each peak may have finally become the basis of a separate lagoon island, under a certain rate of subsidence or variations in it, provided the outer reef were so broken as to admit the influence of waves and winds. Some of the large atolls of the Maldives are properly atoll archipelagoes.

The sizes of atolls offer no objection to these views, as they do not exceed those of many barrier reefs.

All the conditions from fringing to barrier and from the barrier island to the atoll are admirably illustrated in the Louisiade Archipelago, Plate VII. The small amount of included high land within the enormous barrier, the linear form of the high islands, and the many islets which continue the line westward, the appendage-like relation to the large barrier-island of the islands at its northeast and northwest ends, look as if all the pieces of high land were parts of a nine-tenths-buried mountain-chain; and so much like it that any other supposition is evidently unreasonable.

According to the principles explained and the facts illustrating them, an atoll that is wooded through the larger part of its circuit, especially if not below medium size, bears evidence in this fact that the subsidence through which it was formed has probably ceased; and on the contrary that atolls which are wholly or mostly covered with the sea at high tide, with few islets above high-water mark, are still undergoing subsidence. On this principle we may infer that the larger part of the Paumotus have passed to a period of cessation of subsidence, and that Keeling atoll in the Indian Ocean is of like character. Many of the northern Carolines, on the contrary, may be still subsiding.

It is of interest to follow still further the subsidence of a coral island, the earlier steps in which are illustrated in the preceding figures.

It is to be noted in this connection that if an atoll-reef is not undergoing subsidence the coral and shell material produced that is not lost by currents serves: (1) to widen the reef; (2) to steepen, as a consequence of the widening, the upper part of the submarine slopes: (3) to accumulate, on the reef, material for beaches and dry land; and (4) to fill the lagoon. In regions of barrier reefs the inner channel may be a large receiver, like the lagoon of the atoll. But if, while subsidence is in progress, the contributions from corals and shells exceed not greatly or feebly the loss by subsidence and current waste, the atoll-reef, unable to supply sufficient debris to raise the reef above tide-level by making beaches and dry-land accumulations, would (1) remain mostly a bare tide-washed reef; (2) lose in diameter or size because the debris that is not used to keep the reef at tide-level is carried over the narrow reef to the lagoon by the waves whose throw on all sides is shoreward; (3) lose in irregularity of outline and thus approximate toward an annular form; (4) lose the channels through the reef into the lagoon by the growth of corals and by consolidating debris; and (5) become at last a small bank of reef-rock with a half obliterated lagoon-basin. Some of the islands of the equatorial Pacific in this last condition are described on page 198.

Moreover, the subsidence, if more rapid than the increase of the coral reef, would become fatal to the atoll, by gradually sinking it beneath the sea. Such a fate, as stated by Darwin, has actually befallen several atoll-formed reefs of the Chagos Group, in the Indian Ocean (p. 192); one of them has only "two or three very small pieces of living reef rising to the surface." Darwin calls such reefs *dead reefs*.

The southern Maldives have deeper lagoons than the northern, fifty or sixty fathoms being found in them. This fact indicates that subsidence was probably most extensive to the south, and perhaps also most rapid. The sinking of the Chagos Bank, which lies farther to the south in nearly the same line, may therefore have had some connection with the subsidence of the Maldives. Other drowned atoll reefs, of similar character, exist in the China Sea and to the north of Madagascar.

The submerged Macclesfield Bank, and the Tizard Bank five degrees farther south, have been described by W. J. L. Wharton [1] and Captain Aldrich.[2] The Tizard Bank is 10 miles broad, has depths of 30 to 47 fathoms in the lagoon part, and 4 to 10 fathoms over the border on which alone are growing corals; but the border extends to the surface in eight places and at three of them are islets. The Macclesfield Bank is 70 by 40 miles in area; it is like the Tizard, but lies deeper, the lagoon in places being 40 to 60 fathoms under water and the margin 4 to 10 fathoms. The Saya de Malha Bank, east of northern Madagascar, measures two degrees across, has depths of 60 to 70 fathoms within the lagoon part, and a border on the north and northeast sides at a depth of 10 to 17 fathoms, a portion of which comes within 8 to 9 fathoms of the surface. Darwin remarks on its close resemblance to reefs of the Chagos Bank. To the south is the submerged Nazareth Bank, and Cargados Carajos at the south end of a reef region common to the two; and to the northeast, the Seychelles, of great area. The Seychelles have some granite islands near the centre, but constitute otherwise a great submerged bank; on the western border are shoals 3 to 7 fath-

[1] Nature, 1888, Feb. 23.
[2] Bulletin of Hydrographic Department, London, for February, 1889.

oms under water more or less covered with growing corals. The seas about these sunken reefs of the Indian Ocean are 2,000 to 2,600 fathoms in depth. Nearer to northern Madagascar there are coral islands that are not submerged.

The following are other evidences in favor of the theory of subsidence.

The theory explains all the varying depths of lagoons, from the condition of near obliteration to that of a basin one to three hundred feet deep.

It gives a satisfactory reason for the existence of great and abrupt depths about many atolls, and off great barriers, and the steepest of submarine declivities. The powers of growth in the reef, through the limestone material derived from the waters by the polyps, enable it to keep itself at the water-level in spite of the deepening that is going on. Such facts as those from the depths alongside of the eastern Bahamas, the reef-islands southwest of Cuba, and many atolls in the deeper oceans have here their full elucidation.

The sunken atolls of the ocean, like the Chagos Bank (page 191), derive from Darwin's theory their only explanation. The basin-shaped reef with high borders, the bottom dead because of the too great depth, the borders in places growing corals and having some surface islets over spots of more luxuriant growth where rate of progress was sufficient to keep up with the subsidence, — all the facts are a natural consequence of the method of origin. A model of such a lagoon-bank with its raised margin and few tall and steep islet towers, 20 to 30 feet above the rest of the border, would be one of the best of demonstrations for the subsidence theory. The coral-growing areas over the great lagoons of atolls and the barrier-bounded channels of the Feejees and other archipelagoes and those of the outer waters about islands or their barriers, show no tendency to grow with large depressed centres, but rather with flat tops, as vegetation might grow, or else with elevated centres. It is only when nearing the surface where the waves can help vigorously the growth and the accumulation of material on the border and injure the interior corals, that anything like a lagoon-basin begins and the atoll takes shape; and it is only through continued subsidence under such conditions that the margin can be made to grow so much faster than the interior as to produce thereby a basin-like interior 50 to 300 feet deep. Corals will grow most rapidly where food is most freely supplied by currents, as observed by Mr. Agassiz. The principle serves to explain the unequal progress in some reef-banks; but food is seldom deficient. Darwin draws a good argument for his theory, also, from the fact that lines of coral islands are the continuations of lines of high islands, and, also, that lines of the two kinds of islands often run parallel with one another; for example, the Hawaiian line of high islands four hundred miles long, ending off to the westward in a longer line of atolls, and the many parallel lines in the Pacific.

There is, further, not merely probable but positive evidence of subsidence in the deep coast-indentations of the high islands within the great barriers. The long points and deep fiord-like bays are such as exist only where a land, after having been deeply gouged by erosion, has become half submerged. The author was led to appreciate this evidence when on the ascent of Mt. Aorai on Tahiti, in September of 1839.[1] Sunk to any level above that of five hundred feet,

[1] A map of Tahiti and an account of the ascent are contained in the author's "Volcanoes and Hawaiian Volcanic Phenomena." The map is published, also, in the American Journal of Science, 1886, xxxii. 247.

the erosion-made valleys of Tahiti would become deep bays, and above that of one thousand feet, fiord-like bays, with the ridges spreading in the water like spider's legs; and this is a common feature of the islands and islets within the lagoons of barrier islands. The evidence of subsidence admits of no doubt. It makes the conclusion from the Gambier group positive; and equally so that for Raiatea and Bolabola represented on the charts in Darwin's "Coral Islands;" and that for the Exploring Isles and others of the Feejee group; and that for islands, great and small, in the Louisiade Archipelago and in other similar groups over the oceans.

Other arguments for the thickening of reefs through subsidence are afforded by the existence of elevated reefs, and of sunken and buried fringing reefs.

The island of Metia is 250 feet in height (p. 193), full twice the coral-growing depth, and consists of horizontally stratified limestone. At the island of Mangaia, in the Hervey group, the coral rock is raised 300 feet out of water. Such thick beds could not have been made by corals growing in depths not exceeding 150 feet without a sinking of scores of feet during their progress.

Christmas Island, in the eastern part of the Indian Ocean, according to Mr. J. J. Lister and Captain Aldrich, R. N., although 1,200 feet high, has a series of horizontal terraces of coral-made rock to the top. There is at bottom a vertical cliff of 30 feet; then above the 120-foot level, a cliff of 85 feet begins; above that of 475 feet, two cliffs together of 95 feet; next a steep, rough slope for 650 feet of the height, ending in a top layer. Captain Aldrich, who ascended to the summit, says that he saw no rock but coral rock, and implies that the rock is in successive layers. The facts, taken as stated, prove a thickness of reef-rock of 1,200 feet. One writer has since said, that perhaps the coral rock encases a volcanic mountain; another has gone further and dropped the *perhaps*. But these statements are at present unwarranted.

On Cuba, according to Prof. W. O. Crosby,[1] coral rock occurs in successive terraces up to a height of nearly 2,000 feet, and, excepting small breaks, makes the circuit of the island. The terraces are described as a striking feature in the view from the water. One terrace-plain, at 30 feet elevation, is in places nearly a mile wide and extends almost horizontally for hundreds of miles. A second, of 200 to 250 feet, rises steeply from the inner edge of the first, and a third reaches a level of 500 feet. Near Havana the elevation is over 1,200 feet, and the rock, as reported by Mr. A. Agassiz, is true reef-rock. The mountain El Yunque, five miles west of Baracoa, 1,800 feet in height, is volcanic rock below, but coral for the upper 1,000 feet. Further coral limestone has been found by Mr. Sawkins, on Jamaica, at a height of 2,000 feet. Mr. Crosby concludes that the great thickness of the now elevated reefs could have been produced only "during a progressing subsidence," so that "we have apparently no recourse but to accept Darwin's theory."

We are thus led to the conclusion that each coral atoll once formed a fringing reef around a high island. The fringing reef, as the island subsided, became a barrier reef, which continued its growth while the land was slowly disappearing. The area of waters within finally contained the last sinking peak. Another period, and this had gone, leaving only the barrier at the surface and an islet or two of coral in the enclosed lagoon. Thus the coral wreath encircling the lofty island becomes afterward its monument, and a record of its past existence. The Paumotu Archi-

[1] Proceedings of the Boston Society of Natural History, 1882–1883, xxii. 124.

pelago is accordingly a vast island cemetery, where each atoll marks the site of a buried island; and the whole Pacific is scattered over with these simple memorials.

In view of the facts that have been presented, it is further evident that a barrier reef indicates approximately the former limits of the land enclosed. The Exploring Isles (Feejee chart), instead of having an area of only *six* square miles, the whole extent of the existing land, once covered *three hundred* square miles; and the outline of the former land is indicated by the course of the enclosing reef. A still greater extent may be justly inferred. For since a barrier, as subsidence goes on, gradually contracts its area, owing to the fact that the sea bears a great part of the material inward over the reefs, the declivity forming the outer limit of the sub-marine coral formation has a steep angle of inclination. In the same manner it follows that the island Nanuku, instead of *one* square mile, extended once over *two hundred* square miles, or had two hundred times the present area of high land. Bacon's Isles once formed a large triangular island of equal extent, though now but two points of rock remain above the water.

The two large islands in the western part of the group Vanua Levu and Viti Levu, have distant barriers on the western side. Off the north point of the former island, the reef begins to diverge from the coast, and stretches off from the shores till it is twenty and twenty-five miles distant; then, after a narrow interruption, without soundings, the Asaua islands commence in the same line, and sweep around to the reef which unites with the south side of Viti Levu; and, tracing the reef along the south and east shores, we find it at last nearly connecting with a reef extending southward from Vanua Levu. Thus these two large islands are nearly encircled in a single belt; and it would be doing no violence to principles or probabilities to suppose them once to have formed a single island, which subsidence has separated by inundating the low intermediate area. We may thus not only trace out the general form of the land which once occupied this large area (at least 10,000 square miles), but may detect some of its prominent capes, as in Wakaia and Direction Island. The present area is not far from 4,500 square miles. The Feejee Group, exclusive of coral islets, includes an area of about 5,500 square miles of dry land; while, at the period when the corals commenced to grow, there were at least, as the facts show, 15,000 square miles of land, or nearly three times the present extent of habitable surface.

OBJECTIONS TO THE SUBSIDENCE THEORY.

The objections to the theory of coral reefs which have been recently urged are mostly independent hypotheses which are supposed to meet the facts without requiring subsidence, and not strictly objections to Darwin's theory. Two or three real objections, however, are among them. The discussion brings out many points of interest.

An improbability. — *So extremely slow* a subsidence, keeping pace so well with the upward growth, is improbable. This objection is put forth by those who are not aware that so slow subsidences are those with which geology is most familiar. A movement of the kind has been proved to be in progress along the coast of New Jersey and some other parts of the North American Atlantic border, and in western Greenland; and geology is now inquiring as to whether any regions are absolutely stable, or wholly free from movement up or down.

Another improbability. — *So great* a subsidence is declared improbable. The thickness of coral limestone, attributed under the theory to some coral-reef formations, is pronounced by Dr. J. J. Rein[1] to be far beyond that of any reefs of earlier time, and therefore improbable. But precedent, whether a fact or not, settles nothing. Coral-made limestones are not essentially different in origin from shell-made limestones; and the past year we have reported from Mexico, by Dr. C. A. White, a Cretaceous limestone, having similar fossils from bottom to top, and yet 4,000 feet thick. It could not have been made, as Dr. White states, without 4,000 feet of slowly progressing subsidence, for the fossils prove that it is not of deep-water origin. Nevada has Devonian limestones, according to Hague and Walcott, 6,000 feet thick, and some similar fossils in the upper and lower portions which are proof of a gradual subsidence. No thick formation of any kind of rock was ever made, or could be made, by shore or shallow-sea operations without a slowly continued subsidence or a corresponding change of water level.

But there is *another improbability* and it is the most improbable of all suppositions that can be made with regard to the globe; that, while the continents have had their great changes of level, both upward and downward by the thousands of feet, the oceanic basins, of nearly three times the area, and volcanic in the constitution of many high islands, have had no changes of level except some local elevations, for this is implied by the objectors; not a subsidence anywhere of a thousand feet or even a hundred, in the breadth of thirty millions of feet between America and the East India Seas. Whence this stability?

[1] Dr. Rein's Memoir on Bermuda is mentioned in the note on page 218. The above argument is given here from the citation by Dr. Geikie, the publication not being accessible to the writer.

The Elevation Theory. — The view has been presented that, in place of subsidence, elevation is at the bottom in the origin of barriers and atolls. Coral reefs may, like sea-beaches, be made at different heights on the slopes of rising land; but this is not the result of elevation which is implied; for barrier reefs and atolls are the objects whose origin is to be accounted for.

a. Mr. G. C. Bourne[1] found at Diego Garcia, an atoll of the Indian Ocean southeast of the Chagos Bank, that in wells sunk over the island, the rock, for a short way down, consists of horizontal layers, eighteen inches to three feet thick, of coral sand in two or three alternations with coral shingle containing corals in coarse masses; and he concludes that the coarser layer corresponds to a layer of growing corals and the sand layer to a deposit of sand that was spread over and killed the corals; and that this process was repeated two or three times or more. Then he says: "*Raise* the formation to the surface and you get that stratification which you see on so many parts of the island, a stratification which cannot be explained on any theory of subsidence." He does not seem to be aware that the elevation did not make the stratification; and that the stratification is on his view positive evidence of a period of submergence; and that the thickening of such a series by additions above, as in the process described, would require a continued subsidence previous to the final elevation. In any case, the final emergence is all there is in such facts to support an elevation theory of coral islands.

The case of Christmas Island, 1,200 feet high (p. 274), is one of upheaval; but the upheaval, if the horizontal terraces are parts of successive layers, did not make the layers.

[1] Bourne, Nature, April 5, 1888.

If they are only fringing reefs marking different stages in the elevation, they are like elevated sea-beaches, and if each is no thicker than the depth of growing corals, they have no bearing on any theory of coral islands. But the descriptions say that only coral rock exists on the island.

b. The fact that elevated reefs and other evidences of elevation occur at the Pelews, a region of wide barrier reefs and atolls, has been presented by Prof. Karl Semper,[1] after a study of those islands, as bearing in the same direction; that is, against the theory of subsidence, for by the subsidence theory we have in such facts (in the words of another), "a cumbrous and entirely hypothetical series of upward and downward movements." Professor Semper reports the existence of reefs raised 200 to 250 feet above the sea-level in the southern third of the larger of the islands, while the other two thirds exhibit evidence of but little, if any, elevation. The facts are like those of other elevated reefs and atolls discussed on former pages. The Pelew region is one of comparatively modern volcanic rocks and this renders local displacements a probability. The elevations are proof of *local* change of level; and likewise of a *recent* change in each case; for the top layer of the elevated reef-rock and all below it through the coral-made structure were completed previous to the uplift. They prove nothing as to the changes that were in progress when all this coral-rock was in process of formation.

c. The occurrence of great numbers of large and small masses of coral rock, in some places crowded together, upon the *western* or *leeward* reef of the several Pelew islands, and

[1] First in 1868, Zeitschr. Wissensch. Zoöl. xiii. 558; additions in Die Philippinen und ihre Bewohner, Würzburg, 1869, and still later in his "Animal Life" published in Appleton's International Scientific Series in 1881.

of none on the eastern reef, is mentioned as evidence against subsidence and in favor of some elevation: because, Professor Semper says, the strongest wind-waves on the western side are too feeble to break off and lift on the reef so large masses, some of them (as his words imply rather than distinctly state) ten feet thick.

But the difficulty does not exist in fact; for earthquakes may have made the waves. The region just west of the Pelews is one of the grandest areas of active volcanoes on the globe. It embraces the Philippine Islands, Krakatoa and other volcanic islands of the Sooloo Sea, Celebes, etc. The agents that could do the work were there in force. To the eastward, in contrast, lie the harmless islands of the Caroline Archipelago, mostly atolls, serving, perhaps, as a breakwater to the Pelews.

Professor Semper has other steps in his theory which are considered beyond.

The idea of elevation as a requisite is not suggested by the atolls of the ocean. In the Paumotu Archipelago, covering four hundred and fifty thousand square miles, the nearly uniform height of the land, eight to ten feet, in the seventy to eighty atolls, with the shore platform a hundred yards or more wide near third tide-level, does not favor the assumption that elevation had put them into their present uniform positions.

1. *The talus-theory.* — Mr. John Murray, one of the able naturalists of the Challenger Expedition, has proposed the following theory: that shore-reefs extend themselves out within coral-growing depths on the basement of debris derived from the growing margins.

The fact that reefs widen by the process here mentioned when subsidence ceases is recognized in the author's Expedition Report; but that this is the means of attaining great width and thickness with no aid from subsidence is the new view of Mr. Murray. The method has been described in the words: Reefs grow out on their own talus. The view is supported by Dr. Guppy, Mr. A. Agassiz, and others.

a. Mr. Murray's observations were made at Tahiti. He reports the following facts derived from soundings off northern Tahiti, made under his supervision and that of the surveying officer.

Along a line outward from the edge of the barrier reef there were found: (1) for about 250 yards, a shallow region covered partly with growing corals, which deepened seaward to 40 fathoms; (2) for 100 yards, between the depths of 40 and 100 fathoms, a steeply but irregularly sloping surface which commenced with a precipice of 75° and had a mean angle exceeding 45°;[1] then (3) for 150 yards a sloping bottom 30° in angle; (4) then a continuation of this sloping surface, diminishing in a mile to 6°, at which distance out the depth found was 590 fathoms (3,540 feet). Over the area (2), or the 100 yards between 40 and 100 fathoms, the bottom was proved to be made of large coral masses, some of them "20 to 30 feet in length," along with finer debris; outside of this, of sand to where the slope was reduced to 6°; and then of mud, composed "of volcanic and coral sand, pteropods, pelagic and other foraminifers, coccoliths, etc."

These observations have great significance. They show (1) that the feeble currents off this part of Tahiti carry little of the coral debris in that direction beyond a mile outside of the growing reef; (2) that a region of large masses of coral

[1] Dr. Archibald Geikie gives in his Presidential Address before the Royal Physical Society of Edinburgh in 1883 (Proc. viii. 1, 1883) a section of the soundings "on a true scale, vertical and horizontal," and in it the upper steepest part of this 100 yards has a slope of about 75°.

rock and finer material occurs at depths between 240 and 600 feet; (3) that, a mile out, the bottom has the slope nearly of the adjoining land, and in this part is covered with the remains of pelagic life.

From the second of these facts, — the great accumulation of coral blocks below a level of 240 feet, — Mr. Murray draws the conclusion that, in the making of fringing, barrier, and atoll reefs, the widening goes forward (*a*) by making first upon the submarine slopes outside of the growing reef a pile of coral debris up to the lower limit of living reef-corals; and then (*b*) by building outward upon this accumulation as a basement.

b. But these observations fail to prove that an accumulation of coral blocks over the slopes below the reef-coral limit is a result of the process appealed to. In truth they set aside his conclusion by making the fact of a subsidence unquestionable.

That belt of coarse debris — including "masses 20 to 30 feet" long — was found over the steeply sloping bottom at depths between 240 and 600 feet. These depths are far below the limit of forcible wave-action. They are depths where the waters, however disturbed above by storms, have no rending and lifting power, even when the bottom is gradually shelving; depths, in this special case, against a slope which for 100 yards is 75° in its upper part, and in no part under 45°, the vertical fall being 360 feet in the 100 yards. Strokes against the reef-rock thus submerged, and under such conditions, would be extremely feeble. Waves advancing up a coast, whether storm-driven waves or earthquake waves, do little rock-rending below the depth to which they can bare the bottom for a broadside plunge against the obstacle before them, although the velocity gives them transporting power to a greater depth. It is the throw of an immense mass of water against the front, with the velocity increased by the tidal flow over a shelving bottom, — the rate sometimes amounting, according to Stevenson, to 36 miles an hour or 52·8 feet a second, — together with the buoyant action of the water, that produces the great effects.

A vertical surface below the sea-level of 20 feet made bare for the broadside stroke is probably very rarely exceeded even in the case of earthquake-waves; and with storm-waves, or recorded earthquake-waves, the displacement of the water at a depth of 240 feet would be at the most only a few inches. I saw on atoll reefs no upthrown masses of coral rock over ten feet in thickness and twenty feet in length or breadth. It is therefore plainly impossible that such a belt of debris should have been made at its present level, or even at a depth of twenty feet; and hence the debris affords *positive proof of a large subsidence during some part of the reef-making era.*

c. But if such accumulations of great blocks cannot result from the dropping of masses from the edge of the reef, the facts show that fine coral debris may be spread over the bottom for a mile outside of the surface reef, and contribute thereby toward a rising basement. But the expression that they grow out on their own talus is wholly fallacious; for there is nothing visible that is of this nature. Outside of the emerged reef there is a region of growing corals, as has been explained, and spots and areas of sand exist among the luxuriant groups and plantations. Outside of this there is more or less of deeper pelagic life and thinner deposits of sand from the reef; but nowhere a talus of debris. The sea makes debris as the waves and inflowing tides move toward the shores; but the action is almost wholly landward, transporting nearly all the debris over the emerging reef and into the inner channels or lagoons; little is carried off and dropped in the deeper waters outside. The condition is like that on other coasts which the sea is extending. But there is this difference that the corals, the chief source of the debris, have a hold on the bottom because attached species, and the calcareous sands are easily cemented; so that the reef they make becomes a solid bank. And further, the waves and tidal waters have this great area of reef and inner channels to receive the sands they distribute. Little debris reaches the outer slopes; and the most of this little finds lodgment among the corals within coral-growing depths.

The Florida reefs well illustrate the facts. Off the great emerged banks there is, first, the region of growing corals, called the "Florida reefs," half a mile to a mile wide, and one to nine fathoms deep, where some spots of reef reach the surface; and outside of this, on the south, there is the Pourtalès plateau at depths down to two hundred and fifty fathoms, growing pelagic species. There is no talus. Some debris drops over the plateau; yet, as Mr. Agassiz's figure shows, the amount is very small. The Florida Bank gets nearly all, and thus it has derived its height and extent.

d. The view which Mr. Agassiz sustains that the Florida corals grew out on a basement made by pelagic growth or on the inner part of the Pourtalès plateau, and thus extended the great bank, has more to sustain it than the talus-theory. With only the facts that are open to view in the Florida seas no other explanation would be thought of. But there is one difference between banks over such a bottom and those increasing through a subsidence. With the former, the slope of the bottom would usually be gentle. While the explanation may answer as well as the subsidence-theory for the

Florida Bank, it does not appear to suffice for the Eastern Bahamas, with their steep submarine slopes toward the ocean, or for the Grand Cayman and other reefs southwest of Cuba, or for the great majority of the atoll and barrier reefs of the Pacific. It is, however, not yet proved to be true for Florida.

e. By Darwin's theory, the growing reef increases its thickness as the slow subsidence progresses; and the inside channel, so common a feature, is a consequence in the way that has been explained. But by the Murray method, after the outer edge of the reef has a thickness equalling the range in depth of reef-corals for the region, the reef, as it further enlarges, keeps extending out into deeper and deeper water. But the width cannot be doubled without using three times as much material as for the preceding part in case the slope of the bottom is unchanged and the coast is a straight line, and much more than three times if the coast line is convex like that of Tahiti, and still more if the slope of the bottom increases. With the feeble amount of debris to be had, the rate of growth would therefore be extremely slow,—not over one hundredth of that for the first one thousand feet. During all the long era of this extension the waves and tidal movements and winds would be at their usual work, throwing the chief part of the debris on the reef and beyond into the channel; and thus the channel, the process being aided by its own growing corals, would be sure to become filled and nearly obliterated; for it is ever receiving, and has no chance to increase its capacity or relieve itself of the debris received.

Among examples of a reef undergoing such an extension where there was little or no subsidence, is that of the north side of Upolu, of the Samoa Group, which the author's Expedition Report describes as nearly a mile wide and yet having no channel deep enough for a canoe. The whole amount of subsidence estimated in the Report is one to two hundred feet — and whatever the amount it may have long since ceased. The same conclusion comes from the Florida Bank. The reef of Tahiti, on the contrary, is far as possible from such a condition. Its channel is partly a ship channel, as already described; and such deep waters are common within Pacific barrier reefs.

The thick coral-made beds reached by artesian borings on Oahu (see Appendix), regarded as evidence of the subsidence of the island attending their formation, are explained by Mr. A. Agassiz on the Murray hypothesis: "the extension seaward of a growing reef, active only within narrow limits near the surface, which was constantly pushing its way seaward upon the talus formed below the living edge."[1]

The above considerations may be deemed sufficient to set aside the suggestion; for it is only a suggestion, since no facts are mentioned in its support. The borings give it none. Some of them commence in the elevated reef which is the inner part of the fringing reef of the island, within three or four hundred yards of the mountain slopes, and go down through coral rock interruptedly for two hundred feet or more. There is no reason for regarding any part of it talus-made.

f. Although no sufficient reason is found for believing in talus-made basements, a characteristic by which they might be known if lifted into view may be mentioned. The debris is laid down on a sloping surface, whence the beds would have a corresponding pitch. The deposit would thus differ from ordinary coral formations and, too, from all great examples of limestone strata of which we have knowledge. In

[1] Bulletin of the Museum of Comparative Zoölogy, 1889, xvii. No. 3.

the elevated coral island, Metia, two hundred and fifty feet high, the stratification is horizontal; the terraces of Christmas Island are horizontal; and the same is true of the elevated reefs of Cuba.

If a satisfactory decision in any case is not arrived at by the methods or criteria which have been described, there is the best of evidence to be had by artesian borings that shall go to the bottom and bring up a core six inches in diameter. It may thus be decided whether the limestone passed through is of reef-coral, or talus-debris, or partly or wholly of pelagic constitution.[1]

2. *Courses of reefs and channels determined by marine currents.*— The view has been urged by Lieut. E. B. Hunt, U. S. N. and Messrs. A. Agassiz, Murray, Semper, and Guppy that the positions of reefs off coasts are sometimes and generally located by drift currents at considerable distances from coasts, and hence that the wide intervals of water inside of barrier reefs may result without aid from subsidence; and Dr. Guppy has urged, as remarked on another page, that atolls may be so shaped.

a. The facts, presented by Lieutenant Hunt, and more fully by Mr. Agassiz with regard to the effects of the eddy current of the Gulf Stream have been mentioned on page 207. They show that coral reefs may be elongated, and also that

[1] The kind of submarine slopes to be ordinarily looked for off coral reefs is ilustrated by the Challenger soundings. And it is interesting to note that the facts sustain instead of correcting those announced by earlier observers. Beechey and Darwin make the mean slope about 45°, and my Report says 40° to 50°. I have assumed for the slope of the bottom outside of the reef-limit the same angle as for the surface-slope of the island just above the water-level; 5° to 8° off Tahiti, of which 5° is accepted as most correct, and 3° to 5° off Upolu; and the assumption as regards Tahiti is sustained by the Challenger soundings. My Report states (from the Expedition surveys) that off Upolu, the bottom "loses more and more in the proportion of coral sand till we finally reach a bottom of earth," and introduces this as an argument against the indefinite drifting of coral sands into the deep ocean; and this argument the Tahiti soundings sustain.

inner channels may be made, by the drifting of coral sands. The action with coral sands is essentially the same as with other sands; and illustrations of this drifting process occur along the whole eastern coast of North America from Florida to Long Island. We there learn that drift-made beaches run in long lines between broad channels or sounds and the ocean; that they have nearly the uniform direction of the drift of the waters, with some irregularities introduced by the forms of the coast and the outflow of the inner waters which are tidal and fluvial and have much strength during ebb tide. The easy consolidation of coral sands puts in a peculiar feature, but not one that affects the direction of drift accumulation.

b. The great barrier reef off eastern Australia, a thousand miles long, has some correspondence in position to the sand-reefs off eastern North America. But it is full of irregularities of direction and of interruptions, and follows in no part an even line. In the southern half, it extends out one hundred and fifty miles from the coast and includes a large atoll-formed reef; in the northern half, the barrier, while varying much in course, is hardly over thirty miles from the land. There is very little in its form to suggest similarity of origin to the drift-made barriers of sand.

c. In the Pacific Ocean, the trends of many of the coral island groups, and of the single islands, do not correspond with the direction of the oceanic currents, or with any eddy currents, except such as are local and are determined by themselves.

Near longitude 180°, as the map of the Central Pacific (Plate IX.) illustrates, the equator is crossed by the long Gilbert (or Kingsmill) Group, at an angle with the meridian of 25° to 30°, and not in the direction of the Pacific current which is approximately equatorial. This obliquely crossing chain of atolls is continued northward in the Ratack and Ralick Groups (or the Marshall Islands), making in all a chain over 1,200 miles long; and, adding the concordant Ellice Islands on the south, and extending the Ratack line to Gaspar Rico, its northern outlier, the chain is nearly 2,000 miles long. Nothing in the direction of the long range, excepting local shapings of some of the points about the atolls, can be attributed to the Pacific currents. Moreover, none of the diversified forms of atolls have any sufficient explanation in the drift process.

Dr. Guppy urges the idea that banks of reef after reaching the surface are converted into atolls by means of the marine currents.[1] In his last paper he speaks of the conversion *after the island has been thrown up by the waves*; in the earlier he appears to speak of *elevation* of some kind as necessary; but the currents would act the same, whatever the means of reaching the surface. In the groups of atolls above referred to, neither the forms of the atolls nor the currents favor such an hypothesis. In the Paumotus, there are no currents of strength enough for work of this kind, as shown on page 296. He speaks of Keeling Atoll as a *horse-shoe* or *crescentic* island, and states that such forms are common among atolls. But the Keeling Atoll, according to the best maps, is an ordinary atoll, the lagoon nearly encircled with reef, and the application of such terms to it is wholly misleading. The shaping of a reef by the horse-shoe method of drifting and making an eddy to leeward which he describes, is wholly inapplicable to the ordinary atolls of the ocean; for there are no means for producing the result.

d. Further, drifting by currents may make beaches and

[1] On the Solomon Islands, Proceedings of the Royal Society of Edinburgh, 1885–1886, xiii. 857; On the Keeling Atoll, Nature, January, 1889, xxxix. 236.

inner channels whether subsidence is going on in the region or not, and are not evidence for or against either a movement downward or upward. Sandy Hook, the long, sandy point off the southern cape of New York harbor, has been undergoing (as the United States Coast Survey has shown) an increase in length, or rather variations in length, through the drifting of sands by an outside and an inside current; and this is no evidence that Prof. G. H. Cook is wrong in his conclusion that the New Jersey coast is slowly subsiding.

3. *Planting of corals on basements made and raised to the right level by the growth of pelagic limestone or by other means.* — The theory has been sustained by Mr. Semper, Dr. Rein, Mr. Agassiz, Mr. Murray, Dr. Guppy, and others, that since the growing calcareous deposits of the sea-bottom are slowly rising toward the surface by successive accumulations of the shells and other debris of pelagic species, they may have been built up locally in various regions of the deep seas (as they actually are now about some islands) until they were near enough to the surface to become next a plantation of corals; and that in this way, without any subsidence, atolls became common within the area of the tropical oceans.

In support of this view, Dr. Guppy states that in elevated coral reefs of the Solomon Islands, one hundred to twelve hundred feet high, the coral reef rock forms a comparatively thin layer over impure earthy limestone abounding in foraminifers, pteropods, and other pelagic organisms. Such observations have great interest, but they only prove that in coral-reef seas corals will grow over any basis of rock that may offer where the water is right in depth and other circumstances favor. They are not evidence against the subsidence theory, but simply local examples under the general principle just stated.

The wide oceans are, however, wonderfully free from banks approaching the surface within one hundred fathoms. The Indian Ocean and the China seas afford exceptions. But the principal submerged banks of these waters have the lagoon-basins and raised borders of an atoll and thus bear, as has been explained (page 272), positive evidence of a former atoll existence and therefore of subsidence. They illustrate the fact that the rate of subsidence has not always been within the narrow maximum limit that is favorable to the atoll, but sometimes has exceeded it to their destruction. The regions of such sunken atolls in the China seas and Indian Ocean have many spots of shallow soundings which were probably sunk at the same time.

Mr. Murray observes that "the soundings of the 'Tuscarora' and 'Challenger' have made known numerous submarine elevations; mountains rising from the general level of the ocean's bed at a depth of 2,500 or 3,000 fathoms up to within a *few hundred fathoms* of the surface." But "a few hundred fathoms," if we make "few" equal two means twelve hundred feet or more, which leaves a long interval unfilled.[1]

The atoll of the Tortugas, and others in the West Indies, are regarded by Mr. Agassiz as having a basement, up to the coral-growing limit, of pelagic limestone or of some other material. It may be so; but there is as yet no proof of it.

[1] The actual depths over the elevations in the "Tuscarora" section between the Hawaiian Islands and Japan, numbering them from east to west are as follows: (1) 11,500 feet; (2) 7,500 feet; (3) 8,400 feet; (4) 12,000; (5) 9,000 (this seven miles west of Marcus Island); (6) 9,600 feet. Whether ridges or peaks, the facts do not decide; probably the former. No. 1 has a base of 185 miles with the mean eastward slope 40 feet per mile (= 1 : 132) and the westward 128 feet per mile. No. 2 has a breadth of 396 miles, with the mean eastern slope mostly 37 feet per mile, but 51 feet toward the top, and the westward 55 feet per mile (= 1 : 96). No. 3 was the narrowest and steepest, it being about 100 miles broad at base, and having the mean eastern slope 192 feet per mile and the mean western 200 feet.

The basement, according to Mr. Murray, may be a volcanic cone or a submerged mountain-peak at the proper level; and if too low, it may be raised up to it by pelagic life-relics; if too high, like the "emerged volcanic mountains situated in the ocean basins," it may be razed by abrading agencies to the water-level and finally lowered by the waves and currents to the needed depth. It is true that the basement for growing corals may be anything that has the proper depth. But this shaving off of a mountain and carrying the erosion to a few fathoms below the sea without a change of level is beyond physical possibility. Land-waters cut out valleys or gorges, and indefinite time would be required for the final levelling. Waves are too shallow in their action, the rising, tidal waters too protective, and the rocks under a cover of water too resisting, for the marine part of the degradation.

But this making of atolls and barrier reefs on banks submerged at the right distance without submergence, encounters a fatal difficulty wherever there are deep lagoons and deep channels, which difficulty has not been overcome though various methods have been suggested.

4. *Lagoon basins and channels made largely by abrading and solvent action.* It is urged, in agreement with Darwin, that the outer portions of reefs increase faster than the inner, owing to the purer water about them and the more abundant life for food; that the inner parts are not only at a disadvantage in these respects, but suffer also from coral debris thrown over them. Some writers have considered this of itself sufficient, saying that the edges of the bank will thus reach the surface, while the interior makes little progress; and so comes the lagoon basin. But the above authors add to the causes of unequal growth mentioned by Darwin the solvent and abrading action of the waters.

It is, hence, concluded by them that, under these conditions, the simple bank of growing corals may have a depression made at centre, which, as the process continues, will become a lagoon basin, and the reef, thereby, an atoll with its lagoon; that the atoll, so begun, may continue to enlarge through the external widening of the reef and the further action of current abrasion and solution within; or, in the case of fringing reefs, that the change may go on until the reef has become a barrier-reef with an inner channel and inner reefs. It is admitted that subsidence may possibly have helped in the case of the deepest lagoons.

Dr. Geikie expresses his opinion on the subject thus:—"As the atoll increases in size the lagoon becomes proportionally larger, partly from its waters being less supplied with pelagic food, and therefore less favorable to the growth of the more massive kinds of corals, partly from the injurious effects of calcareous sediment upon coral growth there, and partly also from the solvent action of the carbonic acid of the sea-water upon the dead coral." The argument has been enforced by observations on the solvent power of carbonic acid. But this is a point about which there is no ground for dispute.

a. Mr. Semper gives examples of the effects of currents at the Pelew Islands, stating that by striking against or flowing by the living corals they make the reef grow with steeper sides and determine its direction, and urging that abrasion and solution have made, not only the deep lagoon-like channels, but the deeper channels between the islands. He holds that in Kriangle, which he describes as a true atoll with no channel leading into the lagoon from the sea, that the lagoon may have been "the result of the action of currents on the porous soil during a period of slow upheaval."[1] He says,

[1] Animal Life, pp. 269, 270.

further, that the large channel in the main island of the group, "forty fathoms deep and many miles wide. . . . finds an easy explanation on the assumption of an upheaval;" it became "wider in proportion as the enclosed island, consisting of soft stone [tufa], was gradually eaten away, and during slow upheaval it would continue to grow deeper in proportion as the old porous portions of the reef and the rock in which it was forming were more and more worn down by the combined action of boring animals and plants, and of the currents produced by the tides and by rain." Mr. Semper refers to the dead depressed tops of some masses of Porites near tide-level as the effects of the deposit of sediment over the top of the living coral and of erosion by the waves and exposure to rains while the sides continued to grow; and the fact is made an example on a very small scale of atoll-making. In addition, experiments on the solvent power of sea-water are appealed to. Examples of the action of currents, sediment, boring species, and the solvent action of carbonic acid in the waters, are mentioned by Mr. Agassiz, in his excellent account of the "Tortugas and Florida reefs," and in his "Three Cruises of the Blake;" but in his paper on the Coral Reefs of the Hawaiian Islands he concludes that the fact that "the majority of reefs are of great width goes to show also that solution alone is not active enough to remove great masses and form lagoons." [1]

b. The theory, if satisfactory, accounts not only for the origin of an atoll, but for the origin of atolls of all sizes, shapes, and conditions, and for great numbers of them in archipelagoes and chains; not only for channels through fringing reefs, like those that abrasion in other cases makes, but for all the irregular outlines of barriers, for the great

[1] Bulletin of the Museum of Comparative Zoölogy, 1889, vol. xvii. No. 3

barriers reaching far away from any land, and for the positions and indented coasts of the small included lands. Is it a sufficient explanation of the facts?

c. The currents that influence the structure of reefs are: (1) the general movement or drift of the ocean, in some parts varying with seasonal variations in the winds; (2) the currents connected with wave action and the inflowing tide over a shelving bottom; and (3) the currents during the ebb, flowing out of channels; together with (4) counter-currents. Each region must have its special study in order to mark out all the local effects that currents occasion. Such effects are produced whether a secular subsidence is in progress or not, and hence a particular review of the subject in this place is unnecessary.

The shaping of the outside of the reef and the determination of the width and level surface of the shore-platform are due chiefly to the tidal flow and the accompanying action of wind-waves as explained on preceding page.

The current that accompanies the ebb is locally the strongest. Owing to the great width of many barrier reefs and of the channels and harbors within them, the tide flows in over a wide region. At the turn in the tide the waters escape at first freely over the same wide region; but with a tide of but two or three feet, there is little fall before the reef — which lies at low tide level and a little above it — retards it by friction; and thus escape by the open entrances is increased in amount and in rate of flow. The facts are the same in atolls where the lagoons have entrances.[1]

[1] The currents of the tropical Pacific Ocean are of very unequal rate in its different parts, and very feeble in the Paumotu Archipelago and the Tahitian and Samoan regions. Captain Wilkes reports that in the cruise of the Expedition through the Paumotu Archipelago to Tahiti, a distance of a thousand miles, during a month from August 13 to September 13, 1839, the drift of the vessels was only seventeen miles; and that during fourteen days in the first half of October, between Tahiti

d. Examples of massive corals having the top flat, or depressed and lifeless, while the sides are living, are common in coral-reef regions, wherever such corals are exposed to the deposition of sediment, and where they have grown up to the surface so that the top is bare above low tide. A disk of Porites, having the top flat and the sides raised (owing to growth) so as to give it an elevated border, is figured on Plate LV. of the author's Report on Zoöphytes. Many such were found in the impure waters of a shore reef at the Feejees. At Tongatabu one flat-topped mass of Porites was twenty-five feet in diameter; and both there and in the Feejees, others of Astræids and Mæandrinas measured twelve to fifteen feet in diameter.

Over the dead surfaces, as Mr. Semper observes, the coral may be eroded by the solvent action of the waters and especially where depressions occur to receive any deposits; and

and Upolu of the Samoan group, nearly eighteen hundred miles, the drift was only forty-three miles.

The "Challenger," on her route from the Hawaiian Islands to Tahiti, found, between the parallel of 10° S. and Tahiti, "the general tendency of the current westerly, but its velocity variable;" between the parallel of 10° S. and 6° N., the direction was westerly with "the average velocity thirty-five miles per day, the range seventeen to seventy miles per day," the maximum occurring along the parallel of 2° N. Farther west, about the Phœnix group, the equatorial current, as described by Mr. Hague (loc. cit. p. 237) has "a general direction of west-southwest and a velocity sometimes exceeding two miles per hour." At times it changes suddenly and flows as rapidly to the eastward. The drifting of the sands about Baker's Island (in latitude 0° 13′ N., longitude 176° 22′ E.) has much interest in connection with this subject of current action, and the facts are here cited from Mr. Hague's paper. The west side of the little island (1 × ⅗ m. in area) trends northeast, and the southern east by north, and at the junction a spit of sand extends out. During the summer the ocean swell, like the wind, comes from the southeast, and strikes the south side; and consequently the beach sands of that side are drifted around the point and heaped up on the western or leeward side, forming a plateau along the beach two or three hundred feet wide, and eight or ten feet deep over the shore platform. With October and November comes the winter swell from the northeast, which sweeps along the western shore; and in two or three months the sands of the plateau are all drifted back to the south side, which is then the protected side, extending the beach of that side two or three hundred feet. This lasts until February or March when the operation is repeated.

boring animals may riddle the coral with holes or tubes. But generally the erosion is superficial; the large masses referred to showed little of it. Such dead surfaces in corals are generally protected by a covering of nullipores and other incrusting forms of life, and the crusts usually spread over the surfaces *pari passu* with the dying of the polyps.

e. Every stream, says Mr. Semper (when explaining, as cited on a preceding page, the origin of the deep channel of the large Pelew Island, whose depth is "35 to 45 fathoms"), "has a natural tendency to deepen its bed." But there is a limit to this action. The eroding or deepening power of a stream through abrasion and transportation is null, or nearly so, below the level of its outlet. A basin or channel 45 fathoms (270 feet) deep with an outlet of much less depth could not be deepened by such means nor protect itself from shallowing. The depth of the outlets is not stated except that they are said to be ship-channels. Moreover, with a tufa bottom, solution could not contribute to the removal, since carbonated waters, although decomposing the tufa, dissolve very little of its ingredients. An elevation in progress would result in making the channel a closed lake and finally dry land.

For the same reason, the small atoll, Kriangle, having, as described, a *closed* lagoon, could have no deepening of the lagoon from abrasion by tidal currents or wave-action during the progress of an elevation. And if a lagoon have an outlet, the rapid current of the ebb would be confined to the narrow passage-way and a portion of the bottom near it; through the larger part of the lagoon, as in any other lake, the waters would have scarcely perceptible motion, and therefore slight energy for any kind of work. Hence a lagoon would lose very little by this means, and shallowing would go on unless there were great loss through the *solvent action* of the waters. An elevation would only hurry the shallowing and end in emptying the lagoon.

f. Erosion through solvent action is promoted by the presence in the waters both of carbonic acid and organic acids. The material within reach of the tides or waves exposed to this action is dead corals and shells, or their debris, and bare coral rocks, occurring over: (1) the outer region of living corals and for a mile or so outside; (2) the shore platform and the reef, bare at low tide, on which there is comparatively little living coral; and (3) the lagoon basin. There is nothing in the material within the lagoon to favor solution more than in either of the other two regions; in fact, the platform and bare reef are most exposed to the action because of the small amount of living corals over them. The outside waters take up what they can through the carbonic acid they contain, and supply thereby the wants of the lime-secreting polyps, shells, etc., and carry on the process of solidification in the debris; the same waters move on over the atoll reef and take up more lime as far as the acid ingredient is present; and then they pass to the lagoon for work similar to that outside, with probably a diminished amount of free carbonic acid, on account of the loss over the reef-ground previously traversed.

The lagoon-basin is not, therefore, the part of the atoll that loses most by solution, any more than by abrasion and transportation. The outer reefs suffer the most; and yet, if the island is not subsiding at too rapid a rate, they keep extending and encroaching on the ocean, instead of wasting through the drifting into the ocean at large of calcium carbonate in grains and solution, and the shore-platform also preserves its unvaried level notwithstanding the daily sweep of the tidal floods, and the holes that riddle its outer portion.

The remark: "It is a common observation in atolls that the islets on the reefs are situated close to the lagoon shore;" such "facts point out the removal of matter which is going on in the lagoons and lagoon channels," I know nothing to sustain. The width of the shore-platform on the seaward side is always greater than that on the lagoon side; but the outside shore-platform has its width determined by tidal and wave action, and this action is powerful on the ocean side, and feeble on the lagoon side; it produces a high coarse beach on the outside as the inner limit of the platform, and a finer, lower and much more gently sloping beach on the inside. The amount of erosion is far greater, as it should be, on the side of the powerful agencies.

g. The loss to the lagoon by abrasion and solution *is reduced to a minimum, in the majority of atolls, by the absence of lagoon entrances,* which leaves them with only concealed leakage passages for slow discharge.

Nine tenths of atolls under six miles in length (or in longer diameter), half of those between six and twenty miles, and the majority of all atolls in the Pacific ocean, have no entrances to the lagoon a fathom deep; and the larger part of those included in each of these groups have no open entrances at all.

For evidence on this subject, reference may be made to the Wilkes Expedition Hydrographic Atlas. This atlas contains maps of nearly sixty coral islands from the surveys of its officers, drawn on a large scale — one or two miles, rarely four, to the inch.

Out of the number, nine, ranging from $1\frac{1}{2}$ to 3 English miles in the longer diameter of the reef, *have no lagoon,* but only a small depression in its place; two of these take in water at high tide, and the rest are dry.

Of those *under six miles in length having lagoons*, seventeen in number, sixteen are represented as having *no entrances to the lagoon* at low tide; and the one having an entrance is 5×4 miles in size. The smallest is about a mile in diameter.

Of those that are *six miles or over* in length, twenty-nine in number, seventeen have channels and twelve have none. Those having channels are mostly over ten miles in length. A list of them is here given with their sizes, and also the proportion of the reef around the lagoon which is under water above one third tide, and bare at low tide, — a feature of much interest in this connection: —

Ellice Group. — Depeyster's, 6×6 m.; three fourths of the encircling reef bare. Ellice's, 9×5 m.; three fourths bare.

Gilbert Group. — Apia, 17×7 m.; half bare. Tarawa, 21×9 m.; half bare. Taritari, 18×11 m.; two thirds bare. Apamama, 12×5 m.; half bare. Tapateuea, west side mostly submerged.

Marshall Islands (northern). — Pescadores, 10×8 m.; four fifths bare. Korsakoff, 26 m.; four fifths bare.

Paumotus. — Peacock, 15×7 m.; nearly all wooded. Manhii, 13×5 m.; nearly all wooded. Raraka, 6×9 m.; three fourths wooded. Vincennes, 13×9 m.; mostly wooded. Aratica, 18×11 m.; three fifths bare. Tiokea, 18×4 m.; two thirds wooded. Kruesenstern's, 16×10 m.; mostly wooded. Dean's (or Nairsa), 53×18 m.; half or more bare.

h. The absence of open channels in so large a proportion of lagoons, and especially in lagoons of the smaller atolls, is fatal to the abrasion-solution theory. The method of enlarging atolls through currents and solution can act only feebly, if at all, where waters have no free outlet; and this is eminently so with the smaller atolls which have been assumed by the theory to be most favorable in purity of water and in abundant life for progress; if the small cannot grow, the large lagoons cannot be made from them by the proposed method.

Reverse the method, letting the large precede the small, and then, under the subsidence theory, we have a consistent order of events. We have large atoll reefs with several large entrances (like the great barrier reef about a high island in this and other respects) gradually contracting, and the entrances concurrently narrowing through the growing corals and the consolidating debris, in spite of the efforts of abrasion and solution to keep them open and make them deeper; and, afterwards, the atoll becoming still smaller until the entrances close up; and finally the lagoon-basin reduced to a dry depression with nothing of the old sea-water remaining except, perhaps, some of its gypsum.

i. Instead of small lagoons having the purest waters, the reverse is most decidedly and manifestly the fact, and this accords with the reversal in the history just suggested. Since atolls of middle and larger size commonly have one third to two thirds of the encircling reef covered with the sea at one third tide, making the ocean and lagoon for more than half the time continuous, the large lagoon in such a case has as pure water as the ocean, and commonly as good a supply of food-life, and sometimes as brilliant a display of living corals. But in the smaller atolls, the area of the lagoon has little extent compared with the length and area of the encircling reef; coral sands and other calcareous material consequently have possession of the larger part of the bottom, and the waters, since they are less pure than those outside, contain fewer and hardier kinds of corals and less life of other kinds. They are exposed, also, to wider variations of temperature than the outer, with injury to many species, and, at lowest tides, may become destructively overheated by the midday sun, as many a plantation of corals with dead tops for a foot or more bears evidence. In the smallest atolls, the lagoons are liable also to alternations of excessive saltness from evaporation and excessive freshness from rains, and consequently no corals can grow inside, though still flourishing well in the shallow sea about the outer reef. The above are the facts, not the suggestions of theory.

j. We read: "So great is the destructive and transporting influence of the sea under the combined or antagonistic working of tides, currents, and wind-waves that the whole mass of the reef, as well as the flats and shoals inside, may be said to be in more or less active movement."[1] This description of the Tortugas reefs is not applicable to the atolls of the Pacific nor to the Tortugas. Notwithstanding the testimony of Captain Beechey and others about occasional catastrophes — which are mostly catastrophes to the islets and banks within the lagoons — I was led to look upon a coral island as one of the most stable of structures. Through the wind-made and tidal movements, the loose sands are drifted along the shores and over the reef; edges of the reef are broken off in gales or by earthquake waves; and occasionally a mushroom islet in the lagoon, where growing corals are not compacted by wave-action, is overthrown by the same means; but beyond this, the structure is singularly defiant of the encroaching waters. Earthquakes may bring devastation; and so they may to other lands.

5. *Lagoon-basins made by caving in.* — Mr. Fewkes has suggested[2] that the lagoon-basin of the Bermudas may have

[1] Dr. Geikie's Address, p. 23.

[2] Fewkes, Proceedings of the Boston Society of Natural History, 1888, p. 518.

been made by the caving in of caverns with which the reef-rock is supposed to have been honey-combed, but does not apply the theory to all other atolls. The view is opposed by Mr. Heilprin, after a more recent study of the islands.[1] There is nothing to sustain it among the Pacific atolls that were visited by the author. Ordinary atolls have no caves; for caves in reef-limestones are made only after their elevation. The constant effort and action of the sea upon submerged reefs is to fill up all cavities and consolidate all sands. In the drift-sand ridges or hills, however, they may be formed without an elevation of the island; but these do not exist in the region of the lagoon-basin.

As a further reply to the arguments adverse to Darwin's theory from the West Indian seas, the following facts are here added.

The arguments from the Florida and West Bahama reefs in favor of no subsidence have more weight than for most coral-reef regions. They appear to indicate that any subsidence once in progress long since ceased; but they are far from proving that the reefs of the seas have been formed without help from subsidence. There is evidence that a great subsidence occurred during the coral-reef era, affording all that the Darwinian theory demands.

In a valuable paper by Mr. Alexander Agassiz, published in 1879 in the Bulletin of the Museum of Comparative Zoölogy,[2] the author points out that the South American continent, in comparatively recent geological times, had connection with the West India islands through two lines: (1) one along a belt from the Mosquito Coast to Jamaica, Porto Rico, and

[1] Heilprin, Bermuda Islands, p. 44. 1889.

[2] An abstract of the paper is contained in the American Journal of Science, 1880, xviii. 230.

Cuba; and (2) the other through Trinidad to Anguilla, of the Windward Islands. He sustains the conclusion by a review of the soundings made by the steamer "Blake" under the command of J. R. Bartlett, U. S. N., and a consideration of the facts connected with the distribution of marine and terrestrial species. As the soundings show, the former of the two connections requires for completeness an elevation of the region amounting to 4,060 feet over the part south of Jamaica, 4,830 feet between Jamaica and Hayti, and 5,240 feet between Hayti and Cuba. The other line of connection requires an elevation of 3,450 feet. An open channel, as he observes, would thus be left between Anguilla and the Virgin Islands, where there is now a depth of 6,400 feet. The close relations in the existing fauna of the Gulf to that of the Pacific waters prove that it continued to be a salt-water gulf through the era of elevation.

Mr. Agassiz infers that the connection of the West India islands with South America existed before the Quaternary era. But there are other facts which seem to prove that it was continued into, or at least was a fact, in the Quaternary.

The opinion as to a connection of the Windward Islands with South America in the Quaternary was presented by Prof. E. D. Cope in 1868 (and earlier, as he states, by Pomel), on the ground of the discovery in the caves of Anguilla of a species of gigantic rodent related to the chinchilla, as large as the Virginia deer, and nearly equalling the Quaternary *Castoroides* of Ohio.[1] Further, De Castro, as cited by Dr. J.

[1] Proceedings of the Academy of Natural Sciences of Philadelphia, 1868, 313, and of the American Philosophical Society, Philadelphia. 1869, 183; also Smithsonian Contributions to Knowledge, 30 pp. 4to with 5 plates, Washington, 1883. The last paper (prepared in 1878) contains descriptions of the following species from the Anguilla bone-cave: *Amblyrhiza inundata* Cope (the large rodent announced in 1869), *A. quadrans* Cope, *A. latidens* Cope, an Artiodactyl, apparently of the *Bovidæ* and a little smaller than *Ovis aries*. With them was obtained an implement ("a spoon-shaped scraper or chisel") made of the lip of the large *Strombus gigas*.

Leidy in his "Mammalian Fauna of Dakota and Nebraska." 1869, announced, in 1865, a gigantic sloth of the Quaternary, from Cuba, which he referred to the genus *Megalonyx*, and Dr. Leidy named *Megalocnus rodens*, proving a Quaternary connection between the continent and Cuba.

The fact of an elevated condition of the region sufficient to make Cuba and Anguilla part of the continent during the earlier Quaternary, if not in the Pliocene also, is thus made quite certain. This is fully recognized by Wallace.[1] Such a condition could hardly have existed without a large elevation also of Florida, though probably not, as Mr. Agassiz holds, to the full amount of the depression between it and Cuba — nearly 3,000 feet — because Cuba is most closely related in fauna to South America. The subsidence which brought the region to the present level was consequently within the coral-reef period. It is hence hardly to be doubted that the making of the Florida, Bahama, and other West India coral reefs was going on during the progress of a great subsidence. None of the facts mentioned by observers are opposed to this view.

On this point Mr. Heilprin says:[2] —

"Dr. Supan, in reviewing Professor Dana's paper in the American Journal of Science for 1885,[3] criticises the views relative to subsidence in the Floridian region, since it is claimed that even if direct connection did exist between the West Indian Islands and the southern continent, there is no proof that this connection extended northward to the North American continent; and he further denies — without, however, giving any reason for his denial — that there ever was any (Quaternary ?) connection between the West Indies and

[1] Geographical Distribution of Animals, ii. 60, 78.

[2] "The Bermudas," 227.

[3] Petermann's Mittheilungen, vol. xxxii. pl. 1; Litteraturbericht, p. 5. 1886.

North America. This notion is probably based upon the old idea (advanced by L. Agassiz and Le Conte) of the making of the Floridian peninsula, in which no movements of either elevation or subsidence were supposed to have been involved. Since, however, this conception has proved to be a myth, there is no further reason, except so far as the case may be supported by fact, to adhere to the old views of continental (or oceanic) stability in this region. My own observations have conclusively proved a peninsula uplift as late as the Post-Pliocene period, and extending as far south as Lake Okeechobee. But I am by no means convinced, as I have elsewhere stated (in chapter on the Coral-reef Problem) that a nearly simultaneous subsidence did not take place in (and from) what are now known as the straits of Florida. The existence of such a subsidence (*Bruch*) is considered likely by Suess[1] who has paralleled it with (a supposed) similar occurrence in the eastern basin of the Mediterranean. This view of the formation of the deep Gulf-channel, I must confess, appears to me far more captivating than that which ascribes it to the wash of the Gulf-current."

Mr. Heilprin brings forward, also, additional evidence of great weight.

"But I believe direct evidence pointing to (although by no means proving) a former connection between the Floridian peninsula and the mainland is not wanting. In a paper on 'The Value of the "Nearctic," as one of the Primary Zoölogical regions,' published in the Proceedings of the Academy of Natural Sciences of Philadelphia for 1882, I pointed out certain facts in favor of considering the lower portion of the peninsula as part of the Neotropical rather than the Nearctic realm; more recent zoölogical researches have still further

[1] Antlitz der Erde, vol. i.

demonstrated the correspondence existing between this southern fauna and that of the tract lying to the south. But more significant is the finding of the large assemblage of mammalian remains which have been lately brought to light from various parts of the peninsula. These have been determined by Dr. Leidy[1] to be the skeletal parts of the elephant, mastodon, llama, rhinoceros, tapir, Hippotherium, the sabre-toothed tiger (Machærodus), Glyptodon, etc. Neither the Sabre-tooth nor the Glyptodon, both of which are so closely related to the commoner South American forms as to be barely distinguishable from them, have heretofore been found in the southern United States. Of course they may yet be found, and indicate a passage over from South America by way of Mexico and the southern United States. But the great abundance of these remains on the Floridian peninsula, and their absence, either in whole or part, from the Gulf States, are facts which, so far as they go, point to a former direct land-connection across what is now an arm of the Gulf."

CONCLUSION. — With the theory of abrasion and solution to make lagoon-basins and the deep channels inside of barriers incompetent, and also that of current-drift, all the hypotheses of objectors to Darwin's theory are alike weak; for they have made these processes their reliance, whether appealing to a calcareous, or volcanic, or pelagic-growth, or mountain-peak basement for the structure. The subsidence which the Darwinian theory requires has not been opposed by the mention of any fact at variance with it, nor by setting aside the arguments in its favor; and it has found new support in the facts from the "Challenger's" soundings off Tahiti that had been put in array against it, and strong corroboration in the evidences of subsidence from the West Indies.

[1] Leidy, Proceedings of the Academy of Natural Sciences of Philadelphia, 1884–1889.

Darwin's theory, therefore, still remains as the theory that accounts for the origin of atolls and barrier islands, which is not true of any other that has been proposed. Fringing reefs and isolated coral-reef banks may form in shallow water within the growing depths of reef-making corals, and on any kind of bottom. But atolls, barrier-reefs, and coral formations of great thickness require, as a rule, the aid of slow subsidence, — as has been true for nearly all the thick rock formations over the continents.

V. — THE COMPLETED ATOLL.

The atoll, a quiet scene of grove and lake, is admirably set off by the contrasting ocean. Its placid beauty rises to grandeur when the storm rages, and the waves foam and roar about the outer reefs; for the child of the sea still rests quietly, in unheeding and dreamy content. This coral-made land is firm, because as has been already explained, it is literally *sea-born*, it having been built out of sea-products, by the aid of the working ocean. And so with the groves: they were planted by the waves; and hence the species are those that can defy the encroaching waters, and meet the various conditions in which they are placed. The plants therefore take firm hold of the soil, and grow in all their natural strength and beauty.

Only an occasional coral island has a completely encircling grove, and is hence a model atoll. But the many in which a series of green islets surround the lagoon are often but little less attractive, especially when the several islets present varied groupings of palms and other foliage. To give perfection to the coral island landscape there ought to be, here and there, beneath the trees, a pretty cottage or villa, and other marks of taste and intelligence; and now and then a barge should be seen gliding over the waters. As it is, the inhabitants are swarthy and nearly naked savages, having little about them that is pleasant to contemplate; and their canoes with a clumsy outrigger to keep them right side up, as well as their thatched huts, are as little in harmony as themselves with Nature's grace and loveliness.

Where the islets of a coral reef are heaped up blocks of coral rock, blackened with lichens, and covered with barely enough of trailing plants and shrubs to make the surface green in the distant view, the traveller, on landing, would be greatly disappointed. But still there is enough that is strange and beautiful, both in the life of the land and sea, and in the history and features of the island, to give enjoyment for many a day.

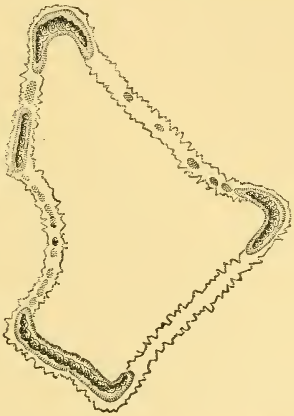
The great obstacle to communication with a majority of atolls, especially the smaller, is the absence of an entrance to the lagoon, and hence of a good landing-place. In that case landing can be effected only on the leeward side, and in good weather; and best, when the tide is low. Even then, the sea often rolls in, so heavily, over the jagged margin of the reef, that it is necessary for the boat to take a chance to mount an in-going wave and ride upon it over the line of breakers, to a stopping-place somewhere on the reef or shore-platform.

Less easy is the return through the breakers, especially if the sea has risen during the ramble ashore. The boat, in order to get off again, would naturally take one of the narrow channels or inlets indenting the margin of the reef. But, with the waves tumbling in one after another, roughly lifting and dropping it, as they pass, and with barely room between the rocks for the oars to be used, there is a fair chance of its being dashed against the reefs to its destruction, or thrown broadside to the sea and swamped under a cataract of waters.

COCOANUT GROVE AT FAKAAFO OR BOWDITCH I.

If another boat with its crew were lying at the time off the reef, a line, carried to it through the surf by an expert swimmer, might prove a means of rescue:—and so, in 1840, we safely reached our ship. To those approaching such a shore in a boat, prudence would give the advice—first, drop, some distance outside of the breakers, a kedge or anchor, for aid both in landing on, and leaving, the reef. But the bottom off a coral island is often bad anchoring ground. And then, if the kedge thus planted holds firm, in spite of the jerking waves, well and good. If not ——.

The accompanying plate represents a scene on Bowditch or Fakaafo Island, sketched by Mr. A. T. Agate, one of the artists of the Wilkes Exploring Expedition, and copied from Volume V. of Wilkes's Narrative of the Expedition. This island is

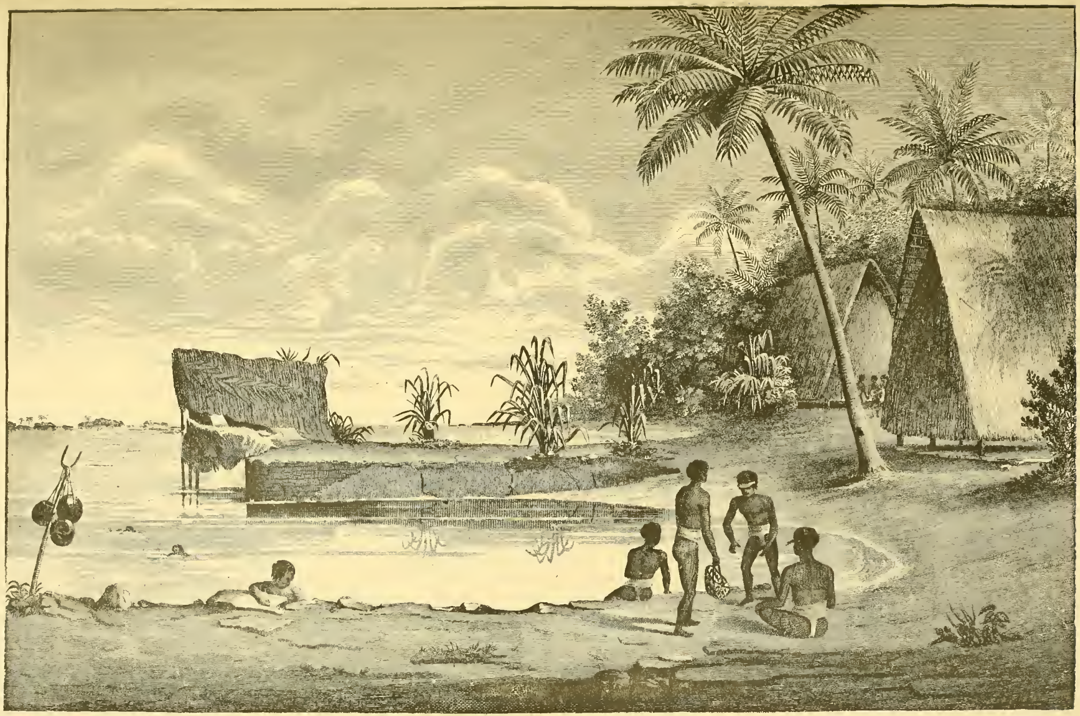


FAKAAFO, OR BOWDITCH ISLAND.

the easternmost of three small atolls, situated to the north of the Samoan or Navigator Group, near the parallels of $8\frac{1}{2}°$, $9°$, and $9\frac{1}{2}°$ S., and between the meridians of $171°$ and $172\frac{1}{2}°$ W., and has already been described (p. 168). The grove of cocoanut trees contains the sacred or public house of the island—a well-made structure measuring fifty feet by thirty-five in length and breadth, and twenty feet in height. In front of the building stands the deity of the place, consisting of a block of stone fourteen feet high, enveloped in mats; and also near by, a smaller idol, partially covered with matting. In the left corner there is a young cocoanut palm—usually a more beautiful object than the full-grown tree.

This island and the two others near it were among the few, perhaps the last, examples that remained until 1840, of Pacific lands never before visited by the white man. The people therefore were in that purely savage state which Captain Cook found almost universal through the ocean in the latter part of last century. A few words respecting our reception at this coral island, may not, therefore, be an improper digression.

The islanders knew nothing of any other land or people: —an ignorance not surprising, since the lagoons of the group have no good entrances, and a nation cannot be great in navigation or discovery without harbors. As a consequence, our presence was to them like an apparition. The simple inhabitants took us for gods from the sun, and, as we landed, came with abundant gifts of such things as they had, to propitiate their celestial visitors. They, no doubt, imagined that our strange ship had sailed off from the sun when it touched the water at sunrise, or sunset, and any child among them could see that this was a reasonable supposition. The king, after embracing Captain Hudson, as the latter states in his Journal (Wilkes's Narrative), rubbed noses, pointed to the sun, howled, moaned, hugged him again and again, put a mat around his waist, securing it with a cord of human hair, and



SCENE AT [illegible] ISLAND

repeated the rubbing of noses and the howling; and the moment the captain attempted to leave his side, he set up again a most piteous howl, and repeated in a tremulous tone, "Nofo ki lalo, mataku au," "Sit down, I am afraid." While thus in fear of us, they showed a great desire that their dreaded visitors should depart; some pointed to the sun, and asked by their gestures about our coming thence, or hinted to us to be off again.

But with all their reverence toward their mysterious guests, they became after awhile quite familiar, and took advantage of every opportunity to steal from us. Our botanist gave his collecting-box to one of them to hold, and, the moment his back was turned, off the native ran, and a hard chase was required to recover it—a most undignified run on the part of the celestial.

While the men wore the maro, the equivalent of tight-fitting breeches six inches or less in length, the women were attired in a simple bloomer costume, consisting solely of a petticoat or apron, twelve to eighteen inches long, made of a large number of slit cocoanut leaves, and kept well oiled. Besides this they had on, as ornaments, necklaces of shell or bone. The girls and boys were dressed *au naturel*, after the style in the garden of Eden. These primitive fashions, however, were not peculiar to the group, being in vogue also in other parts of the Pacific.

As a set-off against the geographical ignorance of these islanders, we may state that Captain Hudson and the best map-makers of the age knew nothing of the existence of Bowditch Island until he discovered it; and from him comes the name it bears, given in honor of the celebrated author of "Bowditch's Navigator" as well as of the translation of Laplace's Mécanique Céleste.

The annexed plate—also from Wilkes's Narrative, Vol. V.

—represents a scene on Duke of York's Island, another of the same solitary group of atolls. The view was taken on the lagoon side, and exhibits the placid lake, the border of verdure far away in the distance, and, near by, the margin of a native village beneath its cocoa-nut grove. A few young plants of the Pandanus stand along the point. The houses are like those of other islands to the west and northwest. The point in front of the village is one of three small quays, two feet out of water. The house, resting partly upon it and partly on poles in the water, and thatched with leaves of the Pandanus, was apparently a shelter for canoes and fishing-tackle.

The Gilbert Group affords an example of a less isolated coral-island people. A beautiful view representing a part of the village of Utiroa, on Drummond's Island, is contained in the same volume of Wilkes's Narrative with the preceding. The public-house of the island is even larger than that on Bowditch's Island, measuring one hundred and twenty feet in length, forty-five feet in width, and forty in height to the ridge-pole. This island, unlike the Duke of York's, was densely peopled, and, owing apparently to the scant supply of fish and vegetables thus occasioned, many of the natives were afflicted with leprosy, and also had bad teeth, both circumstances unusual for the Pacific. Lean in body and savage in look and gesture, they strangely contrasted with their fat, jolly kinsmen on some of the more northern islands of the same group. An old, fat chief who came from one of these islands to the ship's side in his canoe was actually too large to have reached the deck except by the use of a tackle. It was evident that infanticide—a necessity according to their system of political economy—was more thoroughly practised than on Drummond's Island, and that the population was thus kept from becoming uncomfortably numerous. The obesity was

UTIROA.

probably owing to their having nothing to do, and plenty, in the vegetable way, to eat; for these equatorial islands, somewhat elevated, as elsewhere observed, are unusually productive for atolls,—just the place for a voluptuous barbarian.

The people on Drummond's Island were great thieves, and knew the pleasures of a cannibal feast. Without metals, or any kind of hard stone, they make, out of the teeth of the sharks caught about the reefs, a sharp, jagged edging for long knives, swords and spears; and the women, jealous of one another, sometimes, as Mr. Hale says, carry about with them for months a small weapon of shark's teeth concealed under their dress, watching for an opportunity to use it; and desperate fights sometimes take place. The same author mentions, also, some good points in them: observing that the women are, for the most part, better treated than is common among uncivilized people; that the men do the hard out-door work, while the women clear and weed the ground, and attend to the domestic duties that naturally fall to them. "Custom also requires that when a man meets a female he shall pay her the same mark of respect that is rendered to a chief, by turning aside to let her pass,"—a rule that probably does not always hold in practice. He adds: "The word *manda* signifies among the Gilbert Islanders a man thoroughly accomplished in all their knowledge and arts, and versed in every noble exercise; a good dancer, an able warrior, one who has seen life at home and abroad, and enjoyed its highest excitements and delights—in short, a complete man of the world. In their estimation this is the proudest character to which any person can attain; and such a one is fully prepared to enter, at his death, on the highest enjoyments of their elysium."

Thus much for the human productions of coral islands.

Coral islands are exposed to earthquakes and storms like the continents, and occasionally a devastating wave sweeps across the land. During the heavier gales, the natives sometimes secure their houses by tying them to the cocoanut trees, or to a stake planted for the purpose. A height of ten or twelve feet, the elevation of their land, is easily overtopped by the more violent seas; and great damage is sometimes experienced. The still more extensive earthquake-waves, such as those which have swept up the coast of Spain, Peru, and the Sandwich Islands, would produce a complete deluge over these islands. We were informed by both Grey and Kirby that effects of this kind had been experienced at the Gilbert Islands; but the statements were too indefinite to determine whether the results should be attributed to storms, or to this more violent cause.

But while coral islands have their storms, the region in their vicinity is generally one of light winds and calms, even when the trades are blowing strongly all around them. The heated air which rises from the islands lifts the currents to a considerable height above the island. J. D. Hague mentions that on Jarvis' and the two neighboring islands, under the equator, near 180° in longitude from Greenwich, he "often observed the remarkable phenomenon of a rain squall approaching the island, and, just before reaching it, separating into two parts, one of which passed by on the north, the other on the south side, the cloud having been cleft by the column of heated air rising from the white coral sands."

An occasional log drifts to the shores, and at some of the more isolated atolls, where the natives are ignorant of any land but the spot they inhabit, they are deemed direct gifts from a propitiated deity. These drift-logs were noticed by Kotzebue, at the Marshall Islands, and he remarked also that they often brought stones in their roots. Similar facts have been observed at the Gilbert Group, and also at Enderbury's Island, and many other coral islands in the Pacific. The stones at the Gilbert Islands, as far as could be learned, are generally basaltic or volcanic, and they are highly valued among the natives for whetstones, pestles, and hatchets. The logs are claimed by the chiefs for canoes. Some of the logs seen by the author, like those of Enderbury's Island, were forty feet or more long. Several large masses of compact cellular lava occur on Rose Island, a few degrees east of the Navigator Group; they were lying two hundred yards inside of the line of breakers. The island is uninhabited, and the origin of the stones is doubtful; they may have been brought there by roots of trees, or perhaps by some canoe.

Fragments of pumice and resin are transported by the waves to many of the islands in the Central Pacific. We were informed at the Gilbert Islands that the pumice was gathered from the shores by women and pounded up to fertilize the soil of their taro patches; and that it is common for a woman to pick up a peck a day.

Where this pumice comes from is not ascertained. It is probably drifted from the westward, and perhaps from volcanic islands of the Ladrones or Phillipines. In addition, volcanic ashes are sometimes distributed over these islands, through the atmosphere. In this manner the soil of the Tonga Islands has been improved, and it may thus have derived its reddish color. This group has its own active volcano to supply the ashes, and the volcanic group of the New Hebrides is not far distant to the southwest.

The mineralogy of an atoll is usually confined to one species, — calcite, or carbonate of lime, — the material of the coral rock. On some of the smaller islands, in the drier equatorial part of the ocean, there are, in addition to this and the stones brought by logs with the floating pumice, beds of gypsum which have been made through the evaporation of sea-water (which holds it in solution) in the gradually drying lagoon-basins; and also large deposits of guano from the multitudes of sea birds that occupy them. Such are Jarvis, Baker's, Howland's, Malden's, McKean's, Birnie's, Starbuck's, Enderbury's, and probably other islands in the dry central Pacific (Plate IX. and p. 168). As these deposits are connected with the completion of the coral island and its accompanying reduction in size, and illustrate one of the ways by which new minerals are added to a destitute land, a few facts are here cited from an article in the "American Journal of Science," volume xxxiv. (1862), by J. D. Hague, who resided for several months on the islands he describes.

Baker's Island is situated in lat. 0° 13′ north, and long. 176° 22′ west from Greenwich, and, excepting Howland's Island, forty miles distant, is very remote from any other land. It is about one mile long and two thirds of a mile wide. The surface is nearly level; the highest point is twenty-two feet above the level of the sea, showing some evidence of elevation.

Above the crown of the beach there is a sandy ridge which encircles the guano deposit. This marginal ridge is about one hundred feet wide on the lee side of the island, and is there composed of fine sand and small fragments of corals and shells, mixed with considerable guano; on the eastern, or windward, side it is much wider, and formed of coarser fragments of corals and shells, which, in their arrangement, present the appearance of successive beach formations. Encircled by this ridge lies the guano deposit, occupying the central and greater part of the island. The surface of this deposit is nearly even, but the hard coral bottom which forms its bed has a gradual slope from the borders toward the centre, or, perhaps more properly, from northwest to southeast, giving the guano a variable depth from six inches at the edges to several feet.

Howland's Island is situated in lat. 0° 51′ north, and long. 176° 32′ west from Greenwich. It is about a mile and a half long by half a mile wide, containing, above the crown of the beach, an area of some four hundred acres. The highest point is seventeen feet above the reef, and ten or twelve feet above the level of high tide. The general features of the island resemble those of Baker's.

The main deposit of guano occupies the middle part of the island, and stretches, with some interruptions of intervening sand, nearly from the north to the south end. Its surface is even, and in many places covered by a thick growth of purslane, whose thread-like roots abound in the guano where it grows. The deposit rests on a hard coral bottom, and varies in depth from six inches to four feet. The fact observed at Baker's that vegetation flourishes most where the guano is shallow, is also quite apparent here, and the consequent characteristic difference between the guano of the deep and shallow parts is distinctly marked.

Some interesting pseudomorphs occur buried in the guano of this island. Coral fragments of various species were found that had long been covered up under the deposit, and in some of which the carbonic acid had been almost entirely replaced by phosphoric acid. In such I have found seventy per cent of phosphate of lime. In many others the change was only partial, and, on breaking some of these, in the centre was usually found a nucleus or *core* of coral.

Jarvis Island is situated in lat. 0° 22′ south, and long. 159° 58′ west from Greenwich. It is nearly two miles long by one mile wide, and contains about 1,000 acres. Like Baker's and Howland's, it has the general features of a coral island, but it differs from them essentially in the fact that the lagoon, which it once contained, has gradually been filled up with sand and detritus, while the whole island has undergone some elevation. It therefore presents a basin-like form, the surface being depressed from the outer edge toward the centre. It is encircled by a fringing reef, or shore platform, about three hundred feet wide; from this a gradually sloping beach recedes, the crown of which is from eighteen to twenty-eight feet high, forming a ridge or border, of varying width, which surrounds the island like a wall, from the in-shore edge of which the surface of the island is gently depressed.

Within this depression there are other ridges, parallel to the outer one, and old beach lines and water marks, the remaining traces of the waters of the lagoon, marking its gradual decrease and final disappearance.

This flat depressed surface in the centre of the island is about seven or eight feet above the level of the sea. It bears but little vegetation, consisting of long, coarse grass, Mesembryanthemum, and Portulaca, and this is near the outer edges of the island, where the surface is formed of coral sand, mixed with more or less guano. In the central and lower parts the surface is composed of sulphate of lime (gypsum), and it is on this foundation that the principal deposit of guano rests.

In examining the foundation of the guano deposit on Baker's or Howland's Island by sinking a shaft vertically, the hard conglomerate reef-rock is found directly underlying the guano. Resting on this foundation the guano has undergone only such changes as the climate has produced. On Jarvis Island, however, after sinking through the guano, one first meets with a stratum of sulphate of lime (sometimes compact and crystalline, sometimes soft and amorphous) frequently two feet thick, beneath which are successive strata of coral sand and shells, deposited one above the other in the gradual process by which the lagoon was filled up. These horizontal strata were penetrated to a depth of about twenty feet. They were composed chiefly of fine and coarse sand with an occasional stratum of coral fragments and shells.

Of the origin of this sulphate of lime there can hardly be any doubt. As the lagoon was nearly filled up, while, by the gradual elevation of the island, the communication between the outer ocean and the inner lake was constantly becoming less easy, large quantities of sea-water must have been evaporated in the basin. By this means deposits would be formed containing common salt, gypsum, and other salts found in the waters of the ocean. From these the more soluble parts would gradually be washed out again by the occasional rains, leaving the less soluble sulphate of lime as we find it here.

Some additional light is thrown on this matter by the different parts of the surface, which, though nearly flat, shows some slight variety of level. The higher parts, particularly around the outer edges, are composed chiefly of coral sand, either mixed with or underlying guano. Nearer the centre is a large tract, rather more depressed, forming a shallow basin, in which the bulk of the sea-water must have been evaporated, the surface of which (now partly covered with guano) is a bed of sulphate of lime, while, further, there is a still lower point, the least elevated of the whole, where the lagoon waters were, without doubt, most recently concentrated. This latter locality is a crescent-shaped bed, about six hundred feet long by two hundred or three hundred feet wide, having a surface very slightly depressed from the outer edge toward the middle. Around the borders are incrustations of crystallized gypsum and common salt, ripple-marks, and similar evidences of the gradually disappearing lake. The whole is composed of a crystalline deposit of sulphate of lime, which, around the borders, as already observed, is mixed with some common salt, while near the centre, where rain water sometimes collects after a heavy shower, the salt is almost entirely washed out, leaving the gypsum by itself. It is closely, but not hard, packed, and is still very wet. By digging eighteen to twenty-four inches down, salt water may generally be found.

These facts help us to understand the varying conditions in which we now find the guano beds. The most important part, and that from which the importations have thus far come, rests on a bed of sulphate of lime, of an earlier but similar origin to that just described above; part rests on a coral formation; while still another part, covering a large tract, has been by the action of water mixed with coral mud.

The first named deposit, lying on the sulphate of lime bed, has a peculiar character. It is covered by, or consists of, a hard crust, that is from one-fourth of an inch to an inch and a half in thickness, beneath which lies a stratum of guano, varying in depth from one inch to a foot. In many places where the guano was originally shallow, the whole is taken up and formed into the hard crust which then lies immediately on the sulphate. This crust, when pure, is snow-white, with an appearance somewhat resembling porcelain, but is usually colored more or less by organic matter. Generally it is very hard, and strongly cohesive, though sometimes friable, and it lies unevenly on the surface in rough fragments that are warped and curved by the heat of the sun. It consists chiefly of phosphoric acid and lime, but, owing to the variable amount of sulphate of lime with which it is mechanically mixed, there is a lack of uniformity in different samples. Hence the percentage of phosphoric acid varies from over fifty per cent to less than thirty per cent.

The gypsum, or sulphate of lime, is usually soft and amorphous, sometimes crystalline, and, at a depth of eighteen inches to two feet, occurs in hard, compact, crystalline beds. It is of a light snuff color, and where it underlies guano, is mixed with considerable phosphate of lime, which has been washed down from the surface. Similar deposits of sulphate of lime occur on many other elevated lagoon islands of the Pacific.

Starbuck's, Starve, or Hero Island is an elevated atoll, and is worthy of mention, because like Jarvis, McKean's, and other islands of similar structure, it contains a large deposit of gypsum. Its supposed guano I have found to consist of the hydrated sulphate of lime, containing about twelve per cent of phosphate of lime, and colored by a little organic matter. So far as my observation extends, all elevated lagoons have similar deposits of gypsum.

As regards the distribution of these phosphatic guano deposits, I believe them, in this region of the Pacific, to be confined to latitudes very near the equator, where rain is comparatively of rare occurrence. In latitudes more remote from the equator than 4° or 5°, heavy rains are frequent, and this circumstance is not only directly unfavorable to the formation of guano deposits, but it encourages vegetation, and when an island is covered with trees and bushes, the birds prefer to roost in them, and there is no opportunity for the accumulation of guano deposits.

An article in the same Journal (vol. xl., 1865), by A. A. Julien, gives an account of the various phosphatic minerals formed from the guano deposits on a coral island, Sombrero, in the Caribbean Sea.

Lord Byron, of the "Blonde," mentions that phosphate of lime (apatite) was collected by him on Mauke, an elevated coral island of the Hervey Group, west of the Society Islands, but its exact condition in the rock is not stated.

Water is to be found commonly in sufficient quantities for the use of the natives, although the land is so low and flat. They dig wells five to ten feet deep in any part of the dry islets, and generally obtain a constant supply. These wells are sometimes fenced around with special care; and the houses of the villagers, as at Fakaafo, are often clustered about them. On Aratica (Carlshoff) there is a watering place fifty feet in diameter, from which vessels of the Wilkes Exploring Expedition obtained three hundred and ninety gallons. The Gilbert Islands are generally provided with a supply sufficient for bathing, and each native takes his morning bath in fresh water, which is esteemed by them a great luxury. On Tari-tari (of the Gilbert Group, p. 165), as Mr. Horatio Hale, philologist of the same expedition, was informed by a Scotch sailor by the name of Grey, taken from the island, there is a trench or canal several miles long, and two feet deep. They have taro plantations (which is possible only where there is a large supply of water), and besides some bread-fruit. He spoke of the taro as growing to a very large size, and as being in great abundance; it was planted along each side of the pond. Grey added further that ten ships of the line might water there, though the place was not reached without some difficulty. There were fish in the pond which had been put in while young. The bottom was adhesive like clay. These islands have been elevated a little, but are not over fifteen feet above the sea.

Kotzebue observes, that "in the inner part of Otdia (one of the Marshall Islands) there is a lake of sweet water; and in Tabual, of the Group Aur, a marshy ground exists. There is no want of fresh water in the larger islands; it rises in abundance in the pits dug for the purpose." (*Voyage*, London, 1821, iii. 145.)

The only source of this water is the rain, which, percolating through the loose sands, settles upon the hardened coral rock that forms the basis of the island. As the soil is white or nearly so, it receives heat but slowly, and there is consequently but little evaporation of the water that is once absorbed.

Water is sometimes obtained by making a large cavity in the body of a cocoanut tree, two feet or so from the ground. At the Duke of York's Island, and probably also at the adjacent Bowditch Island, this method is put in practice; the cavities hold five or six gallons of water.

The extensive reefs about coral islands, as already stated, abound in fish, which are easily captured, and the natives, with wooden hooks, often bring in larger kinds from the deep waters. From such resources a population of seven thousand persons is supported on the single island of Taputeuea, whose whole habitable area does not exceed six square miles.

There are also shell-fish of edible kinds, and others that are the source of considerable activity in pearl-fishing.

Although the vegetation of coral islands has the luxuriance that characterizes more favored tropical lands, the number of species of land plants is small. A work on the "Botany of the Paumotus" would contain descriptions of only twenty-eight or thirty species. The most common kinds are the following:—

Portulaca oleracea, L. (lutea of *Solander*).
Triumfetta procumbens, *Forst.*
Tournefortia argentea, *L.*
Scævola Konigii, *Vahl.*
Ipomæa longiflora, *R. Br.*
Lepidium piscidium, *Forst.*
Pemphis acidula, *Forst.*
Pandanus odoratissimus, *L. f.*
Pisonia grandis, *Parkinson.*
Morinda citrifolia, *L.*
Guettarda speciosa, *L.*
Cassytha filiformis, *L.*
Gouldia Romanzoffiensis, *A. Gr.*
Euphorbia Chamissonis, *Boiss.*
Boerhavia diffusa, *L.*
Boerhavia hirsuta, *Wild.*
Achyranthes canescens, *R. Br.*
Heliotropium prostratum, *R. Br.*
Nesogenes euphrasioides, *A. DC.*
Asplenium Nidus, *L.*
A polypodium, and a species of grass.

Still, there is a better supply than might be supposed. For the cocoanut, in view of its uses, is a dozen trees in one. Its trunk furnishes timber for the houses of the natives, and the best of wood, on account of its weight and strength, for clubs and spears, — weapons much in use, besides serving as ornamental side-arms. Its leaves supply material for thatching; for coarse matting to sit on, and beautiful fine mats for use in the way of occasional dress; also for the short aprons or petticoats of the women, above alluded to. The fruit, besides its delicately flavored hollow kernel, affords, by the grating of this kernel, a milky juice that is richer than cream for purposes of native cookery, and which we explorers often used with satisfaction in coffee, cows being unknown in those regions; also, from each nut, a pint of the thinner "cocoanut milk," a more agreeable drink in the land of cocoanuts than in New York; also an abundant oil, much valued for sleeking down their naked bodies, and sometimes offered to a friendly visitor whom they would honor with a like anointing. Further, from the young fruit, three fourths grown, comes a delightful beverage as brisk nearly as soda-water, besides a rich creamy pulp; both of these far better than the corresponding products of the ripe fruit. The husk is excellent for cordage, twine, thread, fishing-lines; and the smaller cord serves in place of nails for securing together the beams of their domestic and public buildings, and also for ornamenting the structure within, the cord being often wound with much taste and diversity of figures. The nut, when opened, is a ready-made drinking-cup or cooking utensil. Finally, the developing bud, before blossoming, yields a large supply of sweet juice, from which molasses is sometimes made, and then, by fermentation, a spirituous liquor, called among the Gilbert Islanders by a name that sounded very much like toddy, and possessing qualities that answer to the name; but this is procured at the expense of the fruit, and the good of the tree, and also of the best interests of the natives.

It is doubted whether the ocean is ever successful in planting the cocoanut on coral islands. The nut seems to be well fitted for marine transportation, through its thick husk, which serves both as a float and a protection; but there is no known evidence that an island never inhabited has been found supplied with cocoanut trees. The possibility of a successful planting by the waves cannot be denied; but there are so many chances that the floating nut will be kept too long in the water, or be thrown where it cannot germinate, that the probability of a transplanting is exceedingly small. This palm — the *Cocos nucifera* of the botanists — is not included in the above list of native Coral Island plants.

Another tree, peculiarly fitted for the region, is the Pandanus or *Screw-Pine* — well named as far as the syllable *screw* goes, but having nothing of a *pine* in its habit. Its long sword-like leaves, of the shape and size of those of a large Iris, are set spirally on the few awkward branches toward the extremity of each, and make a tree strikingly tropical in character. It grows sometimes to a height of thirty feet. It is well fitted for the poor and shallow soil of a coral island; for, as it enlarges and spreads its branches, one prop after another grows out from the trunk and plants itself in the ground; and by this means its base is widened and the growing tree supported. The fruit, a large ovoidal mass made up of oblong dry seed diverging from a centre, each near two cubic inches in size, affords a sweetish husky article of food, which, though little better than prepared corn stalks, admits of being stored away for use when other things fail; and at the Gilbert Islands and others in that part of the ocean it is so employed.

The Pisonia is another of the forest trees, and one of handsome foliage and large beautiful flowers, sometimes attaining a height of forty feet, and the trunk a girt of twenty feet.

Among the species that are earliest in taking root in the emerging coral debris over the reef, there are the *Portulaceæ* (species of purslane); the *Triumphetta procumbens*, a creeping, yellow-flowering plant of the Tilia family; the *Tournefortia sericea*, a low, hoary shrub of the family *Borraginaceæ*, and *Scævola Konigii*, a sub-fleshy seashore plant.

On Rose Island, just east of the Navigator Group, Dr. C. Pickering, of the Wilkes Exploring Expedition, found only a species of *Pisonia* and of *Portulaca*. This is a small atoll, under water at high-tide, excepting two banks, one of which is covered with trees.

In the Marshall Group, on the contrary, where the vegetation is more varied, and the islands have probably undergone some elevation since they were made, Chamisso observed fifty-two species of land plants, and in a few instances the banana, taro, and bread-fruit were cultivated. At the elevated coral island, Metia, north of Tahiti (p. 193), 250 feet above the sea, sugar-cane and bread-fruit and many plants of the Society Group occur.

The tropical birds of the islands are often more in keeping with the beautiful scenery about them than the savage inhabitants. On one atoll, — Honden Island, of the Paumotus, — where no natives had ever dwelt, the birds were so innocent of fear, that we took them from the trees as we would fruit; and many a songster lost a tail feather, as it sat perched on a branch, apparently unconscious that the world contained an enemy. Our ornithologist went ashore with powder and shot. But the sportsman could find no pleasure in shooting; indeed he could help himself without.

During a ramble over the island I came across a noble bird as white as snow and nearly as large as an albatross. In my zeal for science I began to contemplate it as a very fine specimen — indeed, a magnificent specimen; and although it was not my special line of research, it seemed a failure of duty to neglect the opportunity to secure it. By a simple process, the work of death is easily accomplished. I went up to him. He stood still, not offering to fly. I commenced to carry out my plan. A slight point of blood soiled the white plumage, and my zeal gave out. It was another's part to serve as executioner, not mine; and stroking down his feathers and wishing him well, I hurried away. But as I glanced back from time to time, on my retreat, there the bird stood, his eye still fixed upon me, and that reproachful look followed me until a far-off grove came in between us. I take it the bird recovered, as I shared not the fate of the "Ancient Mariner."

Ever since, the words of the old Mariner have seemed to rise in melody from that island Paradise: —

"He prayeth well who loveth well
Both man and bird and beast.
He prayeth best, who loveth best
All things both great and small;
For the dear God who loveth us
He made and loveth all."

Mr. J. D. Hague gives an account of the birds of Jarvis and some other uninhabited islands in the equatorial Pacific, in which it appears that, after all, there are evil-doers even among tropical birds. He gives the following facts: —

"From fifteen to twenty varieties of birds may be distinguished among those frequenting the islands, of which the principal are gannets and boobies, frigate birds, tropic birds, tern, noddies, petrels, and some game birds, as the curlew, snipe, and plover. Of Terns there are several species, the most numerously represented of which is what I believe to be the *Sterna hirundo*. These frequent the island twice in the year for the purpose of breeding. They rest on the ground, making no nests, but selecting tufts of grass, where such may be found, under which to lay their eggs. I have seen acres of ground thus thickly covered by these birds, whose numbers might be told by millions. Between the breeding seasons they diminish considerably in numbers, though they never entirely desert the island. They are expert fishers and venture far out to sea in quest of prey. The noddies (*Sterna stolida*) are also very numerous. They are black birds, somewhat larger than pigeons, with much longer wings, and are very simple and stupid. They burrow holes in the guano, in which they live and raise their young, generally inhabiting that part of the deposit which is shallowest and driest. Their numbers seem to be about the same throughout the year. The gannet and booby, two closely allied species (of the genus *Sula*), are represented by two or three varieties. They are large birds, and great devourers of fish, which they take very expertly, not only catching those that leap out of the water, but diving beneath the surface for them. They are very awkward and unwieldy on land, and may be easily overtaken and captured, if indeed they attempt to escape at all on the approach of man. They rest on the trees wherever there is opportunity, but in these islands they collect in great groups on the ground, where they lay their eggs and raise their young. One variety, not very numerous, has the habit of building up a pile of twigs and sticks, twenty or thirty inches in height, particularly on Howlands, where more material of that sort is at hand, on which they make their nest. When frightened, these birds disgorge the contents of their stomachs, the capacity of which is sometimes very astonishing. They are gross feeders, and I have often seen one disgorge three or four large flying-fish fifteen or eighteen inches in length.

"The frigate bird (*Tachypetes aquilus*) I have already alluded to. It is a large, rapacious bird, the tyrant of the feathered community. It lives almost entirely by piracy, forcing other birds to contribute to its support. These frigate birds hover over the island, constantly lying in wait for fishing birds returning from the sea, to whom they give chase, and the pursued bird escapes only by disgorging its prey, which the pursuer very adroitly catches in the air. They also prey upon flying fish and others that leap from sea to sea, but never dive for fish and rarely even approach the water.

"The above are the kinds of birds most numerously represented, and to which we owe the existing deposits of guano. Besides these are the tropic birds, which are found in considerable numbers on Howland's Island, but seldom on Jarvis or Baker's. They prefer the former because there are large blocks or fragments of beach rock scattered over the island's surface, under which they burrow out nests for themselves. A service is sometimes required of this bird, which may, perhaps, be worthy of notice. A setting bird was taken from her nest and carried to sea by a vessel just leaving the island. On the second day, at sea, a rag, on which was written a message, was attached to the bird's feet, who returned to the nest, bringing with it the intelligence of the departed vessel. This experiment succeeded so well that, subsequently, these birds were carried from Howland's to Baker's Island (forty miles distant), and on being liberated there, one after the other, as occasion demanded, brought back messages, proving themselves useful in the absence of other means of communication. The game birds, snipe, plover, and curlew, frequent the islands in the fall and winter, but I never found any evidence of their breeding there. They do not leave the island in quest of prey, but may be seen at low-tide picking up their food on the reef which is then almost dry.

"Some of the social habits of these birds are worthy of remark. The gannets and boobies usually crowd together in a very exclusive manner. The frigate birds likewise keep themselves distinct from other kinds. The tern appropriate to themselves a certain portion of the island; each family collects in its accustomed roosting-place, but all in peace and harmony. The feud between the fishing birds and their oppressors, the frigate birds, is active only in the air; if the gannet or booby can but reach the land and plant its feet on the ground, the pursuer gives up the chase immediately."

Notwithstanding the products and the attractions of a coral island, it is in its best condition but a miserable place for human development, physical, mental, or moral. There is poetry in every feature, but the natives find this a poor substitute for the bread-fruit and yams of more favored lands. The cocoanut and pandanus are, in general, the only products of the vegetable kingdom afforded for their sustenance, and fish, shellfish, and crabs from the reefs their only animal food. Scanty too is the supply; and infanticide is resorted to in self-defence, where but a few years would otherwise overstock the half a dozen square miles of which their little world consists — a world without rivers, without hills, in the midst of salt water, with the most elevated point but ten to twenty feet above high tide, and no part more than three hundred yards from the ocean.

In the more isolated coral islands, the language of the natives indicates their poverty, as well as the limited productions and unvarying features of the land. All words like those for mountain, hill, river, and many of the implements of their ancestors, as well as the trees and other vegetation of the land from which they are derived, are lost to them; and as words are but signs for ideas, they have fallen off in general intelligence. To what extent a race of men placed in such circumstances is capable of mental improvement, would be an interesting inquiry for the philosopher. Perhaps the query might be best answered by another, How many of the various arts of civilized life could exist in a land where shells are the only cutting instruments, — the plants of the land in all but twenty-nine in number, — minerals but one, — quadrupeds none, with the exception of foreign rats or mice, — fresh water barely enough for household purposes, — no streams, nor mountains, nor hills? How much of the poetry or literature of Europe would be intelligible to persons whose ideas had expanded only to the limits of a coral island; who had never conceived of a surface of land above half a mile in breadth, — of a slope higher than a beach, — of a change of seasons beyond a variation in the prevalence of rains? What elevation in morals should be expected upon a contracted islet, so readily over-peopled that threatened starvation drives to infanticide, and tends to cultivate the extremest selfishness? Assuredly there is not a more unfavorable spot for moral or intellectual progress in the wide world than the coral island.

Still, if well supplied with foreign stores, including a good stock of ice, they might become, were they more accessible, a pleasant temporary resort for tired workers from civilized lands, who wish quiet, perpetual summer air, salt-water bathing, and boating or yachting; and especially for those who could draw inspiration from the mingled beauties of grove, lake, ocean, and coral meads and grottoes, where

> "—— Life in rare and beautiful forms
> Is sporting amid the bowers of stone."

Yet after all, the dry land of an atoll is so limited, its features so tame, its supply of fresh water so small, and of salt water so large, that whoever should build his cottage on one of them would probably be glad, after a short experience, to transfer it to an island of larger dimensions, like Tahiti or Upolu, one more varied in surface and productions; that has its mountains and precipices, its gorges and open valleys, leaping torrents not less than surging billows, and forests spreading up the declivities, as well as groves of palms and corals by the shores.

CHAPTER IV.

GEOGRAPHICAL DISTRIBUTION OF CORAL REEFS AND ISLANDS.

THE distribution of coral reefs over the globe depends on the following circumstances, arising from the habitudes of polyps already explained.

1. The temperature of the ocean.

2. The character of coasts as regards (*a*) the depth of water; (*b*) the nature of the shores; (*c*) the presence of fresh-water streams; (*d*) the direction and force of currents.

3. Liability to exposure to destructive agents, such as volcanic heat.

It has been stated (p. 108) that *reef-growing* corals will flourish in the hottest seas of the equator, and wherever the average temperature of the waters of the ocean for the winter is not below 68° F. The isothermal line of this temperature (or isocryme) forms, therefore, the boundary line of the coral-reef seas. Other corals not forming reefs grow in colder seas (p. 109) and at great depths, but to those we do not now refer.

This line traverses the oceans between the parallels 26° and 30°, or in general near 28°. But, as has been stated, it undergoes in the vicinity of the continents remarkable flexures from the influence of oceanic currents, the polar currents bending it toward the equator, while the tropical cause a divergence. From a comparison of the thermometrical observations of various voyages with those of the Expedition, the author has been enabled to draw these boundary lines with a considerable degree of accuracy, and they are laid down on the chart, Plate XVI., from the author's Exploring Expedition Report on Crustacea.

In the Pacific Ocean, this coral boundary, or isocryme of 68°, passes near the Galapagos, but to the south of them, and thus approaches closely if it does not cross the equator, instead of being near the parallel of 28° south, its position in mid-ocean. Captain Fitzroy, R. N., found the surface temperature of the sea at the Galapagos, from Sept. 16 to Oct. 18, 1835, 62° to 70° F., while, under the equator, about the middle of the Pacific, the range of surface temperature of the sea through the year is 81° to 88° F.

Change of level would make great changes in the boundary. Mr. A. Agassiz found modern coral limestone near Tilibiche, Peru, at an elevation of two to three thousand feet; showing that, in the early part of the coral-reef era, the continent on the Pacific side stood this much lower than now, and that then corals were growing on part of its Pacific border.

On the side of Asia the boundary line bends far southward, and reaches the coast of Cochin China within 15° of the equator, although 30° from the equator a little to the eastward. On the west side of the Atlantic, the northern line starts at Cape Florida, in latitude 15° N., stretches abruptly northward, and bends around the Bermudas in latitude 33° N. On the African coast opposite, the northern line curves downward to the latitude of the Cape Verdes, and the southern upward nearly to the equator. The following table gives the positions of the coral boundary lines where they meet the coasts of the continents.

	Pacific Ocean.	Atlantic Ocean.
East side of ocean—Northern,	Lat. 21° N	Lat. 10° N.
Southern.	4° S.	5° S.
West side of ocean—Northern.	15° N.	26° N.
Southern.	30° S., N. Holland. 29° S., Africa.	22° S.

It follows from the above, that while the coral-reef seas are about fifty-six degrees wide in mid-ocean, they are

In the Pacific twenty-five degrees wide on the west coast of America, and forty-five degrees on the Asiatic side.

In the Atlantic about fifteen degrees wide on the African coast, and forty-eight degrees on the coast of America.

If we reckon to the extremity of the bend in the Gulf Stream, the whole width of the coral reef sea off the east coast of America, will be over sixty-four degrees; while off the west coast of America, the width is hardly eighteen degrees. It is obvious that these facts enable us to explain many seeming anomalies in the distribution of coral reefs.

The other causes which influence the distribution of reefs, operate under this more general one of oceanic temperature, that is, within the coral-reef boundary lines. The effect of a deep abrupt coast on the distribution of reefs has been pointed out (p. 114). The unfavorable character of sandy or muddy shores, and the action of detritus, marine currents, and fresh waters have also been stated (p. 119), and it is not necessary to touch again upon these points.

Not less striking are the effects of *volcanic action* in preventing the formation of reefs; and instances of this influence are numerous throughout the Pacific. The existence of narrow reefs, or their entire absence, may often be thus accounted for. For example, in the Hawaiian Group, the island Hawaii, still active with volcanic fires, has but few patches of reef about it, while the westernmost islands, which have been longest free from such action, have reefs of considerable extent. The island of Maui exemplifies well the same general fact. The island consists of two peninsulas: one the eastern, recent volcanic in character, with a large crater at summit, and the other, the western, presenting every evidence, in its gorges and peaks and absence of volcanic cones, of having become extinct ages since. In conformity with the view expressed, the coral reefs are confined almost exclusively to the latter peninsula. Other examples are afforded by the Samoan or Navigator Islands. Savaii abounds in extinct craters and lava streams, and much resembles Hawaii in character; it bears proof in every part of being the last seat of the volcanic fires of the Samoan Group. Its reefs are consequently few and small: there is but a narrow line on part of the northern shores, although on the other islands they are very extensive.

This absence of corals results obviously from the destruction of the zoöphytes by heat, consequent on volcanic action. Submarine eruptions, which are frequent as long as a volcano near the sea is in action, heat the waters and destroy whatever of life they may contain. After the eruption of Kilauea, in 1840, there were numerous dead fish thrown on the beach; and many such instances in different regions are on record.

The agencies affecting the growth of coral reefs being before the mind, we may proceed to notice the actual distribution of reefs through the coral seas. The review given is a rapid one, as our present object is simply to explain the absence or presence of reefs within the coral reef limits, by reference to the above facts.

In the valuable work by Mr. Darwin, the geographical distribution of reefs is treated of at length. The facts here detailed have been obtained from independent sources, except where otherwise acknowledged. In accounting for the character and distribution of reefs, Mr. Darwin appears to attribute too much weight to a supposed difference in the change of level in different regions, neglecting to allow the requisite limiting influence to volcanic agency, and to the other causes mentioned. His conclusion that the areas of active volcanos in general, are areas of elevation, and not of subsidence, and the inference that reefs are absent from the shores of islands of recent volcanic action on this account, do not accord with the facts above stated: for example, the condition of Maui, that it has no reefs on the larger half, that of the volcanic cone of recent action, but has them on the other half whose fires were long since extinct; for it is not probable that one end has been undergoing elevation, and the other subsidence.

Pacific Ocean. — The west coast of South America is known to be without coral reefs even immediately beneath the equator; but the seas of the Galapagos grow some corals. The northward deflection of the coral boundary line accounts, as has been shown, for their absence. In the Bay of Panama, and elsewhere on the coast, north and south, corals occur in patches but no reefs, and this is attributed by Verrill to the rough tides of ten to twelve feet. Corals are living at La Paz, on the Peninsula of California (p. 112).

In Captain Colnett's voyage, allusion is made to a beach of coral sand on one of the Revillagigedo Islands, in latitude 18°, and Clipperton Rock is described as an elevated coral island.

Between the South American coast and the Paumotus are two rocky islands, Easter or Waihu and Sala-y-Gomez, both of which are stated to be without reefs.

Captain Beechey mentions, however, that at forty-one fathoms, near Sala-y-Gomez, he found a bottom of sand and coral.

The Paumotus commence in longitude 130° W., and embrace eighty coral islands, all of which, excepting about eight of small size, contain lagoons. Besides these, there are, near the southern limits of the archipelago, the Gambier Islands and Pitcairn, of volcanic or basaltic constitution. The former in 23° S., have extensive reefs. About the latter, in 25° S., there are some growing corals, but no proper reefs.

The Marquesas, in latitude 10° S., have but little coral about them; and this is the more remarkable, since they are in close proximity to the Paumotus. But their shores are mostly very abrupt, with deep waters close to the rocks. An island which, before subsidence has commenced, has some extent of shallow waters around, might have very bold shores after it had half sunk beneath the waves. This would be the case with the island of Tahiti; for its mountain declivities are in general, singularly precipitous, except at base. The Marquesas may, therefore, have once had barrier reefs, which were sunk from too rapid subsidence; and afterward, on the cessation of the subsidence, others failed to form again on account of the deep waters.

The Society Islands have extensive coral reefs, with distant barriers. The reefs of Tahiti extend, in some parts, a mile from the shores. Tetuaroa, to the north of Tahiti, and Tubuai, near Bolabola, are lagoon islands. Maitea, east of Tahiti, is a sugar loaf truncated at summit, four miles in compass, and is said by Forster to have an encircling reef.

South of the Society Islands, near 25° S., is Rapa, which is represented as a collection of rugged peaks without coral shores. The Rurutu and Hervey Islands, just northwest of

Rapa, have coral reefs fringing the shores. There is no evidence of recent volcanic action among them. Some of them are elevated coral islands, as Mitiaro, Atiu, Mangaia and Mauki, and also, according to Stutchbury, Rurutu. Okatutaia is a low coral island but six or seven feet out of water.

Between the Paumotus and the longitude of Samoa are numerous small islands, all of coral origin.

The Samoan or Navigator Islands have extensive reefs. About Tutuila, owing to its abrupt shores, they are somewhat less extensive than around Upolu, and about Savaii they are still smaller, as already explained. The influence of abrupt shores may also be seen in some parts of Upolu; for example, to the west of the harbor of Falifa, where, for several miles, there is no reef, except in some indentations of the coast. Manua is described as having only shore reefs.

The Tonga Islands, south of Samoa, for the most part abound in coral reefs, and Tongatabu and the Hapai Group are solely of coral. Eoa is a moderately high island, with a narrow reef. Tafoa an active volcano, and Kao, an extinct cone, are *without* reefs. Vavau, according to Williams (*Miss. Enterprises*, p. 427, Amer. ed.), is an elevated coral island. Pylstaarts, near Eoa, is a naked rock, with abrupt shores, and little or no coral. Sunday Island, farther south (29° 12′ S.), is beyond the coral-reef limits.

North of Samoa are the Union group and other islands of small size, all of coral.

The Feejee Group, already sufficiently described, abounds in reefs of great extent. There are no active volcanoes, and, where examined, no evidence of very recent volcanic action. The many islands afford a peculiarly favorable region for the growth of zoöphytes, and the displays of reefs and living corals were the most remarkable seen by the author in the Pacific.

North of the Feejees are numerous islands leading up to the Carolines. They are all of coral, excepting Rotuma, Horne and Wallis's Islands, which are high, and have fringing or barrier reefs. The reefs of Wallis's Island are very extensive.

The Gilbert or Kingsmill Islands, the Marshall Islands, and the Carolines, about eighty in number, are all atolls, excepting the three Carolines, Ponape (Pouynipete of Lutke), Kusaie (or Ualan), and Truk (or Hogoleu). Between Ponape and Ualan, the McAskill Islands, three in number, are of coral, but 60 to 100 feet high (*Miss. Herald*, 1856, p. 193).

The westernmost of the Sandwich Islands, Kauai and Oahu, have fringing reefs, while eastern Maui and the island of Hawaii have but few traces of corals. On Hawaii, the only spot of reef seen by us, was a submerged patch off the southern cape of Hilo Bay. We have already attributed the absence of corals to the volcanic character of the island. The small islands to the northwest of Kauai, are represented as coral reefs, excepting the rocks Necker and Bird Island; the line stretches on to 28° 30′ N., the northern limit of the coral seas. *Lisiansky's Voyage*, 1803–'6, in the Neva, 4to., London, 1814, pp. 254, 256, contains an account of some of these islands; also the *Hawaian Spectator*, vol. i.; and also a *Report to the U. S. Bureau of Navigation*, December, 1867, by Capt. Wm. Reynolds, U. S. N., partially reproduced in the *American Journal of Science* for 1871, vol. ii., p. 380.

The Ladrones, like the Hawaian Group, constitute a line or linear series of islands, one end of which has been long free from volcanic action, while the other has still its smoking cones. The appearances of recent igneous action increase therefore as we go northward, and the extent of the coral reefs increase as we go southward; no reefs occur about the northernmost islands, while they are quite extensive on the shores of Guam. This group, consequently, like the Hawaian and Navigator, illustrates the influence of volcanic action on the distribution of reefs.

A short distance southwest of the Ladrones, and nearly in the same line, lie extensive reefs. Mackenzie's is an atoll of large size. Yap (or Eap), Hunter's, Los Matelotas and the Pelews (Palao), are high islands, with large reefs. In the last mentioned, the reef grounds cover at least six times the area occupied by the high land. Still farther south, toward New Zealand, lie the large atolls Aiou, Asie and Los Guedes.

South of the equator again:—The New Hebrides constitute a long group of high islands, remarkable for the absence of coral reefs of any extent, though situated between two of the most extensive coral regions in the world,—the Feejees and New Caledonia. But the volcanic nature of the group, and the still active fires of two vents in its opposite extremities, are a sufficient reason for this peculiarity. Tanna is one of the largest volcanoes of the Pacific; and nearly all the islands of the New Hebrides, as far as known, indicate comparatively recent igneous action, in which respect they differ decidedly from the Feejees.

The Vanikoro Group, north of the New Hebrides, according to Quoy, has large barrier reefs about the southernmost island, Vanikoro; but at the northern extremity of the range there is an active volcano, Tinakoro, and no coral. Tikopia, to the southeast of Vanikoro, is high and volcanic, according to Quoy, though not now with active fires; and it appears from the descriptions given, to have no reefs. Mendana, northeast of Tinakoro, according to Kruesenstern, as stated by Darwin, is low, with large reefs; Duff's Islands have bold summits with wide reefs.

New Caledonia, and the northeast coast of New Holland, with the intermediate seas, constitute one of the grandest reef-regions in the world. On the New Caledonia shores (p. 134), the reefs are of great width, and occur not only along the whole length of the western coast, a distance of 200 miles, but extend to the south beyond the main land 50 miles, and north 150 miles, making in all a line of reef full 400 miles in length. Toward the north extremity, however, it is interrupted or broken into detached reefs. This surprising extent is partly explained by the fact that New Caledonia is not a land of volcanoes; but on the contrary consists of older metamorphic rocks. The streams of so large a land might be expected to exclude reefs from certain parts: and in accordance with this fact, we find the reefs of the windward or rainy side comparatively small, and scarcely indicated on the charts; while on the dry or western side, they often extend thirty miles from the shores. The theory of subsidence accounts fully for the great prolongation of the New Caledonia reefs. The reefs indicate moreover, the existence of a former land near three times the area of the present island.

Between New Caledonia and the New Hebrides are several high islands, one of which, Lafu, has been described (*Quart. J. Geol. Soc.*, 1847, p. 61) by Rev. W. B Clarke as an elevated coral island, with fringing reefs; it appears also from the remarks of this writer, that the other islets of what is called the Loyalty Group, are of the same kind. Lafu, the largest of the number, is about ninety miles in circumference.

South of New Caledonia lies Norfolk Island, in latitude 29° S., about which there is said to be some coral, which is occasionally thrown on the beach, but no reefs.

Between Australia and New Caledonia the islands are all of coral. The Australian reef extending south to the east cape, in latitude 24° S., has already been described. Such long reefs on the shores of continents are not common. In the case of Australia, the zoöphytes are not exposed to the destructive agents usual on continental shores, as the land has a dry climate, the shores are mostly rocky, and there are no streams of any extent emptying into the ocean. The east cape is the southern limit, because here the tropical current, owing to the direction of the coast above, trends off to the eastward of south, away from the land, while a polar current follows up the shores from the south as far as this cape. South of this cape there are only a few scattered coral zoöphytes.

The Louisiade Group is, as has been shown, a region of extensive reefs.

The Solomon Islands, as far as ascertained, are but sparingly fringed, except the two westernmost, which have some large fringing and barrier reefs, and include also some atolls. They are described by Dr. Guppy in the Transactions and Proceedings of the Royal Society of Edinburgh, 1884–86. North of the Solomon Islands are some large reef islands. New Ireland, according to D'Urville, has distant reefs on part of its shores.

The Admiralty Islands, farther west, are enclosed by barrier reefs, and beyond this group there are a few lagoon islands.

The north side of New Guinea is mostly without coral. There are several islands off this coast, which are conical volcanic summits, and one of them, near New Britain, and another, Vulcano, near longitude 145° E., are in action.

From the facts thus far detailed, the connection between the prevalence or extent of reefs, and the various causes assigned as limiting or promoting their growth, is obvious.

The amount of subsidence determines in some cases the distance of barrier reefs from shore; but it by no means accounts for the difference in their extent in different parts of a single group of islands. Indeed, if this cause be considered alone, every grade of extent, from no subsidence to the largest amount, might in many instances be proved as having occurred on a single island. Of far greater importance, as has appeared, is the volcanic character of the land. At whatever time the existing reefs in the Pacific commenced their growth, they began about those of the igneous islands whose fires had become nearly or quite extinct; and as others in succession were extinguished, these became in their turn, the sites of corals, and of coral reefs. Those lands whose volcanoes still burn, are yet without corals, or there are only limited patches on some favored spots. Zoöphytes and volcanoes are the land-making agents of the Pacific. The latter prepare the way by pouring forth the liquid rock, and building up the lofty summit. Quiet succeeds, and then commences the work of the zoöphyte beneath the sea, while verdure covers the exposed heights.

We may add a few more illustrations from other parts of the coral-reef seas.

Along the north and northwest coast of Australia, there appears to be little or no coral in the Gulf of Carpentaria, while some extensive patches occur on the shores west of this Gulf, as far as the northwest cape in latitude 23° S.

In the East Indies, there are large, scattered reef-islands south of Borneo and Celebes, about some of the Molluccas, and near the west end of New Guinea. The islands of Timorlaut, and Timor, with many of those intermediate, have large reefs. The Arru Group consists wholly of coral. This sea, from Arru, to the islands south of Borneo, is more thriving in corals than any other in the East Indies.

Another East Indian coral-reef region of some extent, is the Sooloo Sea, between Mindanao and the north of Borneo. Yet the reefs are mostly submerged. The author saw no wide platforms bordering the high lands, like those of the Pacific. There are, however, some small coral islets in the Balabac Passage.

In other parts of the East Indies, coral reefs are quite inconsiderable. Occasional traces, sometimes amounting to a fringing reef, occur along Luzon and the other Philippines.

The Wilkes Exploring Expedition coasted by the west shore of Luzon to Manila, and thence by Luban, Mindoro, Panay, to Caldera, near Samboangan in Mindanao; and through this distance no reefs were distinguished, as would have been the case, had there been any of much extent. At the last-mentioned place we found coral pebbles on the beach, and by dredging, obtained living specimens in six to eight fathoms of water. The only large reefs were those between Mindoro and the Calaminianes. There are fringing reefs at Singapore. The islands of Borneo, Celebes, Java, and Sumatra, according to all the authorities seen by the writer, have but few coral patches about their shores, although affording long lines of coast for their growth. In the China Seas, there are numerous shoals, banks, and island reefs of coral. Moreover, shore reefs occur about Loochoo, and the islands between it and Formosa. But the whole eastern coast of China appears to be without coral. Quelpaert's island, south of Corea, in 34° N., is described as having coral about it; and this has been confirmed by late information.

Why should the reefs of the East India Archipelago be so limited in extent, and large parts be almost destitute, notwithstanding their situation in the warmest seas of the ocean, and in the most favorable region for tropical productions? We are not prepared for a full answer to this inquiry; for it would demand a thorough knowledge of the shores, as well as of the currents, and of the former and present condition of volcanic fires. From personal observation we may reply satisfactorily, as far as regards part of the southern half of the east coast of Sumatra. This coast is low, and sandy, or muddy, and thus affords the most unfavorable place for zoöphytes. A strong current sweeps through the Straits of Banka, which keeps the water muddy, and the shores in constant change. The same cause may operate on the coasts of other islands, but we cannot say to what extent.

The East Indies have been remarkable for their volcanoes, exceeding, for the area, every other part of the world; and this fact must have had influence on the formation of coral reefs, though there are not data for fixing the extent of the influence. Of the thousand vents which have been in action, several still make themselves felt over wide areas. The Sooloo Islands are about one hundred in number, and nearly all are pointed with volcanic cones, and while some have the broken declivities that are marks of age, others have regular slopes, as if but just now extinguished; a dozen of these cones may sometimes be seen on a single island. These volcanic peaks often rise out of the sea, as if their formation had begun with a submarine eruption. In a region so extensively and so recently igneous, the coral polyps would have found little chance for growth, until volcanic action had become comparatively quiet, and deluges of hot water ceased. There appears, therefore, to be some reason for the fact that the reefs are small, and have seldom reached the surface. The Sooloo Sea is but one of the volcanic centers in these seas. Java, several of the Philippines, and other islands south of these last, with the northern shore of New Guinea, make up a wide region of fires, and it cannot be doubted that the frequent eruptions prevented the growth of any thing more than isolated corals, for a long period, over each of these areas. For other causes we must look to the nature of the coasts, fresh-water streams, and marine currents; we leave it for other investigators to apply the explanation to particular coasts.

The coast of China owes its freedom from corals to the cool temperature of the waters, the coast being wholly outside, as has been stated, of the coral-reef seas.

One interesting fact should be noted:—the most extensive reefs in the East Indies are to be found in the open seas, between the large islands; these islands, at the same time, often being without proper reefs, or with mere traces of coral. This is the case between Borneo and the range of large islands south; the China Sea is another instance of it; north of New Guinea, a few degrees, is another. How far this is due to their being distant from the scenes of igneous action, and from the detritus and fresh water of island streams, remains to be determined. A sinking island becomes a more and more favorable spot for the growth of coral, as it descends; for as its extent diminishes, its streams of fresh water and detritus also decrease. It might, therefore, be expected, on this account alone, that such isolated spots of land, away from all impure waters, in the open ocean, should become the bases of large reefs. The existence of these reef-islands is, therefore, no necessary proof of greater subsidence than the coast adjoining has undergone. Still the fact of a greater subsidence is not impossible or improbable.

In the *Indian Ocean*, the Asiatic coast is mostly free from growing coral. The great rivers of the continent are probably the most efficient cause of their absence, both directly, through their fresh waters, and through the detritus they transport and distribute along the shores. It will be observed that this agent, so ineffectual on small islands, is one of vast influence upon larger lands. Mr. Darwin alludes to small patches of coral in the Persian Gulf. Ceylon has some fringing reefs.

The islands of the Indian Ocean are, to a great extent, purely of coral. Of this character are the Laccadives, Maldives, Keeling's, the Chagos Group; and, north and east of northern Madagascar, Saya de Malha, Amirante, Cosmoledo; and also, nearer northern Madagascar, a series of raised atolls from Farquhar Island to Aldabra Island.

Madagascar has a fringing reef upon its southwestern point, according to Mr. Darwin, and on some parts of the coast above: also on the north and eastern shores far down as latitude 18° S. The Comoro Islands, between Madagascar and the continent, have large barrier reefs.

The eastern coast of Africa has narrow reefs extending north with some interruptions from Mozambique, in latitude 16° S., to a short distance from the equator. Corals also abound in the Red Sea, occurring in some parts on both shores, though most frequent on the eastern, from Tor, in the Gulf of Suez, to Konfodah. This long continental reef may at first be deemed a little remarkable, after what has been stated about such reefs elsewhere. Yet the surprise is at once set aside by the striking fact that this whole coast, from the isthmus of Suez south, has no rivers, excepting some inconsiderable streams. It affords, therefore, an interesting elucidation of the subject under consideration, and confirms the view taken to account for the absence of reefs from many continental coasts. It is a fact almost universal, that where there are large fresh-water streams, there are earthy, or sandy shores; and where there are no such streams, rocky shores, though not uniformly occurring, are common.

On the African coast there are coral reefs at Port Natal, in latitude 30° S.; and here, owing to the warm currents from the tropical regions, the mean winter temperature of the water is not below 68° F.

Passing from the Indian to the *Atlantic Ocean*, we find little or no coral on the west coast of Africa. The islands of Cape St. Ann and Sherboro, south of Sierra-Leone, are described as coral by Captain Owen, R. N., in the Journal of the Geographical Society (vol. ii., p. 89); but this has been since denied. The Island of Ascension, in 7° 56′ S., and 14° 16′ W., must have been bordered by growing coral, as Quoy and Gaymard mention that a bed of coral rock may be seen buried beneath streams of lava. Quoy also states that the corals which formed these reefs are no longer found alive, and adds that volcanic eruptions have probably destroyed them. The cold polar currents along the western African coast are the cause of the absence of corals from it, to within six or seven degrees of the equator; and these cold waters may at times extend still farther north. The same obstacle to the diffusion of species eastward, mentioned as occurring in the Pacific—that is, westward currents—exists also in the Atlantic.

On the American shores of the Atlantic, north of the equator, there are few reefs, except in the West Indies. The waters of the Orinoco and Amazon, and the alluvial shores they occasion, exclude corals from that part of the coast.

In the West Indies, the reefs of Florida (p. 204), Cuba, the Bahamas (p. 213), and of many of the eastern islands are well known. On the east coast of Florida they continue up as far as Cape Florida, in latitude 25° 40′ N.; and reef-corals are living off Charleston, S. C., according to Prof. Verrill. There are also said to be patches at intervals along the coast of Venezuela and Guatemala; but the west shores of the Gulf of Mexico, as well as the northern, like West Florida, are mostly low, and without reefs; they are within the influence of the Mississippi and other large rivers. Some species of reef corals, however, occur in the vicinity of Aspinwall (p. 113).

South of the equator, on the east coast of South America, there are reefs at intervals, from the vicinity of Cape St. Roque to the Abrolhos shoals in latitude 18°, as described by Prof. C. F. Hartt, while reef corals extend south to Cape Frio. Descriptions of part of the Abrolhos reefs are given on page 140. North of the Abrolhos reefs, there are others of coral stretching on to Point Carumba; again, off the Bay of Porto Seguro, and across the Bay of Santa Cruz; in the vicinity of Camamú, around Quieppe Island; along the shores of Itaparica Island; and at Bahia and Periperi; then, after an interruption, off Maceió, in the vicinity of Pernambuco. Moreover the Roccas, a cluster of reefs in the latitude of Fernando do Noronha, are, as Hartt observes, probably of coral.

It is thus seen that the earth is belted by a coral zone, corresponding nearly to the tropics in extent, and that the oceans throughout it abound in reefs, wherever congenial sites are afforded for their growth. It has also been shown that the currents of extra-tropical seas, which flow westward, and are interrupted and trended *toward* the equator by the continents, contract the coral seas in width, narrowing them to a few degrees on the western coasts of the continents; while the tropical currents flowing eastward, *diverge* from the equator, and cause the belt to widen near the eastern shores. The polar currents flow also by the eastern coasts, preventing the warmer waters from increasing the width of the coral zone as much as it is contracted on the western coasts. Moreover, the trend of the coast and its capes produce other modifications in the direction of the currents, the most of which are apparent in the actual distribution of coral reefs. On the shores of the continents it is observed that there are few extensive reefs, and the coasts on which they occur are those which, owing to the dryness of the climate, have no great rivers to pour freshwater and detritus into the sea. Thus the influence of continental waters and detritus on the distribution of reefs, is shown to be very marked. But about the Pacific Islands, where streams are small, the same cause has had little effect, seldom doing more than modifying somewhat the shores and bottom of a harbor. It has been further demonstrated that in different groups, as the Ladrones, Sandwich Islands, Navigators, New Hebrides, there is an inverse relation between the extent of reefs and the evidences of recent volcanic action in the island; and that the largest reefs exist where there is no proof of former igneous action, or where it has long ceased. The existence of large reef-islands in open seas where the neighboring lands are mostly destitute of coral reefs, harmonizes with the conclusions announced, since such islands are in general removed from the deleterious influences just mentioned; yet it is very probable that in many cases of this kind the region of the open sea may have undergone a subsidence not experienced equally by the lands either side; for the cases in which such seas contain coral islands are many.

The modifications of form and interruptions of reefs, arising from abrupt or sloping shores, and tidal or local currents, have also been exemplified.

CHAPTER V.

ON CHANGES OF LEVEL IN THE PACIFIC OCEAN.[1]

I. EVIDENCES OF CHANGE OF LEVEL.

It has been shown that atolls, and to a large extent other coral reefs, are registers of change of level. From the evidence thus afforded, the bottom of a large part of the Pacific Ocean is proved to have undergone great oscillations in recent geological time. In this direction, then, we find the grandest teachings of coral formations. In treating the subject we necessarily bring into connection with it evidences of change of level from other sources. The proofs of change of level here considered are the following: —

A. Evidences of elevation.

1. *The existence on coral or other islands of patches of coral reef, and deposits of shells and sand from the reefs, above the level where they are at present forming.*

The coral reef-rock has been shown occasionally to increase, by growth of coral, to a height of four to six inches above low-tide level when the tide is but three feet, and to twice this height with a tide of six feet. It may, therefore, be stated as a general fact, that the limit to which coral *may grow* above ordinary low tide is about one sixth the height of the tide, though it seldom attains this height. Its existence

[1] The conclusions and nearly all the facts presented in this chapter are from the author's Exploring Expedition Report, in which the subject is illustrated by a colored chart of the Pacific Ocean.

on an island at a higher level would be proof of an elevation of the land.

When the tide is three feet, beach accumulations of large masses seldom exceed *eight* feet above high tide, and the finer fragments and sand may raise the deposit to *ten* feet; but with a tide of six feet twice this height may be attained. With the wind and waves combined, or on prominent points where these agents may act from opposite directions, such accumulations may be *fifteen* to *twenty* feet in height, and occasionally *thirty* to *forty* feet. These latter are drift deposits, finely laminated, generally with a sandy texture, and commonly without a distinguishable fragment of coral or shell; and in most of these particulars they are distinct from reef-rocks.

2. On islands not coral, *the existence of sedimentary deposits, or layers of rolled stones, interstratified among the layers of igneous or other rocks constituting the hills.*

B. Evidence of subsidence.

1. *The existence of wide and deep channels between an island and any of its coral reefs;* or in other words, *the existence of barrier reefs.*

2. *The existence of lagoon islands or atolls.*

3. *The existence of submerged atolls.*

4. *Deep bay-indentations in the coasts of high islands as the terminations of valleys.* — The kind of evidence here referred to has been fully explained on page 273. It may be added that the absence of coves, or deep-valley bays, may be evidence that no subsidence has taken place, or only one of comparatively small amount.

C. Probable evidence of subsidence now in progress.

1. *An atoll reef without green islets, or with but few small spots of verdure.* — The accumulation requisite to keep the

reef at the surface-level, during a slow subsidence, renders it impossible for the reef to rise above the waves and supply itself with soil, unless the subsidence is extremely slow, or has wholly ceased.

From the above review of evidences of change of level, it appears that *where there are no barrier reefs, and only fringing reefs, the corals may afford no evidence of subsidence.* But it does not follow that the existence of only fringing reefs, or of no reefs at all, is proof *against* a subsidence having taken place. For we have elsewhere shown that through volcanic action, and at times other causes, corals may not have begun to grow till a recent period, and, therefore, we learn nothing from them as to what may have previously taken place. While, therefore, a distant barrier is evidence of change of level, we can draw no conclusion either one way or the other, from the fact that the reefs are small or wholly wanting, until the possible operation of the several causes limiting their distribution has been duly considered.

The influence of volcanoes in preventing the growth of zoöphytes extends only so far as the submarine action may heat the water, and it may, therefore, be confined within a few miles of a volcanic island, or to certain parts only of its shores.

There are two epochs of changes in elevation which may be here distinguished and separately considered. 1. The subsidence indicated by atolls and barrier reefs. 2. Elevations during more recent periods.

II. SUBSIDENCE INDICATED BY ATOLLS AND BARRIER REEFS.

Looking at atolls as covering buried islands, we observe that through the equatorial latitudes such marks of subsidence abound from the Eastern Paumotus to the Western Carolines, a distance of about six thousand geographical miles. In the Paumotu Archipelago there are about eighty of these atolls. Going westward, a little to the north of west they are found to dot the ocean at irregular intervals; and the Kingsmill or Gilbert Group, the Marshall Group, and the Carolines comprise seventy-five or eighty atolls.

If a line be drawn from Pitcairn's Island, the southernmost of the Paumotus, by the Gambier Group, the north of the Society Group, the Navigators, and the Solomon Islands to the Pelews, it will form nearly a straight boundary, trending N. 70° W., running between the atolls on one side and the high islands of the Pacific on the other, the former lying to the north of the line, and the latter to the south.

Between this boundary line and the Hawaiian Islands, an area nearly two thousand miles wide and six thousand long, there are two hundred and four islands, of which only three, exclusive of the eight Marquesas, and the Ladrones with Yap, Hunter's, and Los Matelotas in the line of the Ladrones and Pelews, are not of coral. These three are Kusaie or Ualan, Ponape, and Truk or Hogoleu, all in the Caroline Archipelago. South of the same line, within three degrees of it, there is an occasional atoll; but beyond this distance, there are none excepting the few in the Friendly Group, and one or two in the Feejees.

If each coral island scattered over this wide area indicates the subsidence of an island, we may believe that subsidence was general throughout the area. Moreover, each atoll, could we measure the thickness of the coral constituting it, would inform us nearly how much subsidence took place where it stands; for they are actually so many registers placed over the ocean, marking out, not only the site of a buried island, but also the depth at which it lies covered. We have not the means of applying the evidence; but there are facts at hand, which may give at least comparative results.

a. We observe, *first*, that the barrier reefs are, in general, evidence of less subsidence than atoll reefs (p. 266). Consequently, the great preponderance of the former just below the southern boundary line of the coral island area, and, farther south, the entire absence of atolls, while atolls prevail so universally north of this line, are evidence of some depression just below the line; of less, farther south; and of the greatest amount, north of the line or over the coral area.

b. The subsidence producing an atoll, when continued, gradually reduces its size until it finally becomes so small that the lagoon is obliterated; and, consequently, a prevalence of these small islands is presumptive evidence of the greater subsidence. We observe, in application of this principle, that the coral islands about the equator, five or ten degrees south, between the Paumotus and the Gilbert Islands, are the smallest of the ocean; several of them are without lagoons, and some not a mile in diameter. At the same time, in the Paumotus, and among the Gilbert and Marshall Islands, there are atolls twenty to fifty miles in length, and rarely one less than three miles. It is probable, therefore, that the subsidence indicated was greatest at some distance north of the boundary line, over the region of small equatorial islands, between the meridians of 150° and 180° W.

c. When, after thus reducing the size of the atoll, the subsidence continues its progress, or when it is too rapid for the growing reef, it finally sinks the coral island, which, therefore, disappears from the ocean. Now, it is a remarkable fact that while the islands about the equator above alluded to indicate greater subsidence than those farther south, there is over a region north of these islands, — that is, between them and the Hawaiian Group, — a wide blank of ocean without an island, which is nearly twenty degrees in breadth. This area lies between the Hawaiian, the Fanning and the Marshall Islands, and stretches off, between the first and last of these groups, far to the northwest.

Is it not, then, a legitimate conclusion that the subsidence, which was least to the south beyond the boundary line and increased northward, was still greater or more rapid over this open area; that the subsidence which reduced the size of the islands about the equator to mere patches of reef, was further continued, and caused the total disappearance of islands that once existed over this part of the ocean?

d. That the subsidence gradually diminished southwestwardly from some point of greatest depression situated to the northward and eastward, is apparent from the Feejee Group alone. Its northeast portion (see chart) consists of immense barriers, with only a few points of rock remaining of the submerged land; while in the west and southwest there are mountain islands of great magnitude. Again, along the north side of the Vanikoro Group, Solomon Islands, and New Ireland, there are coral atolls, but scarcely one to the south.

In view of this combination of evidence, we are led to believe that the subsidence increased from the south to the northward or northeastward, and was greatest between the Navigator and Hawaiian Islands, near the centre of the area destitute of islands, about longitude 170° to 175° W., and latitude 8° to 10° N.

But we may derive some additional knowledge respecting this area of subsidence from other facts.

Hawaiian Range. — We observe that the western islands in the Hawaiian Range, beyond Bird Island, are atolls, and all indicate a large participation in this subsidence. To the eastward in the range, Kauai and Oahu have only fringing reefs, yet in some places these reefs are half a mile to three fourths in width. They indicate a long period since they began to grow, which is borne out by the features of Kauai showing a long respite from volcanic action. We detect proof of subsidence, but not of a large amount. Moreover, there are no deep bays; and, besides, Kauai has a gently-sloping coast plain of great extent, with a steep shore acclivity of one to three hundred feet. The facts favor the idea of much less subsidence since the time when the corals began to grow in the region of Kauai and Oahu than along the range to the westward. The rather small width of the reefs about these two islands may be owing to the former action of their volcanoes, which may have been burning during the earlier part of the coral-reef era. But deep-sea soundings must be made along the whole chain, including the line to the westward, before we can speak positively about the change of level.

The western islands of the range bear some evidence of having, in recent times, commenced a new subsidence after a temporary cessation. They all have little dry land and vegetation about the reefs. Brooks's Island, in latitude 28° 15′ N., and longitude 177° 20′ W., eighteen miles in circumference, has on its north and east sides a compact coral wall of about five feet elevation, which continues for four and a quarter miles, and then becomes a line of detached rocks at tide level.

This bare wall, thus described by Capt. Wm. Reynolds, U. S. N., appears to be an indication that the land was once finished off under a cessation of subsidence, but that a sinking of small amount has since taken place, amounting perhaps to *four* or *five feet.*

Ocean Island, in 28° 25′ N., 178° 25′ W., another of this range, is very similar to Brook's in its wall of coral rock on the east; and so also is *Pearl* and *Hermes*' reef, in 27° 50′ N., 176° W., though the wall of the latter is more a series of detached rocks than a continuous parapet.

Marquesas.—The Marquesas are remarkable for their abrupt shores, often inaccessible cliffs, and deep bays. The absence of gentle slopes along the shores, their angular features, abrupt soundings close alongside the island, and deep indentations, all bear evidence of subsidence to some extent; for their features are very similar to those which Kauai or Tahiti would present, if buried half its height in the sea, leaving only the sharper ridges and peaks out of water. They are situated but five degrees north of the Paumotus, where eighty islands or more have disappeared, including one at least fifty miles in length. There is sufficient evidence that they participated in the subsidence of the latter, but not to the same extent. They are nearly destitute of coral, and apparently because of the depth of water about the islands.

Gambier Group.—In the southern limits of the Paumotu Archipelago, where, in accordance with the foregoing views, the least depression in that region should have taken place, there are actually, as we have stated, two high islands, *Pitcairn's* and *Gambier's.* There is evidence, however, in the extensive barrier about the *Gambier's* (see cut on page 266), that this subsidence, although less than farther north, was by no means of small amount. On page 157, we have estimated it at 1,150 feet—possibly 1,750. These islands, therefore, although toward the limits of the subsiding area, were still far within it. The valley-bays of the islets of the lagoon are of great depth, and afford additional evidence of the subsidence.

Tahitian Islands.—The Tahitian Islands, along with Samoa and the Feejees, are near the southern limits of the area pointed out. Twenty-five miles to the north of Tahiti, within sight from its peaks, lies the coral island Tetuaroa, a register of subsidence. Tahiti itself, by its barrier reefs, gives evidence of the same kind of change; amounting, however, as we have estimated, to a depression of but two hundred and fifty or three hundred feet. The northwestern islands of the group lie more within the coral area, and correspondingly, they have wider reefs and channels, and deep bays, indicating a greater amount of subsidence.

Samoan or *Navigator Group.*—The island of Upolu has extensive reefs, which, in many parts are three-fourths of a mile wide, but no inner channel. The subsidence is estimated on page 158, at one or two hundred feet. The volcanic land west of Apia, declines with an unbroken gradual slope of one to three degrees beneath the sea. The absence of a low cliff is probable evidence of a depression, as has been elsewhere shown. The island of Tutuila has abrupt shores, deep bays and little coral. It appears probable, therefore, that it has experienced a greater subsidence than Upolu. Yet the central part of Upolu has very similar bays on the north, which would afford apparently the same evidence; and it is quite possible that the facts indicate a sinking which either preceded the ejections that now cover the eastern and western extremities of Upolu, or accompanied this change of level. The large island of Savaii, west of Upolu, has small reefs, small because, probably, of volcanic action; for it bears, everywhere, evidence of comparatively recent eruption; from it, therefore, we gather no certain facts bearing on this subject. East of Tutuila is the *coral island*, Rose. It may be, therefore, that the greatest subsidence in the group was at its eastern extremity.

Feejee Islands. — We have already remarked upon the change of level in this group. A large amount of subsidence is indicated by the extensive reefs in every portion of the group, but it was greatest beyond doubt, in the northeastern part. The subsidence, where least, could hardly have been less than 2,000 to 3,000 feet.

We have thus followed around the borders of the coral area; and, besides proving the reality of the limits, have ascertained some facts with reference to a gradual diminution of the subsidence toward, and beyond, these limits. A line through the Hawaiian Group would pass along the northern boundary line of the area; and, taking the southern boundary as given on page 357, the oblong area narrows eastward. An axis nearly bisecting this space, drawn from the eastern Paumotus toward Japan, passes through the region of greatest subsidence, as above determined and now proved by soundings, and may be considered the *line of greatest depression* for the area of subsidence.

It is worthy of special note, *that this axial line, or line of greatest depression, coincides in direction with the mean trend of the great ranges of islands, it having the course*, N. 56° W.; and it also corresponds approximately with the axial line of the Pacific Ocean. On the map of the Phœnix Group, Plate XI, the axial line is drawn just as it was laid down in the author's Expedition Report. Moreover, this map gives the soundings that have been recently made in the seas, and it is interesting to find full confirmation of the conclusion that was derived over fifty years since from the size and distribution of the atolls; for the line, A A, lies in the 3,000–4,000 area of the central Pacific, and, moreover, passes over the deepest point in it yet observed, — the sounding giving a depth of 3,448 fathoms. The deep central area of the Pacific apparently extends, in the direction of this axial line, to the still deeper waters east of Japan.

The southern boundary line of the coral area, as we have laid it down, lies within the area of subsidence, although near its limits. This area has been prolonged southeastward in some places beyond the boundary line. One of the regions of this prolongation lies between the Samoan or Navigator Group and the Feejees and Tonga Group; another is east of Samoa, along by the Hervey Group. Each of these extensions *trends parallel with the groups of islands.* It would seem, therefore, that the Society and Samoan Islands were regions of less change of level than the deep seas either side of them; that, therefore, instead of a uniform subsidence over the subsiding area, shading off toward the borders, there were troughs of greater subsidence, whose courses were parallel to the ranges of islands; that, in other words, there were in the ocean's bottom, a few broad synclinal and anticlinal flexures, having a common direction nearly parallel to the axial line of the Pacific. The Marquesas and Fanning Groups lie in a common line, and thus may mark the course of a great central anticlinal in the oceanic basin.

The Hawaiian range has probably experienced its greatest subsidence to the northwest, where the islands are all atolls, and show some evidences of recent sinking; and this northwestern extremity of the range is nearer to the axis of the area of subsidence, above laid down, than is the southwestern.

What is the extent of the subsidence indicated by the coral reefs and islands of the Pacific? It is very evident that the sinking of the Society, Samoan, and Hawaiian Islands has been small compared with that required to submerge all the lands on which the Paumotus and the other Pacific atolls rest. One, two, or five hundred feet, could not have buried the many peaks of these islands. Even the 1,200 feet of depression at the Gambier Group is shown to be at a distance from the axis of the subsiding area. The groups of high islands above mentioned contain summits from 4,000 to 14,000 feet above the sea; and it is not probable that throughout this large area, when the two hundred islands now sunken were above the waves, there were none of them equal in altitude to the mean of these heights, or 9,000 feet. Hence, however moderate our estimate, there must still be allowed a sinking of many thousand feet. Moreover, whatever estimate we make that is within probable bounds, we shall not arrive at a more surprising change of level than the continents show that they have undergone; for since the Tertiary began (or the preceding period, the Cretaceous, closed) more than 10,000 feet have been added to the Rocky Mountains, parts of the Andes, and Alps, and 19,000 feet to part of the Himalayas.

Between the New Hebrides and Australia, the reefs and islands mark out another area of depression, which may have been simultaneously in progress. The long reef of one hundred and fifty miles from the north cape of New Caledonia, and the wide barrier on the west, cannot be explained without supposing a subsidence of one or two thousand feet at the least. The distant barrier of Australia is proof of great subsidence, even along the border of that continent. But the greatest amount of sinking took place, in all probability, over the intermediate sea, called the "Coral Sea," where there are now a considerable number of atolls.

III. EFFECT OF THE SUBSIDENCE.

The facts surveyed give us a long insight into the past, and exhibit to us the Pacific once scattered over with lofty lands, where now there are only humble monumental atolls. Had there been no growing coral, the whole would have passed without a record. These permanent registers, exhibit in enduring characters some of the oscillations which the "stable" earth has since undergone.

From the actual size of the coral reefs and islands, we know that the whole amount of high land lost to the Pacific by the subsidence was at the very least fifty thousand square miles. But since atolls are necessarily smaller than the land they cover, and the more so, the further subsidence has proceeded;—since many lands, owing to their abrupt shores, or to volcanic agency, must have had no reefs about them, and have disappeared without a mark; and since others may have subsided too rapidly for the corals to retain themselves at the surface; it is obvious that this estimate is far below the truth. It is apparent that in many cases, islands now disjoined have been once connected, and thus several atolls may have been made about the heights of a single subsiding land of large size. Such facts show additional error in the above estimate, evincing that the scattered atolls and reefs tell but a small part of the story. Why is it, also, that the Pacific islands are confined to the tropics, if not that beyond thirty degrees the zoöphyte could not plant its growing registers?

The island of Ponape, in the Caroline Archipelago, affords evidence of *a subsidence in progress*, as Mr. Horatio Hale, the Philologist of the Wilkes Expedition, gathered from a foreigner who had been for a while a resident on this island.

Mr. Hale remarks, after explaining the character of certain sacred structures of stone: "It seems evident that the constructions at Ualan and Ponape are of the same kind, and were built for the same purpose. It is also clear that when the latter were raised, the islet on which they stand was in a different condition from what it now is. For at present they are actually in the water; what were once paths are now passages for canoes, and as O'Connell [his informant] says, 'when the walls are broken down, the water enters the enclosures.'" Mr. Hale, hence infers "that the land, or the whole group of Ponape, and perhaps all the neighboring groups, have undergone a slight depression." He also states respecting a small islet near Ualan, "From the description given of Leilei, a change of level of one or two feet would render it uninhabitable, and reduce it, in a short time, to the same state as the isle of ruins at Ponape."

In some of the northern Carolines, the Pescadores, and perhaps some of the Marshall Islands, the proportion of dry land is so very small compared with the great extent of the atoll, that there is reason to suspect a slow sinking even at the present time; and it is a fact of special interest in connection with it, that this region is near the axial line of greatest depression, where, if in any part, the action should be longest continued.

Among the Kingsmills and Paumotus, there is no reason whatever for supposing that a general subsidence is still in progress; the changes indicated are of a contrary character.

IV. PERIOD OF THE SUBSIDENCE.

The period during which these changes were in progress, extends back to the Tertiary era, and perhaps still farther back.

In the island of Metia, elevated two hundred and fifty feet, the corals below were the same as those now existing, as far as we could judge from the fossilized specimens. At the inner margin of shore reefs, there is the same identity with existing genera. We do not claim to have examined the basement of the coral islands, and offer these facts as the only evidence on this point that is within reach. We cannot know with absolute certainty that the present races of zoöphytes may not be the successors of others that flourished, on the same sites, even before the Tertiary era in Cretaceous and Jurassic times; but as yet have little reason in facts observed, for such a conclusion. For a long time volcanic action may have been too general and constant over the Pacific, for the growth of corals; and this may have continued to interfere till a comparatively late period, if we may judge from the appearance of the rocks, even on Tahiti. The subsidence has probably for a considerable period ceased in most, if not all, parts of the ocean, and subsequent elevations of many islands and groups have taken place.

V. ELEVATIONS OF MODERN ERAS IN THE PACIFIC.

Since the period of subsidence discussed in the preceding pages, there has been no equally general elevation. Yet various parts of the ocean bear evidence of changes confined to particular islands, or groups of islands. While the former exemplify one of the grander events in the earth's history, in which a large segment of the globe was concerned, the latter exhibit its minor changes over limited areas. The instances of these changes are so numerous and so widely scattered, that they afford convincing evidence of a cessation in the previous general subsidence.

a. Off the North American Coast. — Clipperton Rock, in lat. 10° 17′ N. and long. 109° 19′ W., is an elevated atoll at least 100 feet high, according to W. Harper Pease, as reported in the Proceedings of the California Academy of Sciences, Vol. III., p. 199.

b. Paumotu Archipelago. — The islands of this archipelago appear in general to have that height which the ocean may give to the materials. Nothing was detected indicating any *general* elevation in progress through the archipelago. The large extent of wooded land shows only that the islands have been long at their present level. There are examples of elevation in particular islands, however, some of which are of unusual interest. The instances examined by the Expedition are those of Honden Island, Dean's Island, and Clermont Tonnerre. Besides these, Elizabeth Island has been described by Beechey, and, according to the same author, Ducie's Island and Osnaburgh suggest some elevation.

Honden Island or *Henuake.*—This island is wooded on its different sides, and has a shallow lagoon. The beach is eight feet high, and the land about twelve. There are three entrances to the lagoons, all of which were dry at low water, and one only was filled at high water. Around the lagoon, near the level of high tide, there were numerous deserted shells of the huge Tridacna, often a foot long, lying in cavities in the coral rock, precisely as they occur alive on the shore reef. As these Tridacnas evidently lived where the shells remain, and do not occur alive more than six or eight inches, or a foot at the most, above low tide, they prove, in connection with the other facts, an elevation of at least *two feet.*

Nairsa or Dean's Island.—The south side of Dean's Island, the largest of the Paumotus, was coasted along by the Peacock, one of the Sloops of War of the Wilkes Exploring

Expedition, and from the vessel we observed that the rim of land consisted for miles of an even wall of coral rock, apparently six or eight feet above high tide. This wall was broken into rude columns, or excavated with arches and caverns; in some places the sea had carried it away from fifty to one hundred rods, and then there followed again a line of columns, and walls, with occasional arches as before. The reef, formerly lying at the level of low tide, had been raised above the sea, and subsequently had undergone degradation from the waves. The standing columns had some resemblance in certain parts to the masses seen here and there on the shore platforms of other islands; but the latter are only distantly scattered masses, while on this island, for the greater part of the course, there were long walls of reef-rock. The height, moreover, was greater, and they occurred too on the *leeward* side of the island, ranging along nearly its whole course, while the north side, according to the map, *is wooded throughout.*

The elevation here indicated is at least *six feet*; but it may have been larger; the observations were made from shipboard.

Thirty miles to the southward of Dean's Island, we come to

Metia.—This island has already been described, and its elevation stated at *two hundred and fifty feet.* (See page 193.)

Clermont Tonnerre shows the same evidence of elevation from Tridacnas, as Honden Island. Clermont Tonnerre and Honden are on the northeastern limits of the Paumotus.

Elizabeth Island was early shown to be an elevated coral island by Beechey. This distinguished voyager represents it as having perpendicular cliffs over fifty feet in height. From his description it is obviously like Metia; the elevation is *eighty* feet. It is one of the southeastern Paumotus, near Ducie's.

Ducie's Island is described by Beechey as twelve feet high, which would indicate a probable elevation of *one* or *two* feet.

Osnaburgh Island, according to the same author, affords evidence of having increased its height since the wreck of the Matilda, in 1792. He contrasts the change from a "reef of rocks," as reported by the crew, to "a conspicuously wooded island," the condition when he visited it; and states, further, that the anchor, iron works, and a large gun (4-pounder) of this vessel were two hundred yards inside of the line of breakers. Captain Beechey suggests that the coral had grown, and thus increased the height. But this process might have buried the anchor if the reef were covered with growing corals (which is improbable), and could not have raised its level. If there has been any increase of height (which we do not say is certain), it must have arisen from an upheaval.

c. *Tahitian Group.*—The island of Tahiti presents no conclusive evidence of elevation. The shore plains are said to rest on coral, which the mountain débris has covered; but they do not appear to indicate a rise of the land.

The descriptions by different authors of the other islands of this group do not give sufficient reason for confidently believing that any of them have been elevated. The change, however, of the barrier reef around Bolabola into a verdant belt encircling the island, may be evidence that a long period has elapsed since the subsidence ceased; and, as such a change is not common in the Pacific, we may suspect that it has been furthered by at least a small amount of elevation. The observation by the Rev. D. Tyerman with regard to the shells found at Huahine high above the sea, may be proof of elevation; but the earlier erroneous conclusions with regard to Tahiti (on which island masses of coral are carried by natives up the mountain, to leave at the highest point reached, and also to mark the limits between the land of different chiefs, and are common from these causes, up to a height of fifteen hundred feet), teach us to be cautious in admitting it without a more particular examination of the deposit. Moreover, shells, even large ones, are carried far away from the sea by Hermit Crabs (Pagurids).

d. Hervey and *Rurutu Groups.*—These groups lie to the southwest and south of Tahiti.

Mangaia is girted by an elevated coral reef *three hundred* feet in height. Mr. Williams, in his *Missionary Enterprises*, pages 48, 50 and 249, speaks of it as coral, with a small quantity of fine-grained basalt in the interior of the island; he states again that a broad ridge (the reef) girts the hills.

Atiu (Wateoo of Cook) is a raised coral island. Cook *Voy.*, i. 180, 197, observes, that it is "nearly like Mangaia." The land near the sea is only a bank of coral ten or twelve feet high, and steep and rugged. The surface of the island is covered with verdant hills and plains, with no streams. It is described by Williams in his *Missionary Enterprises*. *Mauke* is a low elevated coral island according to Williams, and *Mitiaro* resembles Mauke. *Okatutaia* is a low coral island, not more than six or seven feet high above the beach, which is coral sand. It has a light-reddish soil.

Rurutu has an elevated coral reef *one hundred and fifty* feet in height, as stated by Stutchbury, and also Williams. Tyerman and Bennet describe the island as having a high central peak with lower eminences, and speak of the coral rock as *two hundred* feet high on one side of the bay and *three hundred* on the other (ii. 102).—Ellis says that the rocks of the interior are in part basaltic, and in part vesicular lava, iii. 393.

With regard to the other islands of these groups, *Manuai*, *Aitutaki*, *Rarotonga*, *Rimetara*, *Tubuai*, and *Raivavai*, the descriptions by Williams and Ellis appear to show that they have undergone no recent elevation.

e. Tonga or Friendly Islands, and others in their vicinity.

All the islands of the Tonga group about which there are reefs, give evidence of elevation: *Tongatabu* and the *Hapaii* islands consist solely of coral, and are elevated atolls.

Eua, at the south extremity of the line, has an undulated mostly grassy surface, in some parts eight hundred feet in height. Around the shores, as was seen by us from shipboard, there is an elevated layer of coral reef-rock, twenty feet thick, worn out into caverns, and with many spout-holes. Between the southern shores and the highest part of the island, we observed three distinct terraces. Coral is said to occur at a height of *three hundred* feet. From the appearance of the land, we judged that the interior was basaltic; but nothing positive was ascertained with regard to it.

Tongatabu (an island visited by us) lies near Eua, and is in some parts fifty or sixty feet high, though in general but twenty feet. It has a shallow lagoon, into which there are two entrances; some hummocks of coral reef-rock stand eight feet out of water.

Namuka and most of the *Hapaii* cluster, are stated by Cook to have abrupt limestone shores, ten to twenty feet in height. Namuka has a lagoon or salt lake at centre, one and a half miles broad; and there is a coral rock in one part twenty-five feet high. It is described by Williams, p. 296.

Vavau, the northern of the Group, according to Williams (p. 427), is a cluster of elevated islands of coral limestone, thirty to one hundred feet in height, having precipitous cliffs, with many excavations along the coast.

Pylstaart's Island, south of Tongatabu, is a small rocky islet without coral. *Tafua* and *Proby* are volcanic cones, and the former is still active.

Savage Island, a little to the east of the Tonga Group, resembles Vavau in its coral constitution and cavernous cliffs. It is elevated, according to Williams (pp. 275, 276), *one hundred feet.*

Beveridge Reef, a hundred miles southeast of Savage, is low coral.

f. Samoan or *Navigator Islands.* — No satisfactory evidences of elevation were detected about these islands.

g. Atolls, north of Samoa.

On account of the high tides (four to six feet), the sea may give a height of twelve to sixteen feet to the land.

Swain's (Gente Hermosas ?), near latitude 11° S., is fifteen to eighteen feet above the sea where highest, and the beach is ten to twelve feet high. It is a small island, with a depression at centre, but no lagoon. Probably an elevation of *two* or *three* feet. This island was named *Swain*, by Capt. Hudson, of the Wilkes Expedition, because not in the position assigned to Gente Hermosas.

Fakaafo, ninety miles to the north, is fifteen feet high. The coral reef-rock is raised in some places three feet above the present level of the platform. Elevation at least *three* feet.

Nukunono, or Duke of Clarence, near Fakaafo, was seen only from shipboard.

Oatafu, or Duke of York's, is in some parts fourteen feet high. Whether elevated or not is uncertain; probably as much so as Fakaafo.

h. Scattered islands farther north, near the equator, east of the Gilbert Group.

Of the Fanning Group, Washington Island, in lat. 4° 41′ S., and long. 160° 15′ W., is three miles in diameter, and is without a proper lagoon; the whole surface is densely covered with cocoanut and other trees. The height of the land is ten or twelve feet. The unusual size of the island for one without a lagoon, and the luxuriance of the forest vegetation, are probable evidence of some elevation, but not beyond *three* feet.

Palmyra Island, northeast of Washington, is described by Fanning as having two lagoons, the westernmost with twenty fathoms water.

Fanning's Island, southeast of Washington, according to the same voyager, is lower than that island. The accounts give no evidence of elevation in either Fanning's or Palmyra.

Christmas Island, in lat. 1° 53′ N., long. 157° 32′ W., is thirty miles long. Cook speaks of the land as in some parts three miles wide, and as having narrow ridges lying parallel with the seacoast, which "must have been thrown up by the sea, though it does not reach within a mile of some of these places." The amount of elevation is uncertain. The account of J. D. Bennett (*Geogr. Journ.*, vii. 226), represents it as a low coral island.

Jarvis's Island, in 0° 22′ S., and 159° 58′ W., is, according to J. D. Hague, eighteen to twenty-eight feet in height, which would indicate an elevation of at least eight or ten feet. See further page 291.

Malden's, in 4° 15′ S., 155° W., two hundred and fifty miles southeast of Jarvis, visited by Lord Byron, is described by him as not over *forty feet* high. It is ten miles long.

Starbuck's, or *Hero Island*, in 5° 40′ S., 155° 55′ W., is an elevated lagoon island; but the amount of elevation is not stated. Like Jarvis's, it contains a large deposit of gypsum, but not much guano.—(J. D. Hague.)

Penrhyn's Island, near 9° S. and 157° W., has a length of nine miles, and an extensive lagoon with a boat entrance into it. According to Captain Ringgold of the Wilkes Expedition, it has a height of fifty feet, which, if correct, would indicate an elevation of full *thirty-five* feet. The northwest side is, throughout, a cocoanut grove.

Flint's Island, in 11° 26′ S., and 151° 48′ W., is only a mile and a half long, but is thickly wooded, according to Captain Ringgold, which is unusual for so small an island.

Staver's Island, in 10° 05′ S., and 152° 22½′ W., is only half a mile across, and yet is well wooded. Both of these islands were passed by Captain Ringgold, but he does not state the height.—(Wilkes's Narr., iv. 277.)

Baker's Island, 0° 13′ N., 176° 22′ W., is one mile long and two-thirds of a mile wide. The greatest height, according to J. D. Hague, is twenty-two feet, "showing some evidences of elevation." (See further, p. 289.) It has probably been elevated at least *six* feet.

Howland's Island, 0° 51′ N., and 176° 32′ W., and about forty miles north of Baker's. It is about one and one-half miles long, and one-half mile wide. The highest point, according to Hague, is ten or twelve feet above high-tide level; which is evidence of but little if any elevation. It is a guano island like Baker's.

McKean's Island, of the Phœnix Group (like Phœnix, Enderbury, and Birnie's), in 3° 35′ S., 174° 17′ W., is a low island, according to Hague, circular in form, *one-quarter* of a mile in diameter, but less elevated than Jarvis Island. It has a lagoon depression in which there is a gypsum and guano deposit; and at high tides the guano is sometimes two feet under water. *Phœnix's Island*, near McKean's, 3° 40′ S., 170° 52′ W., is less than half a mile in diameter, and the border is only eight or ten feet high; so that there is no evidence in the height of an elevation. It is also a guano island.

Enderbury's, in 3° 8′ S., 174° 14′ W., is eighteen feet high. It has probably experienced some elevation. But the height of the tides is such in the seas as to give the beach and drift sands much greater height than they have in the Paumotus. *Birnie's* Island is a small bank of coral, only six feet above the sea, according to Wilkes (Narr., V. 4).

Gardner's, *Hull's*, *Sydney* and *Newmarket* were visited by the Wilkes Expedition. No satisfactory evidences of elevation were observed on the first three. Newmarket is stated by Captain Wilkes to have a height of *twenty-five* feet, which would indicate an elevation of six or eight feet.

h. Sandwich or Hawaiian Islands.—Oahu affords decisive proof of an elevation of twenty-five or thirty feet. There is an impression at Honolulu, derived from a supposed increasing height in the reef off the harbor, that the island is slowly rising. Upon this point we have nothing satisfactory. The present height of the reef is not sufficiently above the level to which it might be raised by the tides, to render it certain, from this kind of evidence, that the suspected elevation is in progress.

Kauai presents us with no evidence that the island, at the present time, is at a higher level than when the coral reefs begun ; or, at the most, no elevation is indicated beyond a foot or two. The drift sand-rock of Koloa appears to be a proof of elevation, from its resemblance to that of Northern Oahu ; but if so, there must have been a subsidence since, as it now forms a cliff on the shore that is gradually wearing away.

Molokai, according to information from the Rev. Mr. Andrews, has coral upon its declivities three hundred feet above the sea.

Mr. Andrews, in his communication, informed the author that the coral occurs " upon the acclivity of the eastern or highest part of the island, over a surface of more than twenty or thirty acres, and extends almost to the sea. We had no means of accurately measuring the height; but the specimens were obtained at least three hundred feet above the level of the sea, and probably four hundred. The specimens have distinctly the structure of coral. The distance from the sea was two to three miles."

Coral has been reported to occur on the western peninsula of *Maui*, in some places eight hundred feet above the sea; but according to C. F. Winslow, the supposed coral does not effervesce with acids, and therefore is not calcareous.

On page 324, it is suggested that the westernmost coral islands of the Hawaian range, Ocean and Brooks's Islands, may have undergone a small subsidence. Should the broken wall of emerged rock turn out, on examination, to be coral reef-rock, instead of the beach sand-rock, the facts would prove an elevation of a few feet, instead of a subsidence. The islands differ from Dean's, in having no long range of wooded land on the windward side.

i. Feejee Islands.—The proofs of an elevation of four to six feet about the larger Feejee Islands, Viti Lebu and Vanua Lebu, and also Ovalau, are given in the author's report on this group. How far this rise affected other parts of the group, he was unable definitely to determine; but as the extensive barrier reefs in the eastern part of the group, rarely support a green islet, they rather indicate a subsidence in those parts than an elevation.

j. Islands north of the Feejees.—Horne Island, Wallis, Ellice, Depeyster, and four islands on the track toward the Kingsmills, were passed by the sloop of war "Peacock," of the Wilkes Expedition; but from the vessel no evidences of elevation could be distinguished. The first two are high islands, with barriers, and the others are low coral. Rotuma (177°

15′ E., and 12° 30′ N.), is another high island, to the west of Wallis's. It has encircling reefs, but we know nothing as to its changes of level. According to J. S. Whitnell, Ellice's Island, or Funafuti, situated in latitude 9° S. and longitude 179° E., has a small lagoon basin, dry at low water, which is shut off from the sea by a wall twenty feet high, consisting of large masses of coral. He regarded the facts as proof of some elevation.

k. Kingsmill or Gilbert Group. (Map, p. 165.)

Tapateuea or Drummond.—This is one of the southern islands of the group. The reef-rock, near the village of Utiroa, is a foot above low-tide level, and consists of large massive Astræas and Mæandrinas. The tide in the Kingsmill seas is seven feet; and consequently this evidence of a rise might be doubted, as some corals may grow to this height where the tide is so high. But these Astræas and Mæandrinas, as far as observed by the writer, are not among the species that may undergo exposure at low tide, except it be to the amount of three or four inches; and it is probable that an elevation of at least one foot has taken place.

Apaiang or *Charlotte's* Island, one of the northernmost of the group, has the *reef-rock* in some parts raised bodily to a height of six or seven feet above low-water level, evidencing this amount of elevation. This elevated reef was observed for long distances between the several wooded islets; it resembled the south reef of Nairsa in the Paumotu Archipelago in its bare, even top, and bluff, worn front. An islet of the atoll, where we landed, was twelve feet high, and the coral *reef-rock* was five or six feet above middle tide. A wall of this rock, having the same height extends along the reef from the islet. There was no doubt that it was due to an actual uplifting of the reef to a height of full *six* feet.

Nonouti, *Kuria*, *Maiana*, and *Tarawa*, lying between the two islands above mentioned, were seen only from the ship, and nothing decisive bearing on the subject of elevation was observed. On the northeast side of Nononti there was a hill twenty or thirty feet in height covered with trees; but we had no means of learning that it was not artificial. We were, however, informed by Kirby, a sailor taken from Kuria, that the reef of *Apamama* was elevated precisely like that of Apaiang, to a height of *five* feet; and this was confirmed by Lieutenant De-Haven, who was engaged in the survey of the reef. We were told, also, that Kuria and Nononti were similar in having the reef elevated, though to a less extent. It would hence appear that the elevations in the group increase to the northward.

Marakei, to the north of Apaiang, is wooded throughout. We sailed around it without landing, and can only say that it has probably been uplifted like the islands south. *Makin*, the northernmost island, presented in the distant view no certain evidence of elevation.

The elevation of the Kingsmills accounts for the long continuity of the wooded lines of land, an unusual fact considering the size of the islands. The amount of fresh water obtained from springs is also uncommon. (p. 324).

l. The Marshall and *Caroline Islands.*—The facts in reference to the islands of these groups, are not yet fully known. The very small amount of wooded land on the Pescadores inclines us to suspect rather a subsidence than an elevation; and the same fact might be gathered, with regard to some of the islands south, from the charts of Kotzebue and Kruesenstern. But McAskill's, as stated on page 342, is an elevated coral island, having a height of 100 feet.

m. Ladrones.—The seventeen islands which constitute this group may all have undergone elevations within a recent period, but owing to the absence of coral from the northern, we have evidence only with regard to the more southern.

Guam, according to Quoy and Gaymard, has coral rock upon its hills more than *six hundred* feet (one hundred toises) above the sea.

Rota, the next island north, afforded these authors similar facts, indicating the same amount of elevation.

n. Pelews, and neighboring Islands.—The island *Feis*, three hundred miles southwest of Guam, of the Ladrone Islands, is stated by Darwin, on the authority of Lutke, to be of coral, and *ninety* feet high. Mackenzie Island, seventy-five miles south of Feis, is a low atoll, as ascertained by the Wilkes Expedition. In the Pelews elevated reefs occur at various heights up to 300 feet, according to Prof. Semper. The most of the islands of the southern half of the group are coral islands, and are more or less elevated. In Pelelew, the western coral cliffs are 250 feet high; the eastern 80 feet.

o. Melanesian Islands. —

New Hebrides. — "Much coral at a great altitude," according to G. Bennett, as reported by Darwin.

Loyalty Islands. — One of the islands is wholly of coral, and is elevated 250 feet, according to Rev. W. B. Clarke, of Sydney, in the Journal of the Geological Society, 1847, p. 61.

Bonin Group. — Peel Island has coral reefs raised 50 feet above tide-level, according to P. W. Graves, in the Journal of the Geological Society, 1855, p. 532.

Solomon Islands. — According to Dr. Guppy, there are elevated coral reefs, varying in height from 100 to 1,200 feet. On St. Christoval, coral occurs to a height not exceeding 500 feet.

The details given on the preceding pages are here presented in a tabular form.

		FEET.
Off North American coast	Clipperton Rock	100
Paumotu Archipelago	Honden	2 or 3
" "	Clermont Tonnerre	2 or 3
" "	Nairsa or Dean's	6
" "	Elizabeth	80
" "	Metia or Aurora	250
" "	Ducie's	1 or 2?
Tahitian Group	Tahiti	1 or 2?
" "	Bolabola	?
Hervey and Rurutu Groups	Atiu	12?
" " " "	Mauke	somewhat elevated.
" " " "	Mitiaro	" "
" " " "	Mangaia	300
" " " "	Rurutu	150
" " " "	Remaining Islands	0?
Tongan Group	Eua	300?
" "	Tongatabu	50 to 60
" "	Namuka and the Hapaii	25
" "	Vavau	100
Savage Island		100
Samoan or Navigator Islands		0
North of Samoa	Swain's	2 or 3
" " "	Fakaafo, or Bowditch	3
" " "	Oatafu, or Duke of York's	2 or 3
Scattered Equatorial Islands	Washington	2 or 3?
" " "	Christmas	?
" " "	Jarvis	8 or 10
" " "	Malden's	25 or 30
" " "	Starbuck's	?
" " "	Penrhyn's	35
" " "	Flint's and Staver's	?
" " "	Baker's	5 or 6
" " "	Howland's	?
" " "	Phœnix and McKean's	0
" " "	Enderbury's	2 or 3?
" " "	Newmarket	6 or 8?
" " "	Gardner's, Hull's, Sydney, Birnie's,	0?
Feejee Islands	Viti Levu and Vanua Levu, Ovalau,	5 or 6
	Eastern of the Feejee Islands	0?
North of Feejees	Horne, Wallis, Depeyster	0?
	Ellice	5 or 6

		FEET.
Sandwich Islands	Kauai	1 or 2
" "	Oahu	25 to 60
" "	Molokai	300 ?
" "	Maui	12
Gilbert Islands	Tapateuea	2 or 3
" "	Nonouti, Kuria, Maiana and Tarawa	3 or more.
" "	Apamama	5
" "	Apaiang or Charlotte	6 or 7
" "	Marakei	3 or more.
" "	Makin	?
Carolines	McAskill's	60
Ladrones	Guam	600
"	Rota	600
Feis		90
Pelews		10 to 300
New Hebrides		several elevations.
Loyalty Islands, one island		250
Solomon Islands, some islands		100 to 1,200
Bonin Group, Peel Island		40–50

Several deductions are at once obvious: —

1. That the elevations have taken place in all parts of the ocean.

2. That they have in some instances affected single islands, and not those adjoining. Metia is 250 feet high, and yet the other Paumotus in that part of the archipelago, and also the Tahitian Islands, have been but little, or not at all, elevated.

3. That the amount is often very unequal in adjacent islands.

4. That in a few instances the change has been experienced by a whole group or chain of islands. The Gilbert Group is an instance, and the rise appears to increase from the southernmost island to Apaiang, and then to diminish again to the other extremity.

The Feejees may be an example of a rise at the west side of a group, and possibly a subsidence on the east; while a little farther east, the Tonga Islands constitute another extended area of elevation. We observe that while the Samoan Islands afford no evidences of elevation, the Tonga Islands on the south have been raised, and also the Fakaafo Group and others on the north.

We cannot, therefore, distinguish any evidence that a general rise is, or has been, in progress; yet some large areas appear to have been simultaneously affected, although the action has generally been isolated. Metia and Elizabeth Island, in the Paumotu Archipelago, may have risen abruptly; but the changes of level in the Feejees and the Friendly Islands appear to have taken place by gradual action.

CHAPTER VI.

GEOLOGICAL CONCLUSIONS.

THE geological bearing of the facts that have been detailed in the preceding pages may have been already perceived by our readers. A brief review of the points of more special interest may serve as a convenient recapitulation of the subject.

I. FORMATION OF LIMESTONES.

Coral reefs are beds of limestone made of corals, with the help of shells and other calcareous relics of the life of the sea. The mode of formation is essentially the same, whichever of the two kinds of organic products — corals or shells — predominate; although in one case the bed would be called coral limestone, and in the other, shell limestone.

The reefs illustrate two different modes of origin of such beds: (1), by undisturbed growth, with only additions of fine material to fill up the intervals; (2), by the grinding of the corals, etc., to fragments, sand, or mud, through the agency of the waves.

Beds made by the former method, have many open spaces between the grouped masses or branches, and could not be turned into a solid layer of limestone, if situated too deep in the ocean to feel sensibly the movement of the waves,—unless Rhizopods, or minute shells of some kinds, multiplied so rapidly over the same sea-bottom, as to fill up the interstices. There is no reason to believe that such aid from shells or

Rhizopods is consistent with the grouping of living corals thickly enough to form reefs.

The other kind of limestone beds referred to, where unmixed with the former, grow up in compact layers to the surface, as a necessary consequence of wave-action ; and limestones are made in such regions, instead of sandstones and shales, because the material exposed to degradation is corals and shells, instead of common rocks.

The facts show that there are formed about coral reefs, in indefinite amount, all the ordinary products of degradation by wave-action—fragments large and small, down to sand, and even mud. With such an agent as the ocean's waves, driven often by the storm, so powerful and so persistent at lifting, rending, grinding, and transporting, it is of little account, at least about outer reefs, that some coral stems or masses are first weakened below by the boring sponge or mollusk ; and neither fish, nor holothurian, nor alcyonoid is needed, in order to keep up the supply of particles for sand or mud-beds. In accordance with these facts, the reef-formations illustrate that not only coral conglomerates, or *coral rag*, may be made of corals, but also the very finest and most compact unfossiliferous limestones ; that fine compact limestone, as flint-like in fracture as any of Silurian time, is one of the most common of coral-reef rocks, and is nothing but consolidated mud, or fine sand, of coral origin.

The elevated portion of the island of Metia, which consists largely of this kind of white, compact, coral-made limestone, appears to correspond to the interior of the original lagoon of the island ; it exemplifies the kind of rock-making which is going forward in most coral island lagoons. In archipelagos like that of the Feejees, where the reef channels are very broad, there is an opportunity for the formation of very large areas of this compact white limestone, and also for others of impure or argillaceous limestones.

Besides the kinds of coral rocks above mentioned, there are also the *Beach* and *Drift Sand-rocks*, which are accumulated and consolidated above low-tide level. These formations illustrate the common mode of origin of *oölitic* limestones. They also afford numerous examples of the formation of coarse and fine conglomerates consisting of beach pebbles—these pebbles being either worn corals, or shells, or sometimes of other kinds, if other rocks are at hand.

The general slope of the beach sand-rock and oölite, and the mixed stratification of the drift sand-rock, are identical respectively with those of beach and drift-sand deposits in other regions.

II. BEDS OF LIMESTONE WITH LIVING MARGINS.

The coral reef as it lies at the water's level is in fact a bed of limestone with living margins; and the living part furnishes material for its horizontal extension outward, and also, if a slow subsidence is in progress, for its increase upward. It illustrates an ordinary mode of formation of coral, or of shell, limestone, whatever the age.

III. MAKING OF THICK STRATA OF LIMESTONE.

The coral reef-rock has been shown to have in some cases a thickness of at least 2,000 feet (page 156.) The reefs are, therefore, examples of great limestone strata, nearly as remarkable in this respect as the largest of ancient times.

IV. SUBSIDENCE ESSENTIAL TO THE MAKING OF THICK STRATA.

The coral island reef-rock has been shown to depend for its thickness on a slowly progressing subsidence (p. 263).

This is the only method by which any thick stratum of limestone could be made out of a single set of species, for all such species have a narrow range in depth; and the only way, from any succession of species, if those species are alike in range of depth.

In the case of existing coral reefs, there is yet no evidence that the species of the lower beds differ from those of the top. There is also no evidence, in any part of any ocean, that there is a set of cold-water corals fitted to commence a reef in deep water and build it up to such a level that another set of species may take it and carry it up higher; the facts thus far gathered are all opposed to such an idea. Should it be hereafter proved that the corals of the inferior beds differ in species from those now existing, it will probably be found that the predecessors of those now living were also shallow-water species; so that the subsidence in any case was necessary.

V. DEEP-SEA LIMESTONES SELDOM IF EVER MADE FROM CORAL ISLAND OR REEF DEBRIS.

This point has been discussed on pages 143, 211. The facts show that the sediment or débris from a shore is almost wholly thrown back by the waves against the land where it originated, or over its submerged part in the shallow waters, and that it is not transported away to make deep sea formations.

The facts have also a wider bearing, for they teach that lands separated by a range of deep ocean cannot supply one another with material for rocks. The existence of an Atlantic ocean continent—an Atlantis—has sometimes been assumed in order to make it a source of the mud, sand and gravel, out of which the thick sedimentary formations of the Appalachian region of North America were made. But if this Atlantis were a reality, there would still have been needed, in addition to the presence of such an ocean continent, a set of freight carriers that could beat off the waves from their accustomed work, and push aside the ordinary oceanic currents; or else Atlantis would get back all its own dirt.

VI. ABSENCE OF FOSSILS FROM LIMESTONE STRATA.

Absence of fossils has been mentioned as a frequent characteristic of the fine compact coral reef-rock, and also of the beach and drift sand-rock or oölite (pp. 153, 194). The rocks are formed at the sea-level, and in the midst of abundant life, and yet trituration by the action of the waves and winds has in many places reduced all to the finest material, so that an embedded shell is seldom to be found in the beach or drift oölite, and rarely too in much of the fine-grained coral reef-rock.

The interior basins appear to be eminently the place for making these non-fossiliferous limestones. This is the case in two widely different conditions: *first*, over the portions that are below the coral-growing depths, which are sometimes of great area; and *second*, in lagoons that have become so small and shallow that corals and large shells have all disappeared, and the trituration is of the finest kind, producing calcareous mud; such lagoons being properly in a marsh condition. These last appear to illustrate on a small scale the conditions under which many of the ancient non-fossiliferous, or sparingly fossiliferous, limestones were formed.

VII. THE WIDE RANGE OF THE OLDER LIMESTONES NOT EXEMPLIFIED AMONG MODERN CORAL-REEF FORMATIONS.

Coral-reefs, though they may stretch along a coast for scores of miles, are seldom a single mile in width at the surface; and if elevated above the sea, they would stand as broad ramparts separated by passages mostly 20 to 200 feet deep, and often of great width. The substratum, however, is, in general, continuous coral-rock; and if these more elevated parts were removed by any process, after an elevation, they would leave a nearly level area of coral limestone often as extensive as the whole reef-grounds. In an island like Dean's, one of the Paumotus, these reef-grounds are 1,000 square miles in extent. Still greater are the Bahama banks, the largest of them being 350 miles long and 200 wide, an intervening "tongue of the ocean" excepted.

But the most extensive reef-grounds of the oceans are after all of small breadth compared with many of the ancient limestones of the continents; and the reef-rocks also are peculiar in their very abrupt limits, the margins sometimes descending at a steep angle a thousand feet or more. These differences between the new and the old arise in part from the fact that the coral reefs of the present era are made about small oceanic lands, or along the edges of the continents, while the limestones of ancient time were generally formed over the broad surface of a continent as it lay slightly submerged.

The Abrolhos reefs of the Brazilian coast, described on page 140, illustrate one of the methods by which the coral banks extend and finally coalesce into beds of wide extent; but these are small compared with the great limestones of early time, and owe their slight approximation to them as regards extent to the wide range of shallow waters there afforded. These Abrolhos reefs differ from most limestone beds also in being formed largely of the corals in the position of growth.

The tendency of modern reefs to grow up to the surface in narrow banks, separated by channels, appears to be unlike any thing we discover in the old rocks; and it seems to be an unavoidable result of growth in the sea, where the waves pile up barriers, and the currents make, and keep open, channels. The case of the Australian and Feejee reefs are good examples It is possible that such barriers may often have existed in ancient time, and have disappeared through subsequent denudation of the surface. But may not the difference between the great even layers of the continental formations and those of a coral island have proceeded from the difference in the depth of the seas? Over the great shallow continental seas where the limestones were in progress, the waves may have generally been feeble, and therefore there may have been a less tendency to form narrow barriers and deep intervening channels.

The marsh condition of a drying-up lagoon with its forming limestones has been compared above with that under which ancient unfossiliferous limestones were made. The narrow limits of the former make the comparison unsatisfactory; for, in the coral island, coarsely fossiliferous beds are all the while forming about the exterior of the island, but a few miles at the most from the lagoon-marsh; while the ancient limestones retain their unfossiliferous character often through many thousands of square miles. Still, the above mentioned difference between the continental sea and the existing deep oceans may perhaps account for the diversity of results.

VIII. CONSOLIDATION OF CORAL ROCKS.

All true coral-reef rocks are examples of the consolidation of material mainly of coral origin—either mud, sands, fragments, or standing corals, the last with mud or sands intermixed—by (1), an under-water process; (2), at the ordinary temperature; and they exemplify the mode in which all other submarine limestones of organic origin have been consolidated. The process appears to depend on the presence (proved by chemical analysis) of carbonic acid in the sea waters that bathe and penetrate the sands. This carbonic acid is derived from three sources: from (1), the rains which wash it down from the atmosphere; (2) the respiration of all the animal life in the waters, even down to the simplest and minutest; and (3) the decomposition of all vegetable or animal débris in the waters or diffused through the sand or muds. This gas is set free, therefore, just where it is needed for the work, and is always ready to perform its part in the process of consolidation. It enables the water to take up carbonate of lime from the grains of the mass to be solidified, or from outside sources; and then the deposition of the same among the grains through their attractions produces the cementation.

The beach and drift sand-rocks or oölites are different from the reef-rock in being superficial deposits. The carbonic acid of the waters performs the same part as in the latter; but with these, there is alternate wetting and drying during the ebb and flow of the tides and the succession of gales and quiet winds. By this means, the grains become incrusted, and every new wetting and drying adds a new layer to the surface of each; and thus the oölitic structure is produced. Facts are mentioned on page 153 of pebbles of volcanic or basaltic rocks, lying loose on a seashore, becoming incrusted in this way with a milky layer; and of basaltic conglomerates being made by the same means, the carbonate of lime being added until all the intervals between the stones were filled up and the whole made solid; and of an amygdaloidal volcanic rock on a coast having derived its little calcareous kernels or amygdules from the same source. The following additional facts are cited from Mr. Darwin's Journal (p. 588):

" Lieutenant Evans informs me that during the six years he has resided on this island (Ascension) he has always observed that in the months of October and November, when the sand [of a calcareous beach] commences travelling toward the southwest, the rocks which are situated at the end of the long beach become coated by a white, thick, and very hard calcareous layer. I saw portions of this remarkable deposit, which had been protected by an accumulation of sand. In the year 1831 it was much thicker than during any other period. It would appear that the water charged with calcareous matter, by the disturbance of a vast mass of calcareous particles only partially cemented together, deposits this substance on the first rocks against which it impinges. But the most singular circumstance is that, in the course of a couple of months, this layer is either abraded or redissolved, so that after that period, it entirely disappears. It is curious thus to trace the origin of a periodical incrustation, on certain isolated rocks, to the motion of the earth with relation to the sun; for this determines the atmospheric currents which give direction to the swell of the ocean, and this again the arrangement of the sea-beach, and this again the quantity of calcareous matter held in solution by the waters of the neighboring sea."

Mr. Darwin, speaking of a large beach of calcareous sand composed of comminuted and rounded fragments of shells and corals at Ascension, says, "The lower part of this, from the percolation of water containing calcareous matter in solution, soon becomes consolidated and is used as a building stone; but some of the layers are too hard for fracture, and when struck by the hammer, ring like flint."

The surface of hills of drift sand-rock often has small depressions that are coated with a smooth, solid crust, as already explained.

IX. FORMATION OF DOLOMITE OR MAGNESIAN CARBONATE OF LIME.

Analyses of the coral limestone of the elevated coral island Metia, by Prof. B. Silliman, Jr., have determined the singular fact that, although the corals themselves contain very little carbonate of magnesia, magnesia is largely present in some specimens of the rock. The rock is hard (H. = 4), and splintery in fracture, with a specific gravity 2·690. It affords on analysis, 38·07 per cent. carbonate of magnesia, and hence, only 61·93 of carbonate of lime.

Another specimen from the same island, having the specific gravity 2·646, afforded 5·29 per cent. of carbonate of magnesia.

The former was a compact homogeneous specimen, and the latter was partly fragmentary. Recent examinations of coral sand and coral mud from the islands, give no different composition, as regards the magnesia, from that for corals, which, as the analyses on page 99 show, contain very little or no magnesia. The coral sand from the Straits of Balabac, afforded Prof. Silliman carbonate of lime 98·26, carbonate of magnesia 1·38, alumina 0·24, phosphoric acid and silica *a trace.*

This introduction of magnesia into the consolidating under-water coral sand or mud, has apparently taken place (1) in sea waters at the ordinary temperature; and (2) without the agency of any mineral waters except the ocean. But the sand or mud may have been that of a contracting and evaporating lagoon, in which the magnesian and other salts of the ocean were in a concentrated state. It has been already observed (p. 349), that this was probably the actual condition of the elevated portion of the island of Metia, every thing about it looking as if it corresponded to the lagoon part of the old atoll; and also that the idea of the existence of mineral springs there has no support in known facts.

X. FORMATION OF CHALK.

The formation of chalk from coral is known to be exemplified at only one spot among the reefs of the Pacific.

The coral mud often looks as if it might be a fit material for its production; moreover, when simply dried, it has much the appearance of chalk, a fact pointed out by Lieutenant Nelson in his Memoir on the Bermudas (1834), and also by Mr. Darwin, and suggested to the author by the mud in the lagoon of Honden Island. Still this does not explain the origin of chalk; for, under all ordinary circumstances, this mud solidifies into compact limestone instead of chalk, a result which would naturally be expected. What condition then is necessary to vary the result, and set aside the ordinary process.

The one locality of chalk among the reefs of the Pacific, referred to above, was not found on any of the coral islands, but in the elevated reef of Oahu, near Honolulu, of which reef it forms a constituent part. It is twenty or thirty feet in extent, and eight or ten feet deep. The rock could not be distinguished from much of the chalk of England: it is equally fine and even in its texture, as earthy in its fracture, and so soft as to be used on the blackboard in the native schools. Some imbedded shells look precisely like chalk fossils. It contained, according to Professor Silliman, 92·80 per cent. of carbonate of lime, 2·38 of carbonate of magnesia, besides some alumina, oxyd of iron, silica, etc.

The locality is situated on the shores, just above high-tide level, near the foot of Diamond Hill. This hill is an extinct tufa cone, nearly seven hundred feet in height, rising from the water's edge, and in its origin it must have been partly submarine. It is one of the lateral cones of eastern Oahu, and was thrown up at the time of an eruption through a fissure, the lavas of which appear at the base. There was some coral on the shores when the eruption took place, as is evident from imbedded fragments in the tufa; but the reef containing the chalk appeared to have been subsequent in formation, and afforded no certain proof of any connection between the fires of the mountain and the formation of the chalk.

The fine earthy texture of the material is evidence that the deposit was not a *subaerial* seashore accumulation, since only sandstones and conglomerates, with rare instances of more compact rocks, are thus formed. Sand-rock making is the peculiar prerogative, the world over, of shores exposed to waves, or strong currents, either of marine or fresh water. We should infer, therefore, that the accumulation was produced either in a confined area, into which the fine material from a beach may have been washed, or on the shore of a shallow, quiet sea; in other words, under the same conditions nearly as are required to produce the calcareous mud of the coral island. But, although the agency of fire in the result cannot be proved, it is by no means improbable, from the position of the bed of chalk, that there may have been a hot spring at the spot occupied by it. That there were some peculiar circumstances distinguishing this from other parts of the reefs, is evident.

This, if a true conclusion, is to be taken, however, only as one method by which chalk may be made. For there is no reason to suppose that the chalk of the Chalk formation has been subjected to heat. On the contrary, it is now well ascertained that it is of cold-water origin, even to its flints, and that it is made up largely of minute foraminifers, the shells of Rhizopods. Professor Bailey found under his microscope no traces of foraminifers, or of any thing distinctly organic, in the Oahu chalk.

XI. RATE OF INCREASE OF LIMESTONE FORMATIONS.

On page 253 it is shown that coral-reef limestones are of slow formation, the rate of increase in thickness, where all is most favorable, not exceeding perhaps a sixteenth of an inch a year, or five feet in a thousand years. And yet such limestones probably form at a more rapid rate than those made of shells, because the animals are to a larger extent calcareous or make proportionally larger calcareous secretions; and in addition they have the property of rapid multiplication by budding. The mollusks that grow and multiply most rapidly and have proportionally the largest shells are the Lamellibranchs or bivalves, among which the oyster is a famous example; and the Brachiopods were once the full equals of the ordinary bivalves. Large banks of bivalves seldom occur in regions of corals, the species there being to a great extent Gasteropods (or univalves); and hence the contributions of shells to coral reefs from mollusks are small compared with the extent of the beds which, by themselves, they make on other coasts. The coral seas of Florida nowhere have shore shell-beds like those of St. Augustine in northern Florida outside of the coral-reef seas. There is reason for this in the fact that these bivalves that grow in large banks live in beds of ordinary sand or mud, such as reef-regions do not generally supply.

XII. LIMESTONE CAVERNS.

The elevated coral limestone, although in general a hard and compact rock, abounds in caverns. They may be due in part to open spaces, or regions of loose texture, in or between the strata. But in most cases they are a result of solution and erosion by the fresh waters of the land, or the waves and currents of the ocean, subsequent to the elevation.

On the island of Metia, many caverns open outward in the coral limestone cliff and in some were large stalactites, as stated on page 194.

In the raised coral rock of Oahu (p. 371) there are several long winding horizontal chambers, some of which are the sources of subterranean streams that open out on the shores between the layers of the rock, or from the mouths of caverns. These running waters, and others trickling from above, are obviously the eroding agents that have made the caves.

As briefly remarked on page 194, caverns are still more remarkable on the island of Atiu, on which the coral reef-rock stands at about the same height above the sea as on Oahu, Rev. John Williams states that there are seven or eight of large extent on the island. Into one he entered by a descent of twenty feet, and wandered a mile in one only of its branches without finding an end "to its interminable windings." He says, "Innumerable openings presented themselves on all sides as we passed along, many of which appeared to be equal in height, beauty and extent to the one we were following. The roof, a stratum of coral rock fifteen feet thick, was supported by massy and superb stalactitic columns, besides being thickly hung with stalactites from an inch to many feet in length; some of these pendents were just ready to unite themselves to the floor, or to a stalagmitic column rising from it. Many chambers were passed through whose fretwork ceilings and columns of stalactites sparkled brilliantly, amid the darkness, with the reflected light of our torches. The effect was produced not so much by single objects, or groups of them, as by the amplitude, the depth, and the complications of this subterranean world."

Other similar caves exist on the neighboring island of Mauke.

The Bermudas and Bahamas are also noted for their caverns. The great height of the easily eroded drift sand-rock gives these reef-regions a chance for caverns, large and small; a notice of the Bermuda caverns will be found on page 224.

These are examples of the comparatively rapid formation of caverns. The waters which run or percolate through them must be charged with carbonic acid to accomplish such work, and yet they have no source for this ingredient except the atmosphere, animal respiration, and vegetable and animal decomposition in the soil. The flutings and stalactitic incrustations of a precipice facing the sea must depend on the former alone, with the aid perhaps of the spray from the sea brought over the reef by storms.

XIII. OCEANIC TEMPERATURE.

Facts seem to indicate—though perhaps not sufficient to demonstrate—that the Gulf Stream has had, from the Jurassic period in Geological history onward, the same kind of influence on the temperature of the North Atlantic Ocean which it now has.

The existence of a coral reef made out of corals of the Astræa tribe and others, during part of the Oölitic era (middle Jurassic), in England, as far north as the parallel of 52° to 55° is strong evidence that the isocryme of 68° F., the coral-reef boundary, extended then even to that high latitude; for species of the Astræa tribe are now confined to coral-reef seas (p. 109). This isocryme now reaches along the course of the Gulf Stream, to a point just north of the Bermudas, near 33° N.; and 55° is 22° beyond this.

There are no marine fossils in any rocks of that period on the American side of the Atlantic, so that facts fail for definitely locating the *western* terminus of this oölitic isocryme of 68° F. But it is highly improbable that the whole ocean across, on, or near, the parallel of 55° N., should have had, as the mean temperature for the coldest month of the year, one so high as 68° F.; the present average position of the isocryme of 68° F., through the middle of the two oceans, the Pacific and Atlantic, is near the parallel of 27° or 28°, or one-half nearer the equator than the parallel of 55°. It is difficult to account for an oceanic temperature high enough to give England's seas 68° F. as the average for the coldest winter month, even supposing the Gulf Stream to have aided; but it is vastly more difficult if no such northeastward current existed, and the high temperature extended equably so far from the equator. The probability is therefore strong that the existence of coral reefs in the Oölitic era in England was owing to the extension, by the aid of the Gulf stream, of the isocryme of 68° more than 30° in latitude (and over 3,000 miles in distance) beyond its present most extra-tropical position, just outside of the Bermudas; in other words, that the whole ocean was just enough warmer, to allow this oceanic current (part of the great water-circulation of the globe) to bear the heat required for corals as far north as northern England.

The present isocryme of 44° F., as drawn on the chart of the world accompanying this volume, has approximately the course which that of 68° F. probably had in Oölitic times. It should have a little less northing, and the loop to the north should lean more to the eastward. The latter would have been a consequence of the submerged condition at the time of most of the European continent.

The ocean's waters seem to have cooled somewhat before the next period—the Cretaceous—began, since evidence fails of any Cretaceous coral reefs in the British seas; but such reefs prevailed then in central and southern Europe, so that the amount of cooling in the interval since the Oölitic era, had not been large; and as late as the Miocene Tertiary, there were reef corals in the seas of Northern Italy, above latitude 45° N., or that of Montreal, in Canada.

The absence from the American coast of the Atlantic, of any coral reefs in the Cretaceous beds, and of any reef corals, seem to show that the oceanic temperature off this coast was not favorable for such corals; and if so, then the line of 68° F. extended at least 20° farther north on the European side of the ocean, than on the Atlantic—an inequality to be accounted for in part by the existence of the Gulf Stream. But, in addition, the whole range of life in the European Cretaceous, and its vastly greater variety of species, leave no doubt as to the higher temperature of the ocean along its European border; so that the idea of a Cretaceous Gulf Stream must be accepted. And that of a Tertiary is demonstrated by similar facts.

If the Gulf Stream had its present position and force in Oölitic, Cretaceous and Tertiary times, then the ocean had, throughout these eras, its present extension and oceanic character; and, further, no barrier of land extended across from South America to the Canaries and Africa, dividing the South from the North Atlantic, but all was one great ocean. Such a barrier would not annul entirely the flow of the Gulf Stream; yet the North Atlantic is so small an ocean, that if left to itself, its system of currents would be very feeble.

XIV. THE OCEANIC CORAL ISLAND SUBSIDENCE.

Coral islands have been shown to be literally monuments erected over departed lands; and, through the evidence from such records, it is discovered that the Pacific has its deep-water mountain chains, or lines of volcanic summits, not merely hundreds, but thousands of miles in length. Some of the ranges of high islands are proved by such records to have an under-water prolongation, longer than that above water: the Hawaian Islands for example, which have a length of only four hundred miles from Hawaii to Kauai, and five hundred and thirty to Bird Island, the western rocky islet of the group, stretch on westward, as the coral registers show, even to a distance of two thousand miles from Hawaii, or, as far as from New York to Salt Lake City; and how much farther is unknown, as the line of coral islands here passes the boundary of the coral reef seas, or the region where coral records are possible.

Other ranges of submerged summits are shown to extend through the whole central Pacific, even where not a rocky peak remains above the surface; for all the coral islands from the eastern Paumotus to Wakes' Island, near long. 170° E. and lat. 19° N., north of the Ralick and Radack (or Marshall) groups, are in linear ranges; and they have, along with the equally linear ranges of high islands just south, a nearly uniform trend, curving into northwest and north-northwest at the western extremity. The coral islands consequently cap the summits of linear ranges of elevations, and all these linear ranges together constitute a grand chain of heights, the whole over five thousand miles in length. Thus, the coral islands are records of the earth's submarine orography, as well as of slow changes of level in the ocean's bottom.

This coral island subsidence is an example of one of the great secular movements of the earth's crust. The axis of the subsiding area—the position of which is stated on page 363, has a length of more than six thousand miles—equal to one-quarter of the circumference of the globe; and the breadth, reckoning only from the Sandwich Islands to the Friendly Group (or to Tongatabu) is over twenty-five hundred miles, thus equalling the width of the North American continent. A movement of such extent, involving so large a part of the earth's crust, could not have been a local change of level, but one in which the whole sphere was concerned as a unit; for all parts, whether participating or not, must have in some way been in sympathy with it.

This subsidence was in progress, in all probability, during the Glacial era, the thickness of the reefs proving that in their origin they run back through a very long age, if not also into the Tertiary. It was a downward movement for the Tropical Pacific, and perhaps for the warmer latitudes of all the oceanic areas, while the more northern continental lands, or at least those of North America, were making their *upward* movement, preparatory to, or during that era of ice.

The subsidence connected with the origin of coral islands and barrier reefs in the Pacific has been shown (p. 357) to have amounted to several thousands of feet, perhaps full ten thousand. And, it may be here repeated that, although this sounds large, the change of level is not greater than the *elevation* which the Rocky Mountains, Andes, Alps and Himalayas have each experienced since the close of the Cretaceous era, or the early Tertiary; and perhaps it does not exceed the upward bulging in the Glacial era of part of northern North America.

The author has presented reasons for believing (*Am. J. Sci.*, III. v. 1873) that in this Glacial era the watershed of Canada, between the River St. Lawrence and Hudson's Bay, was raised somewhat above its present level (1,500 feet); and that this plateau thus elevated was the origin of the great glacier which moved southeastward over New England. This region is the summit of the eastern arm of the great V-shaped Archæan area of the continent, the earliest elevated land of North America; and it is not improbable that the other arm of the V, reaching from Lake Superior and Huron, northwestward, to the Arctic, was the source of glacial movements over the more central portions of the continent:—we cannot say *western* portions also, since in the *first* place, the facts, according to Prof. J. D. Whitney, do not sustain the statement; and, in the *second*, the great mountain ranges of the west would have been a barrier to all influences from any central continental elevation, and, besides, the slopes of these ranges, even if the Pacific border were higher to the north than now, would have determined the course of all western glacial movements.

The idea that both arms of the great Archæan nucleus were raised together, is not without some support. For the courses of the two were the courses of great continental uplifts or movements, again and again, through the successive subsequent ages; and the present outline of the continent is but the final expression of the great fact; moreover, the elevations parallel to the western arm of the V have been much the greatest. Even the exceptional courses, such as the nearly north and south trend of the Green Mountains, were marked out first in the Archæan, the Archæan peninsula of northern New York with the line of the Adirondacks being an exhibition of it. And all this uniformity of movement, from the laying of the first stone in the developing continent to the last, has been shown by the author to be directly connected with the fact that the continent has always been bordered by the same two great oceanic depressions, the Atlantic, and the larger Pacific, the same in trend of axis as now, the North Atlantic having a northeast and southwest trend, parallel with one arm of the Archæan, and the Pacific a northwest and southeast parallel with the other arm of the Archæan. It is therefore reasonable that, late in geological history, during the Glacial era, after the great mountain chains of the continent had been made and raised to their full height, and the surface crust thickened over all the continent, except that of the Archæan nucleus, by successive beds to a thickness of thousands of feet, even thirty-five thousand by the close of the Paleozoic along the Appalachians, and much beyond this on the Pacific border; and when these thick sediments had in many regions been stiffened by crystallization or metamorphism; I say it is reasonable that, finally, changes of level, through the working still of the old system of forces, should again have affected most the old nucleal Archæan area of the continent, where there had been no thickening except what had taken place internally; and that, if one arm of the V, that along the Canadian watershed, were raised at this time, the other, northwestern in trend, should also have been raised. This is at least probable enough to become a question for special examination over the region. See further the author's Manual of Geology, 1874.

The northern continental upward movements which introduced the Glacial era, carrying Arctic cold toward the tropics, may have been a balance to the *downward* oceanic movements that resulted in the formation of the Pacific atolls. While the crust was arching upward over the former (not rising into mountains, but simply arching upward) it may have been bending downward over the vast central area of the great ocean.

The changes which took place, cotemporaneously, in the Atlantic tropics, are very imperfectly recorded. The Bahamas show by their form and position that they cover a submerged land of large area stretching over six hundred miles from northwest to southeast. The long line of reefs and the Florida Keys, trending far away from the land of southern Florida, are evidences that this Florida region participated somewhat in the downward movement, but to a much less extent than the Bahamas. Again, the islands of the West Indies diminish in size to the eastward being quite small in the long line that looks out upon the blank ocean, just as if the subsidence increased in that direction. Finally, the Atlantic beyond is water only, as if it had been made a blank by the sinking of its lands.

Thus the size of the islands, as well as the existence of coral banks, and also the blankness of the ocean's surface, all appear to bear evidence to a great subsidence.

The peninsula of Florida, Cuba, and the Bahamas look, as they lie together, as if all were once part of a greater Florida or southeastern prolongation of the continent. The northwestern and southwestern trends, characterizing the great features of the American continent, run through the whole like a warp and woof structure, binding them together in one system; the former trend, the northwest, existing in Florida and the Bahamas, and the main line of Cuba; and the latter course, the west-southwest, in cross lines of islands in the Bahamas (one at the north extremity, another in the line of Nassau, and others to the southeast), in the high lands of northwestern and southeastern Cuba, and in the Florida line of reefs, and even further, in a submerged ridge between Florida and Cuba. This combination of the two continental trends shows that the lands are one in system, if they were never one in continuous dry land.

We cannot here infer that there was a *regular* increase of subsidence from Florida eastward, or that Florida and Cuba participated in it equally with the intermediate or adjoining seas; for the facts in the Pacific have shown that the subsiding oceanic area, had its nearly parallel bands of greater and less subsidence, that areas of greatest sinking alternated with others of less, as explained on page 326; and that the groups of high islands are along the bands of least sinking. So in the Atlantic, the subsidence was probably much greater between Florida and Cuba than in the peninsula of Florida itself; and greater along the Caribbean Sea parallel with Cuba, as well as along the Bahama reefs, than in Cuba.

The conclusions of Mr. Thomas Bland, based on the distribution of terrestrial mollusks in the Bahama Islands, a subject with which he had made himself familiar by study in the region, have much interest in this connection. He shows[1] that these mollusks, eighty in number of species, prove that the alliance of the Great Bahama Bank with Cuba is very close, as is apparent in the many species of *Polymeta* and *Strophia*, and the occurrence in both of the genera *Polygyra*, *Thelidomus* and *Melaniella*, not known in Hayti; while Turk Island bears evidence of connection with Hayti through the genus *Plagioptycha* and the species common to the two, *P. Albertsiana* and *P. disculus*.

After mentioning the views in this volume on the diminished size of the islands to the eastward and the evidence thereby of subsidence, he says: —

"The facts regarding the diminution in size of the islands of the West Indies to the eastward are of peculiar interest, not only as affording conclusive evidence of greater subsidence in that direction, but also in connection with geographical distribution. The banks and islands forming the long Bahama chain diminish in size to the southeast, where are situated at its termination the submerged Mouchoir Carré, Silver and Navidad Banks. In a similar manner, the submerged Virgin Island Bank (with Anegada on its northeastern extremity geologically resembling the Bahamas in the opinion of Dr. Cleve). Sombrero and the Anguilla Bank, terminate the chain of the West Indies eastward from Cuba, parallel with the Bahama chain. In the caves of Anguilla the remains of large

[1] Annals of the Lyceum of Natural History of New York, Vol. X., 1873, an abstract of which appeared in the American Journal of Science, 1874, VIII. 231.

extinct Mammalia are found which must have inhabited a far more extensive area subsequently broken up by subsidence."

The position of the lonely Bermuda atoll confirms these deductions. Its solitary state is reason for suspecting that great changes have taken place about it; for it is not natural for islands to be alone. The tongue of warm water due to the Gulf Stream, in which the Bermudas lie, is narrow, and an island a hundred miles or more distant to the north-east-by-east, or in the line of its trend (p. 219), if experiencing the same subsidence that made the Bermuda land an atoll, would have disappeared without a coral monument to bear record to its former existence. Twenty miles to the south-west-by-west from the Bermudas, there are two submerged banks, ten and twenty-four fathoms under water, showing that the Bermudas are not completely alone, and demonstrating that they cover a summit in a range of heights; and it may have been a long range.

In the Indian ocean, again, there is evidence that the coral-island subsidence was one that affected the oceanic area more than the adjoining borders of the continent, and most, the central parts of the ocean. For, in the first place, the Archipelago of the Maldives narrows and deepens to the southward (p. 186). Further, the large Chagos Group, lying to the south of the Maldives, contains but very little dry land in any of its extensive reefs, while some of them, including the Great Chagos Bank, are sunken atolls. Again, still other large reefs nearly bare lie to the southwest of the Chagos Bank, and submerged banks exist in the seas north-east and east of northern Madagascar.

The probability is, therefore, that both the central Atlantic and Indian Oceans included regions of subsidence like the central Pacific, and that the absence of islands over a large part of their interiors may be a consequence of it. A rate of sinking exceeding five feet in a thousand years (if the estimate on page 253 is right) would have buried islands and reefs together in the ocean; while, with a slower rate, the reefs might have kept themselves at the water's surface. So small may have been the difference of rate in the great movement that covered the Pacific with coral islands, but left the Indian Ocean a region of comparatively barren waters, with some "half-drowned" atolls, and the central Atlantic almost wholly a blank.

While thus seeming to prove that all the great oceans have their buried lands, we are far from establishing that these lands were oceanic continents. For as the author has elsewhere shown, the profoundest facts in the earth's history prove that the oceans have always been oceans. These lands in all probability were, for the most part, volcanic islands or summits of volcanic ranges, for of this nature are all the islands over the interior of either ocean that are not of coral origin.

The course of argument leads us to the belief that a very large number of islands, more than has been supposed, lie buried in the ocean. Coral islands give us the location of many of these lands; but still we know little of the extent to which the earth's ranges of heights, or at least of volcanic peaks, have disappeared through oceanic subsidence. Recent dredgings and soundings have proved that the bottom of the oceanic basin has little of the diversity of mountain chains and vallies that prevails over the continents; and, through this observation (and also by the discovery that some ancient types of animal life, supposed to have been long extinct, are perpetuated there), they have afforded new demonstration of the proposition, above stated, that *the oceans have always been oceans.* But while the facts do not imply the existence deep in the ocean of many granitic mountain chains, they do teach that there are long ranges, or lines, of volcanic ridges and peaks, and some of these may be among the discoveries of future dredging expeditions. A range of deep-sea cones, or sunken volcanic islands, would be as interesting a discovery as a deep-sea sponge or coral, even if it should refuse, excepting perhaps a mere fragment, to come to the surface in the dredge.

We may also accept, with some confidence, the conclusion that atolls and barrier reefs originated in the same great balance-like movement of the earth's crust that gave elevation and cold, in the Glacial era, to high-latitude lands. If so, the tropics and the colder latitudes were performing their several works simultaneously in preparation for the coming era; and it is a gain to us in our contemplations, that we hence may balance the beauty and repose of the tropics, through all the progressing changes, against the prolonged scenes of glacial desolation that prevailed over large portions of the continents.


ISOCRYMAL CHART
OF THE OCEANS.
THE ISOTHERMS SHOWING THE AVERAGE TEMPERATURE OF THE COLDEST MONTH.
TO ILLUSTRATE THE
GEOGRAPHICAL DISTRIBUTION
OF
CORALS & OTHER OCEANIC SPECIES
BY
JAMES D. DANA.
NORTH AMERICA
SOUTH AMERICA
EUROPE
NEW HOLLAND
N. FRIGID
SUBFRIGID
COLD TEMPERATE
SUBTEMPERATE
TEMPERATE
WARM TEMPERATE
SUBTORRID
N. TORRID
SUPERTORRID
S. TORRID
EQUATOR
S. FRIGID
San Francisco
Aleutian Is.
CAROLINES
GALAPAGOS
PAUMOTU
Rio Janeiro
Valparaiso
Auckland
Campbell
Georgia

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APPENDIX.

I. ARTESIAN WELLS ON SOUTHERN OAHU.

On page 287 reference is made to artesian borings on Oahu of the Hawaiian Islands, that descended through coral reef strata of much thickness and at large depths, which are believed to be good evidence of a former higher level of the island by some hundreds of feet, and therefore of a gradual subsidence since, the only doubt coming from the possibility that the coral rock at the lower levels may be not true reef rock but of pelagic origin. The following are the details as to fifteen of these borings in the area between the centre of the city of Honolulu and Diamond Head on the coast to the eastward. The level of the surface from which they start is not above thirty feet.

The positions of these wells may be learned from the following map, — a reduced copy of a chart received from the surveyor general of the Hawaiian Islands, Prof. W. D. Alexander. Part of the shore region of Southern Oahu is here represented, from the city of Honolulu, on the west, to the tufa cone, Leahi or Diamond Head, whose southern brow has a height of 761 feet. Puowaina, or Punchbowl, standing just back of Honolulu and 498 feet high, is also a tufa-crater. Rocky Hill, near Oahu College, and some low hills near by, appear to have been made by flows of lava from fissures of comparatively recent date. The large and deep valleys of the mountains Nuuanu and Manoa, and the narrower Palolo valley, open out on this shore-region near the northern limit of the map.

The map also shows the position and width of the coral reef of the coast, and of the harbor of Honolulu, which owes its existence to the reef. The larger part of this shore-region is covered by the elevated fringing reef, which has a height above the sea of fifteen to twenty-five feet. Its surface is covered by six to ten feet of a glassy black volcanic sand, which may have been ejected from the Rocky Hill vent, and four to six feet of surface soil. The borings descend through the soil and sand, and then the elevated fringing reef of coral limestone, to a bottom of solid lava, and intersect at some levels, besides coral rock, layers of tufa, lava, "clay," sand or bowlders, which are the results of occasional eruptions during the growth of the reef, or of deposition from the streams of the valleys.

The positions of the artesian wells are indicated on the map by small circles, and those referred to beyond have their names attached in small capitals. They are also numbered within the circles. (A magnifying-glass may be needed to read the names on the much-reduced map.) The records of the superintendent of the borings, Mr. J. A. McCandless, were received through Prof. W. D. Alexander, excepting that of the Atherton well, for which and for specimens of the materials of the successive beds, the author is indebted to Mr. W. C. Merritt, President of Oahu College.

The wells are topographically of three groups. Seven of them (numbers 1 to 7) are situated around the base of Punchbowl; four (8 to 11) southwest of the base of Rocky Hill; and four (12 to 15) northwest to southwest of Diamond Head, the last one at its base, and only a short distance from the seashore. In order to interpret the sections it should be noted that the prevalent winds under whose action the tufa cones were made are the trades, or from the northeast. The thickness of beds and depth are given in feet. To aid in the comparison of the results, the sections that are most similar are placed in parallel columns.

1. ARTESIAN WELLS ABOUT THE BASE OF PUNCHBOWL (Nos. 1 TO 7).

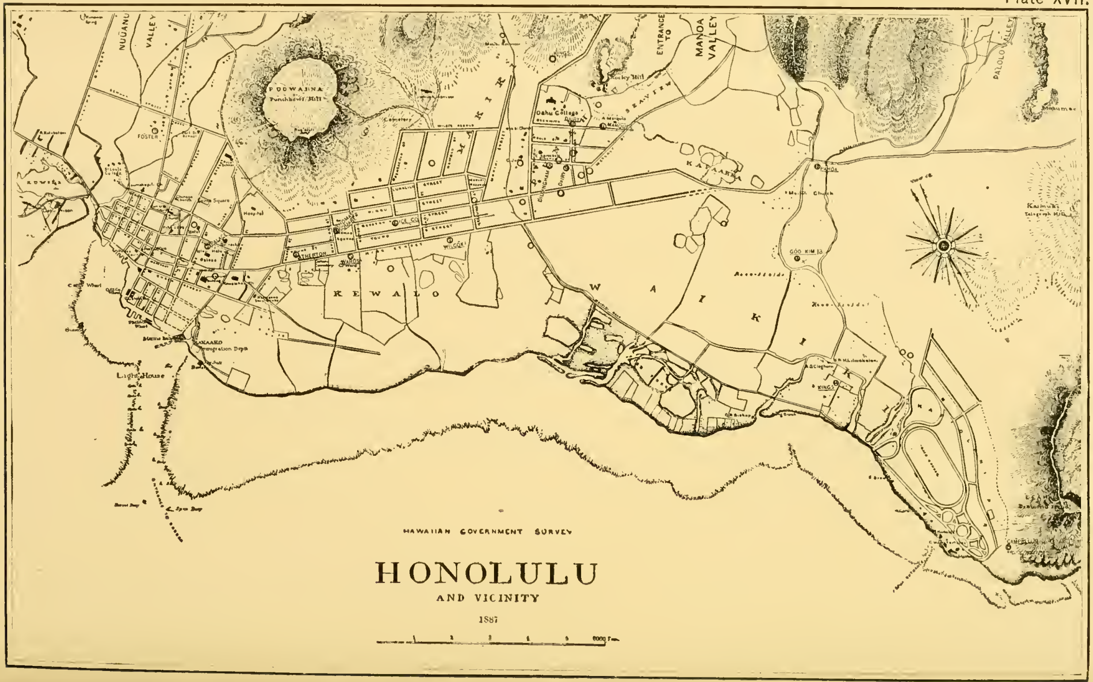
1. Foster Well, e. of Punchbowl. 2. Palace Well, s. of Punchbowl.

	Thickness.	Depth.		Thickness.	Depth.
Soil 4 ft., black sand 4	8		Soil 4, black sand 4	8	
Bowlders	6	14	Coral	64	72
Lava	40	54	*Lava*	6	78
Clay 16, bowlders 12	28	82	White Coral	60	138
Clay 20, bowlders 8	28	110			
Clay	300	410	Clay	240	378
Coral	40	450	Coral	75	452
Clay, gravel, 110; clay, bowlders, 180	290	740	Clay and gravel	254	707
Lava or bed-rock	27	767	*Lava* or bed-rock	55	762

3. Atherton Well, s. of Punchbowl.

	Thickness.	Depth.		Thickness.	Depth.
Soil 6, black sand 6	12		Coral (clay 5 incl.)	75	480
Coral (clay 5 incl.)	178	190	Gravel and clay	25	505
Red clay	10	200	Coral	10	565
Coral	30	230	Clay, sand, some coral, gravel	80	595
Brown clay (coral 5 incl.)	60	290	Bed-rock or *lava*	60	655
Coral	30	320			
Brown clay	35	355			

Plate XVII.


NUŪANU
VALLEY
PUOWAINA
Punchbowl Hill
FOSTER
Cemetery
Square
Hospital
ENTRANCE
TO
MANOA
VALLEY
Rocky Hill
Oahu College
K E W A L O
W A I K I K I
KAPAAHRA
PALOLO VALLEY
Kaimuki
Telegraph Hill
Light House
KAKAAKO
Immigration Depot
ATHERTON
WILCOX
ICE CO
GOO KIM 13
KINGS
HAWAIIAN GOVERNMENT SURVEY
HONOLULU
AND VICINITY
1887

4. Thomas Square Well, s. of Punchbowl.

	Thickness.	Depth.
Soil 6, black sand 6, clay 4	16	
Coral	200	216
Brown clay	44	260
Coral	10	270
Brown clay	60	330
White Coral	50	380
Brown clay	80	460
Bed-rock or *lava*	49	509

6. Ice Co. (Sass') Well, s. of Punchbowl.

	Thickness.	Depth.
Soil 4, black sand 10	14	
Coral	200	214
Brown clay	38	252
Coral	25	277
Clay	40	317
Coral	80	397
Clay	53	450
Lava, bed-rock	53	503

5. Ward's, s. of Punchbowl.

	Thickness.	Depth.
Soil and sand	15	
Coral	204	219
Yellow clay	4	260
Hard Coral	1	261
Yellow clay	109	370
Coral	23	393
White and yellow clay, sand	111	504
Lava	4	508

7. Wilcox, s. of Punchbowl.

	Thickness.	Depth.
Soil 4, black sand 6	10	
Coral	50	60
Hard lava (fr. Rocky Hill ?)	40	100
Clay	30	130
Coral	120	250
Clay	30	280
Coral	70	350
Clay	100	450
Bowlders, clay, gravel	85	535
Lava bowlders 40, clay 45	85	620
Lava or bed-rock	40	660

2. ARTESIAN WELLS SOUTHWEST OF ROCKY HILL.

8. Dillingham Well.

	Thickness.	Depth.
Loam, gravel, clay	90	
Coral	40	130
Clay	60	190
Coral	20	210
Clay, black sand	40	250
Lava (fr. Rocky Hill ?)	50	300

9. Dairy Well (southern).

	Thickness.	Depth.
Soil, sand, clay	60	
Coral	10	70
Clay	35	105
Coral (clay 5 incl.)	100	205
Black clay	25	230
Coral	10	240
Clay 30, sand, gravel	40	280
Lava, black (fr. Rocky Hill ?)	10	290

10. Dairy Well (northern).

	Thickness.	Depth.
Soil, clay	30	
Bowlder clay	90	120
Coral and clay	15	135
Coral	10	145
Clay, sand, gravel	25	170
Bed-rock, *lava*	43	213

11. Marques Well.

	Thickness.	Depth.
Earth	10	
Sandy, soft Coral	20	30
Lava, layers of gravel	40	70
Clay	30	100
Lava in layers	195	295

The above four wells all bear evidence of their nearness to Rocky Hill, a lateral lava vent, and of their distance from the seashore.

3. ARTESIAN WELLS NORTHWEST TO SOUTHWEST OF DIAMOND HEAD.

12. Pahoa Well, 6300 feet from the Coast.

	Thickness.	Depth.		Thickness.	Depth.
Clay	37		Coral	50	175
Bowlders 17, clay 10	27	64	Clay	20	195
Clay and coral	8	72	Coral	80	275
Bowlders	8	80	Clay, sand	100	375
Coral	26	106	*Lava*, or bed-rock	32	407
Lava	19	125			

13. Goo Kim's Well, 4000 feet from the Coast.

	Thickness.	Depth.		Thickness.	Depth.
Soil 10, gravel 13	23		Clay	20	290
Lava	43	66	Coral	50	344
Clay	58	124	Clay	20	380
Coral	26	150	Coral	50	430
Lava	26	176	Clay	45	485
Coral	94	270	*Lava*, bed-rock	65	540

14. King's Well, about 1000 feet from the Coast.

	Thickness.	Depth.		Thickness.	Depth.
Soil and coral	38		Soft Coral, 30, white, 45[1]	75	495
White Coral	22	60	Clay	30	525
Yellow sand	43	103	Coral, white	100	625
Lava	47	150	Clay (tough)	5	630
White Coral	110	260	Coral and clay	70	700
Clay	120	380	Clay 28, black sand 2	30	730
Coral, hard	40	420	*Lava*, bed-rock	120	850

15. Campbell's Well, near the Foot of Diamond Head, about a Mile more to the South than Well No. 14.

	Thickness.	Depth.		Thickness.	Depth.
Gravel, beach-sand	50		White coral, soft	28	1048
Tufa, like that of Diamond Head	270	320	Rock soft like soapstone	20	1068
Coral, hard, white, like marble	505	825	Brown clay, with broken coral	110	1178
Dark brown clay	75	900	*Lava*	45	1223
Washed gravel	25	925	Black clay 10, red pipe clay 18	28	1251
Very red clay	95	1020	*Lava*	249	1500

[1] 5 foot layer of clay included.

The great distance of the Pahoa well from the coast is a reason for the small amount of coral rock.

The water of Campbell's well was "as salt as brine;" it stood in the casing about a foot higher than the water of a surface well adjoining.

The artesian wells indicate great diversity in the thickness of the coral formation, and a dependence, as regards thickness, on distance from the hills. Campbell's well, No. 15, is about 4,000 yards from the hills, and has a limestone bed of "hard coral rock, like marble" over 500 feet thick, which at bottom is 865 feet below the sea-level, besides a bed of probably similar origin over 200 feet lower; while King's well, about one half nearer the hills has the bottom of the lowest coral bed at 700 feet. The same level in Goo Kim's well, No. 13, is at 430 feet, and in the Pahoa well, No. 12, still nearer the hills (the distance but 1,500 feet), 275 feet. All these levels are below the limit of growing corals, and far below the Hawaiian limit, which, according to Mr. Agassiz, is less than 100 feet. But the intercalation of beds of lava, tufa, and clay (either tufa beds or decomposed lava) make a close comparison of the sections in this respect with one another impracticable.

The wells about Punchbowl have great interest. The Foster and Palace wells, Nos. 1 and 2, are about 600 yards from the base of Punchbowl, and bear N. 70° W., and S. 65° W., from its centre. In each, the bottom bed of coral extends to a depth of about 450 feet (450 in No. 1, and 452 in No. 2), which, as No. 2 shows, is 442 feet below the top of the elevated fringing reef.

Hence, in the case of each, the coral reef rock at bottom is more than 350 feet below the Hawaiian limit of growing corals. Difference in position must account for the difference in the upper portion of the two sections; and the chief fact as to position is that the Foster well is within the Nuuanu Valley, where clay and bowlders may have been carried down by its running waters. But in an important feature they are alike, the coral bed just referred to having over it, in one, 300 feet of "clay," and in the other, 278 feet. This thick bed of "clay" was very probably made by cinder-ejections from Punchbowl; for the tufa of Punchbowl (a kind of palagonite), if brought up from a boring, would feel and look much like clay. This is further sustained by the fact that in the wells more to the south of Punchbowl, little of the clay-bed was found, the localities being too far to the eastward to receive much of the cinders; their bearings from the centre of Punchbowl are between S. 30° W., and S. 5° E.

In each of the five wells, Nos. 3 to 7, the top layer consists of 12 to 16 feet of soil and black sand. Below this, in Nos. 3 to 6, there are, severally, 178, 200, 200, 204 feet of the coral limestone of the elevated fringing reef; and the lower limits of the bottom layer of coral are, severally, at 515, 380, 397, 393 feet. In the Wilcox well, No. 7, a bed of lava, 40 feet thick (perhaps from Rocky Hill) with 30 feet of "clay" below it, intervenes between the first and second beds of coral limestone, which two have together a thickness of 170 feet. It is an interesting example of the adverse circumstances attending coral growths about an island of active fires.

The author is unable to find in the facts from these wells evidence that sustains, as urged by Mr. A. Agassiz,[1] the Murray hypothesis, or anything that sets aside the various objections to this hypothesis that have been presented. In two of the Oahu wells, the Jaeger well and one of the Government wells on the Waikiki road, according to Professor Alexander, carbonized cocoanut-wood was found at a depth of about 150 feet, beneath a 150-foot stratum of coral. This and all the other observations in connection with the wells are fully explained by the theory of subsidence.

Oahu is an example of an island that has had an upward shove, notwithstanding the progressing subsidence. The amount of elevation indicated by the elevated coral reef is about 25 feet on the south side and 50 to 60 feet on the north side. The Kahuku bluffs of the vicinity of the north cape are not made wholly of drift sand, as Mr. Agassiz concluded from his observations. The bluffs have a top layer of wind-drift origin, while the rest, 50 to 60 feet high above the sea-level by estimate, is true coral reef rock, as the author has illustrated elsewhere. Such a change of level, as already stated, is not against the subsidence theory; it is one of the common incidents of a volcanic region.[2]

II. RATE OF GROWTH OF CORALS AND CORAL REEFS.

Arrangements made at Tahiti for measuring the rate of growth of a coral reef. — The arrangements made by Captain Wilkes for measuring the rate of growth of coral reefs are mentioned on page 257. A memoir by MM. Le Clerc and De Benazé was published at Paris in 1872, giving an account of their attempts to make use of the stone planted by Captain Wilkes. They made various measurements; but they observe that Wilkes does not state

[1] Coral Reefs of the Hawaiian Islands, by Alexander Agassiz, Bulletin of the Museum of Comparative Zoölogy, 1889, XVII., 121.

[2] The fact that corals were growing about Oahu during the time when tufa eruptions were in progress over the southern border of the island, is proved by facts recently communicated (Dec. 11, 1889) to Professor Alexander, by Rev. S. E. Bishop, of Honolulu. He observes that in Halawa, Ewa, at the cutting for the railway across two small bays of Pearl Lochs, and south of Kuahua Island, there occur, in the finely laminated tufa, layers of comminuted shells and corals. Mr. Bishop concludes that these materials were "probably torn off from the sides of the fissure of ejection that was presumably opened through the anciently subsided strata of corals and shells." Fragments of corals and shells were still more abundant over the top of the tufa. Scattering pieces of coral were also observed by Mr. Bishop imbedded in the tufa of the low craters southwest of Koko Head.

whether he measured from the top of a head of coral, or from the solid bank on which the corals were growing: and, further, that the use of our "excellent spirit level" from a stone of so little length is not sufficiently exact for correct results, and hence they draw no conclusions from their trials.

Before leaving the region, they made the following arrangements with reference to future measurements. They planted two blocks of coral, cementing them below, nearly burying them in the soil, placing them 0.21 metres above the Wilkes' stone, which is between them. They then put a mark upon them on plates of metal directed toward the place of observation on the shoal. A third stone was placed forty metres from the southwest angle of the Point Venus lighthouse, in order to give a second observation on the position of the spot on which the soundings were to be made. This spot was found to bear from the two new stones N. 77° 30′ E.; from the third stone, N. 70° 55′ E ; from the bell of the new Mission Church, S. 81° 40′ E. A horizontal line passing from the mark on the new stone is 7.460 metres above the madreporic heads.

They also made observations which satisfied them that Tahiti was not at present undergoing any general elevation. Two maps accompany the pamphlet: one is copied from Wilkes; the other is from a chart by Lieutenants Le Clerc and Minier, and contains lines showing the positions of the points referred to above. See page 246.

The following letter on the *Rate of Growth of Florida Corals*, for which the author is indebted to Mr. H. T. Woodman, the investigator of the subject, was received too late for the use of the facts in the earlier part of this work. It is dated: —

BUFFALO, N. Y. Jan. 25, 1890.

"Herein I enclose a copy from the diary which I kept while on the Florida Reef during the winter of 1881–82. It gives almost the exact growth of such massive corals as I found or placed in a shallow channel across the reef just east of the Tortugas Group in the winter of 1867–68. The water on the reef at this point was only about three feet deep with two feet more in the channel at lowest tide. From the healthy appearance of the Madrepora cervicornis on both sides of the channel, with Millepora alcicornis and Porites clavaria in close proximity, as well as good specimens of Mæandrina labyrinthica, Orbicella cavernosa, and a Dichocœnia within a few feet of the centre of the channel, I was inclined to think that no more favorable locality to watch the growth of some of the massive corals could be found. I therefore added to the above-named massive forms, a Siderastræa, Orbicella annularis, Porites astræoides, Diploria cerebriformis, Manicina areolata, Mæandrina sinuosa, and M. clivosa.

In the winter of 1881–82, the last time they were examined, their growth for the fourteen years was as follows: —

Dichocœnia had an upward growth of a fraction less than half an inch; Orbicella cavernosa, seven eighths of an inch; O. annularis, one and a quarter inches large; Siderastræa, a fraction less than five eighths of an inch; Diploria cerebriformis, almost three fourths of an inch; Mæandrina sinuosa, an inch and a quarter large; M. labyrinthica, an inch and seven eighths; Manicina areolata, a fraction less than five eighths of an inch.

We could not get the exact rate of growth of the Mæandrina clivosa for the reason that it was not regular. The specimen, when placed in the channel, measured less than six inches and in the fourteen years had spread out over eight inches, being, when last measured, about fourteen inches in diameter, while its upward growth was three or four inches in some places and less than an inch in others; and what appeared still more strange was the fact that the thickest piece was near the edge. I regard the growth of this species very uncertain. I have frequently seen it on bricks and other objects in the form of an incrusting coral and measuring six or more inches in diameter with perhaps less than half an inch in thickness. It is the most abundant coral at Fort Taylor as well as at Fort Jefferson.

Madrepora cervicornis had so encroached upon the channel as to obliterate all of my marks, hence I know but little of its rate of growth; but it is certain that the channel had been narrowed from six to eight or perhaps ten feet by this coral.

The temperature of the water has much to do with the growth of some species of corals. I do not now recall a single instance of finding a specimen of Dichocœnia or of Orbicella cavernosa, except in close proximity to the Gulf Stream. The largest specimen of O. cavernosa I have ever found was in a four foot channel where the waters of the Gulf Stream encroached upon the reef. This specimen, as nearly as I can recall, was about eighteen or twenty inches in diameter and is now in the Washington University, St. Louis, Mo. Should I live until 1892–93 it is my intention to remove these corals, when I shall be glad to give you the exact increase in twenty-five years."

Respecting the *supply of food for the growing corals* of a reef, it is to be considered that the amount of life is elsewhere unequalled. Prof. T. Fuchs, in his paper on the Distribution of Oceanic Life (page 118), speaks of such seas within the depth of twenty fathoms as "the gathering ground of an extremely rich fauna;" a fauna that embraces "the whole splendor of the animal life of the Indian and Pacific Oceans," and as being of so peculiar character that the terms "coral fishes" and "coral mollusks" would not be inappropriate.

III. NAMES OF SPECIES IN THE AUTHOR'S REPORT ON ZOÖPHYTES.

THE following catalogue contains the names that are now accepted for the species of Actinoid Coral Zoöphytes described in the Author's Report. The changes have chiefly resulted from the subdivision of the old genera. The catalogue has been prepared for this place by Prof. Verrill, and the explanatory notes have been added by him.

	NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
Page 159.	Euphyllia pavonina	Flabellum pavoninum *Lesson.*
	“ anthophyllum	“ anthophyllum *E. & H.*
	“ spheniscus	“ spheniscus *E. & H.*
	“ rubra	“ rubrum *E. & H.*
	“ spinulosa	Desmophyllum spinulosum *Verrill.*
	“ glabrescens	unchanged.
	“ gracilis	“
	“ aspera	Eusmilia aspera *E. & H.*
	“ aperta	“ fastigiata *E. & H.* (?)
	“ costata (p. 720)	“ costata *Verrill.*
	“ rugosa	unchanged.
	“ turgida	“
	“ meandrina	Euphyllia fimbriata *E. & H.*
	“ sinuosa	Pterogyra sinuosa *E. & H.*
	“ cultrifera	“ cultrifera *E. & H.*
170.	Ctenophyllia pectinata (not of *Lam.*)	Pectinia Danæ *E. & H.*
	quadrata	“ quadrata *E. & H.*
	pachyphylla	“ pachyphylla *E. & H.*
	profunda	“ profunda *E. & H.*
174.	Mussa[1] fastigiata	
	“ carduus	unchanged.
	“ angulosa	“
	“ corymbosa	“
	“ cactus	“
	“ costata	“
	“ sinuosa (not of *Ellis*)	Mussa tenuidentata *E. & H.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
174. Mussa cytherea	unchanged.
" multilobata	"
" cerebriformis	'
" regalis	"
" crispa (not of *Lam.*)	Mussa Indica *Verrill,* and Mussa radians *Verrill.*
' dipsacea	Isophyllia dipsacea *Verrill.*
" fragilis	" fragilis *Verrill.*
" gyros	Colpophyllia gyrosa *E. & H.*
" recta	unchanged.
" nobilis	"
189. Manicina amarantum	Tracyphyllia amarantum *E. & H.*
" fissa	Colpophyllia.
" areolata [2]	Manicina areolata *Ehr.*
" meandrites	
" hispida	
" prærupta	
" dilatata	
195. Tridacophyllia lactuca	unchanged.
196. " pæonia	"
" manicina	"
198. Caulastræa furcata	"
199. " distorta	'
" undulata	"
205. Orbicella [3] radiata	Orbicella radiata *Dana.*
" argus	" cavernosa *Verrill.*
" glaucopis	" glaucopis *Dana.*
" patula	Acanthastræa patula *E. & H*
" curta	Plesiastræa curta *E. & H.*
" rotulosa	Astræa rotulosa *Lam.*
" coronata	Plesiastræa coronata *E. & H.*
" hyades	Solenastræa hyades *Verrill.*
" excelsa	" excelsa *Pourtales*
" pleiades	" pleiades *Verrill.*
" annularis	Orbicella annularis *Dana.*
" stellulata	" stellulata *Dana.*
stelligera	Plesiastræa stelligera *E. & H.*
" crispata	Ulastræa crispata *E. & H.*
" microphthalma (not of *Lam.*)	Cyphastræa Danæ *E. & H.*
" ocellina	" ocellina *E. & H.*
720. " orion	Orbicella orion *Dana.*
205. Siderina galaxea	Siderastræa radians *Verrill.*
205. Astræa (Fissicella) speciosa	Astræa[4] speciosa *Dana.*
" " uva	Dichocœnia uva *E. & H.*
" " ananas	Astræa ananas *Lam.*
" pandanus	" pandanus *Dana.*
" ' puteolina	" puteolina *Dana.*
" " pallida	" pallida *Dana.*
" " dipsacea	Acanthastræa dipsacea *Verrill.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
205. Astræa (Fissicella) porcata (not of *Esper*)	Astræa Danæ *Verrill.*
" " flexuosa	Prionastræa flexuosa *Verrill.*
" " fusco-viridis	" fusco-viridis *E. & H.*
" " virens	" virens *E. & H.*
" " echinata	Acanthastræa echinata *E. & H.*
" " fragilis	Astræa fragilis *Dana.*
" " tenella	Acanthastræa tenella *Verrill.*
" " magnifica (not of *Bv.*)	Prionastræa spectabilis *Verrill.*
" " filicosa	Orbicella filicosa *Verrill.*
" " versipora	Astræa versipora *Lam.*
" " " (var.)	" Putnami *Verrill.*
" " denticulata (not of *Lam.*)	" cellulosa *Verrill.*
" " pectinata	" pectinata *Dana.*
" " deformis	Aphrastræa deformis *E. & H.*
" " var. dedalina	Cœloria dædalina *Verrill.*
" " varia	Cœloria spongiosa, var. *E. & H*
" " rigida	Isophyllia rigida *Verrill.*
" " reticularis (not of *Lam.*)	Prionastræa Agassizii *E. & H.*
" " petrosa	Dichocœnia petrosa *Verrill.*
" " purpurea	Leptastræa purpurea *Verrill.*
" " pulchra	" pulchra *Verrill.*
" " pentagona	Goniastræa pentagona *Verrill.*
" " favistella	" favistella *Verrill.*
" " var., from Wakes I.	Astræa Pacifica *Verrill.*
" " eximia	Goniastræa eximia *E. & H.*
" " sinuosa	Prionastræa sinuosa *Verrill.*
" " melicerum	" melicerum *E. & H.*
" " parvistella	Goniastræa parvistella *E. & H.*
" " favulus	Prionastræa favulus *Verrill.*
" " cerium	Goniastræa cerium *E. & H.*
" " intersepta (not of *Lam.*)	Plesiastræa armata *Verrill.*
" " abdita	Prionastræa abdita *E. & H.*
" " tesserifera	" tesserifera *E. & H.*
" " robusta	" robusta *E. & H.*
" " complanata (?)	" complanata *E. & H.*
" " heliopora	Orbicella heliopora *Verrill.*
" " " figured	Prionastræa valida *Verrill.*
" " Hemprichii	Prionastræa Hemprichii *E. & H.*
" " halicora	" halicora *E. & H.*
" " cyclastra	**Astræa cyclastræa** *Dana.*
" " favosa	Prionastræa favosa *E. & H.*
254. Meandrina dedalea (not of *Ellis*)	Cœloria dædalina, var. *Verrill.*
" spongiosa	" spongiosa *E. & H.*
" labyrinthica	Mæandrina labyrinthiformis *Verrill.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
205. Meandrina strigosa	unchanged.
" interrupta	"
" rustica	"
" valida	"
" phrygia (not of *Ellis*)	Mæandrina rudis *Verrill.*
" gracilis	Leptoria gracilis *E. & H.*
" tenuis	" tenuis *E. & H.*
" filograna	Mæandrina clivosa (young) *Verrill*
" cerebriformis	Diploria cerebriformis *E & H.*
" truncata	" truncata *E. & H.*
" mammosa	Mæandrina clivosa *Verrill.*
" cylindrus	Dendrogyra cylindrus *Ehr*
" caudex	" caudex *Ehr.*
266 Monticularia microcona	Hydnophora microconos *E. & H.*
" lobata	" exesa *E. & H.*
" polygonata	" polygonata *E. & H*
270. Phyllastræa tubifex	unchanged.
271. Merulina ampliata	"
" regalis	"
" speciosa	"
" crispa	"
" folium	Hydnophora Demidoffi *Fischer.*
" scabricula	Clavarina scabricula *Verrill.*
" laxa	unchanged.
" rigida	Hydnophora rigida *E. & H.*
278. Echinopora undulata	unchanged.
" rosularia	"
" ringens	"
" reflexa	"
" aspera	Trachypora aspera *Verrill.*
" horrida	Acanthopora horrida *Verrill.*
289. Fungia cyclolites	Cycloseris cyclolites *E. & H*
" tenuis	" tenuis *Verrill*
" glans	" glans *Verrill.*
" discus	unchanged.
" agariciformis	Fungia patella *E. & H.*
" var. tenuifolia	Fungia tenuifolia *Dana* (not *E. & H.*)
" dentata	unchanged.
" echinata (not of *Pallas*)	Fungia Danæ *E. & H.*
" var. from Feejees	" lacera *Verrill.*
" repanda	unchanged.
" integra	"
" confertifolia	"
" horrida	"
" actiniformis	"
" crassitentaculata	"
" Paumotensis	Lobactis Paumotensis *Verrill.*
" dentigera	" Danæ *Verrill.*
" scutaria	Pleuractis scutaria (Ag. MSS.) *Verrill.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
289. Fungia pectinata	Ctenactis echinata (Ag. MSS.) *Verrill*
" Ehrenbergii	" Ehrenbergii *Verrill.*
" var. gigantea	" gigantea *Verrill.*
" asperata	" asperata *Verrill.*
" Ruppellii	" echinata *Verrill.*
" crassa	" crassa *Verrill.*
307. Herpetolithus limacinus	Herpetolitha limax *Esch.*
Herpetolithus interruptus	" "
" foliosus	" "
" stellaris	" "
" strictus	unchanged.
" crassus	"
311. Halomitra pileus (not of *Linn.*)	Halomitra clypeus *Verrill.*
313. Polyphyllia talpa	Cryptabacia talpina *E. & H.*
" leptophylla	" leptophylla *E. & H.*
" sigmoides	" sigmoides *Verrill.*
" pelvis	unchanged.
" fungia	
" pileiformis	Lithactinia pileiformis *E. & H.*
" galeriformis	" galeriformis *E. & H.*
319. Zoöpilus echinatus	unchanged.
321. Pavonia explanulata	Podabacia crustacea *E. & H.*
" crispa	Haloseris crispa *E. & H.*
" papyracea	Leptoseris papyracea *Verrill.*
" elephantotus (not of *Pallas*)	Mycedium elegans *E. & H.*
" cactus	unchanged.
" prætorta	"
" formosa	"
" venusta	"
" divaricata	"
" boletiformis (not of *Lam.*)	Pavonia Danæ *Verrill.*
" frondifera	unchanged.
" decussata	"
" lata	"
" crassa	"
" var. loculata	Pavonia loculata *Verrill.*
" siderea	Siderastræa siderea *Blainv.*
" latistella	unchanged.
" clavus	Siderastræa clavus *Verrill.*
335. Agaricia (Undaria) undata	Undaria[5] undata *Dana.*
" " rugosa (not of *Lam.*)	" monticulosa *Verrill.*
" " speciosa	" speciosa *Dana.*
" " levicollis	" levicollis *Dana.*
" " planulata	Asteroseris planulata *Verrill.*
335 " (Mycedia) cucullata	Mycedium elephantotus *E. & H*
" " purpurea	Agaricia purpurea *Les.*
" " fragilis	Mycedium fragile *Verrill.*
" " gibbosa	Agaricia gibbosa *Dana.*
" " agaricites	" agaricites *E. & H*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
335. Agaricia (Mycedia) cristata (not of *Lam.*)	Agaricia Danæ *E. & H.*
345. Psammocora obtusangula	unchanged.
" plicata (not of *Lam.*)	Psammocora frondosa *Verrill*
" fossata	unchanged.
" columna	"
" exesa	"
349. Monomyces anthophyllum	Flabellum anthophyllum *E. & H.*
" eburneus	Caryophyllia cyathus *Lam.*
370. Cyathina cyathus	" "
" pezita	" "
" Smithii	" Smithii *Stokes.*
" turbinata	" clavus *Scacchi.*
375. Desmophyllum dianthus	Desmophyllum crista-galli *E. & H.* (?)
" stellaria	unchanged.
376. Culicia stellata	"
" tenella	"
" truncata	"
379. Caryophyllia cespitosa	Cladocora cespitosa *Forbes.*
" conferta	" conferta *E. & H.*
" flexuosa	" stellaria *E. & H.* (?)
" arbuscula	" arbuscula *Edw.*
" cornigera	Dendrophyllia cornigera.
" anthophyllum	Lophohelia anthophyllites *E. & H.*
" solitaria	Astrangia solitaria *Verrill.*
" pocillum	Phyllangia pocillum *Verrill.*
" dilatata	
385. Dendrophyllia [6] ramea	unchanged.
" micrantha	"
" nigrescens	"
" aurantiaca	
" coccinea	Dendrophyllia Danæ *Verrill.*
" diaphana	unchanged.
" rubeola	
" scabrosa	Balanophyllia scabrosa *Verrill*
391. Oculina hirtella	Sclerohelia hirtella *E. & H.*
" horrescens	Acrohelia horrescens *E. & H.*
" prolifera	Lophohelia prolifera *E. & H.*
" axillaris	Cyathohelia axillaris *E. & H.*
" varicosa	unchanged.
" oculata	
" pallens	unchanged.
" virginea	Lophohelia oculata *Pourt.*
" diffusa	unchanged.
399. Anthophyllum musicale	Galaxea musicalis *Oken.*
" fasciculatum	" fascicularis *Oken* (in part)
" astreatum	" astræata *E. & H.*
" cespitosum	" cespitosa *Verrill.*
" hystrix	" hystrix *Verrill*
" cuspidatum	" cuspidata *Oken.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
399. Anthophyllum clavus	Galaxea clavus *E. & H.*
404. Stylina echinulata	unchanged.
406. Astroitis calicularis	"
" viridis	Goniopora viridis *E. & H.*
409. Gemmipora palifera	Turbinaria palifera *E. & H.*
" peltata	" peltata *E. & H.*
" patula	" patula *E. & H.*
" crater	" crater *Oken.*
" cinerascens	" cinerascens *Oken.*
" frondens	" frondens *Verrill.*
" brassica	" brassica *E. & H.*
414. Astræopora pulvinaria (not of *Lam.*)	Astræopora profunda *Verrill.*
" punctifera	unchanged.
" fungiformis	Turbinaria fungiformis *Verrill.*
" stellulata	" stellulata *E. & H.*
418. Isaura Hemprichii	unchanged.
" Savignii	"
" aster	"
" speciosa	"
420. Zoantha Ellisii	Zoanthus Ellisii *Lam.*
" sociata	" sociatus *Les.*
" Solandri	" Solandri *Les.*
" dubia	" dubius *Les.*
" Bertholetii	" Bertholetii *Ehr.*
423. Palythoa denudata	Mammillifera denudata *Ehr*
" auricula	" auricula *Les.*
" nymphæa	" nymphæa *Les.*
" fuliginosa	" fuliginosa *Ehr*
" mammillosa	unchanged.
" ocellata	"
" glareola	"
" flavo-viridis	"
" argus	"
" cæsia	"
435. Madrepora	Madrepora.
Names of species unchanged except the following:	
No. 23, corymbosa (not of *Lam.*)	Madrepora convexa (young) *Dana.*
" 26, plantaginea (not of *Lam.*)	" appressa (var.) *Dana.*
" 28, acervata	" plantaginea *Lam.*
" 56, secunda	" nobilis (var.) *Dana.*
" 90, deformis (not of *Mich.*)	" Danæ *Verrill.*
491. Manopora	Montipora.
Names of species unchanged, except the following:	
No. 1, gemmulata	Turbinaria gemmulata *Verrill.*
" 6, crista-galli (not of *Ehr.*)	Montipora aspera *Verrill.*
" 7, spumosa (not of *Lam.*)	M. hispida (var.) *Dana.*
" 8, circumvallata	M. monasteriata *E. & H.*

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
No. 9, foliosa (not of *Pallas*)	M. Ehrenbergii *Verrill.*
" 21, nudiceps	M. crista-galli *E. & H.*
" 25, tuberculosa (not of *Lam.*)	M. Danæ *E. & H.*
511. Alveopora retepora	unchanged.
" dedalea (from Red Sea)	"
" " (specimen figured)	Alveopora Verrilliana *Dana.*
" spongiosa	unchanged.
" rubra	Montipora rubra *E. & H.*
" fenestrata	unchanged.
" viridis	"
515. Sideropora digitata	Stylophora digitata *E. & H.*
" elongata	" "
" pistillata	" pistillata *Schweigger.*
" subdigitata	" "
" palmata	" Danæ *E. & H.*
" mordax	" mordax *Verrill.*
519. Seriatopora subulata	unchanged.
" lineata	"
" hystrix	"
" octoptera	"
" caliendrum	"
" var. gracilis	Seriatopora gracilis *Dana.*
" valida	unchanged.
523. Pocillopora	Pocillipora.
Names of species unchanged, excepting:	
No. 3, brevicornis (var. from Sandwich Is.)	Pocillipora cespitosa *Dana.*
" 6, favosa (var. from Feejees)	" Danæ *Verrill.*
" " (var. from Sandwich Islands)	" aspera *Verrill.*
" 7, verrucosa (var. from Sandwich Islands)	" nobilis *Verrill.*
" 15, plicata (var. from Sandwich Islands)	" aspera (var. lata) *Verrill.*
540. Heliopora cœrulea	unchanged.
543. Millepora alcicornis	"
" moniliformis	Millepora alcicornis (var.) *Linn.*
" ramosa	unchanged.
" pumila	"
" tortuosa	"
" plicata	"
" complanata	A variety of plicata. (?)
" squarrosa	unchanged.
" platyphylla	"
" mordax	"
" compressa	"
" clavaria	"
" flexuosa	"

NAMES IN THE AUTHOR'S REPORT.	NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
551. Porites furcata	unchanged.
" recta	Porites furcata (var.) *Lam.*
" divaricata	unchanged.
" conferta	"
" nigrescens	"
" var. mucronata	Porites mucronata *Dana.*
" palmata	unchanged.
" levis	"
" cylindrica	"
" contigua (not of *Esper*)	Synaræa Danæ *Verrill.*
" astræoides	unchanged.
" conglomerata (not of *Lam.*)	Porites lutea *E. & H.*
" lobata	unchanged.
" fragosa	"
" limosa	"
" favosa	"
" cribripora	"
" informis	Synaræa informis *Verrill.*
" erosa	" erosa *Verrill.*
" monticulosa	" monticulosa *Verrill.*
" lichen	unchanged.
" reticulosa	"
" arenacea	Porites arenosa *E. & H.*
569. Goniopora pedunculata	unchanged.
" columna	"
" Savignyi	"
571. Errina aspera	"
575 Antipathes [7] spiralis	"
" anguina	"
" larix	"
" eupteridea	"
" pectinata	Hyalopathes pectinata *E. & H.*
" myriophylla	unchanged.
" subpinnata	"
" reticulata	"
" flabellum	"
" ericoides	"
" mimosella	"
" pinnatifida	"
" cupressus	"
" paniculata	"
" pennacea	"
" scoparia	"
" fœniculum	"
" corticata	Hyalopathes corticata *E. & H.*
" lacerata	unchanged.
" pyramidata	Hyalopathes pyramidata *E. & H.*
" Boscii	unchanged.
" alopecuroides	"
" arborea	"

NAMES IN THE AUTHOR'S REPORT.			NAMES NOW ACCEPTED, WHEN DIFFERING FROM THOSE OF THE REPORT.
575.	Antipathes	dichotoma	unchanged.
	"	glaberrima	Leiopathes glaberrima *E. & H.*
	"	compressa	" compressa *E. & H.*

[1] The genus, *Mussa*, as here restricted, includes both *Mussa* and *Symphyllia* of Milne-Edwards and Haime,—different specimens of the same species sometimes differing in the same way, and to the same extent, as do these two so-called genera. The only difference given, is dependant upon the mode of growth.

[2] It is probable that this, and some of those following it, are only varieties of one species.

[3] The name *Orbicella* is now restricted to the genus of which *O. annularis* and *O. cavernosa* are types. This group is equivalent to *Heliastræa* of Edwards and Haime, of more recent date.

[4] The genus, *Astræa*, is here restricted to the group of which *A. rotulosa* is the type. This was the original type named by Lamarck, in 1801, when the genus *Astræa* was first established. The genus, thus limited, is equivalent to *Favia* of Oken, 1815.

[5] The genus, *Undaria*, is equivalent to *Pachyseris* Edw. and Haime, of later date.

[6] *Cœnopsammia* is recombined with *Dendrophyllia*, because in certain species part of the corallets have the structure of the former genus, and others that of the latter, even in the same specimen. The only distinction made is that the former genus has a smaller number of lamellæ,—a character that is by itself seldom of generic value.

[7] The genus, *Antipathes*, as here adopted, includes *Cirrhipathes*, *Arachnopathes*, and *Rhipidopathes* of Edwards and Haime. Those divisions were based only upon the modes of growth and branching, which are quite insufficient for establishing genera among Polyps.

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