Memoirs of the Museum of Comparative Zoölogy
AT HARVARD COLLEGE.
Vol. VII. No. 1.

REPORT

ON THE

FLORIDA REEFS

By LOUIS AGASSIZ.

ACCOMPANIED BY ILLUSTRATIONS OF FLORIDA CORALS,

From Drawings by A. Sonrel, Burkhardt, A. Agassiz, and Roetter.
With an Explanation of the Plates by L. F. Pourtalès.

Published by Permission of A. D. Bache and Carlile P. Patterson,
Superintendents of the U. S. Coast Survey.

CAMBRIDGE:
Printed for the Museum.
1880.

JOHN WILSON & SON.
UNIVERSITY PRESS.

PREFACE.

The greater number of the Plates which accompany this Report were originally prepared for the final Report of Professor Louis Agassiz on the Coral Reefs of Florida, which for various reasons was never published. In order to make known the beautiful drawings of corals lithographed by the late Mr. Sonrel, it was my intention to publish these plates, as "Illustrations of Florida Corals,"[1] with an explanation kindly supplied by Mr. Pourtalès. He has also selected a few additional species, which have been lithographed and added to the original plates in order to make these illustrations as far as possible characteristic of the prominent Florida species, both the reef-builders and those found within the reef area.[2]

On consultation with the Superintendent of the Coast Survey, the Hon. Carlile P. Patterson, it was deemed advisable to publish at the same time, as far as it could be found, the Report of Professor Agassiz on the Florida Reefs, extracts of which were published in the Annual Report of the Superintendent of the Coast Survey for 1851, — a publication but little known to naturalists before the days of deep-sea dredging. To this Report I have appended, with the permission of the publishers, Messrs. Houghton, Osgood, & Co., the sketch of Florida found in Professor Agassiz's "Methods of Study," and based entirely upon his investigations of the Florida Reefs under the auspices of the Coast Survey. I have added a sketch map of southern Florida, with the Keys, compiled from Coast Survey maps, to facilitate the reading of this Report.[3]

[1] During his frequent visits to all parts of our sea-coast, a number of drawings of polyps and of other marine animals which can only be drawn directly from life, were made under the direction of Professor Agassiz; these I hope from time to time to publish in the Museum Memoirs, with the necessary explanations, and the Florida corals form the first part of these illustrations.

[2] For the deep-sea corals see Pourtalès, No. IV. Illust. Cat. M. C. Z. Mem. Mus. Comp. Zoöl., Vol. II.

[3] For further details see the large Coast Survey charts Nos. 166, 167, 168, 169, issued since the date of Professor Agassiz's report.

ALEXANDER AGASSIZ.

CAMBRIDGE, MASS., March, 1880.

REPORT ON THE FLORIDA REEFS.

REPORT OF PROFESSOR AGASSIZ TO THE SUPERINTENDENT OF THE COAST SURVEY, ON THE EXAMINATION OF THE FLORIDA REEFS, KEYS, AND COAST.

CAMBRIDGE, August, 1851.

SIR, — The following report of the examination made by me of the Florida reefs, keys, and coast is prepared in compliance with your request.

Topography of Florida.

To form a correct idea of the Florida reefs, it is of paramount importance to keep in mind the topographical features of the whole country. The peninsula of Florida projects between the Gulf of Mexico and the Atlantic, from the 30th degree of northern latitude nearly to the 24th, as a broad, flat, low promontory, which has generally been considered a continuation of the low lands of the Southern States. But, as we shall see hereafter, this is not the case, or, at least, not with respect to the southern extremity of the peninsula, which consists of the same formations as the reef itself. Again, in a physical point of view, Florida is not limited to those tracts of land, forming the peninsula, which rise above the level of the sea, for the extensive shoals along its southern extremity, between the main-land and the keys and reefs, as well as those extending to the west as far as the Tortugas, whence they stretch along the western coast, in fact belong to it, and are intimately connected with it, by their physical character. There is a similar tract of flats along the eastern shore, but it is not so extensive as on the southern and western shores, nor does it partake as largely of the peculiar character of the peninsula, being chiefly formed of the alluvial sand, drifted ashore by the waters of the Atlantic.

We shall have occasion, however, to show hereafter that the narrow longitudinal islands, which extend close to the main-land almost for the whole length of the eastern shore, are probably a direct continuation of the keys, covered with drifted sand.* This is certainly the case with the range of keys extending from the main-land to Cape Florida, which limits to the east the bay of Miami, their formation being of coral rock, but covered by silicious drift-sand.

As to the southernmost extremity of the main-land proper, it is very difficult to determine its outlines, as it consists of innumerable islands, sometimes separated by narrow channels, and sometimes assuming the character of real islands only at high water, being mostly connected with the main-land by very shallow flats. This is especially the case along the southwestern extremity of the peninsula. The outline of the southern shore, however, between Cape Florida and Cape Sable, is better defined,—presenting, in almost unbroken continuity, steep bluffs of the same coral limestone which forms the bottom of the everglades, and may be traced, without interruption, along the Miami from the seashore to the everglades.

South of the main-land, between it and the range of keys, there are extensive flats, which, even at high water, are but slightly covered, and which the retreat of the tide lays bare, leaving only narrow and shallow channels between the dry flats, with occasional depressions of greater depth. These mud flats extend not only between the main-land and the keys as far as Cape Sable, but may be traced to the north along the western shores of the continent, and to the west along the northern shores of the keys, not only as far as Key West and the Marquesas, but even to the Tortugas.

There is, however, this remark to be made,—that to the west the mud flats become covered, by degrees, with deeper and deeper water; or, in other words, that these low grounds, extending between the main-land and the main range of keys, dip slightly to the west, being gradually lost in the shoals extending north of the Marquesas and the Tortugas, along the western shore of the peninsula. These flats are interspersed with innumerable low islands, known in the country by the generic appellation of the Mangrove Islands, respecting which we shall give further details hereafter.

The shoals between Cape Sable, Cape Florida, and the main range of

* A direct investigation of this point, which did not come within the limits of my survey, would be of considerable practical importance, inasmuch as it may lead to the discovery of a basis of coral rock, affording a far more solid foundation for the construction of the lighthouses wanted along that coast, than the loose shore-detritus.

keys are literally studded with these Mangrove Islands. Sometimes they are distributed without apparent regularity; sometimes, as to the north of Key Largo, they form a continuous range between the main-land and the keys. They are also very numerous along the main keys, or at least along that side of them which is turned towards the most extensive mud flats. Sometimes these Mangrove Islands form little archipelagoes of innumerable small islets, so intimately interwoven, and separated by such narrow and shallow channels, as to be almost impenetrable. Such archipelagoes occur chiefly to the north of Bahia Honda and the Pine Islands, as well as to the northwest of Key West. The luxuriant vegetation which rises from these low islands, consisting chiefly of mangroves, gives them a very peculiar appearance. We shall have occasion to return to this subject when we attempt to explain the formation of the different islands connected with the Florida Reef and the main-land. The whole tract between Cape Sable and the keys, east of Bahia Honda, as far as Cape Florida, or at least as far as Soldier Key, is so shoal that it will forever remain inaccessible, except to very small vessels.

The keys consist of an extensive range of low islands, rising but a few feet, perhaps from six to eight or ten, or at the utmost to twelve or thirteen feet, above the level of the sea. They begin to the north of Cape Florida, where they converge towards the main-land, extending in the form of a flat crescent in a southwesterly direction, gradually receding from the main-land until, opposite Cape Sable, they have so far retreated as to be separated from it by a shallow sheet of water forty miles wide. Farther to the west they project in a more westerly course, with occasional interruptions, as far as the Tortugas, which form the most western group. They consist either of accumulated dead corals, of coral rocks, or of coral sand, cemented together with more or less compactness. Their form varies, but is usually elongated and narrow, their greatest longitudinal extent following the direction of the main range, except in the group of the Pine Islands, where their course is almost at right angles with the main range, — a circumstance which we shall attempt hereafter to explain.

Most of these islands are small, the largest of them, such as Key West and Key Largo, not exceeding ten or fifteen miles in length; others only two or three, and many scarcely a mile. Their width varies from a quarter to a third or half a mile, the largest barely measuring a mile across; but whatever the difference in their size, they all agree in one respect, — that their steepest shore is turned towards the Gulf Stream, while their more gradual slope inclines towards the mud flats which they encircle.

This is a point which it is important to notice, as it will assist us in our comparison between the keys and the shore bluffs of the main-land, as well as with the outer reef and the reefs of other seas, in all of which we find that the seaward shore is steeper than that turned towards the main-land, or, in the case of circular reefs enclosing basins (atolls), than that which borders the lagoon.

The reef proper extends parallel to the main range of keys for a few miles south or southeast of it, following the same curve, and never receding many miles from it. The distance between the reef and the main range of keys varies usually from six to two or three miles, the widest separation being south of Key West and east of the Ragged Keys, where the space is about seven miles. Between this reef, upon which a few small keys rise at distant intervals, and the main range of keys already described, there is a broad, navigable channel, extending the whole length of the reef, from the Marquesas to Cape Florida, varying in depth from three to six and seven fathoms, and, except off Looe Key, where the passage is not more than fourteen feet deep at low water, averaging from three to four fathoms.

Farther east the average depth is again the same as at Looe Key; but it becomes gradually more and more shoal towards the east, measuring usually about two fathoms, or even less, to the east of Long Key and Key Largo, but deepening again somewhat towards Cape Florida, where the reef converges towards the main keys and the main-land. Protected by the outer reef, this channel affords a very safe navigation to vessels of medium size, and would allow a secure anchorage almost everywhere throughout the whole length of the reef, were the numerous deep channels which intersect the outer reef well known to navigators, and marked by a regular system of signals. As it is, however, the reef seems to present an unbroken range of most dangerous shoal grounds, upon which thousands of vessels, as well as millions of property, have already been wrecked. These facts have a stronger claim upon the attention of the government, since there are, as already remarked, numerous passages across the reef which might enable even the largest vessels to find shelter and safe anchorage behind this threatening shallow barrier.

The reef proper, as we have remarked above, runs almost parallel to the main range of keys from Cape Florida to the western extremity of the Marquesas, where it is lost in the deep. It follows in its whole extent the same curve as the keys, encircling to the seaward the ship-channel already mentioned. This is properly the region of living corals.

Throughout its whole range it does not reach the surface of the sea except in a few points where it comes almost within the level of low-water mark, giving rise to heavy breakers, such as Carysfort, Alligator Reef, Tennessee Reef, and a few other shoals of less extent, but perhaps not less dangerous. In a few localities fragments of dead coral and coral sand begin to accumulate upon the edges of the reef, forming small keys, which vary in form and position according to the influence of gales blowing from different directions, — sometimes in the direction of the Gulf Stream from southwest to northeast, but more frequently in the opposite direction, the prevailing winds blowing from the northeast. Such are Sombrero Key, Looe Key, the Sambos, and Sand Key. Here and there are isolated coral boulders, which present projecting masses above water, such as the Dry Rocks, west of Sand Key; Pelican Reef, east of it; with many others, more isolated. Though continuous, the outer reef is, however, not so uniform as not to present many broad passages over its crest, dividing it, as it were, into many submarine elongated hillocks, similar in form to the main keys, but not rising above water, and in which the depressions alluded to correspond to the channels intersecting the keys. These broad passages leading into the ship channel, which may be available as entrances into the safe anchorage within the reef, are chiefly the inlet in front of Key Largo and to the west of Carysfort Reef, with nine feet of water; a passage between French Reef and Pickle's Reef, with ten feet; another between Conch Reef and Crocker's Reef, also with ten feet; another between Crocker's Reef and Alligator Reef, with two fathoms; another between Alligator Reef and Tennessee Reef, with two fathoms and a half; and a sixth to the west of Tennessee Reef, varying in depth from two and a half to three fathoms.

The remark which has been made respecting the mud flats and their gradual deepening from east to west applies equally to the general features of the main reef, as well as to the intervening channel. To the eastward the channel is shallower, the ground around the keys and reef becomes shoaler, and there is a gradual dip towards the west, which makes the connection less marked between the keys west of Key West, in the large groups of the so-called Mangrove Islands, and the Marquesas, beyond which there is even an extensive interruption in the succession of the keys before we reach the Tortugas. These last, however, as well as the bank west of these keys, belong none the less to the main range of keys, from which they are only separated by a more extensive and deeper depression. West of Sand Key the reef itself becomes gradually less elevated, until it is finally lost where the ship channel, south of the Marquesas, expands into the broad depression, separating that group of keys and shoals from the Tortugas.

In order to understand fully not only the topography, but also the mode of formation of all these keys and reefs, it must be remembered that the rising reefs, which form more or less continuous walls, reaching at unequal heights nearly to the surface, or above the level of the waters, are only a particular modification of those formations growing upon coral grounds under special circumstances. It has been ascertained, whenever similar investigations have been made, that living corals do not occur in depths exceeding twenty fathoms, that the reef-building species prosper from a depth of about twelve fathoms nearly to the surface, and that different species follow each other at successive heights. Now, if we keep in mind these facts, we shall see that all the coral-bound islands of the West Indies, as well as of the main-land of Central America, constitute an extensive coral field, divided by broad, deep channels, over which the coral reefs extend, with different features, according to the depths in which they occur and the changes which their own growth has gradually introduced upon the localities where they are found, influenced and modified to some extent also by the direction of the prevailing currents and the action of the tides.

The formation of the main range of keys in their primitive condition as a reef, — for, as we shall see hereafter, they have been a submarine reef before they rose as islands above the level of the ocean, — the formation of this range, we repeat, at gradually greater distances from the main-land, as we follow their course from east to west, has been simply owing to the depth of the bottom from which the reef has risen. It has followed the line of ten or twelve fathoms' depth; and if there is so wide an interruption between the Marquesas and the Tortugas, it is because the ground is deeper over that space. Again, if the Pine Islands have a northwesterly direction, while the main range runs more from east to west, it is no doubt because the body of water emptying from the northern part of the gulf, along the western shores of the peninsula, has, for a time, run chiefly over that field, while the tract of mud flats between the keys and the main-land was filling prior to the formation of the outer reef the rising of which, as an external barrier, must have modified greatly the course of the currents north of the keys at a later period, leaving between them only a few narrow but navigable channels, such as exist now between the Marquesas and the Mangrove Islands, between these and Key West, and between the Pine Islands and the group of Bahia Honda.

When describing in detail the different parts of the general reef, we shall occasionally touch again upon different theoretical points only alluded to thus far, and illustrate them more fully in their connection with the facts. For the present a general idea of the topography will suffice.

We would only add that the absence of corals along the western shore of the peninsula, at present, is probably owing to the character which that shore has assumed in the progress of time; for the peninsula itself has once been a reef, at least as far as the 28th degree of north latitude, as is shown by the investigation of the everglades, and by the examination of the rocks at St. Augustine.

This latitude is the natural northern limit of the formation of coral reefs, as also of the extensive growth of stony corals, though on the southern shores of the North American continent, these formations seem to have extended far beyond their usual bounds, probably under the influence of the high temperature of the Gulf Stream; for not only do the narrow longitudinal islands which extend along the eastern shore, and their direct connection with the small keys north of Cape Florida, indicate their coralline origin, but we have even under the 32d degree of north latitude extensive coral formations at the Bermudas, still flourishing in the present day. If the growth of corals has been stopped along the eastern shore, it must be ascribed to the invasion of drift sand, which extends over the everglades, as well as along the eastern shores as far south as the Miami, Key Biscayne, and the bay of the Miami.

Mode of Formation of the Reefs.

The reefs of Florida, as they have been described in the foregoing sketch of the topography of that State, and, indeed, the separate parts of each of these reefs, in their extensive range from northeast to southwest, present such varieties as will afford, when judiciously combined, a complete history of the whole process of their formation.

Here we have groups of living corals, beginning to expand at considerable depth, and forming isolated, disconnected patches, the first rudiments, as it were, of an extensive new reef. There we have a continuous range of similar corals in unbroken continuity for miles, or even hundreds of miles, rising at unequal heights nearly to the surface.

Here and there a few heads or large patches, or even extensive flats of corals, reach the level of low-water mark, and may occasionally be seen above the surface of the waters, when the sea is more agitated than by the simple action of the tides. In other places coral sands or loose fragments of corals, larger or smaller boulders, detached from lower parts of the living reef, are thrown upon its dying summits, and thus form the first accumulation of solid materials, rising permanently above low-water mark; collected sometimes in such quantities and at such heights as to remain dry, stretching their naked heads above high water.

In other places these accumulations of loose, dead materials have entirely covered the once living corals, as far as the eye can reach into the depth of the ocean: no sign of life is left, except perhaps here and there an isolated bunch of some of those species of corals which naturally grow scattered, or of those other organisms which congregate around or upon coral reefs; but the increase of the reef by the natural growth of the reef-building corals is at an end. Again, in other places, by the further accumulation of such loose materials, and the peculiar mode of aggregation which results from the action of the sea upon them, and which will be more fully explained hereafter, extensive islands are formed, ranging in the direction of the main-land, which support them. Elsewhere we may find the whole extent of the reef thus covered, which, after a still more protracted accumulation, perhaps becomes united with some continental shore.

Now it must be obvious, that from a comparison of so many separate stages of the growth of a coral reef, a correct insight may be obtained into the process of its formation; and, indeed, in thus alluding to the different localities which came under our own observation, we have already given a general history of its progress, which we now proceed to illustrate more in detail.

We would, however, first remark, that the extraordinary varieties which exist in the natural condition of different parts of the same reef, or of different reefs, when compared with each other, fully explain the discrepancies between the reports which have been obtained, respecting the reefs of Florida, prior to our investigations.

It had been stated that the reefs consisted solely of living corals; and, indeed, this report is true of the outer reef, which is called by all the inhabitants of Florida "*the reef*" *par excellence,* and is unfounded only with regard to those few islands which rise above the surface of the sea at Sand Key and the Sambos. Others, who had noticed only the larger accumulations of coral fragments which occur on the shores of some of the islands forming part of the Florida Reef, had reported the islands to be formed of coral rocks; while some who had perhaps observed the extensive excavations made around Key West have told us only of the existence of oolitic and compact rocks, almost destitute of corals or other remains of animal life; and from still other localities comes the opinion, that the rocks consist of nothing but more or less disintegrated shells, cemented together.

Animal Life.

This fulness and variety of animal life is particularly obvious within the boundaries of coral fields, the natural limits assigned to the growth of these animals being those in which animals of other classes range in greater profusion, and the coral reefs themselves also affording very favorable circumstances for the display of numerous living forms. Hence the extraordinary assemblage of all classes of animals upon the reef, where, besides those particular kinds of corals which contribute largely to its formation, we find upon it, or on the foundation from which it rises, a great variety of other corals, which, though too insignificant in size to take a conspicuous part in building up these extensive accumulations of organic lime-rock, add none the less their small share in the work, contributing especially to fill up the vacant spaces left by the more rapid and durable growth of the larger kinds. They are to the giants of the reef what the more slender plants are to the lords of the forest, adding the elegance and delicacy of slighter forms to the strength, power, and durability of their loftier companions.

But besides the stony corals, we find in the reef a great variety of soft polyps, either attached to the surface of dead corals, dead shells, or of the naked rock, or boring into the coral sand and mud.

A variety of Medusa nurses arise everywhere, either as delicately branching tufts or as permanently attached Medusæ from the same foundation. Their free progeny may be seen floating quietly in myriads in the waters above.

An endless variety of Gorgonias, for the most part too little known yet to be fully characterized, grow in tufts between the coral heads or upon the coral sands and in the mud flats. Among them are the Halcyonia growing in clusters, the branching Gorgonias forming dense bushes, and the beautiful sea-fans, a kind of Gorgonia, the branches of which spread in flat expansions forming a network of anastomoses, the meshes of which are covered with distinct animals. Again, innumerable polyps, like mollusks belonging to the lower families of that class, spread over the same ground, frequently aping, in their manifold combinations, the diversity of corals on which they rest. So similar are some of them to the true corals that they have only recently been recognized as mollusks, and referred to that type under the name of Bryozoa. Among them is one species of particular interest for the geologist, because it is the first living analogue ever found of that curious extinct family, the Graptolites, so common among the oldest fossiliferous rocks. Its modern representative was discovered in the shoal waters of Key West.

The Echini are more numerous here than upon any other part of the American coast. They belong to the genera Echinus, Tripneustes, Diadema, Cidaris, Clypeaster, and Encope. We found no Spatangoids, though they are known to occur on the West India Islands. The Diademas are found among the coral boulders, generally in nests together, frequently concealed in the larger excavations of the coral heads. The Clypeasters and Encopes on the contrary, live upon the coral sand flats, while the Cidaris prefer the shoal grounds of the Corallines and Nullipores. Holothuria swarm in myriads upon the mud flats; suggesting by their numbers the feasibility of collecting them for sale as Trepang. This is an important article of commerce in China and the East Indies, and their edible species resembles ours so closely that I believe the latter might be used in the same way and furnish a profitable industry. So may the sponges of Florida, for which there is already considerable demand. Beside this wealth of animal life, the reef abounds in tropical sea-weeds. Of these the well-known Gulf-weed is the most striking. It seems strange that the origin of these floating weeds should be doubted when they are found growing so abundantly. Even a brief description of the immense number of shells, worms, crabs, lobsters, shrimps, craw-fishes, and fishes, seen everywhere upon the reef, would be out of place here. In variety, in brilliancy of color, in elegance of movement, the fishes may well compare with the most beautiful assemblage of birds in tropical climates.

Among the creatures mentioned above are many which bore deeply into the stems of the corals, or into the mass of the coral rock.

Such are different species of Arca, the date-fish among the Mollusca, and many worms, especially Serpula among articulates, the agency of which in the formation of the keys will be described hereafter. All these animals and plants contribute, more or less, to augment the mass of solid materials which is accumulating upon the reef, and increase its size. Not only are the hard parts of shells, echinoderms, worms, or their broken fragments, heaped among the detritus of the corals, but occasionally even the bones of fishes and turtles, which are very numerous along the reef, may be found in the coral formations.

The decaying soft parts of all these animals undoubtedly have their influence upon the chemical process by which the limestone particles of their solid frame are cemented together in the formation of compact rocks. Upon this point we may expect further information from Professor Horsford, who is now submitting to chemical analysis all the variety of rocks and the solid stems of the different corals obtained in Florida. Respecting the relations of the solid and soft parts of the living coral, and their mode of growth, we would refer to a paper of ours now in press, to appear in the next volume of the "Smithsonian Contributions to Knowledge."

The Keys.

The main range of keys has a very uniform character; the separate keys differing from each other chiefly in their more or less advanced formation. We need only, therefore, describe in detail a certain number which may serve as illustrative of various steps toward completion. Some consist simply of accumulated coral boulders heaped upon an old coral reef rising more or less above the sea-level. Upon this foundation fragments of the more brittle kinds of coral, shells, coral sand, are heaped as they are upon the dry rocks west of Sand Key or upon Rock Key, east of Sand Key, a formation resembling, indeed, that of Sand Key itself, or the Sambos or Looe Key. Such a comparison shows at once the connection between these larger keys and the incipient keys upon the reef. We have only to imagine the accumulation of coral boulders, corals, shells, and coral sand upon the small keys of the reef to be continued and increased till this cap of loose materials should extend several miles along the rising crest of the reef and down its slope on either side, and we have keys corresponding in essential features to those forming the main range. The difference, however, is not simply one of greater or less accumulation. There is a regular gradation in the character of the materials. All these loose materials, in proportion to their size and the violence of the waves, are now acted upon by the sea. The smaller fragments, even under the gentle flow of the ordinary tides, are constantly moved to and fro, while heavier winds and storms break away the larger masses and split them into smaller bits, and may in the end grind them to rounded pebbles, and finally to sand or to an almost impalpable coral powder. This powder is stirred up from the bottom by the waves, and often remains suspended in the water for days, giving it a milky hue. Of course a great portion of these débris, both large and small, will be thrown upon the reef, and find a resting-place there. Of such materials the Florida keys are made. It is worth our while to study the mode of formation of these deposits, since it may throw some light on the extensive accumulations, always a puzzle to geologists. The nature of the larger boulders, and even of the pebbles, cannot be mistaken, since the organic structure of the coral stocks is perceptible in them all, and yields but slowly to decomposition or attrition. Such changes as they undergo may be observed in coral stems the summits of which are still alive and growing. Meantime the lower parts are gradually dying or filling with amorphous limestone. This limestone often has within the very centre of the coral stem a crystalline structure as perfect as any crystalline limestone. When so acted upon, these corals resemble the corals of the Paleozoic rocks. From such well-preserved specimens to the smaller fragments, where only some traces of organic characters remain, and from these again to the still finer pebbles, particles, or powder from which all signs of organization have disappeared, the transition is so gradual as to leave no doubt that even the sand is of coral origin. Here and there the stronger shells, such as Strombus gigas, Fusus giganticus, Fasciolaria Rhinoceros, and others, may be preserved among the coral fragments; but the more delicate shells, as well as the carcasses of crabs and lobsters, the solid parts of sea-urchins and starfishes, are very soon ground to powder. This explains the rarity of well-preserved organic remains in coral rock. Seeing the profusion of animal life on the reef, one is at first surprised at this; but a little observation shows that the hard parts of both animals and plants, about the reef, are transformed by long-continued attrition into coral breccia, coral oolites or compact limestone.

We cannot therefore infer from the absence of organized beings in ancient formations of this character, that they were deposited in a pelagic sea, destitute of life. This has already been pointed out by Mr. Dana,* in his Report on the Coral Reefs of the Pacific. It must not, however, be supposed that organic remains are wholly wanting in coral formations. There are, on the contrary, localities where they are found in considerable numbers. In such cases the action of the sea has probably been less violent, or in some instances shells may have accumulated in such quantity, before being cemented together, as to offer a certain resistance to destructive influences. Occasionally also, delicate shells or sea-urchins may be lodged in the cavities of coral stems, afterwards filled in with sand, and thus protected.

We see everywhere that the larger boulders and the coarser fragments have been the first to find a resting-place upon the dead reef; the minuter particles and coral sand, which are periodically washed away from its crest during heavy gales, never accumulating upon it till large boulders and more solid materials have collected to such an extent as to form sufficient protection for the more movable looser fragments. This fact is beautifully illustrated by an accurate survey of Sand Key, where a wide field of large boulders is partially laid bare at low water, presenting the appearance of an extensive key, with a low hill of minute materials, the product of some heavy gale, heaped upon the summit, against which the sea plays without disturbing it materially, even at high water, when it leaves in sight only a nucleus, as it were, for a greater accumulation of such loose materials which may in time cover the whole surface of the larger boulders. We have here in reality the same phenomenon which is observed upon all beaches, where larger materials have first accumulated on a shoal shore, being followed, in the course of time, by more minute fragments which have found a resting-place upon levels where the sea was powerless to increase the collection of coarser matter. In attempting to understand these formations, it must be remembered that the accumulation of the larger materials, collected at a certain level, may modify the action of the water at a subsequent period, thus producing a combination of substances, heaped unconformably upon each other. This is, in reality, the case throughout the whole main range of keys, which have been raised to their present level by the action of the tides and gales for ages past; the fragments of which they are composed having been thrown up at different periods, and over-

* Geology of the United States Exploring Expedition.

lying each other in such a manner as to present the same irregularity which is found in all drift stratification. Layers upon layers are seen resting unconformably, dipping in different directions so as to present all the modifications which may be observed in torrential stratification, each layer following, with more or less regularity, the course of the flood under which it has been accumulated.

This dip varies for several degrees, but rarely exceeds 7 to 8 degrees upon any extensive surface where the sea has had full play. In enclosed bays or narrow channels, however, the materials accumulate at much steeper angles. In sheltered places, slopes of coral sand are formed at angles of 20 or even 30 degrees. At the Tortugas, Lieutenant Wright pointed out to us accumulations of coral sand sloping at an angle of more than 33 degrees, exceeding decidedly, therefore, the steepest slopes of silicious sand-banks. This circumstance corroborates the assertion of Mr. Darwin, that coral sand possesses an adhesive property which enables it to accumulate at higher angles than other loose materials, owing, perhaps, to the viscosity of the animal matter still pervading the coral fragments.

By a process not yet fully understood, but to which we shall return hereafter, these loose collections are gradually cemented into solid rock, presenting the most diversified appearance, according to the substances of which it is composed. Then we find a coarse breccia, consisting of larger fragments of corals and shells, enclosing sometimes coral boulders; and this is the sort of rock which generally overlies the immediate surface of that portion of the keys which has been formed by the progress of the reef, growing *in situ*. Such rock was seen among the foundations of the new lighthouse at Sand Key, where the large boulders are very numerous, and seem almost as fresh as if they had been lying on the spot but for a few years. It may be, indeed, that during the hurricane of 1846, the whole cap of the reef was renewed at that spot.

Similar rock, but of more breccia-form character, containing remains of shells in greater quantity than I have seen elsewhere in the coral rock, was brought up from excavations made in twelve feet water, when the foundations of Fort Taylor were laid in Key West. The same coarse-grained rock is observed, at low water, in many places where the tidal action has worn away parts of the primitive rock of the keys. Above these materials are generally found layers of what seems, at first sight, a coarse-grained oolite, but upon closer examination it is seen to consist, not of grains of limestone with concentric layers, like true oolite, but of rounded, minute fragments of corals cemented together. These rocks are generally of a pure white color, though occasionally tinged with gray or brown, — the coloring matter derived, no doubt, from decomposed organic matter. At higher levels a fine-grained oolite usually comes in with more distinct traces of stratification. Even here, however, the oolitic grains are also mostly comminuted fragments of coral, as the microscope readily shows. Only here and there the most minute oolites seem to be formed by several concentric coatings of amorphous limestone. Alternating with these different layers of oolite are found small seams, varying from a line to half an inch in thickness, of compact, homogeneous limestone, so uniform as to ring under the hammer. An important fact — inasmuch as it may help to explain the formation of this compact limestone — is that a layer of it constantly occurs upon the surface of all other rocks forming the keys. It forms a last surface, as it were, even upon the highest points of the most elevated keys, a crust following all the external sinuosities and irregularities. Evidently, therefore, it cannot have been formed under the level of the water, but merely by the action of the spray; and the successive seams of similar compact limestone, intervening between the layers of oolite, would indicate the successive surfaces of the keys during the progress of their formation.

A careful survey of the character of the rocks in the keys affords satisfactory evidence that they have been formed, at whatever height they may rise, by the same action which is now going on upon the reef, — that is, by the accumulation of loose materials above the water-level. That part of the keys which rises above the level of the water is, therefore, a subaerial and not a submarine accumulation of floating matter, thrown above high-water mark by the tempestuous action of the water. We insist upon the fact that the keys furnish in themselves, by the internal structure of their rock, the fullest evidence that they have been formed above high-water mark by the action of gales and hurricanes, instead of having grown as a reef up to the water-level, and been subsequently raised to their present height. The evidence of this statement rests upon certain facts obtained from observation of the reef itself, at Sand Key and the Sambos.

These facts are as follows: First, that their stratification has all the character of a tidal shore stratification; secondly, that their different layers are separated by crusts of compact limestone similar to that now found upon all keys, whatever be their height; and, lastly, that the level of the highest keys, such as Key Largo and Key West, marks the height above the sea-level to which the severest hurricanes, like that of 1846, have been known to drive the loose materials.

These facts in their connection are especially important, as giving us the means of settling the question about the upheaval, depression, or permanence of level of the coral fields of Florida. It should be mentioned here that the fossil remains of animals and plants are rare in coral rock. It will be seen hereafter that the mode of formation and accumulation to which the reefs and keys owe their origin would be unfavorable to the preservation of such remains. When they are found in the coral rock, it is chiefly in the brecciform limestone, where they have been sheltered in some excavation, and thus protected from complete attrition. Here and there small species of thick-shelled univalves occurs in a tolerable state of preservation, and we have found several bones of a large turtle in the coarse oolite near Key West. All the remains so found are identical with species now living on the reef.

Let us now return from this digression to the consideration of the keys themselves, under the different aspects which they present. Some have very abrupt shores, and rise like narrow ridges, with ragged edges and without a beach, from the deeper water. These were undoubtedly formed upon the narrowest parts of the old reef. Others are more spreading, have a wide beach, and dip gradually under the sea, their submarine slopes being covered with coral sand and mud. These must have been formed on the broader parts of the reef, where it slopes gently on both sides. In still others, the shores have been rendered abrupt by the denudation of some of their earlier deposits. Such denudations may have been filled again by more recent deposits, thus giving to a formation of the present geological era a diversity usually characteristic rather of unconformable deposits belonging to different geological ages. The northernmost keys, which converge toward the main-land, are covered by silicious sand. Their beaches are of like character, and slope towards the Atlantic, while their mud flats spread along the western shores. South of Cape Florida no more silicious sand is to be seen, and even in the immediate vicinity of Cape Biscayne there is a mud shoal, laid partly bare at low water, over which grow branching Millepora, with small tufts of Oculina and Caryophyllia rising between them, and here and there a few Porites furcata. Such flats are very soft, and one sinks ankle-deep in the dense coral growth. A most astonishing variety of sea-worms is found between the branches of the Porites and Oculina. This is also the play-ground of many Ophiurans and Asterians. Cidaris metularia are found here also, and other species of Echini. Such mud-shoals, composed of the most minute sand and mud, frequently encircle the keys, often extending for miles beyond their shores. Wherever they are laid bare at low water they are overgrown by Milleporas; but where they are always covered, even at the lowest tides, with a few inches of water, the Porites take the ascendency. The latter are chiefly of two species, the Porites furcata and Porites clavaria. A black Ascidian is often attached to their branches in great numbers. Great numbers of Holothurians make their home upon these mud flats. Large holes, sometimes close together, sometimes at small distances from each other, are frequently to be met with. These holes, widening at the surface in the shape of a funnel, having a depth of several feet and a diameter of several inches, are occupied by a gigantic worm of the genus Eunicea. Large Actiniæ of various colors are also numerous, and a deep orange colored Starfish and Manicinas show themselves also, though not in great numbers, and an endless variety of Gorgonias. Such shoals are the best field for the collector. Similar mud flats are found everywhere around the Mangrove Islands. But of these, more presently.

Soldier Key rises about five miles to the south of Cape Florida. It is connected with an extensive mud flat, which stretches nearly to the lighthouse, being separated from it only by a narrow channel from nine to ten feet deep. The Ragged Keys come next, — a series of some half-dozen small islands formed by coral boulders rising but little above the surface of the water, and surrounded on both sides, and especially on their western shores, by wide mud flats. These keys, as well as Soldier Key, are covered by mangroves. It is noticeable that some of the Mangrove Islands have beaches, — a fact explained by their mode of formation. To the westward follows Elliott's Key, the first whose surface does not consist solely of coral boulders, coral sand having formed a succession of layers of oolitic rock upon it. Here also we first find white sand beaches dipping to seaward, and see a variety of trees mingling with the mangroves. On the southernmost extremity there is a spur formed by a mud flat, while another more extensive one juts to the eastward, and is connected with Old Rhodes, the next key. Key Largo, which follows, is the largest of all the islands in the main range of keys. It is not less than twenty-five miles long and from one to three miles in width. Nowhere does it rise more than thirteen feet above the level of the sea. The hill ninety feet high, said to exist on its eastern extremity, resolves itself into a tuft of very high mangroves.

The vegetation of the whole key is very rich, the trees more diversified and larger than on any other island in the range. The rock formations are also very diversified. The seaward shore is rather abrupt, the ocean having worn away the sloping edges. The foundation of the key consists chiefly of large coral boulders, the flat Mæandrina heads being most numerous, though Porites and Astræans are also abundant. They are so distributed upon the lower level of the island that one would think they had grown where they are found. On closer examination they are seen to be detached coral heads heaped together, and, owing to their peculiar form, stranded in an upright position. Whoever has seen Mæandrina heads broken off by boring shells will not wonder to see these flat hemispheres resting on their broad, flat bases rather than on their rounded side. But though they are thus found in their natural position, suggesting the idea that they have grown where they now lie, the fact that among them are some which are overturned, and others broken in halves, contradicts this conclusion, and show that, notwithstanding the regularity of the foundation, this key, like the others, rests on an accumulation of detached coral boulders. Indian Key has a similar foundation; the evenness of the accumulation and the natural position of the heads misled me at first into the belief that I had found a proof of the upheaval of the keys. But a closer survey satisfied me that their upper formations consist here, as elsewhere, of coarse and fine oolites, with intervening seams, as at Key West, of compact limestone, and an overlying crust whereon the sea does not encroach upon the older formations.

As has already been remarked, the shore is rocky, and, except in small patches, no sand beach is seen along this extensive island. There are, however, large mud flats along its southeastern extremity, among which rise Key Rodriguez, Dove Island, two Mangrove Keys, and another off Plantation Island, known as Tavernier Key. These mud flats abound in animals of all kinds. Nowhere are Holothuria more numerous; cartloads might easily be gathered. The Eunices are also more numerous than elsewhere, and nothing can exceed the beauty of the Actinias, Gorgonias, and Chitons to be found on every rock upon the shore. The best evidence that Key Largo, notwithstanding the fictitious height assigned to some parts of it, may have been formed in the same manner as the other keys, is found in the fact that a brig was drifted in a heavy gale half way across the Island off French Reef. Plantation Island, Windly's Island, the upper and lower Matecumbe which follow Key Largo, are not so high, and are more like Elliott's Key. Plantation Island is encircled to the seaward by a spreading mud flat, from which, upon an extensive spur, Key Tavernier rises to the east. The others, Upper and Lower Matecumbe, as well as Long Key, Tea-table Key, and Lignum Vitæ Key are connected with Mangrove Keys. To the seaward of the two Matecumbes, however, there are sand beaches, while Indian Key, which stands out into the ship-channel, is entirely rocky, resembling, as already stated, the eastern shore of Key Largo. A mud flat runs along the inside of all these keys, from Lower Matecumbe to the northernmost extremity of Key Largo. It extends for several miles to the north of the keys, and is separated from the mud flats which reach the main-land only by a narrow channel varying from three to four or five feet in depth. This channel is marked by dots upon the map. Another mud flat projects like a spur from Lignum Vitæ Key between Upper and Lower Matecumbe. Yewfish Key, Duck Key, and the Grassy Keys, as well as Key Vaccas, Boot Key, and The Sisters, constitute a series of small low keys, mostly covered by mangroves, with here and there a sand beach on the seaward side, while spurs of mud flats jut out from the leaward side. The Bahia Hondas have a similar appearance, but here the reef begins to change its character. Indeed, the change is already marked farther east, west of Key Vaccas and the Boot Keys. Instead of longitudinal islands bearing east, northeast and west-northwest, we now have an archipelago of low islands rising above extensive mud flats which are also interspersed with innumerable mangrove islands crowded together in small groups, the main islands bearing north-northwest. The principal of these islands are known as Little Pine Island and Pine Island. The main channels intersecting this archipelago run also north-northwest, between Little Pine Islands and the Bahia Hondas, and between the western and eastern Pine Islands. The main islands of this group are very flat, and consist of thin layers of a regularly stratified and somewhat oolitical limestone, evidently formed by deposits of limestone mud. The uppermost layers have evidently been solidified above the level of the sea, for they present numerous cracks of shrinkage such as are everywhere observed upon dry mud flats; the edges of these fissures being here and there slightly raised, and even upturned, so as to be separated from the layers below. There could hardly be a more conclusive evidence that the keys have been formed above high-water mark. These islands take their name from the pine woods with which they are partially covered. A beautiful palmetto flourishes there also, considerably smaller than the cabbage-palmetto of the Southern States, and, as far as I can ascertain, an undescribed species. It is remarkable for its smooth stem, and for the silvery lustre of the lower surface of its leaves. The great width of the mud flats surrounding the Pine Islands, and the peculiar direction of that group of keys, suggest the idea that they were formed when the Gulf discharged its waters more freely from the north into the Gulf Stream, and when the range of keys extended only abreast of Cape Sable. This supposition is sustained by the fact that the whole reef dips to the west. The outer reef rises to the same level as the Marquesas; but west of Key West, as far as the Tortugas, the main range of keys has not yet reached the same height above the sea level as the eastern parts of the reef. We may therefore suppose, that the group of Key West, which is again as high as Key Largo, stood to the Key Vaccas in the same relation as the Tortugas now stand to the Marquesas, leaving a broad, deep depression between them. This has gradually been filled by drifting sand, just as the Marquesas, by like accumulations, are spreading toward the Tortugas. The groups of Boca Chica, of which Key West and Saddle Bunch Key are the largest, have again a more westerly direction, corresponding with the general curve of the reef. These islands share the character of the eastern reef, but have also some features of the Pine Islands. Their lower strata consist of coral boulders and coral breccia, as was ascertained during the excavation preparatory to the foundation of the fort of Key West. Their upper layers, however, namely, all that portion which rises above low-water mark, rest upon a coarse oolite, above which follow layers of finer grain, overlaid by very thin layers of muddy limestone. These surface layers resemble those of the Pine Keys, especially on their northern and northeastern shores, which are very level, spreading out into submarine mud flats, while the southern shore is more abrupt, and worn by the action of the tides. The stratification of Key West is not, however, so regular as that of the Pine Islands, nor do the strata dip so uniformly to the north as in the latter. They incline, indeed, in all directions on the western shore, showing that the trend of the tidal deposits has been constantly shifting. The cross-stratification is nowhere better seen, in the main range of keys, than on the westernmost promontory of Key West. Upon this island, also, the intervening seams of compact limestone between layers of oolite are especially numerous; and here the superficial crust is more continuous than elsewhere, frequently consisting, beside the compact limestone, of small fragments of oolite rock, with patches here and there of oolitic sand. Occasionally such a mixture entirely fills large excavations,—excavations worn by the tides in former ages, and filled again by later deposits. Along the northern shores, where flat beds, similar to those of the Pine Islands, extend under the mud flats, their dip is but from two to three or four degrees. Near the fort, where the oolitic beds have been quarried for building purposes, they have a dip of seven or eight degrees, the stratification being clearly indicated by successive seams of compact limestone, and also by the projecting edges of the seams of coarser oolite rising from the vertical walls of the artificial excavations. The so-called Mangrove Islands, west of Key West, constitute a group of low keys connected by mud flats, similar to all the other mangrove islands north of the Pine Islands and of Key West. They may be considered a prolongation of the extensive flats encircling the whole group of keys from the upper Bahia Hondas to Boca Grande. They are separated from Key West by a navigable ship-channel, running north-northwest like those intersecting the Pine Islands, showing that, notwithstanding the more westerly course of Key West and the whole Boca Chica group, all this part of the reef has a common character. The westernmost groups, the Marquesas and Tortugas, although they lie in the direction of the main range of keys, have again another character.

The islands forming this group are among the most interesting of the whole reef, because, without the phenomena of subsidence to which the Atoll or Lagoon Islands of the Pacific are due, they nevertheless closely resemble them in character. The Atolls in the Pacific are formed by the sinking of some island around which corals have established themselves. By the growth of the corals the reef rises as the foundation subsides, and finally reaches the surface as a ring often broken by channels and enclosing a harbor. In such cases the wall of the reef is precipitous and often sinks to a depth at which the reef-building corals cannot live. But, as the process is very gradual, the dead base of the reef affords a foundation for the living portion until the latter finally reaches the water level.

It is my belief that the Tortugas (though no change has taken place in the sea-bottom on which they rest) were built up by the coral growth around a submarine hill. The group consists of a circle of flat, low islands, not far apart from one another, divided by deep channels and enclosing a sheet of water, — a circular harbor as it were. Instead of steep walls like the Pacific lagoons, these islands have extensive shoals; but the channels and the harbor are deep, safe, and accessible, so that the fort now rising upon Garden Key will have especial advantages as a maritime station. These islands are not built of the débris of coral animals. The rock consists chiefly of the remains of corallines. This confirms my belief that they have grown up around a submarine rising ground; for the coralline or limestone Algæ, especially that kind of coralline of which the Tortugas rock is chiefly composed, do not prosper in deep water, but thrive on shoal flats. The reef-building corals have combined with this extensive coral vegetation to bring the Tortugas to their present condition. It seems, at first, astonishing that a sea-plant should build these extensive rocky islands. But we must remember that the corallines absorb lime and form limestone secretions no less than the stony corals themselves. Indeed, the coralline rocks of the Tortugas are no more an anomaly than the coal beds: in the former, the rock is built of the limestone secretions of the plants; in the latter, of their woody or cellulose tissue.

Coral Reefs.

After examining a growing coral reef, so full of life, so fresh in appearance, so free from heterogeneous materials, in which the corals adhere so firmly to the ground, or, if they rise near the surface, seem to defy the violence of the ocean, standing uninjured amid the heaviest breakers, an observer cannot but wonder why, in the next reef, the summit of which begins to rise above the level of the water, the scene is so completely changed. Huge fragments of corals, large stems, broken at their base, gigantic boulders, like hemispheres of Porites and Mæandrina, lie scattered about in the greatest confusion, — flung pell-mell among the fragments of more delicate forms, and heaped upon those vigorous madrepores which reach the surface of the sea.

The question at once arises, how is it that even the stoutest corals, resting with broad base upon the ground, and doubly secure from their spreading proportions, become so easily a prey to the action of the same sea which they met shortly before with such effectual resistance? The solution of this enigma is to be found in the mode of growth of the corals themselves. Living in communities, death begins first at the base or centre of the group, while the surface or tips still continue to grow, so that it resembles a dying centennial tree, rotten at the heart, but still apparently green and flourishing without, till the first heavy gale of wind snaps the hollow trunk and betrays its decay. Again, innumerable boring animals establish themselves in the lifeless stem, piercing holes in all directions into its interior, like so many augers, 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, Lithodomus, several Saxicava, Petricola, Arca, 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 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 holes 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 throughout.

The outer reef, or, as it is generally called on the spot, *The Reef*, is the main seat of the present activity and growth of the reef-building corals in Florida. This reef consists of a narrow wall, rising nearly to the surface of the water, with a steep seaward slope, and a gentler one on the inner side toward the ship-channel. Its greatest width varies from one to two miles, though it is frequently not more than half a mile wide. This is true, for instance, of all those narrow ledges which have risen to within a few feet of the surface, such as Fowey Rocks off Soldier Key, Triumph Reef off Ragged Key, Long Reef off Elliott's Key, Ajax Reef off Cæsar's Creek, Pacific Reef off Old Rhodes, Turtle Reef off the eastern extremity of Key Largo, and the extensive reef of Carysfort facing for several miles Key Largo. This spot is one of the most instructive on the reef. Here the reef, for a stretch of several miles, nearly reaches the surface and forms a long level ledge entirely covered with living corals (chiefly the large spreading

Madrepora palmata) as with a close shrubbery. One is reminded of the bank or beds of Kalmia or rhododendron spreading so uniformly over certain favorable spots. These beds of Madrepora palmata are yellowish in color, and broken here and there by a few heads of Millepora alcicornis or Mæandrina labyrinthica. The growth is so close that there are hardly any intervals to be filled by dead corals. Only on the borders of the ledge, and especially to the leaward where it slopes to the ship-channel, do we find accumulations of coral sand and coral débris between the heads of the Mæandrinas and Porites. These become more numerous as the depth increases, and are accompanied by a great variety of Gorgonia. Within the ship-channel the accumulation of coral sand increases, and several sand ridges may be traced parallel to Carysfort Reef along its inner slope, rising to some eight or nine feet below the surface of the water. Upon these sand ridges may be seen occasional heads of Mæandrina, patches of Millepora and Madrepora, and also a variety of Gorgonia, especially the beautiful purple Gorgonia flabellum, known as the sea-fan. On the steep seaward slope, and below the range of the Madrepora palmata, the heads of Mæandrina and Porites are very numerous. To the west of Carysfort, the edge of the reef sinks to a depth of some nine or ten feet, the greatest depression on the reef west of Cape Florida. Between the reefs above mentioned, for instance, there is hardly anywhere more than six or seven feet of water, so that from Fowey Rocks to Carysfort Reef we have an unbroken range of living corals. French Reef, again, is separated from Pickle's Reef by a depression of about ten feet, as is also Conch Reef from Crocker's Reef. Between this and Alligator Reef the depression is still greater; about twelve feet. The outer reef itself rises for a longer stretch near the surface at Alligator Reef than anywhere else west of Carysfort or east of Sombrero. Between Alligator and Tennessee Reefs, and between these and Coffins Patches, there is upon the edge of the reef not less than fifteen to seventeen feet of water, and about twenty between Coffins Patches and Sombrero. Sombrero is a small island of a few acres, formed of large coral fragments heaped up on the edge of the reef. Between Sombrero and Looe Key another large depression occurs on the reef some twenty feet deep throughout.

Thus not only are the higher ledges upon the reef gradually separated by wider intervals, but the reef itself, as a whole, is deepening westward, as is shown by the increasing depth and extent of the depressions. In fact the reef, as well as the mud flats, dips from east to west. At Looe Key, a small island formed chiefly of broken shells and coral fragments thrown up on the edge of the reef, a new feature begins. The higher ledges approach each other again, and the depressions between them are shallower than those to the east. We have here in close succession from east to west the American Shoal under six feet of water, the Pelican Reef with about four feet of water, and East, Middle and West Sambos, three little keys of a few acres in extent, consisting chiefly, like Looe Key, of broken shells and coral fragments, forming so light a crust upon the edge of the reef that storms occasionally wash away the whole accumulation. Between West Sambo and Sand Key, another depression on the reef, with a depth of water varying from four to five fathoms, forms the main channel leading into Key West. Toward Sand Key the reef widens considerably, but the corals are less crowded upon it. Large accumulations of coral sand intervene between the living heads, and detached masses and fragments of corals are thrown up in quantities upon the ridge, forming extensive shoals. To the east of Sand Key these shoals are known as the Eastern Dry Rocks and Rock Key; to the west, as the Western Dry Rocks. Sand Key itself is a small island also consisting chiefly of coral fragments and coral sand heaped above the field of large coral boulders stretching almost uninterruptedly from Eastern Dry Rocks to Western Dry Rocks. This part of the reef contrasts remarkably with the Sambos, and, taken together, they explain the process by which a living reef is transformed into a dry key. At the Sambos as at Carysfort we have a field of Madrepora palmata mixed with a few stocks of Millepora alcicornis and bunches of Gorgonia rising as a level ledge to the surface of the water at low tide. Upon the most prominent points of this ledge, coral boulders and sand are accumulated, every such accumulation forming the nucleus for a key. Comparing such incipient keys with Sand Key, we there find that the collection of coral boulders and sand has increased so much as to cover entirely the summit of the once living reef, spreading also far down upon its slopes. Before the storm of 1846, vegetation was spreading over Sand Key, and a lighthouse was built upon it. In the hurricane of the 11th of October, the lighthouse was washed away with the mass of coral boulders on which it stood. This mass of loose materials had in fact been mistaken for continuous coral rock sufficiently solid to support the structure based upon it. This unfortunate event has shown that the loose cap resting upon the more solid reef should always be removed before laying the foundation of a lighthouse. The solid rock is not to be reached at the level of low-water mark, but lies several feet below that. The able engineer now building a lighthouse on that very spot has provided against a similar misfortune by uncovering the reef as the first step in his work. Mr. Dana has already pointed out another fact of the utmost importance, with reference to the construction of lighthouses. Even the lower and more solid mass of the reef is not continuous throughout, but has cavities filled with sand, débris, loose material of all kinds. Any point selected for the erection of a lighthouse should, therefore, be carefully surveyed, and the solidity of the reef should be tested by boring small holes throughout its thickness. If not weakened by such cavities, it will afford a safe foundation for beacons, signals, or lighthouses. The reef-building corals are, indeed, not only the largest, but also the most compact and hardest, and their order of succession in their growth, with the closer, heavier kinds below and the lighter ones above, give durability and strength to their masonry. The foundation of the reef is built by the massive heads of Astræa and Porites, in the middle range Mæandrinas and Milleporas come in, and only above these do we find the Madreporas, the stoutest and strongest of which form the uppermost growth upon the reef of Florida. As if to give additional firmness to the structure, the dying corals, as they reach the surface, become incrusted with Nullipores of different kinds. One species forms a close coating of the hardest limestone, not less than half an inch thick, over the dead corals. In the empty spaces grow other more branching kinds, which gradually fill the small cavities and act as a natural mortar cementing the whole. Upon this basis the broken, floating materials are thrown up, forming that loose cap of sand and débris which rests on the top of the reef and is liable to be carried away by storms.

The reef in its easternmost part north of Fowey Rocks, and in the direction of Bearcut and Virginia Bay, converges toward Cape Florida. Here it is covered by silicious drift sand, as are also the keys north of Cape Florida. The character of these formations, evidently the work of corals like other parts of the reef, favors the supposition that the longitudinal narrow islands stretching in almost unbroken continuity along the eastern coast of the peninsula are, like the Everglades upon the main-land, a prolongation of the reef now covered by drift sand.

Ship-Channel.

The broad channel extending the whole range of the reef, between the main keys and the outer reef, is rather uniform, having the same width throughout, with the exception of those few places where the reef widens, or the mud flats from the keys encroach upon it. Its narrowest passages are between Looe Key and the Pine Islands, between Pickle's and French Reefs, and between Key Rodriguez and Tavernier. Is is also somewhat narrowed between Alligator Reef and Indian Key, and is widest off Key West. Its depth varies also slightly, being shoaler in its eastern range than to the west. The shallowest part is between Pickle's Reef and Key Rodriguez, and between Looe Key and Pine Islands.

But if we do not take into account those spots where the depth is reduced from local circumstances, we may say that, as a whole, the ship-channel begins to the east, with a depth of about two fathoms between Fowey Rocks and Soldier Key, increasing gradually thence until it reaches three fathoms between Pacific Reef and Old Rhodes, then becomes again slightly reduced between Carysfort Reef and Key Largo; after which, with the exception of the shoals between Pickle's Reef and Key Rodriguez, it deepens again to three, four, five, or even six fathoms, until, between Looe Key and Pine Islands, it shoals once more to fourteen feet. Farther on, it increases again to five, six, and seven fathoms, the average depth between Key West and the Reef being five or six fathoms; and still beyond, more towards the west, sinks to eight, nine, and ten fathoms between the western extremity of the Marquesas and the western end of the reef, where it spreads into the great depression separating the Tortugas from the Marquesas. The character of the bottom varies in different parts, as do also the living beings which it supports. Where it is the most shoal, as between Fowey Rocks, Triumph Reef, and Long Reef, on one side, and Soldier Key and the Ragged Keys on the other, the bottom consists of coral sand, overgrown with what is called the country *grass;* that is to say, a variety of the limestone algæ mingled with Gorgonia, among which rise a number of coral heads.

These heads are hemispheres of Porites or Astræa. In the shoaler parts Mæandrinas and Millepora alcicornis also occur; they are more numerous near the reef than near the keys, and are, indeed, the inner expansion of the reef itself where the corals are less continuous, forming isolated patches rising out of coral sands.

To the west of Long Reef, especially between Carysfort and Key Largo, the coral sand rises here and there in the form of shoal sand-banks, intermixed with coral heads, — an arrangement which is probably owing to the more rapid currents flowing in that part of the channel, which is precisely the turning-point of the direction of the reef. Such heads occur again about a mile and a half off Vermont Key, half way between Key Tavernier and Indian Key, outside of which Gorgonia and sponges are very abundant, upon a hard, white sand bottom. Similar heads are seen between Long Key and Tennessee Reef, and nearer the reef there are shoals of white coral sand, covered with Gorgonia; but farther west, off Duck Key, the bottom becomes softer. Off Bahia Honda, again, it is rocky, — that is, studded with large heads, surmounted with soft, muddy sand. This change in the character of the bottom is more obvious westward, where the heads are fewer and the bottom more generally muddy, or covered with finer-grained sand. For instance, hard sand is observed between Loggerhead Key and Saddle bluff; but nearer the reef, as far as the American Shoals, we have soft mud, with shoals and coral heads. Off Boca Chica, the channel way has also a bottom of soft coral mud, while shoals, with coral heads, may be traced for three fourths of a mile along the shores, as, again, towards the Sambos, in a depth of from three to two fathoms. The softness of the bottom in the vicinity of Key West, considered in connection with the scarcity of coral heads in that region, shows that a soft mud formation is unfavorable for the growth of corals; and, indeed, this holds also good for the flats north of tke keys.

Between the main-land and the main range of keys, and north of Pine and Mangrove Islands where the mud flats are most extensive, no coral heads are seen. Some of the Gorgonias grow upon hard sand, others chiefly upon coral heads, others in the more muddy places. Gorgonia flabellum, for instance, is most abundant upon hard sand, while Gorgonia anceps is found on the mud flats, and Gorgonia dicotoma, again, upon coral heads. If the mud flats, especially when the mud is very soft and deep, are poor in animal life, they are favorable to the growth of the sea weeds known as limestone algæ, the tissues of which are filled with lime. The Nullipores, also of this family, grow either upon the dying corals near the level of low water or upon mud flats that are almost dry. We have been surprised at the general lack of animal remains in this mud, as well as at the singular appearance of such as were found in it. Shells otherwise well preserved were incrusted with Bryozoa or with patches of hardened mud. Neither did the corals show a clean surface; indeed, all the solid parts of animal remains brought up with this mud reminded us, in their state of preservation, of the fossils found in those beds of the Jura Mountains which Gressly has called "Terrains de charriage." They show signs of attrition, but at the same time are so incrusted as to be protected from farther disintegration, during the transportation of the mud in which they are embedded. The general aspect of the reef indicates that all this mud is slowly moving from east to west, and encroaching upon the free growth of the corals; while it furnishes at the same time the minute materials, which in connection with coral sand fill the intervals between the coral heads and coral boulders. Where it is accumulated by eddies so as to approach the surface, it forms mud flats or may have given rise to the layers of muddy limestone described above.

Several of the keys adjoining the main range, and standing out somewhat into the channel, differ in structure greatly from the main keys. They are not formed by the accumulation of coral boulders and coral fragments upon the edge of the reef, but by the accumulation of coral sand and mud in eddies or shoals. They are, in fact, the highest mud flats, to the consolidation of which the mangrove growth upon them has contributed. Such are Rodriguez Key, Tavernier Key, Sister Key, Loggerhead Key. The formation of similar keys in the course of time may be foretold, off Old Rhodes, upon the Washerwoman's Shoal, and upon the middle ground off Sand Key. Let us suppose the accumulation of coral sand and mud between the main range of keys and the outer reef to have increased so as almost to fill the ship-channel, reducing its deepest part to some eight or nine feet of water, and a number of mangrove keys like Rodriguez and Tavernier to have been formed where we now have only sand shoals or banks and coral heads, as between Carysfort and Key Largo, for instance; we should then have precisely the same conditions as are now presented by the extensive mud flats lying between the main-land and the keys from Cape Sable to Cape Florida. Although we infer by analogy that, when the main keys were only a reef, their inner side supported live coral heads and was bordered by larger or smaller shoals of coral, and inhabited by a fauna similar to that now found in the ship-channel, nothing of all this is now to be seen in that locality. The coral heads and sand ridges have given place to extensive mud flats, intersected by shallow channels and shallow depressions, interspread with innumerable low mangrove islands arranged in little groups, or forming more continuous chains such as the Walker Keys, which stretch almost uninterruptedly, in a southerly direction, from the mainland to Key Largo. In the northernmost part of the reef west of the

Ragged Keys and Soldier Key, the shoals are more distinct from one another, divided by broader and deeper channels than occur in any other part of the tract lying between the main keys and the main-land. This is explained by the freer influence of the Atlantic tides on this part of the reef, as compared with its more western range. West of a line extending from Black Point to Elliott's Key, the whole space between the main-land and the main keys is occupied by an almost uninterrupted mud flat, covered by a shallow sheet of water varying from four to five feet in depth, though in some occasional depressions it may measure seven feet or thereabouts. The monotony of this great stretch of mud flat is broken by the innumerable mangrove islands already mentioned, as well as by the shoaler flats left dry at very low water. What has been said of the shoals off Cape Florida applies equally to those here mentioned, and needs no repetition. The mode of formation of the Mangrove Islands, however, is both peculiar and interesting, and demands a few words of explanation. The mangroves are among the most important geological agents in this region; but for them the loose sand and mud would remain an ever-shifting ground of movable particles. To understand this we must know something of the mode of growth of the mangrove seed. Like that of all viviparous plants it germinates upon the parent stock, the new plant attaining a length of some six inches before it drops from the old tree. As these trees grow down to the water's edge, and as at high tide the interior of the Mangrove Islands is submerged, the new plants are of course dropped into the water, and are swept about and scattered by its movements. Like brownish-green sticks, fusiform in shape, they float about in great numbers, with the heavier end, where the root is to be, slightly sunk below the surface. Floating thus, they suggest the idea that a ship-load of cigars has been wrecked upon the reef, and swept inland by the tides. Presently these fusiform bodies are stranded along the edge of some mud flat, touching ground at last with their heavier loaded end. Their hold is at first very loose, but made to turn, by the rising and falling tides, like a rod upon a pivot, they soon work their way into the soft mud and plant themselves firmly. Immediately the long, rapidly-growing roots begin to shoot out and soon form a close screen, giving stability to all the loose materials about them and holding the mud and sand in place. So spreading is the root that a young mangrove, not more than two feet in height, will send its roots out in all directions over an area of some six feet. As it rises it constantly sends down new roots to reach the ground from higher and higher points on the stem, all of which throw out again fresh shoots. As these mangrove seeds are stranded in great numbers and often close together, such a plantation soon becomes the nucleus around which sand and mud accumulate. The most extensive and shoalest mud flats occur, therefore, wherever the mangrove islands rise. Here the Holothuria are most abundant, while the Gorgonia thrive better on a harder bottom, where the flats are covered with four or five feet of water. The flats and mangrove islands to the north of the Pine Islands and Boca Chica are less muddy, consisting rather of a coral sand resembling very minute oolites. The bottom becomes rather softer, however, to the seaward and north of Key West and Boca Chica. Sea-fans (Gorgonias) frequently occur in this region upon the harder bottom, especially where the flats slope northward into two or three fathoms of water. The sponges are generally found upon hard, smooth sand, or upon coral rock in five or six feet of water. They occur, however, even at a depth of three to five fathoms. We cannot explain the greater prevalence of the oolitic sand in the Pine Islands and Boca Chica group of keys. It may be owing to the greater width of this range of islands, or to the greater width of the reef which gave rise to their formation. Nowhere else do the keys cover so wide an area.

The Main-land.

A careful survey of all the varieties of rock occurring at Key West, as well as their peculiar superposition, had prepared us for a minute comparison between the keys and the main-land; but, nevertheless, we were no less surprised than delighted to find that the solid foundation of the main-land consisted of the same identical modifications of coral rocks which form the keys. Along all that part of the shore which was examined, as well as upon the shores of the Miami, we found everywhere the same coarse, oolitic rock, with cross-stratification, consisting of thin beds, dipping at various angles in different directions, precisely as we find it at the western extremity of Key West, excepting, perhaps, that the cross-stratification is here more prominent, the strata dipping more frequently in several directions within the same extent.

Attention has been called to the resemblance of the main-land to the keys, by Buckingham Smith, Esq., in his Report to the House of Representatives respecting the drainage of the Everglades. He refers the formation, however, to the Post-pliocene, and does not seem to have noticed that it is of coral origin. The connection of these deposits with the Post-pliocene formations of South Carolina, although it seems very probable, needs further proof; but a fact of greater importance, and one about which there can be no doubt, is, that the shore bluffs of the main-land are identical in structure and mode of formation with the subaerial deposits of the main keys. The lithology of the main-land is identical with the rocks of the keys as well as its mode of formation. Along the whole course of the main-land to the edge of the Everglades the appearance is the same. Indeed, a belt of coral rock, several miles in width, encircles the southern coast of the peninsula of Florida. This belt seems like a range of elongated hillocks, because it is broken here and there by cuts and depressions similar to those which separate the successive islands in the main range of keys. Within this belt, on the landward side, begin those inundated prairies known as Everglades. The bottom of these fresh-water swamps consists of the same muddy, semi-oolitic and concretionary limestone so characteristic of the northern shore of Key West, especially about the barracks. The bottom is very uneven, so that the sheet of water covering it varies in depth from a few inches to four or five feet, and in more extensive depressions forms shallow lakes. Where the ground is completely inundated, silicious sand covers it; but wherever the solid foundation rises to the surface, a soft soil is formed by the accumulation of decomposing vegetable matter. Such patches are here and there quite extensive, rising sometimes like islands one or two or even three feet above the shallow waters, and sustaining large trees and a rich vegetation. Such overgrown islands are called *hummocks*, and they make picturesque breaks in the otherwise monotonous flats of the Everglades. I have not yet ascertained by direct observation the extent of this formation in a northerly direction; but Lieutenant Rodgers, who has crossed the Everglades in all directions, informs me that as far north as Lake Okeechobee, near the 27th degree of northern latitude, the character of the peninsula is the same as in those more southern portions which we visited together. Specimens from the shores of Lake Munroe, which I owe to the kindness of Count Pourtalès, satisfy me that these formations extend beyond the 29th degree of northern latitude. Even the Coralline in the neighborhood of St. Augustine, specimens of which have been furnished me by Lieutenant Rodgers, and by Captain Curtis, of Key West, must be, as I believe, the northern prolongation of the same deposits. It is true that the rock there consists almost entirely of fragments of shells, but the fact that the same shell-conglomerate occurs at Cape Sable, in the immediate prolongation of the southernmost shore bluff, convinces me that one and the same geological formation, identical in lithological character with the reef of Florida, and presenting only slight local modifications, extends all over the peninsula of Florida, at least as far north as St. Augustine. Leaving this point, for the settlement of which we have not yet sufficient data, let us limit our comparison to the southernmost extremity of the peninsula and the keys. Here, at least, there can be no doubt that the southernmost shore bluff represents another range of keys similar to the main keys lying north of the mud flats, and that the Everglades within those bluffs are in reality another more extensive mud flat, agreeing in every respect with those lying between the main range of keys and the main-land. The only difference is that the Everglades have risen, with time, above the level of the sea. Were the present mud flats partially drained, or were a few additional feet of soil accumulated and consolidated upon them, their depressions would then correspond to the swampy ground, and their raised portions to the dry patches on the Everglades, while the Mangrove Islands would represent the hummocks. Nor does the agreement end here. About twenty miles from the southernmost shore, within the first prairies, another line of hummocks runs parallel with the first, and with the shore. This ridge, with an instinctive appreciation of its true character, has been called the Long Key. In short, these hummocks and Everglades represent as many ranges of keys divided by mud flats, showing that the present keys and reefs of Florida are the last of a series of reefs advancing gradually from north to south, in a more or less concentric succession. Endeavoring to reconstruct this process, we should suppose that a long time ago, before the outer reef had grown up from its foundation, the present range of main keys was itself a growing reef, not yet reaching the surface. In the place of the mud flats now filling the space between the keys and the main-land was a channel as deep and unobstructed as that now lying between the main range of keys and the reef. Carrying the scene still farther back to an age for the duration of which we have no measure, the present shore bluffs are then the growing reef, rising to the surface here and there so as to form keys, while the southernmost part of the Everglades is changed to an open channel between the Long Key and the shore bluffs. Another backward step, and no reef rises between Cape Sable and Cape Florida, but the ocean beats against the Long

Key, then a growing reef. Here we will stop, since our knowledge of the interior is not sufficiently exact to justify us in pushing our retrograde history farther. Let us reverse the process now, and, starting from Long Key as the then southernmost point of Florida, build seaward. Twelve or twenty miles from the shore the sea has a depth of some twelve to twenty fathoms, and there a reef begins to grow. Gradually it rises, till here and there it reaches the sea level in patches. On such patches broken fragments of coral, sand, and mud accumulate, and they are gradually fashioned into keys. Between this growing reef and Long Key there flows at first a channel; but by the accumulation of coral sand, mud, and débris of all sorts, from the reef or from the main-land, this channel is gradually transformed into a tract of mud flats. These flats are gradually raised to the surface of the water, and they, as well as the shore bluffs, become dry land. Perhaps before this process comes to an end another reef begins to rise, the conditions for its formation being pushed a little farther south by the shore bluffs themselves, since the corals prosper only on a certain slope and at a certain distance from the land. The foundation for the main range of keys is now laid; but the tract now occupied by the mud flats is still open sea, the powerful action of which we may trace to this day in the excavations and erosions of the shore bluffs. At last this new reef reaches the surface, here and there gradually forming the present main range of keys, while the open channel is transformed, by accumulation, into the present mud flats. The main range of keys, like the shore bluffs, determines the position for the next coral wall, and the present outer reef begins to rise, though nearer to the main range of keys then they had been to the shore bluff, because the sea bottom is steeper. As this last reef rises, it modifies, in its turn, the course of the surrounding waters, the channel between it and the keys begins to fill, the shoals encircling the islands increase, and we arrive at last at the present condition of things. We have thus followed the extension of the peninsula of Florida, through the successive annexation of a series of coral reefs, the most recent of which is still in the stage of active and rapid growth.

But it may be asked, What is the practical use of such detailed descriptions of the coral reefs for the coast survey? We need only allude to the universal impression of the dangers arising to navigation from the growth of such reefs to satisfy the most sceptical that a minute knowledge of the extent and mode of formation of those belonging to our own shores must be of paramount importance, were it only with reference to the position of lighthouses. But there is another subject connected with this investigation which is not less momentous. It is well known that, in the Pacific, coral reefs have been raised above the levels at which they were formed, by the agency of the living animals, and also that in other localities, sometimes in close connection with those just mentioned, the ground is subsiding. These changes have been so often observed, whenever coral reefs occur, that the idea of subsidence and upheaval is naturally connected with the features of coral reefs, and the question at once arises, whether the reefs on our shores are thus undergoing variations of level, independently of their natural growth. We have seen how extensive are the changes produced merely by the normal growth of the corals, and the facts accompanying their increase. It now remains for us to ascertain whether this growth has taken place, or does at present take place, upon ground which has changed or is now changing its relative level in reference to the sea.

The facts already described afford a sufficient answer to the question. We are satisfied that as far as coral formations have been observed upon the main-land of Florida, and within the present extent of the coral reefs, no change of the relative level has taken place either by subsidence or upheaval of the coral ground, and that all the modifications which the reef has presented at successive periods have been the natural consequence of the growth of reef-building corals, with the subsequent accumulation of their products in the manner described above.

I am sorry to differ from my friend, Mr. Tuomy, who, in an interesting account of an excursion to Florida, considers the upright coral heads standing above the water level as evidence of the upheaval of the reef. I have already shown that, although at the first glance the position of these heads suggests that they have grown where they are found, they are, in fact, detached boulders, accumulated where they now lie. Setting this aside, the whole coral field of Florida furnishes connected evidence that neither upheaval nor subsidence of the ground on which the coral formations rest has taken place. The maximum height of all these formations including the bluffs on the main-land, is the same, — between twelve and thirteen feet above high-water mark. If we ascribe their present level to a series of upheavals rather than to the natural accumulation on the spot, we must suppose each successive disturbance to have raised the more recent reef and range of keys to exactly the same height as the earlier ones, without in the least deranging the level of the latter. We must suppose this to be true for the main bluffs also, and for all the concentric ranges of hummocks and swamps lying within them. To suppose that in each instance these upheavals were strictly limited to one such narrow belt would be contrary to all our knowledge of such agencies. To suppose all the upheavals to have been simultaneous would be equally opposed to what we know of the mode of growth of coral reefs. Their formation must be successive, since the outer one cannot start till the completion of the previous one furnishes the necessary conditions for its foundation.

There is in reality but one way of accounting for this equality of level in the successive reefs; which is, to suppose that their loftiest ridges are the maximum height at which materials can be accumulated by the natural agency of gales, and we have sufficient evidence to justify the adoption of this view.

The fact that, at present, the highest tides, during the most severe gales, do not reach the level of the bluff summits along the shores of the main-land, or even that of the maximum height of Key Largo or Key West, does not invalidate this supposition, for when the shore bluffs of the main-land were formed, the ocean had full sweep over the ground now occupied by the reef and mud flats, which did not then exist; and when Key Largo and Key West attained their maximum height, the outer reef did not yet form a barrier, checking the violence of the Gulf Stream in that direction. But, even with the present obstruction, we have evidence of the occasional rise of the water to heights which fully justify our assumption that even the highest ridges on the shores of the main-land and on the reef have been formed by the action of severe gales. For, in the year 1846, the water rose eight and a half feet above high-water mark at Key Vacas. Key West was entirely inundated during the same gale; and though that island is somewhat protected by the reef, even at present, the rushes, driven upon it by the flood, may be seen among the trees and bushes, at a height almost equal to its loftiest summit. In 1841 the water rose ten feet above high-water mark at Cape Romaine, on the western shore of the peninsula.

These facts suffice to show that the explanation we have given of the formation of the reef is in accordance with the powers of the agencies to which it is ascribed, and, when taken in connection with the peculiar arrangement of the materials of which they consist, seems to us to prove the justness of this view.

All the keys, all the islands along the whole extent of the reef, and all that part of the peninsula which consists of coral formations, have been formed by subaerial deposits accumulated under tidal agencies. The contrast between these subaerial deposits and the rock of submarine origin is striking. Near the shore the torrential character of the stratification is still evident; but at some distance from the islands and the main-land the strata are more regular, and contain, also, more and better-preserved fossil remains. The depth at which coral reefs start from some given foundation is stated by different authors to be from twelve to twenty fathoms. It would seem that the Florida reef has sprung up in somewhat shallower waters, for below ten or twelve fathoms there are no indications of living coral growth. The outer reef ends off the Marquesas in a depth of about ten fathoms. The ship-channel itself is only some ten fathoms in depth there, and very few coral heads are found in it. Add to this, that the depression between the Marquesas and Tortugas, though for the greater part not exceeding twelve or thirteen fathoms, is entirely unobstructed by coral heads, and that in the ship-channel there are very few coral heads noticed below a depth of six or seven fathoms. We are therefore inclined to believe that, in latitudes bordering on the Tropics, the normal depth for the foundation of a coral reef is from ten to twelve fathoms, and that, if they spring up from greater depths, it must be in the Tropics proper.

Physical Changes in the Gulf Stream.

There are several questions of the deepest scientific interest, which may be advanced by a due consideration of the facts observed upon the reefs of Florida. There we have a peninsula — a narrow, flat strip of land, projecting for about five degrees from the main-land — between the Atlantic Ocean and the Gulf of Mexico, and forming an effective barrier between the waters of the two seas, which otherwise, even by the change of a few feet in the relative level of the intervening peninsula, would communicate freely with one another; and this peninsula we now know to have been added to the continent, step by step, in a southerly direction.

We know that the time cannot be far behind us when the present reef, with its few keys, did not exist, and when the channel, therefore, was broader, and the Gulf Stream flowed directly along the main range of keys. We know, further, that at some earlier period the keys themselves were not yet formed, and that then the channel between Cuba and Florida was wider still, washing freely over the grounds now known as the mud flats, between the keys and the main-land, and that there was then nothing to impede a free communication between the Gulf of Mexico and the Atlantic Ocean. The channel of the Gulf Stream was not only wider, — it was also less shallow along its northern borders; for the whole extent of soundings south of the main-land of Florida was an uncovered coral ground, upon which the deep-water species were just beginning to spread. But we may trace the change farther. There was a time when neither the southern bluffs of the continent, nor Long Key within the Everglades, nor even the Everglades themselves, existed; when, therefore, the Gulf Stream had a broad communication with the Atlantic, and the southern shores of the United States extended in almost unbroken contiguity from west to east, from the shores of Texas and Louisiana to St. Augustine. At that time the gulf-channel was, in reality, a broad bay, as broad as the gulf itself, destitute of all those obstructions which now cause the tropical current to follow such a circuitous course between the West India Islands, through the Caribbean Seas, and around the peninsula of Florida. The influence which the Gulf Stream has upon the climate of the Atlantic is so well known that its connection with the changes which the current itself has undergone within a comparatively recent period cannot be overlooked. If it is true, as we have every reason to believe, that the temperature of the Gulf Stream, in connection with the temperature of the southwesterly winds blowing obliquely across the Atlantic, modifies that of the western coast of Europe; if it is true that the Gulf Stream and the southwest winds have an influence in determining the course of the isothermal lines upon the two sides of the Atlantic, and of raising beyond their normal altitude the mean annual temperatures of northwest Europe, — then we may look to the physical changes which have occurred on the southeastern extremity of the North American continent for the cause — or at least a partial cause — of those changes of temperature which have taken place, in the beginning of the present period, in those very northwestern portions of Europe which are now so much warmer than the corresponding latitudes on the American continent, and which, soon after the accumulation of the glacial drift, had as low mean annual temperatures as the coasts of Labrador, Nova Scotia, and New England in our day.

Changes in Ages to come.

Among the questions contained in your instructions, you ask whether the growth of coral reefs can be prevented, or the results remedied, which are so unfavorable to the safety of navigation. I may say that here, as in most cases where the operations of nature interfere with the designs of man, it is not by a direct intervention on our part that we may remedy the difficulties, but rather by a precise knowledge of their causes, which may enable us, if not to check, at least to avoid the evil consequences. I do not see the possibility of limiting in any way the extraordinary increase of corals, beyond the bounds which nature itself has assigned to their growth. We have seen how successfully several reefs have been formed, more or less parallel, within the limits of the peninsula of Florida, as well as beyond the main-land. We have seen, also, how these parallel or concentric reefs have been gradually transformed into main-land by the accumulation of coral sand and mud with other loose materials, and also that the keys are now slowly annexed to the main-land, by the same process. We may, therefore, safely infer that, as far as the conditions exist for the formation of similar accumulations of loose materials, they will continue to occur, but they will never extend beyond the natural foundation from which a coral reef may rise; and as we now have sufficient evidence that this foundation is a sea-bottom, under from twelve to twenty fathoms, we may be satisfied that outside of the present outer reef, where the slope is steep, sinking rapidly to unfathomable depths, there is no opportunity for the growth of a new reef.

Here and there the reef may widen somewhat, towards the Gulf Stream, within those limits at which the depth does not exceed twenty fathoms; and from the knowledge we already possess of the soundings outside the reef we know positively that this is nowhere a broad stream. We may therefore rest assured that the changes which are going on will chiefly consist in bringing up the reef, for its whole extent, to the surface of the water, with occasional intervening channels kept open by the currents, such as exist now between the keys; that this reef once matured, will be covered by coral débris, becoming transformed into a range of keys, similar to that which exists now inside of it; that the depth of the ship-channel between the reef and the main range of keys will gradually lessen, and the channel itself be changed into mud flats, similar to those stretching now between the keys and the main-land. In still more remote ages the present mud flats may become swamps, elevated above the reach of the tide-waters, like the Everglades; and this process may perhaps be extended to the present ship-channel. But unless some great revolution in nature modifies the present relative level between land and sea, it may safely be maintained that the present outer reef is the final southern boundary of the North American continent, and that the sooner a system of lighthouses and signals is established along the whole reef, the better; for this is, after all, the shore which is to be lighted, and not the range of keys which is within the reef. In relation to the western range of keys, and the western extremity of the reef, we may expect, in course of time, to see the depression between the Marquesas and Tortugas gradually lessened by the increase of the reef, so that the westernmost group of islands may finally stand in as close connection with the keys more to the west as they now bear to each other, the passage between them being reduced to as narrow a channel as Boca Grande, between the Marquesas and the Mangroves.

The shoals west of Cape Sable may, undoubtedly, also increase in extent westward; but how far the currents from the northwest may limit this accumulation, in connection with the changes which the currents themselves may undergo by the increase of the keys to the west, it is beyond the power of human foresight to determine.

These practical results, — for so we venture to call the general conclusions last presented, — although they are purely scientific deductions from general principles, may satisfy the most obstinate supporters of the matter-of-fact side of all questions, of the advantages of scientific illustrations in the daily walks of life, and also justify the course which has been followed with so much success by the Coast Survey, in combining the strictest scientific methods with its practical operation.

Respectfully submitted,

L. AGASSIZ.

Professor A. D. BACHE,

Superintendent of the Coast Survey.

SKETCH OF

THE FLORIDA REEFS AND KEYS.

REPRINTED FROM THE "METHODS OF STUDY."

THE physical as well as the human history of the world has its mythical age, lying dim and vague in the morning mists of creation, like that of the heroes and demigods in the early traditions of man, defying all our ordinary dates and measures. But if the succession of periods that prepared the earth for the coming of man, and the animals and plants that accompany him on earth, baffles our finite attempts to estimate its duration, have we any means of determining even approximately the length of the period to which we ourselves belong? If so, it may furnish us with some data for the further solution of these wonderful mysteries of time, and it is besides of especial importance with reference to the question of permanence of species.

Those who maintain the mutability of species, and account for all the variety of life on earth by the gradual changes wrought by time and circumstances, do not accept historical evidence as affecting the question at all. The relics of those oldest nations, all whose history is preserved in monumental records, do not indicate the slightest variation of organic types from the earliest epoch to this day. The animals preserved within their tombs or carved upon the walls of their monuments by the ancient Egyptians were the same as those that have their home in the valley of the Nile to-day; the negro, whose peculiar features are unmistakable even in their rude artistic attempts to represent them, was the same woolly-haired, thick-lipped, flat-nosed, dark-skinned being in the days of the Rameses that he is now. The apis, the ibis, the crocodiles, the sacred beetles, have brought down to us unchanged all the characters that superstition hallowed in those early days. The stony face of the Sphinx is not more true to its past, nor the massive architecture of the Pyramids more unchanged, than they are. But the advocates of the mutability of species say truly enough that the most ancient traditions are but as yesterday in the world's history, and that what six thousand years could not do sixty thousand years might effect. Leaving aside, then, all historical chronology, how far back can we trace our own geological period, and the species belonging to it? By what means can we determine its duration? Within what limits, by what standard, may it be measured? Shall hundreds, or thousands, or hundreds of thousands, or millions of years be the unit from which we start?

I will begin this inquiry with a series of facts which I myself have had an opportunity of investigating with especial care, respecting the formation and growth of the coral reefs of Florida. But first a few words on coral reefs in general. They are living limestone walls, built up from certain depths in the ocean by the natural growth of a variety of animals, but limited by the level of high water, beyond which they cannot rise, since the little beings that compose them die as soon as they are removed from the vitalizing influence of the pure sea-water. These walls have a variety of outlines: they may be straight, circular, semicircular, or oblong, according to the form of the coast along which the little reef-builders establish themselves; and their height is, of course, determined by the depth of the bottom on which they rest. If they settle about an island on all sides of which the conditions for their growth are equally favorable, they will raise a wall all round it, thus encircling it with a ring of coral growth. The atolls in the Pacific Ocean, those circular islands enclosing sometimes a fresh-water lake in mid-ocean, are coral walls of this kind, that have formed a ring around a central island.

This is easily understood, if we remember that the bottom of the Pacific Ocean is by no means a stable foundation for such a structure. On the contrary, over a certain area, already surveyed with some accuracy by Professor Dana, during the United States Exploring Expedition, it is subsiding; and if an island upon which the reef-builders have established themselves be situated in that area of subsidence, it will, of course, sink with the floor on which it rests, carrying down also the coral wall to a greater depth in the sea. In such instances, if the rate of subsidence be more rapid than the rate of growth in the corals, the island and the wall itself will disappear beneath the ocean. But whenever, on the contrary, the rate of increase in the wall is greater than that of subsidence in the island, while the latter gradually sinks below the surface, the former rises in proportion, and by the time it has completed its growth the central island has vanished, and there remains only a ring of coral reef, with here and there a break, perhaps, at some spot where the more prosperous growth of the corals has been checked. If, however, as sometimes happens, there is no such break, and the wall is perfectly uninterrupted, the sheet of sea-water so enclosed may be changed to fresh water by the rains that are poured into it. Such a water-basin will remain salt, it is true, in its lower part, and the fact that it is affected by the rise and fall of the tides shows that it is not entirely secluded from communication with the ocean outside; but the salt water, being heavier, sinks, while the lighter rain-water remains above, and it is to all appearance actually changed into a fresh-water lake.

I need not dwell here on the further history of such a coral island, or follow it through the changes by which the summit of its circular wall becomes covered with a fertile soil, a tropical vegetation springs up upon it, and it is at last, perhaps, inhabited by man. There is something very attractive in the idea of these green rings enclosing sheltered harbors and quiet lakes in mid-ocean, and the subject has lost none of its fascination since the mystery of their existence has been solved by the investigations of several contemporary naturalists, who have enabled us to trace the whole story of their structure. I would refer all who wish for a more detailed account of them to Charles Darwin's charming little volume on "Coral Reefs," where their mode of formation is fully described, and also to James D. Dana's "Geological Report of the United States Exploring Expedition."

Coral reefs are found only in tropical regions: although Polyps, animals of the same class as those chiefly instrumental in their formation, are found in all parts of the globe, yet the reef-building Polyps are limited to the Tropics. We are too apt to forget that the homes of animals are as definitely limited in the water as on the land. Indeed, the subject of the geographical distribution of animals according to laws regulated by altitude, by latitude and longitude, by pressure of atmosphere or pressure of water, by temperature, light, &c., is exceedingly interesting, and presents a most important field of investigation.

The climatic effect of different levels of altitude upon the growth of animals and plants is the same as that of different degrees of latitude; and the slope of a high mountain in the Tropics, from base to summit, presents in a condensed form, an epitome, as it were, of the same kind of gradation in vegetable growth that may be observed from the Tropics to the Arctics. At the base of such a mountain we have all the luxuriance of growth characteristic of the tropical forest, — the palms, the bananas, the bread-trees, the mimosas; higher up, these give way to a different kind of growth, corresponding to our oaks, chestnuts, maples, &c.; as these wane, on the loftier slopes comes in the pine forest, fading gradually, as it ascends, into a dwarfish growth of the same kind; and this at last gives way to the low creeping mosses and lichens of the greater heights, till even these find a foothold no longer, and the summit of the mountain is clothed in perpetual snow and ice. What have we here but the same series of changes through which we pass, if, travelling northward from the Tropics, we leave palms and pomegranates and bananas behind, where the live-oaks and cypresses, the orange-trees and myrtles of the warmer temperate zone come in, and these die out as we reach the oaks, chestnuts, maples, elms, nut-trees, beeches, and birches of the colder temperate zone, these again waning as we enter the pine forests of the Arctic borders, till, passing out of these, nothing but a dwarf vegetation, a carpet of moss and lichen, fit food for the reindeer and the Esquimaux, greets us, and beyond that lies the region of the snow and ice fields, impenetrable to all but the daring arctic voyager?

I have thus far spoken of the changes in the vegetable growth alone as influenced by altitude and latitude, but the same is equally true of animals. Every zone of the earth's surface has its own animals, suited to the conditions under which they are meant to live; and, with the exception of those that accompany man in all his pilgrimages, and are subject to the same modifying influences by which he adapts his home and himself to all climates, animals are absolutely bound by the laws of their nature within the range assigned to them. Nor is this the case only on land, where river-banks, lake-shores, and mountain-ranges might be supposed to form the impassable boundaries that keep animals within certain limits; but the ocean, as well as the land, has its faunæ and floræ bound within their respective zoölogical and botanical provinces; and a wall of granite is not more impassable to a marine animal than that ocean-line, fluid, and flowing, and ever-changing though it be, on which is written for him, "Hitherto shalt thou come, but no farther." One word as to the effect of pressure on animals will explain this.

We all live under the pressure of the atmosphere. Now, thirty-two feet under the sea doubles that pressure. At the depth of thirty-two feet, then, any marine animal is under the pressure of two atmospheres, — that of the air, which surrounds our globe, and of a weight of water equal to it; at sixty-four feet he is under the pressure of three atmospheres, and so on. There is a great difference in the sensitiveness of animals to this pressure. Some fishes live at a great depth, and find the weight of water genial to them; while others would be killed at once by the same pressure; and the latter naturally seek the shallow waters. Every fisherman knows that he must throw a long line for a halibut, while with a common fishing-rod he will catch plenty of perch from the rocks near the shore; and the differently colored bands of sea-weed revealed by low tides, from the green line of the ulvas through the brown zone of the common fucus, to the rosy and purple-hued sea-weeds of the deeper water, show that the floræ as well as the faunæ of the ocean have their precise boundaries.

This wider or narrower range of marine animals is in direct relation to their structure, which enables them to bear a greater or less pressure of water. All fishes, and, indeed, all animals having a wide range of distribution in ocean-depths, have a special apparatus of water-pores, so that the surrounding element penetrates their structure, thus equalizing the pressure of the weight, which is diminished from without in proportion to the quantity of water they can admit into their bodies. Marine animals differ in their ability to sustain this pressure, just as land animals differ in their power of enduring great variations of climate and of atmospheric pressure.

Of all air-breathing animals, none exhibits a more surprising power of adapting itself to great and rapid changes of external influences than the condor. It may be seen feeding on the sea-shore under a burning tropical sun, and then, rising from its repast, it floats up among the highest summits of the Andes, and is lost to sight beyond them, miles above the line of perpetual snow, where the temperature must be lower than that of the Arctics. But even the condor, sweeping at one flight from tropic heat to arctic cold, although it passes through greater changes of temperature, does not undergo such changes of pressure as a fish that rises from a depth of sixty-four feet to the surface of the sea; for the former remains within the air that surrounds our globe, and therefore the increase or diminution of pressure to which it is subjected must be confined within the limits of one atmosphere; while the latter, at a depth of sixty-four feet, is under a weight equal to that of three such atmospheres, which is reduced to one when it reaches the sea-level. The change is proportionally greater for those fishes that come from a depth of several hundred feet. These laws of limitation in space explain many facts in the growth of coral reefs that would be otherwise inexplicable, and which I now will endeavor to make clear to my readers.

For a long time it was supposed that the reef-builders inhabited very deep waters, for they were sometimes brought up on sounding-lines from a depth of many hundreds, or even thousands, of feet, and it was taken for granted that they must have had their home where they were found; but the facts recently ascertained respecting the subsidence of ocean-bottoms have shown that the foundation of a coral wall may have sunk far below the place where it was laid. And it is now proved, beyond a doubt, that no reef-building coral can thrive at a depth of more than fifteen fathoms, though corals of other kinds occur far lower, and that the dead reef-corals, sometimes brought to the surface from much greater depths, are only broken fragments of some reef that has subsided with the bottom on which it was growing. But though fifteen fathoms is the maximum depth at which any reef-builder can prosper, there are many which will not sustain even that degree of pressure; and this fact has, as we shall see, an important influence on the structure of the reef.

Imagine now a sloping shore on some tropical coast descending gradually below the surface of the sea. Upon that slope, at a depth of from ten to twelve or fifteen fathoms, and two or three or more miles from the main land, according to the shelving of the shore, we will suppose that one of those little coral animals, to whom a home in such deep waters is genial, has established itself. How it happens that such a being, which we know is immovably attached to the ground, and forms the foundation of a solid wall, was ever able to swim freely about in the water till it found a suitable resting-place, I shall explain hereafter, when I say something of the mode of reproduction of these animals. Accept, for the moment, my unsustained assertion, and plant our little coral on this sloping shore, some twelve or fifteen fathoms below the surface of the sea.

The internal structure of such a coral corresponds to that of the sea-anemone. The body is divided by vertical partitions from top to bottom (Plate I. Figs. 2, 3, and 4), leaving open chambers between; while in the centre hangs the digestive cavity, connected by an opening in the bottom with all these chambers. At the top is an aperture serving as a mouth, surrounded by a wreath of hollow tentacles, each one of which connects at its base with one of the chambers, so that all parts of the animal communicate freely with each other. But though the structure of the coral is identical in all its parts with that of the sea-anemone, it nevertheless presents one important difference. The body of the sea-anemone is soft, while that of the coral is hard.

It is well known that all animals and plants have the power of appropriating to themselves and assimilating the materials they need, each selecting from the surrounding elements whatever contributes to its well-being. Now corals possess, in an extraordinary degree, the power of assimilating to themselves the lime contained in the salt water around them; and as soon as our little coral is established on a firm foundation, a lime deposit begins to form in all the walls of its body, so that its base, its partitions, and its outer wall, which in the sea-anemone remain always soft, become perfectly solid in the polyp coral, and form a frame as hard as bone.

It may naturally be asked where the lime comes from in the sea which the corals absorb in such quantities. As far as the living corals are concerned, the answer is easy, for an immense deal of lime is brought down to the ocean by rivers that wear away the lime deposits through which they pass. The Mississippi, whose course lies through extensive lime regions, brings down yearly lime enough to supply all the animals living in the Gulf of Mexico. But behind this lies a question not so easily settled, as to the origin of the extensive deposits of limestone found at the very beginning of life upon earth. This problem brings us to the threshold of astronomy, for the base of limestone is metallic in character, susceptible, therefore, of fusion, and may have formed a part of the materials of our earth, even in an incandescent state, when the worlds were forming. But though this investigation as to the origin of lime does not belong either to the naturalist or the geologist, its suggestion reminds us that the time has come when all the sciences and their results are so intimately connected that no one can be carried on independently of the others. Since the study of the rocks has revealed a crowded life whose records are hoarded within them, the work of the geologist and the naturalist has become one and the same, and, at that border-land where the first crust of the earth was condensed out of the igneous mass of materials which formed its earliest condition, their investigation mingles with that of the astronomer, and we cannot trace the limestone in a little coral without going back to the creation of our solar system, when the worlds that compose it were thrown off from a central mass in a gaseous condition.

When the coral has become in this way permeated with lime, all parts of the body are rigid, with the exception of the upper margin, the stomach, and the tentacles. The tentacles are soft and waving, projected or drawn in at will; they retain their flexible character through life, and decompose when the animal dies. For this reason the dried specimens of corals preserved in museums do not give us the least idea of the living corals, in which every one of the millions of beings composing such a community is crowned by a waving wreath of white or green or rose-colored tentacles.

As soon as the little coral is fairly established and solidly attached to the ground, it begins to bud. This may take place in a variety of ways, dividing at the top or budding from the base or from the sides, till the primitive animal is surrounded by a number of individuals like itself, of which it forms the nucleus, and which now begin to bud in their turn, each one surrounding itself with a numerous progeny, all remaining, however, attached to the parent. Such a community increases till its individuals are numbered by millions; and I have myself counted no less than fourteen millions of individuals in a coral mass of Porites (Plate XVI.) measuring not more than twelve feet in diameter. The so-called coral heads, which make the foundation of a coral wall, and seem by their massive character and regular form especially adapted to give a strong, solid base to the whole structure, are known in our classifications as the Astræans, so named on account of the star-shaped form of the little pits crowded upon their surface, each one of which marks the place of a single more or less isolated individual in such a community.

Thus firmly and strongly is the foundation of the reef laid by the Astræans (Plate IV.); but we have seen that for their prosperous growth they require a certain depth and pressure of water, and, when they have brought the wall so high that they have not more than six fathoms of water above them, this kind of coral ceases to grow. They have, however, prepared a fitting surface for different kinds of corals that could not live in the depths from which the Astræans have come, but find their genial home nearer the surface; such a home being made ready for them by their predecessors, they now establish themselves on the top of the coral wall and continue its growth for a certain time. These are the Mæandrinas (Plate IX.), or the so-called Brain-Corals, and the Porites (Plates XII. and XVI.). The Mæandrinas differ from the Astræans by their less compact and definite pits. In the Astræans the place occupied by the animal in the community is marked by a little star-shaped spot, in the centre of which all the partition-walls meet. But in the Mæandrinas, although all the partitions converge toward the central opening, as in the Astræans, these central openings elongate, run into each other, and form waving furrows all over the surface, instead of the small round pits so characteristic of the Astræans. The Porites resemble the Astræans, but the pits are smaller, with fewer partitions and fewer tentacles, and their whole substance is more porous.

But these also have their bounds within the sea: they in their turn reach the limit beyond which they are forbidden by the laws of their nature to pass, and there they also pause. But the coral wall continues its steady progress; for here the lighter kinds set in, — the Madrepores (Plates XVII., XVIII., and XIX.), the Millepores (Plate XX.), and a great variety of Sea-Fans (Plate XXI.), and Corallines (Plate XXII.), and the reef is crowned at last with a many-colored shrubbery of low feathery growth. These are all branching in form, and many of them are simple calciferous plants, though most of them are true animals, resembling, however, delicate Algæ more than any marine animals; but, on examination of the latter, one finds them to be covered with myriads of minute dots, each representing one of the little beings out of which the whole is built, while nothing of the kind is seen in Algæ.

I would add here one word on the true nature of the Millepores, long misunderstood by naturalists. While pursuing my investigations on the coral reefs of Florida, one of these Millepores revealed itself to me in its true character of Acaleph. It must be remembered that they belong to the hydroid group of Acalephs, of which our common jelly-fishes do not give a correct idea. It is by their soft parts alone, — those parts which are seen only when these animals are alive and fully open, — that their Acalephian character can be perceived, and this accounts for their being so long accepted as Polyps, when studied in the dry coral stock. Nothing could exceed my astonishment when for the first time I saw such an animal fully expanded, and found it to be a true Acaleph. It is exceedingly difficult to obtain a view of them in this state, for, at any approach, they draw themselves in, and remain closed to all investigation.*

With these branching corals the reef reaches the level of high water, beyond which, as I have said, there can be no further growth, for want of the action of the fresh sea-water. This dependence upon the vivifying influence of the sea accounts for one unfailing feature in the coral walls. They are always abrupt and steep on the seaward side, but have a gentle slope towards the land. This is accounted for by the circumstance that the corals on the outer side or the reef are in immediate contact with the pure ocean-water, while by their growth they partially exclude the inner ones from the same influence, — the rapid growth of the latter being also impeded by any impurity of foreign material washed away from the neighboring shore and mingling with the water that fills the channel between the main-land and the reef. Thus the coral reefs, whether built around an island, or along a straight line of coast, or concentric to a rounding shore, are always shelving toward the land, while they are comparatively abrupt and steep toward the sea. This should be remembered, for, as we shall see hereafter, it has an important bearing on the question of time as illustrated by coral reefs.

I have spoken of the budding of corals, by which each one becomes the centre of a cluster; but this is not the only way in which they multiply their kind. They give birth to eggs also, which are carried on the inner edge of their partition-walls, till they drop into the sea, where they float about, little, soft, transparent, pear-shaped bodies (Plate XVI. Figs. 7, 10, and 11), as unlike as possible to the rigid stony structure they are to assume hereafter. In this condition they are covered with vibratile cilia or fringes, that are always in rapid, uninterrupted motion, and by means of which they swim about in the water. These little germs of the corals, swimming freely about during their earliest phases of life, continue the growth of the reef, those that prosper at shallower depths coming in at the various heights where their predecessors die out; otherwise it would be impossible to understand how this variety of building material, as it were, is introduced wherever it is needed. This point, formerly a puzzle to naturalists, has become quite clear since it has been found that myriads

* See also Agassiz, L., Cont. Nat. Hist. U. S., Vol. III. Pl. XV. and H. N. Moseley, Phil. Trans. R. S., Vol. CLXVII. Part 1.

of these little germs are poured into the water surrounding a reef. There they swim about till they find a genial spot on which to establish themselves, when they become attached to the ground by one end, while a depression takes place at the opposite end, which gradually deepens to form the mouth and inner cavity, while the edges expand to form the tentacles, and the productive life of the little coral begins: it buds from every side, and becomes the foundation of a new community.

I should add, that, beside the Polyps and the Acalephs, Mollusks also have their representatives among the corals. There is a group of small Mollusks called Bryozoa, allied to the Clams by their structure, but excessively minute when compared to the other members of their class, which, like the other corals, harden in consequence of an absorption of solid materials, and contribute to the formation of the reef. Beside these, there are certain plants, limestone Algæ, — Corallines (Plate XXII.), as they are called, — which have their share also in the work. . . . .

A few miles from the southern extremity of Florida, separated from it by a channel, narrow at the eastern end, but widening gradually toward the west, and rendered every year more and more shallow by the accumulation of materials constantly collecting within it, there lies a line of islands called the Florida Keys.* They are at different distances from the shore, stretching gradually seaward in the form of an open crescent, from Virginia Key and Key Biscayne, almost adjoining the main-land, to Key West, at a distance of twelve miles from the coast, which does not, however, close the series, for sixty miles farther west stands the group of the Tortugas, isolated in the Gulf of Mexico. Though they seem disconnected, these islands are parts of a submerged coral reef, parallel with the shore of the peninsula and continuous underneath the water, but visible above the surface at such points of the summit as have fully completed their growth.

This demands some explanation, since I have already said that no coral growth can continue after it has reached the line of high water. But we have not finished the history of a coral wall, when we have followed it to the surface of the ocean. It is true that its normal growth ceases there, but already a process of partial decay has begun that insures its further

* See Map of Florida Keys, by Pourtalès, Memoirs, M. C. Z., Vol. II., Ill. Cat., No. IV. Also Pl. XXIII. of this Memoir, Sketch Map of the Straits of Florida.

increase. Here, as elsewhere, destruction and construction go hand in hand, and the materials broken or worn away from one part of the reef help to build it up elsewhere. The corals forming the reef are not the only beings that find their home there: many other animals, — shells, worms, crabs, star-fishes, sea-urchins, — establish themselves upon it, work their way into its interstices, and seek a shelter in every little hole and cranny made by the irregularities of its surface. In the Zoölogical Museum at Cambridge there are some large fragments of coral reef which give one a good idea of the populous aspect that such a reef would present, could we see it as it actually exists beneath the water. Some of these fragments consist of a succession of terraces, as it were, in which are many little miniature caves, where may still be seen the shells or sea-urchins which made their snug and sheltered homes in these recesses of the reef.

We must not consider the reef as a solid, massive structure throughout. The compact kinds of corals, giving strength and solidity to the wall, may be compared to the larger trees in a forest, giving it shade and density; but beneath these larger trees grow all kinds of trailing vines, ferns, and mosses, wild-flowers, and low shrubs, filling the spaces between them with a thick underbrush. The coral reef also has its underbrush of the lighter, branching, more brittle kinds, filling its interstices, and fringing the summit and the sides with their delicate, graceful forms. Such an intricate underbrush of coral growth affords an excellent retreat for many animals that like its protection better than exposure to the open sea, just as many land-animals prefer the close and shaded woods to the open plain. A forest is not more thickly peopled with birds, squirrels, martens, and the like, than is the coral reef with a variety of animals which do not contribute in any way to its growth, but find shelter in its crevices, or in its near neighborhood.

But these larger animals are not the only ones that haunt the forest. There is a host of parasites besides, principally insects and their larvæ, which bore their way into the very heart of the tree, making their home in the bark and pith, and not the less numerous because hidden from sight. These also have their counterparts in the reef, where numbers of boring shells and marine worms work their way into the solid substance of the wall, piercing it with holes in every direction, till large portions become insecure, and the next storm suffices to break off the fragments so loosened. Once detached, they are tossed about in the water, crumbled into coral sand, crushed, often ground to powder by the friction of the rocks and the constant action of the sea.

After a time, an immense quantity of such materials is formed about a coral reef. Tides and storms constantly throw them up on its surface, and at last a soil collects on the top of the reef, wherever it has reached the surface of the water, formed chiefly of its own débris, of coral sand, coral fragments, even large masses of coral rock, mingled with the remains of the animals that have had their home about the reef, with sea-weeds, with mud from the neighboring land, and with the thousand loose substances always floating about in the vicinity of a coast, and thrown upon the rocks or shore with every wave that breaks against them. Add to this the presence of a lime-cement in the water, resulting from the decomposition of some of these materials, and we have all that is needed to make a very compact deposit and fertile soil, on which a vegetation may spring up, whenever seeds floating from the shore, or dropped by birds in their flight, take root on the newly-formed island. . . . .

Such caps of soil on the summit of a coral reef are of course very insecure, till they are consolidated by a long period of accumulation, and they may even be swept completely away by a violent storm. It is not many years since the lighthouse, built on Sand Key for the greater security of navigation along the reef, was swept away, with the whole island on which it stood. Thanks to the admirably conducted investigations of the Coast Survey, this part of our seaboard, formerly so dangerous on account of the coral reefs, is now better understood, and every precaution has been taken to insure the safety of vessels sailing along the coast of Florida.

I cannot deny myself the pleasure of paying a tribute here to the high scientific character of the distinguished superintendent of this survey, who has known so well how to combine the most important scientific aims with the most valuable practical results in his direction of it. If some have hitherto doubted the practical value of such researches, — and unhappily there are always those who estimate intellectual efforts only by their material results, — one would think that these doubts must be satisfied, now that the Coast Survey is seen to be the right arm of our navy. Most of the leaders in our late naval expeditions have been men trained in its service, and familiar with all the harbors, with every bay and inlet of our southern coasts, from having been engaged in the extensive researches undertaken by Dr. Bache, and carried out under his guidance. Many even of the pilots of our southern fleets are men who have been employed upon this work, and owe their knowledge of the coast to their former occupation. It is a singular fact, that at this very time, when the whole country feels its obligation to the men who have devoted so many years of their lives to these investigations, a proposition should have been brought forward in Congress for the suspension of the Coast Survey on economical grounds. Happily, the almost unanimous rejection of this proposition has shown the appreciation in which the work is held by our national legislature. Even without reference to their practical usefulness, it is a sad sign, when, in the hour of her distress, a nation sacrifices first her intellectual institutions. Then, more than ever, when she needs all the culture, all the wisdom, all the comprehensiveness of her best intellects, should she foster the institutions that have fostered them, and in which they have been trained to do good service to their country in her time of need.

Several of the Florida keys, such as Key West and Indian Key, are already large, inhabited islands, several miles in extent. The interval between them and the main-land is gradually filling up, by a process similar to that by which the islands themselves were formed. The gentle landward slope of the reef, and the channel between it and the shore, are covered with a growth of the more branching lighter corals, such as Sea-Fans, Corallines, &c., answering the same purpose as the intricate roots of the mangrove-tree. All the débris of the reef, as well as the sand and mud washed from the shore, collect in this net-work of coral growth within the channel, and soon transform it into a continuous mass, with a certain degree of consistence and solidity. This forms the foundation of the mud-flats which are now rapidly filling the channel, and must eventually connect the keys of Florida with the present shore of the peninsula.

Outside the keys, but not separated from them by so great a distance as that which intervenes between them and the main-land, there stretches beneath the water another reef, abrupt, like the first, on its seaward side, but sloping gently toward the inner reef, and divided from it by a channel. This outer reef and channel are, however, in a much less advanced state than the preceding ones. Only here and there a sand-flat large enough to afford a foundation for a beacon, or a lighthouse, shows that this reef also is gradually coming to the surface, and that a series of islands corresponding to the keys must eventually be formed upon its summit.

Some of my readers may ask why the reef does not rise evenly to the level of the sea, and form a continuous line of land, instead of here and there an island. This is accounted for by the sensitiveness of the corals to any unfavorable circumstances impeding their growth, as well as by the different rates of increase of their different kinds. Wherever any current from the shore flows over the reef, bringing with it impurities from the land, there the growth of the corals will be less rapid, and consequently that portion of the reef will not reach the surface so soon as other parts, where no such unfavorable influences have interrupted the growth. But in the course of time the outer reef will reach the surface for its whole length, and become united to the inner one by the filling up of the channel between them, while the inner one will long before that time become solidly united to the present shore-bluffs of Florida by the consolidation of the mud-flats, which will one day transform the inner channel into dry land.

What is now the rate of growth of these coral reefs? We cannot, perhaps, estimate it with absolute accuracy, since they are now so nearly completed; but coral growth is constantly springing up wherever it can find a foothold, and it is not difficult to ascertain approximately the rate of growth of the different kinds. Even this, however, would give us far too high a standard; for the rise of the coral reef is not in proportion to the height of the living corals, but to their solid parts which never decompose. Add to this that there are many brittle, delicate kinds that have a considerable height when alive, but contribute to the increase of the reef only so much additional thickness as their branches would have if broken and crushed down upon its surface. A forest in its decay does not add to the soil of the earth a thickness corresponding to the height of its trees, but only such a thin layer as would be left by the decomposition of its whole vegetation. In the coral reef, also, we must allow not only for the deduction of the soft parts, but also for the comminution of all these little branches, which would be broken and crushed by the action of the storms and tides, and add, therefore, but little to the reef in proportion to their size when alive.

The foundations of Fort Jefferson, which is built entirely of coral rock, were laid on the Tortugas Islands in the year 1846. A very intelligent head-workman watched the growth of certain corals that established themselves on these foundations, and recorded their rate of increase. He has shown me the rocks on which corals had been growing for some dozen years, during which they had increased at the rate of about half an inch in ten years. I have collected facts from a variety of sources and localities that confirm this testimony. A brick placed under water, in the year 1850, by Captain Woodbury of Tortugas, with the view of determining the rate of growth of corals, when taken up in 1858 had a crust of Mæandrina upon it a little more than half an inch in thickness. Mr. Allen also sent me from Key West a number of fragments of Mæandrina from the breakwater at Fort Taylor; they had been growing from twelve to fifteen years, and have an average thickness of about an inch. The specimens vary in this respect, — some of them being a little more than an inch in thickness, others not more than half an inch. Fragments of Oculina gathered at the same place and of the same age are from one to three inches in height and width; but these belong to the lighter, more branching kinds of corals, which, as we have seen, cannot, from their brittle character, be supposed to add their whole height to the solid mass of the coral wall. Millepora gives a similar result.

Estimating the growth of the coral reef according to these and other data of the same character, it should be about half a foot in a century; and a careful comparison which I have made of the condition of the reef as recorded in an English survey made about a century ago with its present state would justify this conclusion. But, allowing a wide margin for inaccuracy of observation or for any circumstances that might accelerate the growth, and leaving out of consideration the decay of the soft parts and the comminution of the brittle ones, which would subtract so largely from the actual rate of growth, let us double this estimate and call the average increase a foot for every century. In so doing, we are no doubt greatly overrating the rapidity of the progress, and our calculation of the period that must have elapsed in the formation of the reef will be far within the truth.

The outer reef, still incomplete, as I have stated, and therefore of course somewhat lower than the inner one, measures about seventy feet in height. Allowing a foot of growth for every century, not less than seven thousand years must have elapsed since this reef began to grow. Some miles nearer the main-land are the keys, or the inner reef; and though this must have been longer in the process of formation than the outer one, since its growth is completed, and nearly the whole extent of its surface is transformed into islands, with here and there a narrow break separating them, yet, in order to keep fully within the evidence of the facts, I will allow only seven thousand years for the formation of this reef also, making fourteen thousand for the two.

This brings us to the shore-bluffs, consisting simply of another reef exactly like those already described, except that in course of time it has been united to the main-land by the complete filling up and consolidation of the channel which once divided it from the extremity of the peninsula, as a channel now separates the keys from the shore-bluffs, and the outer reef, again, from the keys. These three concentric reefs, then, — the outer reef, the keys, and the shore-bluffs, — if we measure the growth of the two latter on the same low estimate by which I have calculated the rate of progress of the former, cannot have reached their present condition in less than twenty thousand years. Their growth must have been successive, since, as we have seen, all corals need the fresh action of the open sea upon them, and if either of the outer reefs had begun to grow before the completion of the inner one, it would have effectually checked the growth of the latter. The absence of an incipient reef outside of the outer reef shows these conclusions to be well founded. The islands capping these three reefs do not exceed in height the level to which the fragments accumulated upon their summits may have been thrown by the heaviest storms. The highest hills of this part of Florida are not over ten or twelve feet above the level of the sea, and yet the luxuriant vegetation with which they are covered gives them an imposing appearance, recalling the islands of the Pacific.

But this is not the end of the story. Travelling inland from the shore-bluffs, we cross a low, flat expanse of land, the Indian hunting-ground, which brings us to a row of elevations called the Hummocks. This hunting-ground, or Everglade as it is also called, is an old channel, changed first to mud-flats and then to dry land by the same kind of accumulation that is filling up the present channels, and the row of hummocks is but an old coral reef with the keys or islands of past days upon its summit. Seven such reefs and channels of former times have already been traced between the shore-bluffs and Lake Okee-cho-bee, adding some fifty thousand years to our previous estimate. Indeed, upon the lowest calculation, based upon the facts thus far ascertained as to their growth, we cannot suppose that less than seventy thousand years have elapsed since the coral reefs already known to exist in Florida began to grow.

When we remember that this is but a small portion of the peninsula, and that, though we have no very accurate information as to the nature of its interior, yet the facts already ascertained in the northern part of the State formed, like its southern extremity, of coral growth, justify the inference that the whole peninsula is formed of successive concentric reefs, we must believe that hundreds of thousands of years have elapsed since its formation began. Leaving aside, however, all that part of its history which is not susceptible of positive demonstration in the present state of our knowledge, I will limit my results to the evidence of facts already within our possession; and these give us as the lowest possible estimate a period of seventy thousand years for the formation of that part of the peninsula which extends south of Lake Okee-cho-bee to the present outer reef.

So much for the duration of the reefs themselves. What, now, do they tell us of the permanence of the species by which they were formed? In these seventy thousand years has there been any change in the corals living in the Gulf of Mexico? I answer most emphatically, *No.* Astræans, Porites, Mæandrinas, and Madrepores were represented by exactly the same species seventy thousand years ago as they are now. Were we to classify the Florida corals from the reefs of the interior, the result would correspond exactly to a classification founded upon the living corals of the outer reef to-day. There would be among the Astræans the different species of Astræa (Pl. IV.) proper, forming the close, round heads, — the Mussa, growing in smaller stocks, where the mouths coalesce and run into each other as in the Brain-Corals, but in which the depressions formed by the mouths are deeper, — and the Caryophyllians (Cladocora Pl. III., Figs. 1–7), in which the single individuals stand out more distinctly from the stock; among Porites, the P. Astræoides (Pl. XVI., Figs. 1–12), with pits resembling those of the Astræans in form, though smaller in size, and growing also in solid heads, though these masses are covered with club-shaped protrusions, instead of presenting a smooth, even surface like the Astræans, — and the P. Clavaria (Pl. XII., Figs. 4, 5, and 6), in which the stocks are divided in short, stumpy branches, with club-shaped ends, instead of growing in close, compact heads; among the Mæandrinas we should have the round heads we know as Brain-Corals (Pl. IX.), with their wavy lines over the surface, and the Manicina (Pls. V., VI.), differing again from the preceding by certain details of structure; among the Madrepores we should have the Madrepora prolifera (Pl. XIX.), with its small, short branches, broken up by very frequent ramifications, the M. cervicornis (Pl. XVIII.), with longer and stouter branches and less frequent ramifications, and the cup-like M. palmata (Pl. XVII.), resembling an open sponge in form. Every species, in short, that lives upon the present reef is found in the more ancient ones. They all belong to our own geological period, and we cannot, upon the evidence before us, estimate its duration at less than seventy thousand years, during which time we have no evidence of any change in species, but, on the contrary, the strongest proof of the absolute permanence of those species whose past history we have been able to trace.

Before leaving the subject of the coral reefs, I would add a few words on the succession of the different kinds of Polyp corals on a reef as compared with their structural rank and also with their succession in time, because we have here another of these correspondences of thought, those intellectual links in creation, which give such coherence and consistency to the whole and make it intelligible to man.

The lowest in structure among the Polyps are not corals, but the single, soft-bodied Actiniæ. They have no solid parts, and are independent in their mode of existence, never forming communities, like the higher members of the class. It might at first seem strange that independence, considered a sign of superiority in the higher animals, should here be looked upon as a mark of inferiority. But independence may mean either simple isolation, or independence of action; and the life of a single Polyp is no more independent in the sense of action than that of a community of Polyps. It is simply not connected with or related to the life of any others. The mode of development of these animals tells us something of the relative inferiority and superiority of the single ones and of those that grow in communities. When the little Polyp coral—the Astræan or Madrepore, for instance—is born from the egg, it is as free as the Actinia, which remains free all its life. It is only at a later period, as its development goes on, that it becomes solidly attached to the ground, and begins its compound life by putting forth new beings like itself as buds from its side. Since we cannot suppose that the normal development of any being can have a retrograde action, we are justified in believing that the loss of freedom is in fact a stage of progress in these lower animals, and their more intimate dependence on each other a sign of maturity.

There are, however, structural features by which the relative superiority of these animals may be determined. In proportion as the number of their parts is limited and permanent, their structure is more complicated; and the indefinite multiplication of identical parts is connected with inferiority of structure. Now in these lowest Polyps, the Actiniæ, the tentacles increase with age indefinitely, never ceasing to grow while life lasts, new chambers being constantly added to correspond with them, till it becomes impossible to count their numbers. Next to these come the true Fungidæ. They are also single, and, though they are stony corals, they have no share in the formation of reefs. In these, also, the tentacles multiply throughout life, though they are usually not so numerous as in the Actiniæ. But a new feature is added to the complication of their structure, as compared with Actiniæ, in the transverse beams which connect their vertical partitions, though they do not stretch across the chambers so as to form perfect floors, as in some of the higher Polyps.

In the Astræans, the multiplication of tentacles is more definite and limited, rising sometimes to ninety and more, though often limited to forty-eight in number, and the transverse floors between the vertical partitions are more complete than in the Fungidæ. The Porites have twelve tentacles only (Pl. XVI., Figs. 15 and 16), never more and never less, and in them the whole solid frame presents a complicated system of connected beams. The Madrepores have also twelve tentacles, but they have a more definite character than those of the Porites, on account of their regular alternation in six smaller and six larger ones (Pl. XVIII., Figs. 5, 6, and 7); in these also the transverse floors are perfect, but exceedingly delicate. Another remarkable feature among the Madrepores consists in the prominence of one of the Polyps on the summit of the branches (Pl. XIX., Fig. 7), showing a kind of subordination of the whole community to these larger individuals, and thus sustaining the view expressed above, that the combination of many individuals into a connected community is among the Polyps a character of superiority when contrasted with the isolation of the Actiniæ. In the Sea-Fans, the Halcyonoids, as they are called in our classification, the number of tentacles is always eight, four of which are already present at the time of their birth, arranged in pairs, while the other four are added later. Their tentacles are lobed all around the margin, and are much more complicated in structure than those of the preceding Polyps.

According to the relative complication of their structure, these animals are classified in the following order: —

STRUCTURAL SERIES.

HALCYONOIDS: eight tentacles in pairs, lobed around the margin, always combined in large communities, some of which are free and movable like single animals.

MADREPORES: twelve tentacles, alternating in six larger and six smaller ones; frequently a larger top animal standing prominent in the whole community, or on the summit of its branches.

PORITES: twelve tentacles, not alternating in size; system of connected beams.

ASTRÆANS: tentacles not definitely limited in number, though usually not exceeding one hundred, and generally much below this number; transverse floors. Mæandrinas, generally referred to Astræans, are higher than the true Astræans, on account of their compound Polyps.

FUNGIDÆ: indefinite multiplication of tentacles; imperfect transverse beams.

ACTINIÆ: indefinite multiplication of tentacles; soft bodies and no transverse beams.

If now we compare this structural gradation among Polyps with their geological succession, we shall find that they correspond exactly. The following table gives the geological order in which they have been introduced upon the surface of the earth:—

GEOLOGICAL SUCCESSION.

Present,	Halcyonoids.
Pliocene, Miocene, Eocene,	Madrepores.
Cretaceous, Jurassic, Triassic, Permian,	Porites and Astræans.
Carboniferous, Devonian, Silurian,	Fungidæ.

With regard to the geological position of the Actiniæ we can say nothing, because, if their soft, gelatinous bodies have left any impressions in the rocks, none such have ever been found; but their absence is no proof that they did not exist, since it is exceedingly improbable that animals destitute of any hard parts could be preserved. . . . .

PLATE I.

Fig. 1. Oculina varicosa Lesueur, natural size; variety with less prominent calicles.

Fig. 1a. Oculina varicosa Lesueur, natural size ; small branch with crowded calicles.

Fig. 2. Oculina varicosa Lesueur, magnified, with one polyp fully, and several partly, expanded.

Fig. 3. Oculina varicosa Lesueur, polyp expanded, magnified.

Fig. 4. Oculina varicosa Lesueur, polyp contracted.

Fig. 5. Oculina implicata Ag. ms., natural size. North Carolina.

Fig. 6. Oculina arbuscula Ag. ms., natural size. South Carolina.

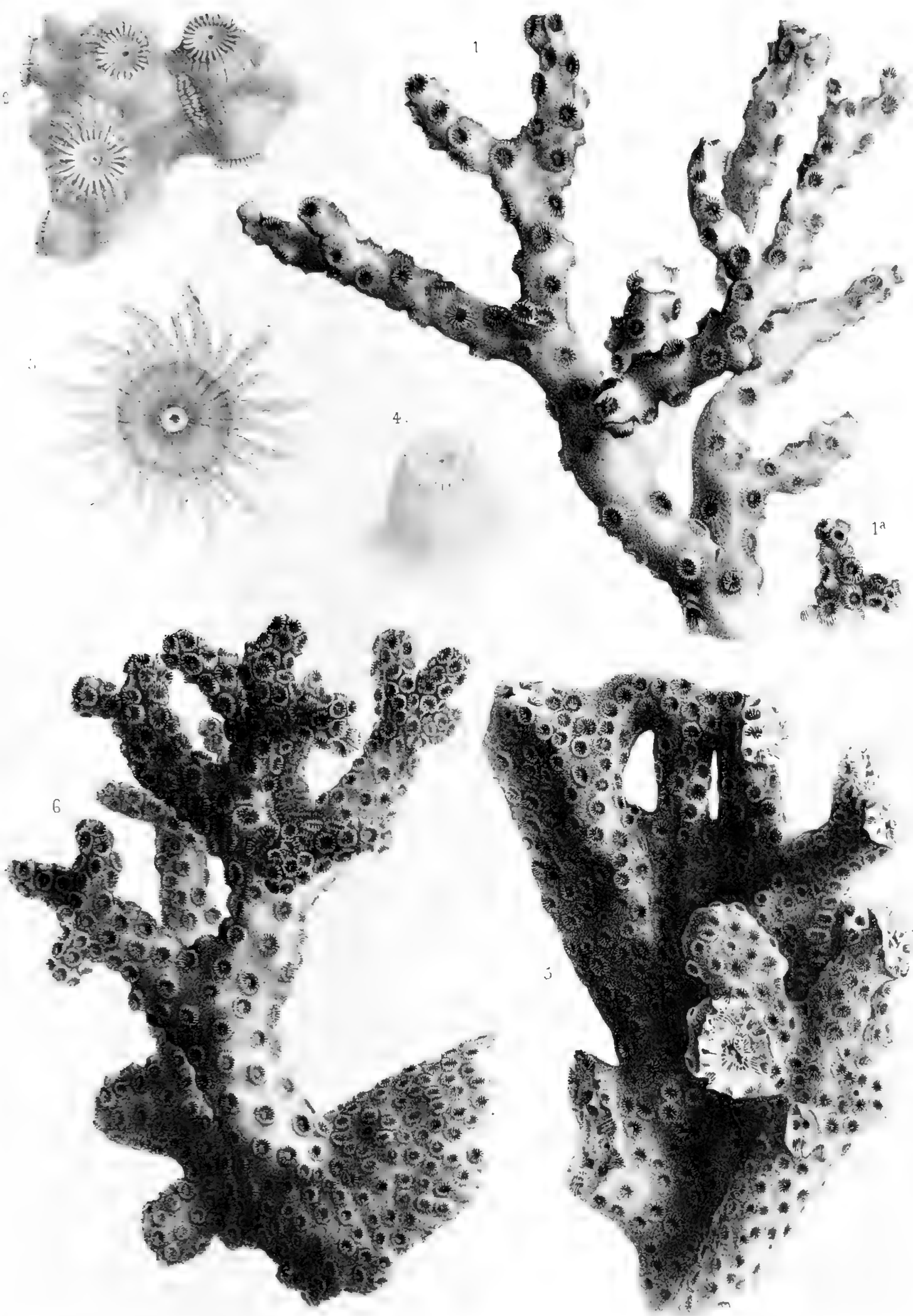
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PLATE II.

Fig. 1. Oculina robusta Pourtalès (Illust. Cat. Mus. Comp. Zoöl. No. IV.), natural size.

Fig. 2. Oculina robusta Pourtalès, calicle, magnified.

Fig. 3. Oculina varicosa var. Lesueur, natural size. Bermudas.

Fig. 4. Oculina varicosa Lesueur, calicle, magnified.

Fig. 5. Astrocœnia pectinata Pourtalès (Illust. Cat. Mus. Comp. Zoöl. No. IV.), natural size.

Fig. 6. Astrocœnia pectinata Pourtalès, calicles, magnified.

Fig. 7. Astrocœnia pectinata Pourtalès, section of calicle, magnified, showing columella and pectinated septa.

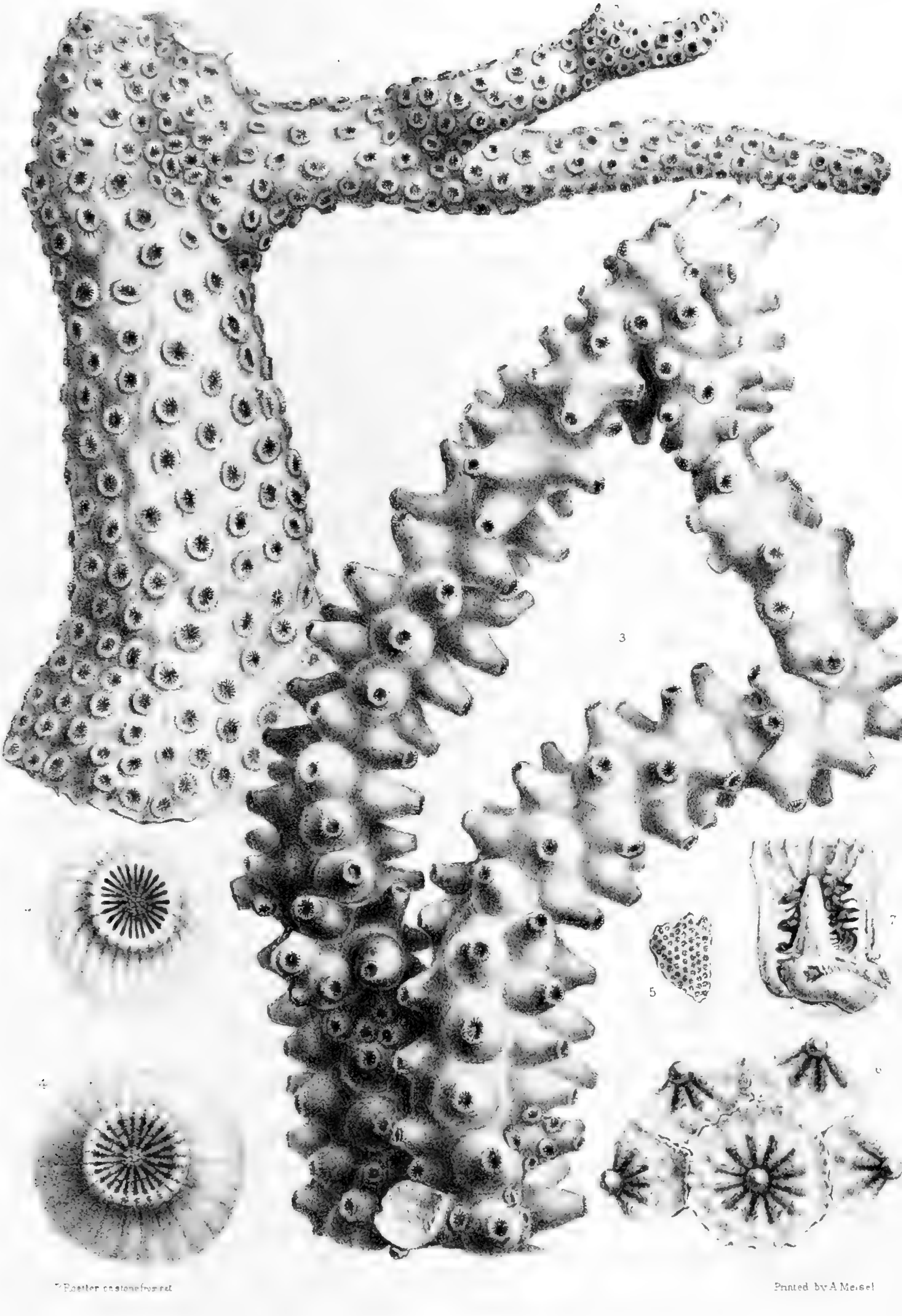

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PLATE III.

Fig. 1. Cladocora arbuscula Milne-Edw. and Haime, natural size.

Fig. 2. Cladocora arbuscula Milne-Edw. and Haime, with polyps expanded, natural size.

Fig. 3. Cladocora arbuscula Milne-Edw. and Haime, calicle, magnified.

Fig. 4. Cladocora arbuscula Milne-Edw. and Haime, calicle with buccal membrane dried, magnified.

Fig. 5. Cladocora arbuscula Milne-Edw. and Haime, vertical and horizontal sections of branches, showing dissepiments, magnified.

Fig. 6. Cladocora arbuscula Milne-Edw. and Haime, polyp expanded, magnified.

Fig. 7. Cladocora arbuscula Milne-Edw. and Haime, young calicle, magnified.

Fig. 8. Oculina varicosa Lesueur, calicle, magnified.

Fig. 9. Oculina varicosa Lesueur, section of calicle, magnified.

Fig. 10. Oculina diffusa Lamarck, calicle, magnified.

Fig. 11 and 12. Oculina diffusa Lamarck, groups of calicles, slightly magnified.

Fig. 13. Oculina diffusa Lamarck, transverse section of branch through calicles, magnified.

Fig. 14 and 15. Oculina pallens Ehr., calicle, magnified.

Fig. 16. Oculina pallens Ehr., transverse section of branch, magnified.

Fig. 17. Oculina pallens Ehr., longitudinal section of branch, showing also transverse section of three calicles.

Fig. 18 and 19. Stylaster sanguineus Val., front and side views, natural size. (The researches of Moseley have shown the Stylasteridæ to be Hydroids. They were drawn on the same plate with Oculinidæ on account of their supposed relations to that family, according to Milne-Edw. and Haime.

Fig. 20. Stylaster sanguineus Val., side view of branch, magnified, showing calicles in a row on the side. The front of the branch, seen in profile, is smooth. The back, on the left, shows the ampullæ containing the gonophores.

Fig. 21. Stylaster sanguineus Val., Ampullæ containing the gonophores, magnified.

Fig. 22. Stylaster sanguineus Val., vertical section of calicle and part of a horizontal section below, magnified. The small holes surrounding the central opening in the lower section ought also to be shown in the intervals between the pseudo septa in the vertical section. The style ought to be represented somewhat hirsute.

Fig. 23. Stylaster sanguineus Val., rear surface of branch, magnified.

Fig. 24. Stylaster sanguineus Val., calicle, magnified.

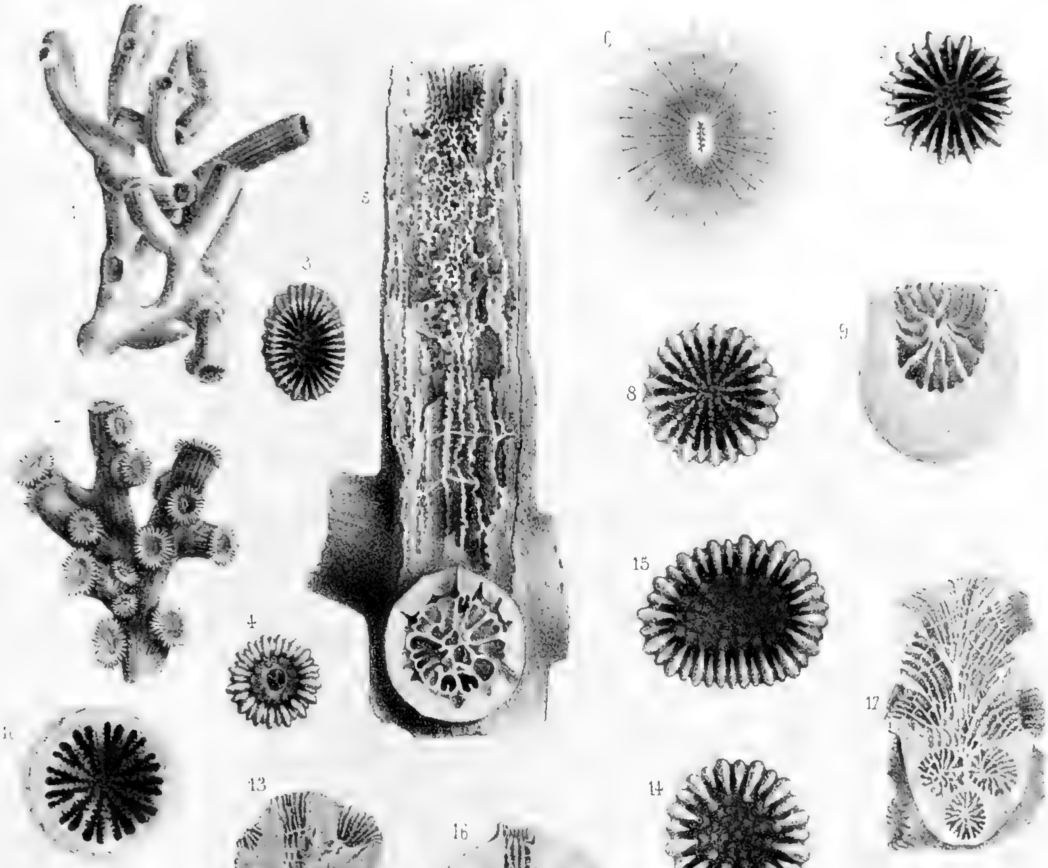

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PLATE IV.

Fig. 1. Orbicella annularis Dana, a small head, natural size.

Fig. 2. Orbicella annularis Dana, a group of calicles, magnified, showing the process of multiplication by gemmation (small calicle in the middle), and by division in the large double calicle below.

Fig. 3. Orbicella annularis Dana, a calicle, more magnified.

Figs. 4, 6. Orbicella annularis Dana, calicles, in profile, magnified.

Fig. 5. Orbicella annularis Dana, calicles from above, magnified.

Fig. 7. Orbicella annularis Dana, group of polyps, contracted, natural size.

Fig. 8. Orbicella annularis Dana, part of group figured in fig. 7, magnified; the mouth-disc and the tentacles are concealed by the contraction of the outer sphincter.

Fig. 9. Orbicella annularis Dana, a polyp expanded, magnified.

Fig. 10. Orbicella annularis Dana, polyp expanded, seen from above.

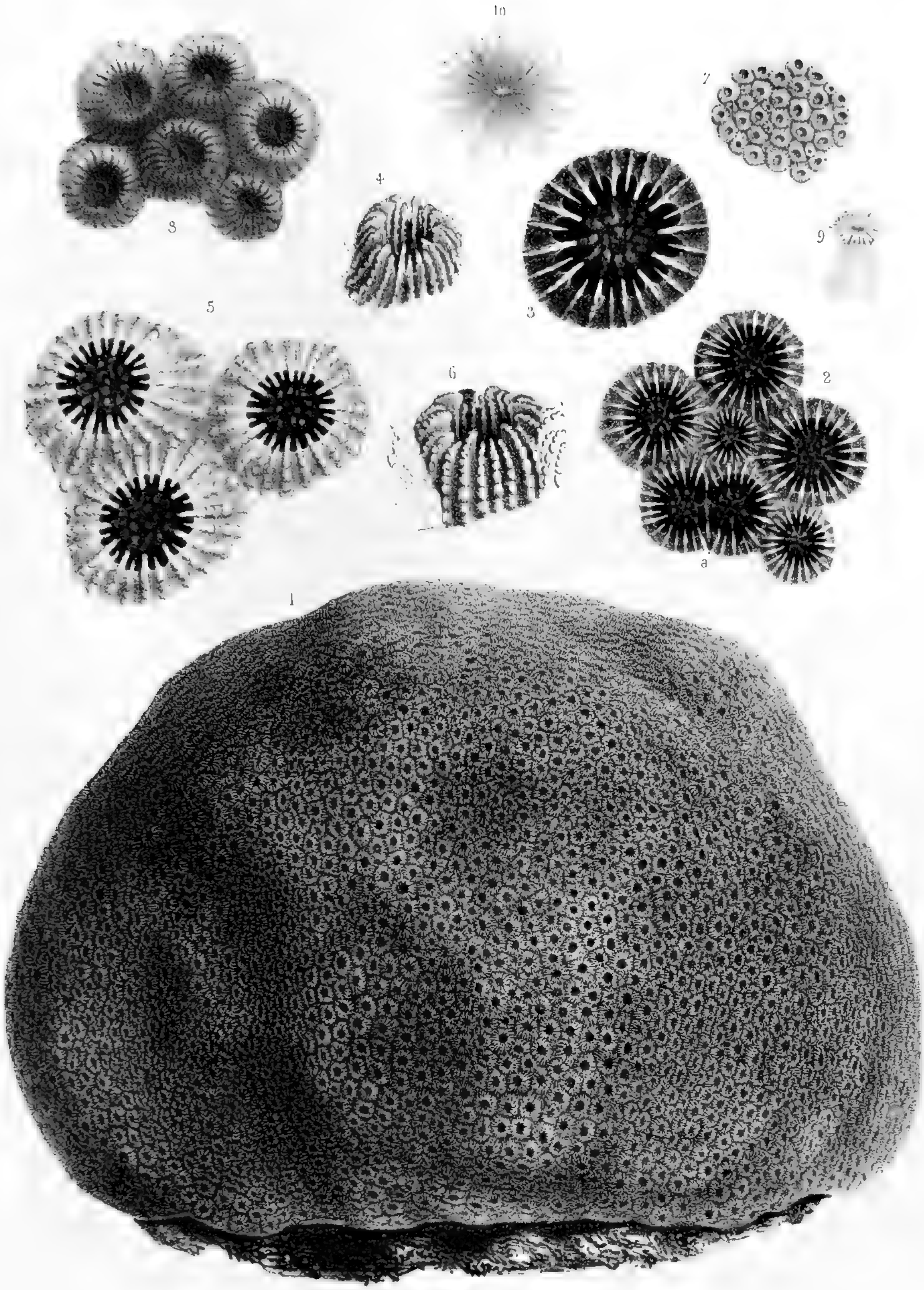
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PLATE V.

Figs. 1–11. Manicina areolata Ehr., series of young specimens in various stages of development, but still in the simple state, natural size and magnified.

Figs. 12–15. Manicina areolata Ehr., young specimens further advanced, showing process of division, natural size and magnified.

Figs. 16, 17. Manicina areolata Ehr., young specimen still attached, natural size.

Fig. 18. Manicina areolata Ehr., specimen more advanced.

Fig. 19. Manicina areolata Ehr., living specimen with tentacles expanded in upper part, retracted in the rest. The mouths are represented in various stages of expansion.

Fig. 20. Manicina areolata Ehr., lasso-cell with the thread partly projected and partly coiled up inside.

Fig. 21. Manicina areolata Ehr., lasso-cell with the thread fully projected.

Fig. 22. Manicina areolata Ehr., lasso-cell with the thread entirely coiled inside.

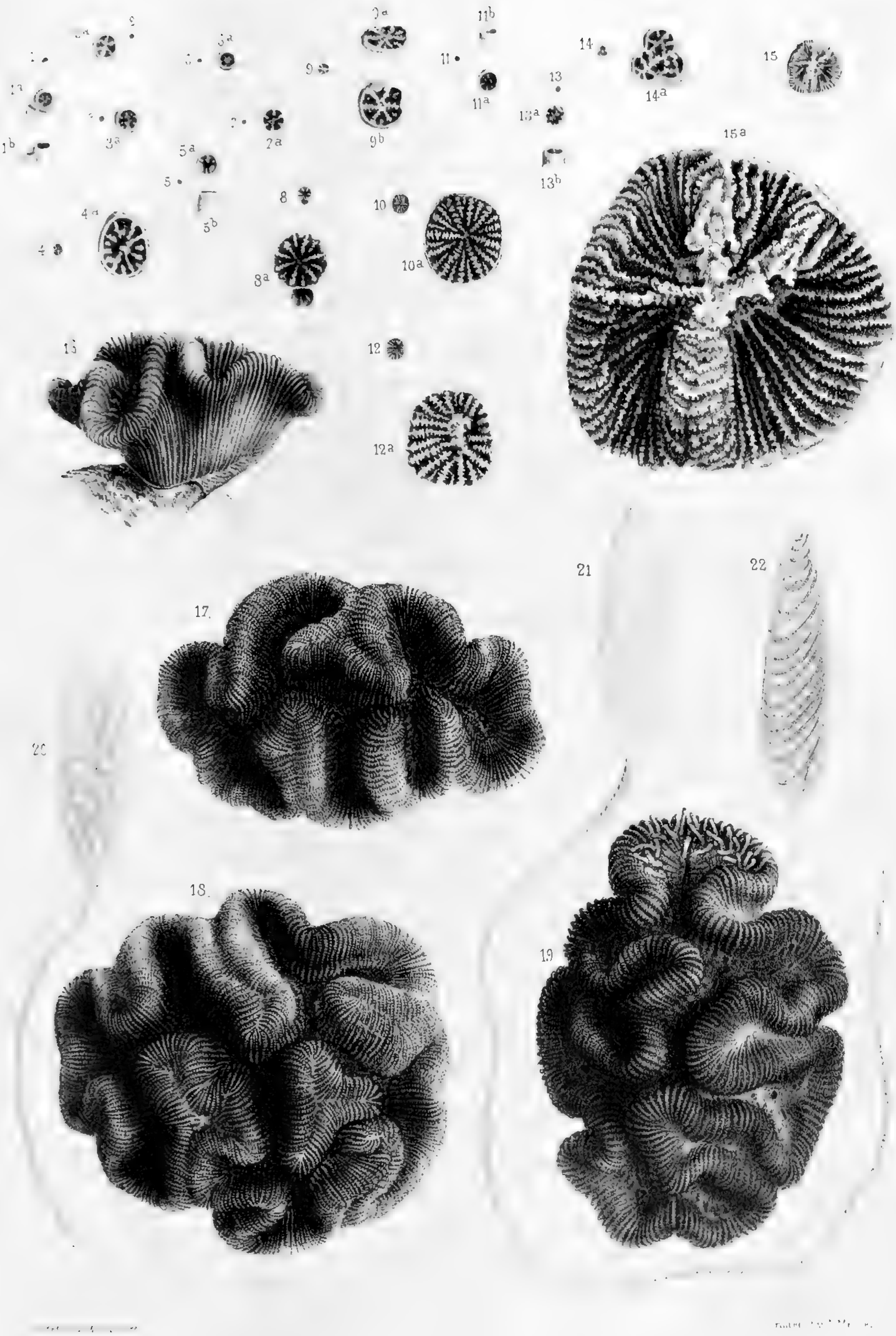

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PLATE VI.

Fig. 1. Manicina areolata Ehr., vertical section.

Fig. 2. Manicina areolata Ehr., specimen in which some of the ridges have been broken away.

Figs. 3, 5, 7. Manicina areolata Ehr., showing different modes of growth.

Fig. 4. Manicina areolata Ehr., diagram of septa seen from above.

Fig. 6. Manicina areolata Ehr., diagram showing denticulation of the septa.

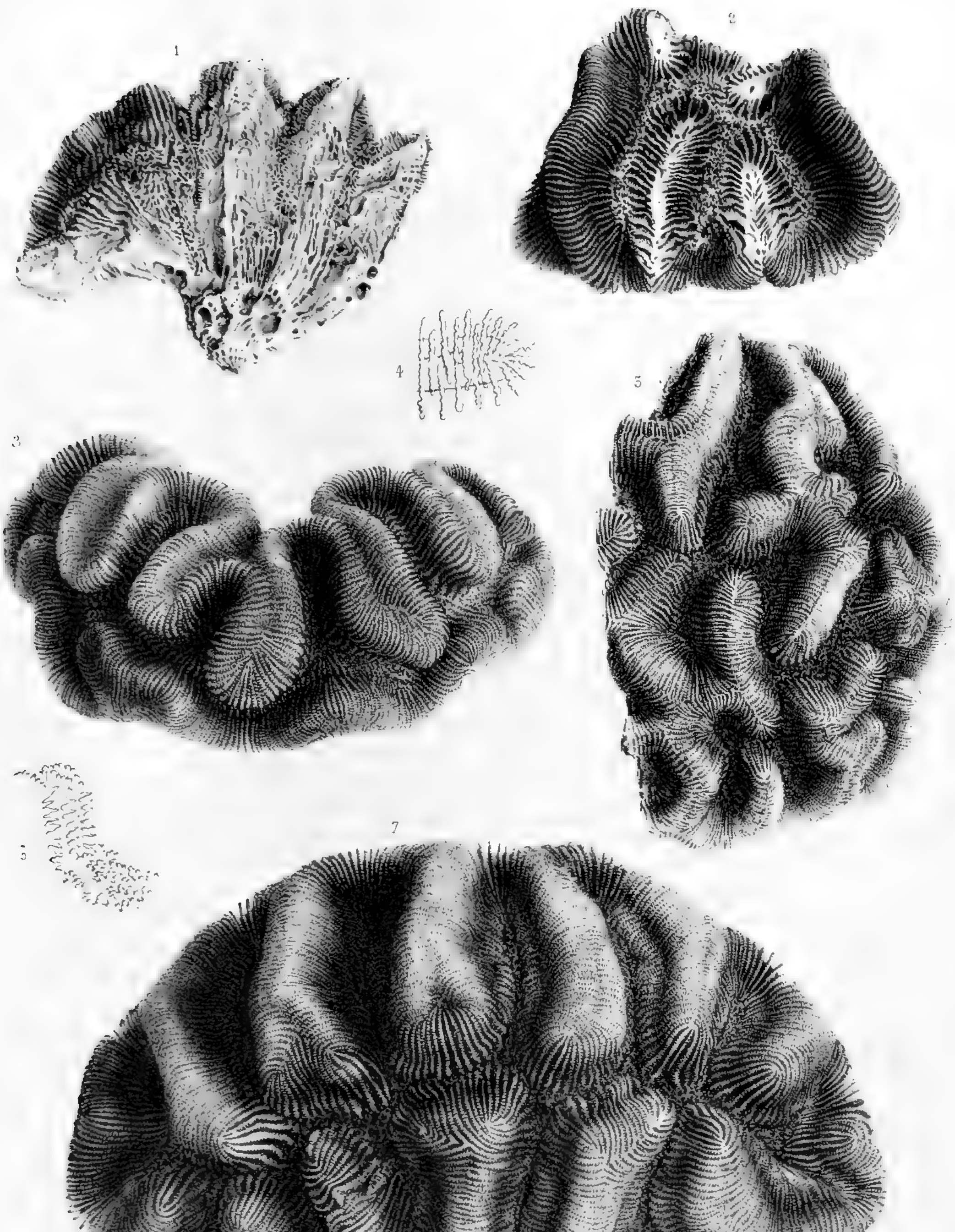

PLATE VII.

Figs. 1–7. Isophyllia dipsacea Ag., at various ages.
Fig. 8. Isophyllia dipsacea Ag., vertical section.

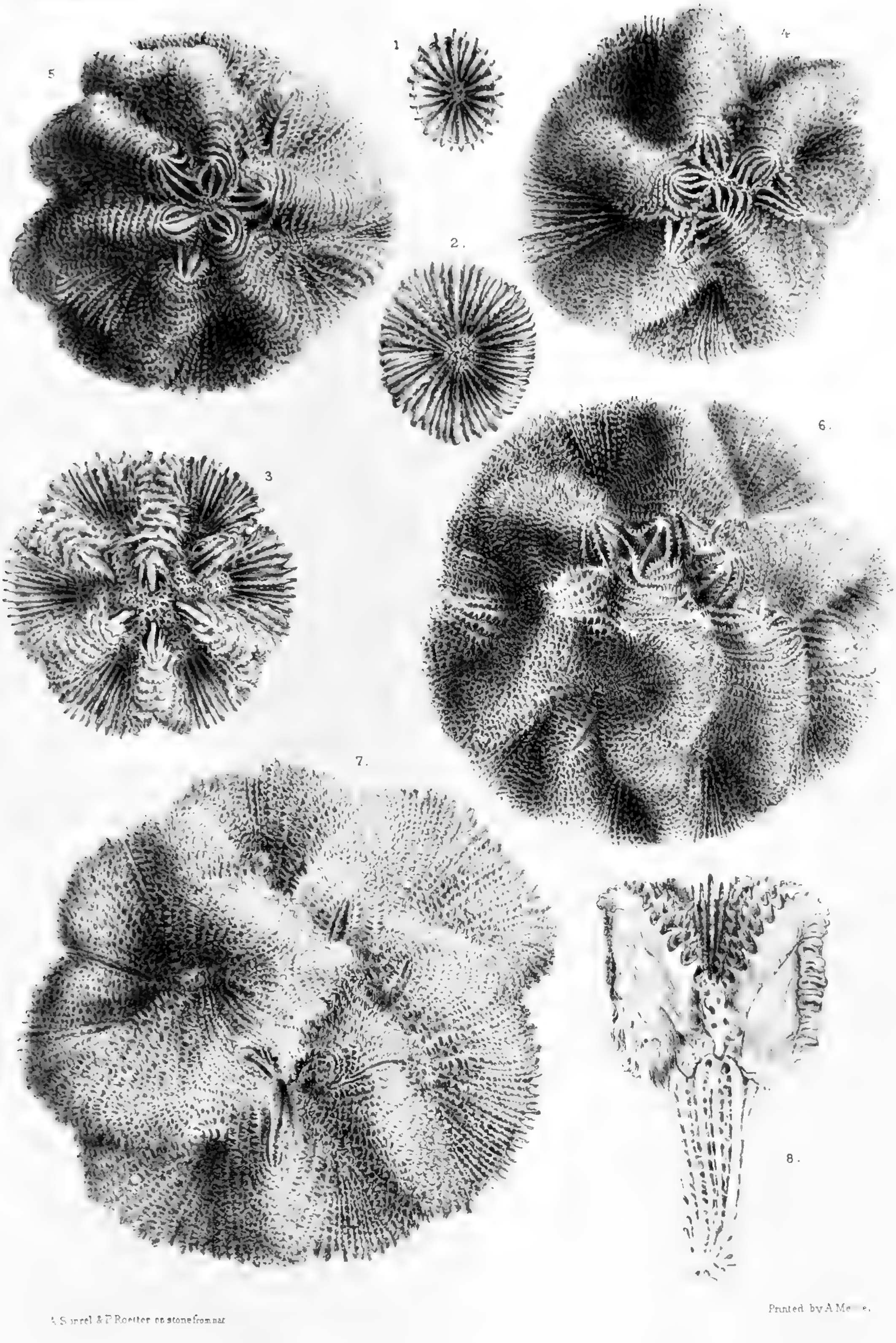

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PLATE VIII.

Fig. 1. Colpophyllia gyrosa Milne-Edw. and Haime, horizontal section, natural size.

Fig. 2. Colpophyllia gyrosa Milne-Edw. and Haime, part of a waterworn specimen showing the double wall separating the sinuses.

Figs. 3–5. Colpophyllia gyrosa Milne-Edw. and Haime, vertical sections.

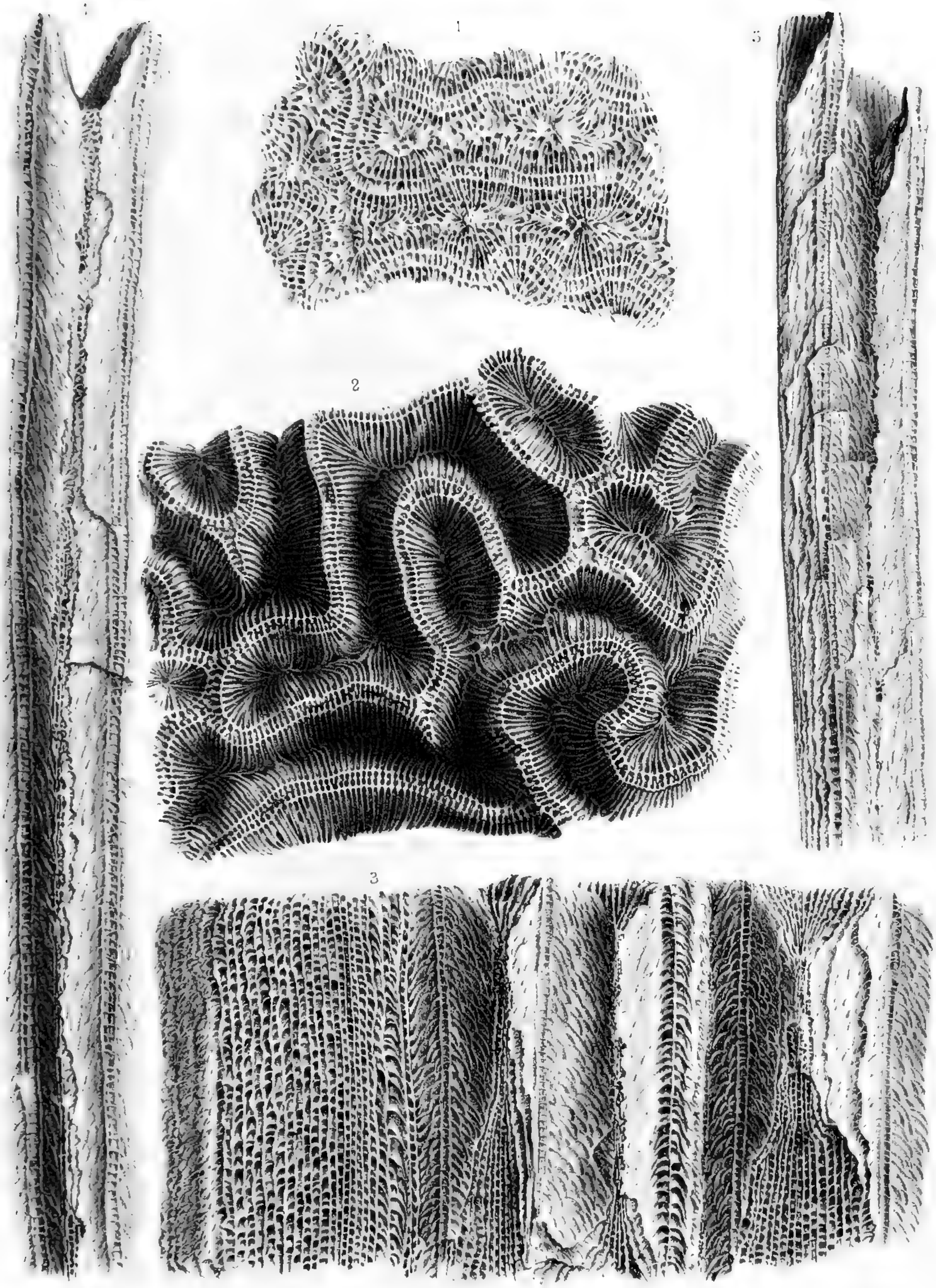

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PLATE IX.

Fig. 1. Mæandrina clivosa Verrill, reduced one half.

Fig. 2. Mæandrina clivosa Verrill, details slightly magnified.

Fig. 3. Mæandrina clivosa Verrill, septa, magnified.

Fig. 4. Mæandrina clivosa Verrill, section through the ridge, magnified.

Fig. 5. Mæandrina clivosa Verrill, polyps expanded.

Figs. 6, 7. Mæandrina strigosa Dana, portions magnified, seen in profile and from above.

Fig. 8. Mæandrina strigosa Dana, septa, magnified.

Fig. 9. Mæandrina strigosa Dana, section through ridge, magnified.

Figs. 10, 11. Mæandrina labyrinthiformis Oken, portions magnified, seen in profile and from above.

Fig. 12. Mæandrina labyrinthiformis Oken, section through ridge, magnified.

Fig. 13. Colpophyllia gyrosa Milne-Edw. and Haime, portion with polyps partly expanded, natural size.

Fig. 14. Colpophyllia gyrosa Milne-Edw. and Haime, polyp, magnified.

Fig. 15. Colpophyllia gyrosa Milne-Edw. and Haime, a polyp before division, magnified.

Fig. 16. Colpophyllia gyrosa Milne-Edw. and Haime, tentacles, magnified.

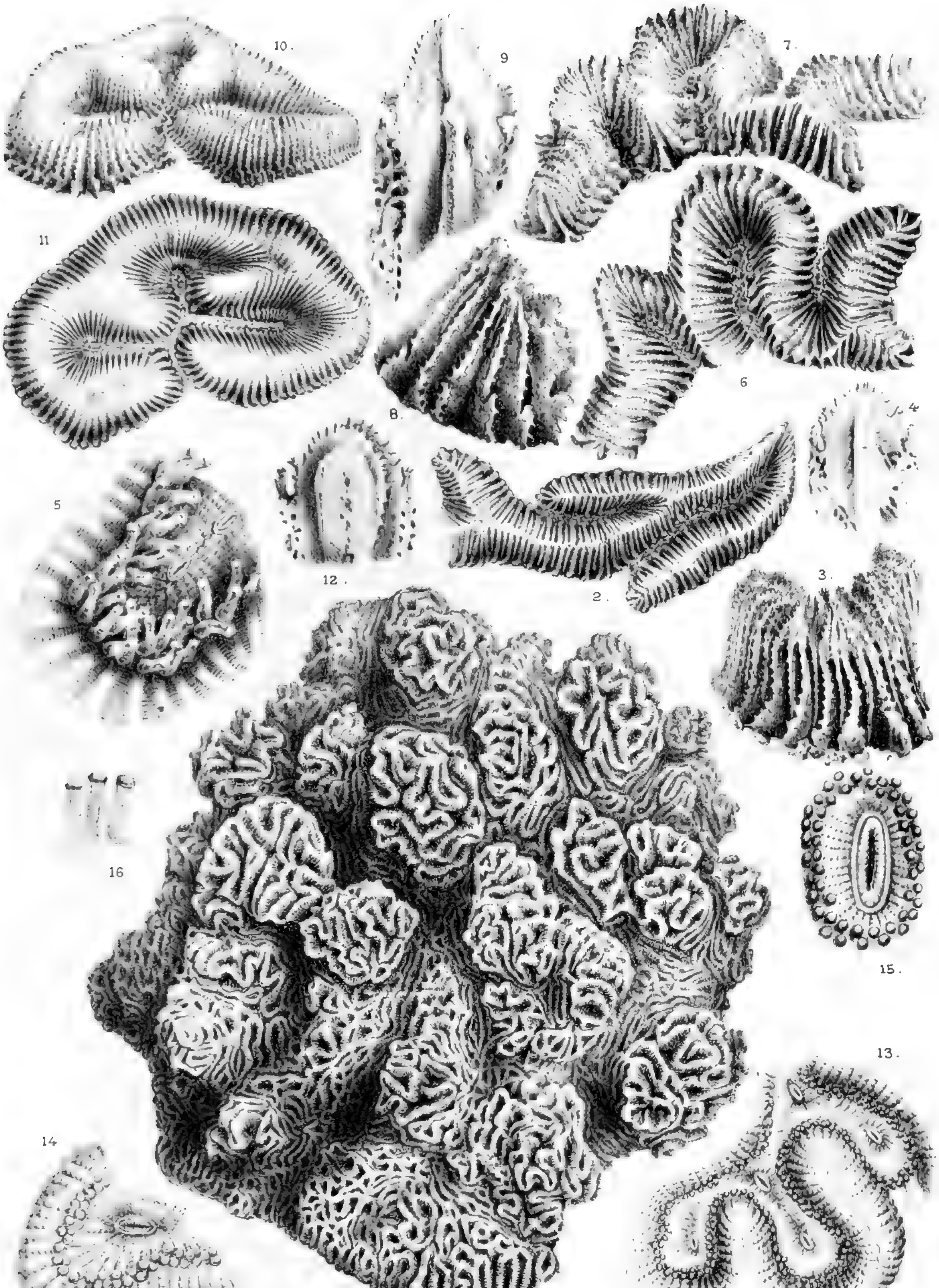

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PLATE X.

Fig. 1. Dichocœnia porcata Milne-Edw. and Haime, variety from Nassau, Bahamas, reduced four fifths.

Fig. 2. Dichocœnia porcata Milne-Edw. and Haime, portion magnified.

Fig. 3. Dichocœnia porcata Milne-Edw. and Haime, profile view of a septum of same specimen, with paliform lobe, magnified.

Figs. 4, 5. Dichocœnia porcata Milne-Edw. and Haime, parts of another specimen, magnified.

Fig. 6. Dichocœnia porcata Milne-Edw. and Haime, profile view of septum of preceding specimen, magnified.

Fig. 7. Dichocœnia porcata Milne-Edw. and Haime, two primary septa and intermediate secondary seen from above, magnified.

Fig. 8. Dichocœnia porcata Milne-Edw. and Haime, horizontal section through two calicles, showing solid filling up of outer part of chambers.

Fig. 9. Dichocœnia porcata Milne-Edw. and Haime, vertical section through a calicle showing dissepiments.

Fig. 10. Dichocœnia porcata Milne-Edw. and Haime, part of another specimen with more pointed septa, magnified.

Fig. 11. Dichocœnia porcata Milne-Edw. and Haime, septum of preceding specimen in profile, magnified.

Fig. 12. Dichocœnia porcata Milne-Edw. and Haime, part of specimen from Cumana with crowded and prominent calicles, magnified.

Fig. 13. Dichocœnia porcata Milne-Edw. and Haime, septum of preceding specimen in profile, magnified.

Fig. 14. Dichocœnia porcata Milne-Edw. and Haime, part of a specimen from Nassau, with coarsely granulated cœnenchyma, magnified.

Fig. 15. Dichocœnia porcata Milne-Edw. and Haime, septum of preceding specimen in profile, magnified.

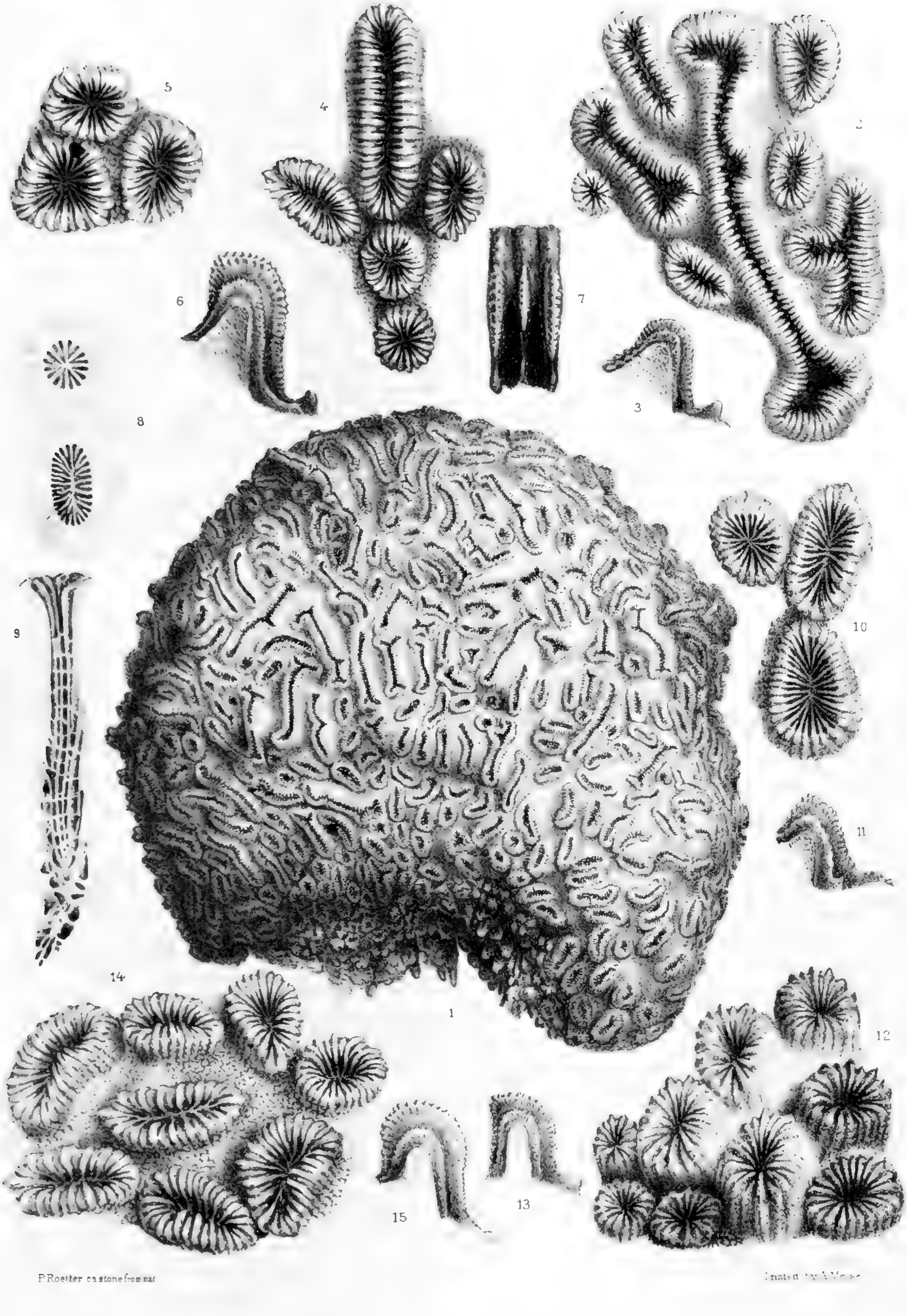

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PLATE XI.

Figs. 1–7. Mycedium fragile Dana, young specimens still simple.

Fig. 8. Mycedium fragile Dana, young specimens with first circle of buds surrounding the central calicle.

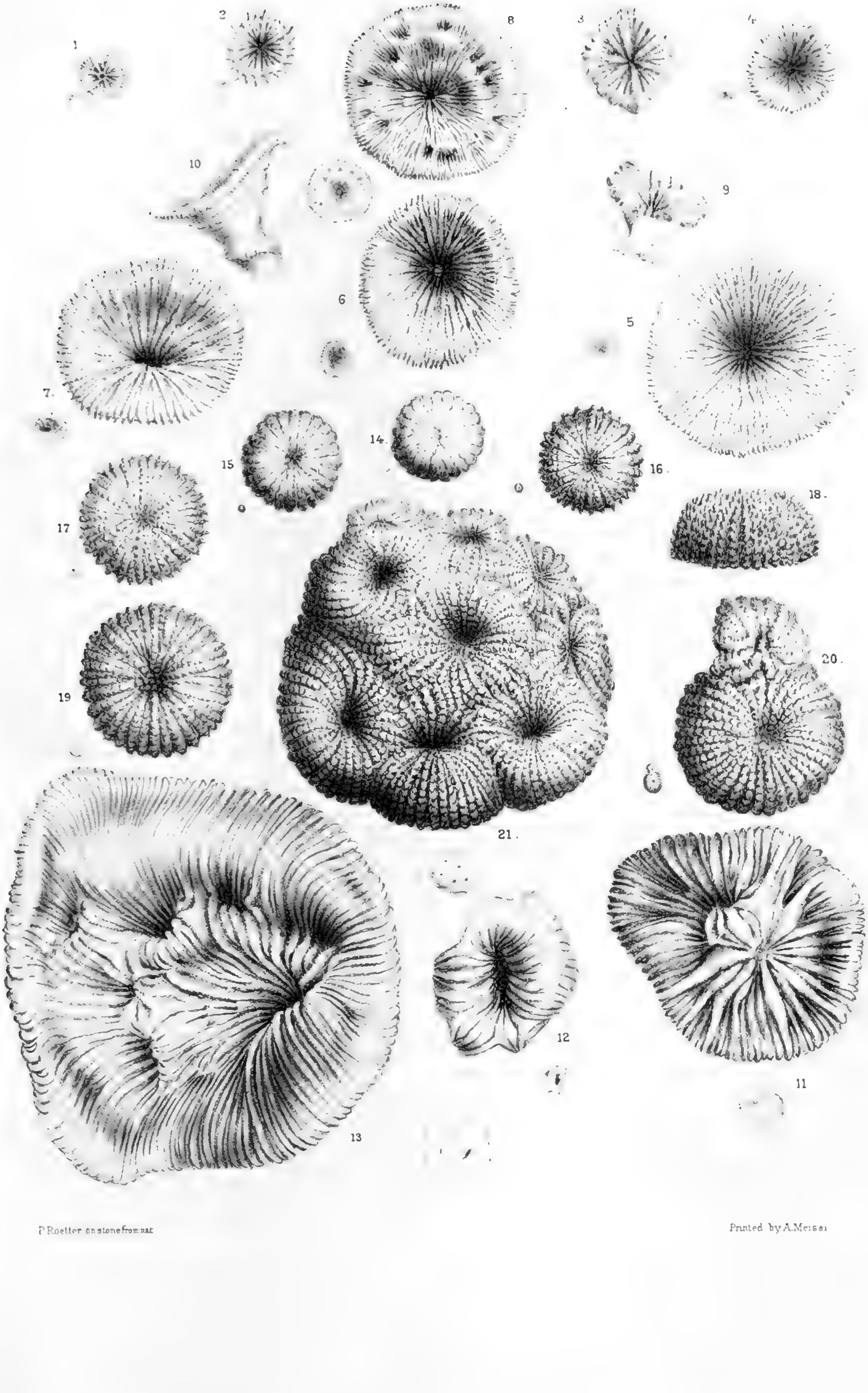
Figs. 9, 10. Mycedium fragile Dana, young specimens in profile, figured from above in 3 and 7.

Figs. 11, 12, 13. Agaricia agaricites Milne-Edw. and Haime, young specimens.

Figs. 14 – 19. Siderastræa galaxea Milne-Edw. and Haime, young specimens still in the simple state.

Figs. 20, 21. Siderastræa galaxea Milne-Edw. and Haime, young specimens multiplying by gemmation.

All the figures are magnified, the natural size being indicated by the small figures.



P. Roetter on stone from nat.

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PLATE XII.

Fig. 1. Agaricia agaricites Milne-Edw. and Haime, natural size.

Fig. 2. Agaricia agaricites Milne-Edw. and Haime, two calicles, magnified.

Fig. 3. Parasitic cirrhiped covered with coral growth, magnified. Three of them are seen in natural size in fig. 1.

Fig. 4. Porites clavaria Lamarck, natural size.

Fig. 5. Porites clavaria Lamarck, three calicles, magnified.

Fig. 6. Porites clavaria Lamarck, section through branch, magnified.

Fig. 7. Porites furcata Lamarck, natural size.

Fig. 8. Astrangia solitaria Verrill, natural size, branching variety.

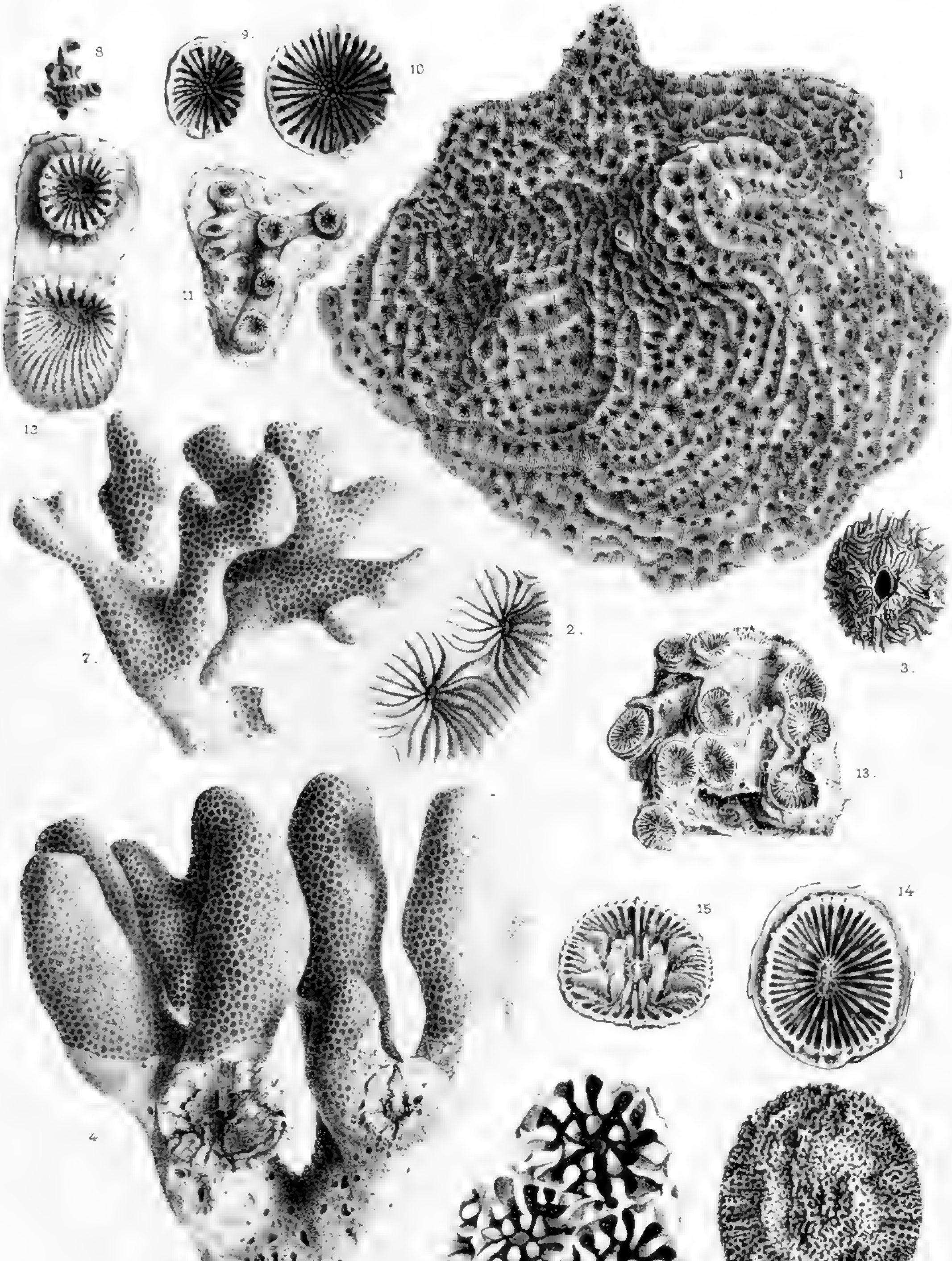
Figs. 9, 10. Astrangia solitaria Verrill, calicles magnified.

Fig. 11. Astrangia solitaria Verrill, spreading variety, natural size.

Fig. 12. Astrangia solitaria Verrill, part of stolon with two calicles, magnified.

Fig. 13. Colangia immersa Pourtalès, natural size (Illust. Cat. Mus. Comp. Zoöl. No. IV.).

Figs. 14, 15. Colangia immersa Pourtalès, calicle magnified in profile and from above.



& I. Roetter on stone from

PLATE XIII.

Figs. 1, 2. Mycedium fragile Dana, natural size.

Fig. 3. Mycedium fragile Dana, simple calicle, magnified.

Fig. 4. Mycedium fragile Dana, calicle in process of division, magnified.

Fig. 5. Mycedium fragile Dana, cross-section of corallum, showing septal ridges (upper surface) on the left, costal ridges, lower surface on the right, magnified.

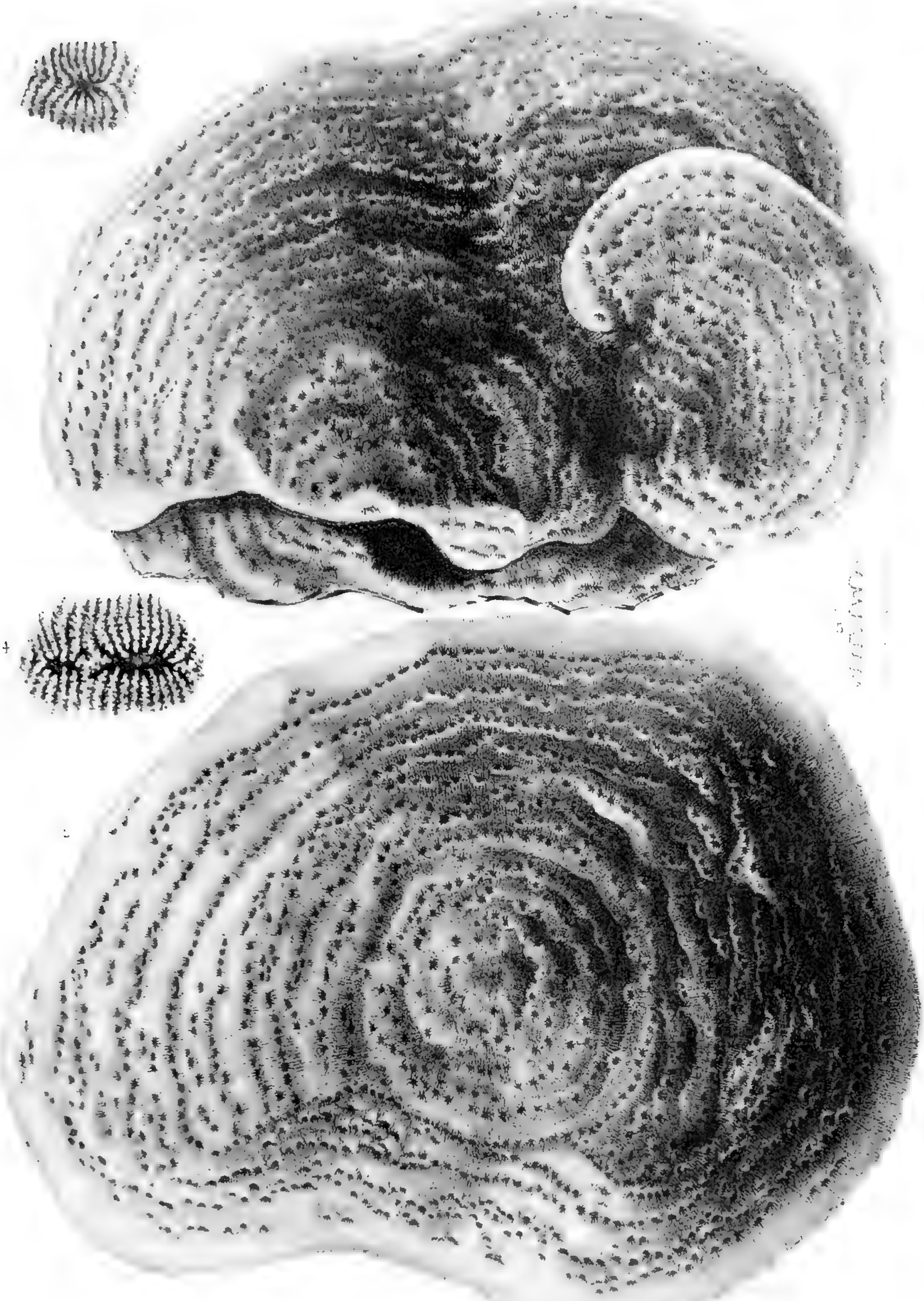


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PLATE XIV.

Fig. 1. Mycedium fragile Dana, in profile, showing lower surface destitute of polyps, natural size.
Fig. 2. Mycedium fragile Dana, portion of lower surface, magnified, showing the costal striæ.
Fig. 3. Mycedium fragile Dana, diagram of vertical section through the corallum, natural size.
Fig. 4. Mycedium fragile Dana, central calicle and surrounding ones, magnified.
Fig. 5. Mycedium fragile Dana, part of lower surface, natural size.
Fig. 6. Mycedium fragile Dana, specimen broken through the centre.
Fig. 7. Mycedium fragile Dana, section near the edge, slightly magnified.
Fig. 8. Mycedium fragile Dana, portion of large specimen, natural size.
Fig. 9. Mycedium fragile Dana, portion of the edge and neighboring calicles, magnified.

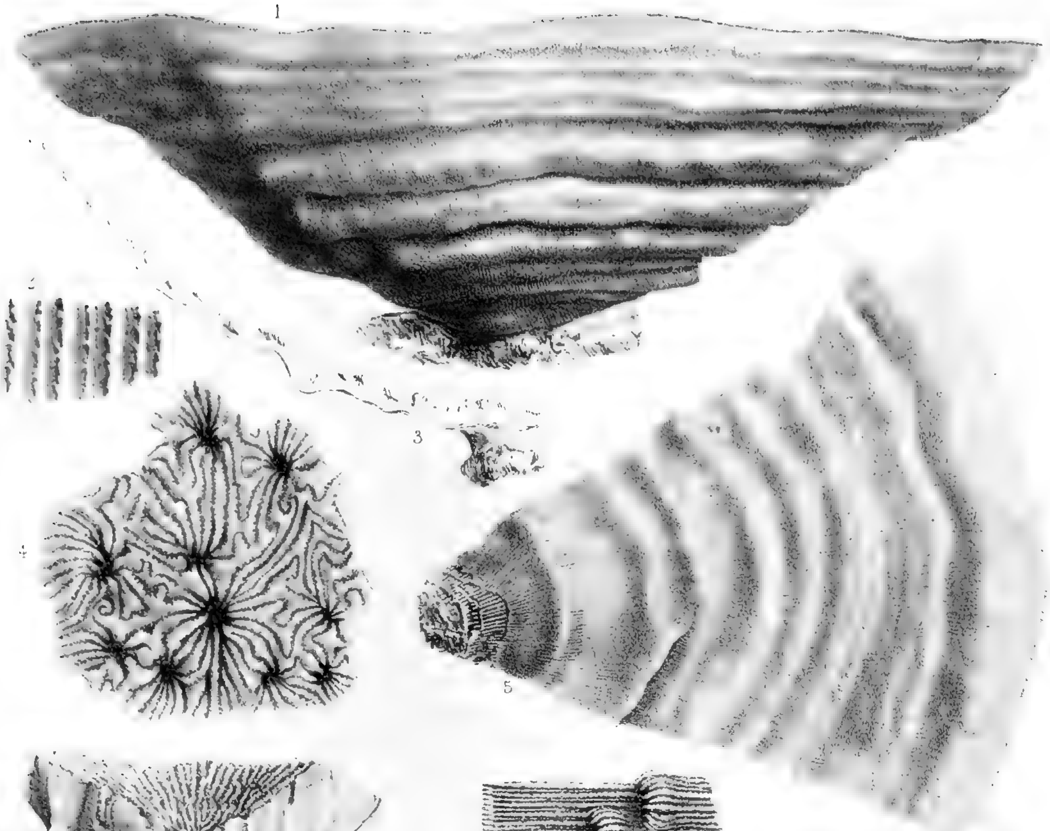

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PLATE XV.

Fig. 1. Siderastræa galaxea Blainv., specimen with polyps half expanded, natural size.

Fig. 2. Siderastræa galaxea Blainv., part of specimen fully expanded, natural size.

Fig. 3. Siderastræa galaxea Blainv., a polyp contracted, magnified.

Fig. 4. Siderastræa galaxea Blainv., polyp partly contracted, in profile, magnified.

Fig. 5. Siderastræa galaxea Blainv., part of disc contracted, magnified.

Figs. 6, 7. Siderastræa galaxea Blainv., polyps fully expanded, showing the peculiar bilobate tentacles. No note was found accompanying the figures to explain the difference in size of the tentacles in the two figures; possibly No. 7 represents Siderastræa galaxea, and No. 6, Siderastræa siderea.

Fig. 8. Siderastræa galaxea Blainv., specimen divested of animal matter, natural size.

Fig. 9. Siderastræa galaxea Blainv., groups of calicles, magnified, multiplying by gemmation.

Fig. 10. Siderastræa galaxea Blainv., large calicle in process of division.

Fig. 11. Siderastræa galaxea Blainv., vertical section, showing the synapticula and dissepiments, magnified.

Fig. 12. Siderastræa galaxea Blainv., horizontal section, showing the synapticula extending across the interseptal chambers as in Fungidæ (see figs. 15 and 17). The following figures of Fungia integra Dana, from the Pacific Ocean, were given on this plate to show by direct comparison the Fungian character of siderastræa.

Fig. 13. Fungia integra Dana, part of a specimen, natural size.

Fig. 14. Fungia integra Dana, vertical section, showing synapticula, natural size.

Fig. 15. Fungia integra Dana, horizontal section, showing synapticula extending across the chambers. (Compare with fig. 12.)

Fig. 16. Fungia integra Dana, section through centre, natural size. (Compare with fig. 11.)

Fig. 17. Fungia integra Dana, part of fig. 15, magnified.

Fig. 18. Fungia integra Dana, outline of part of specimen, natural size.

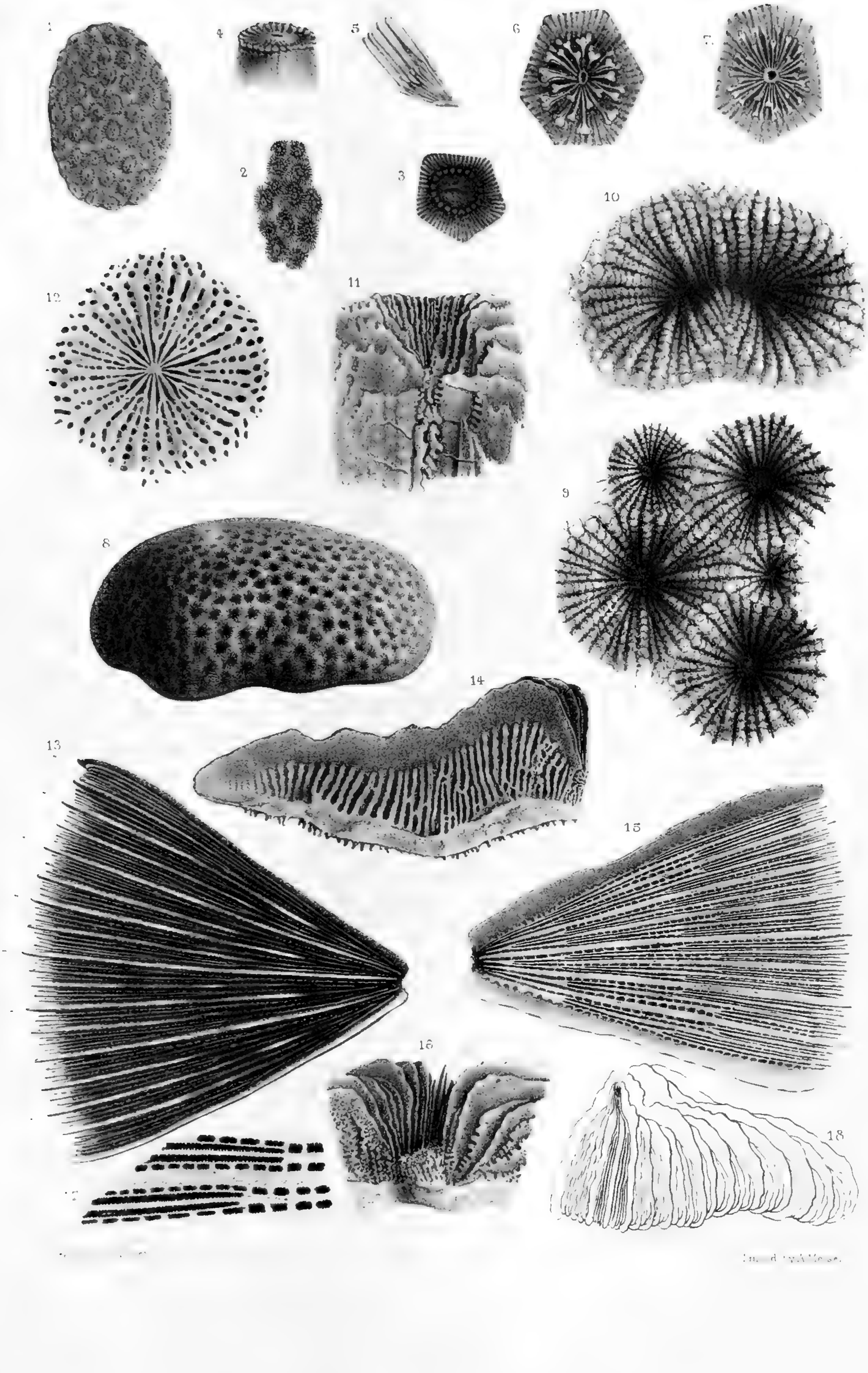
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PLATE XVI.

Fig. 1. Porites astræoides Lamarck, natural size.

Fig. 2. Porites astræoides Lamarck, portion of living specimen with polyps contracted.

Fig. 3. Porites astræoides Lamarck, portion of fig. 1, magnified.

Fig. 4. Porites astræoides Lamarck, calicles more highly magnified.

Fig. 5. Porites astræoides Lamarck, horizontal section through a calicle, magnified.

Fig. 6. Porites astræoides Lamarck, polyp with tentacles contracted, slightly magnified.

Fig. 7. Porites astræoides Lamarck, polyp giving passage to a planula through the mouth.

Fig. 8. Porites astræoides Lamarck, polyp of fig. 7, more highly magnified with mouth wide open for the passage of the planula.

Fig. 9. Porites astræoides Lamarck, fig. 6, more highly magnified.

Fig. 10. Porites astræoides Lamarck, planula magnified.

Fig. 11. Porites astræoides Lamarck, part of the planula more highly magnified, showing the vibratory cilia.

Fig. 12. Porites astræoides Lamarck, young polyp seen from above, magnified.

Fig. 13. Porites furcata Lamarck, living branch with polyps fully expanded; natural size.

Fig. 14. Porites furcata Lamarck, three calicles divested of animal matter, magnified.

Figs. 15, 16. Porites furcata Lamarck, polyps fully expanded, seen from the side and from above, magnified.

Figs. 17–20. Porites furcata Lamarck, lasso-cells in various stages of expansion.

Figs. 21, 22. Porites astræoides Lamarck, vertical sections through calicles, magnified.

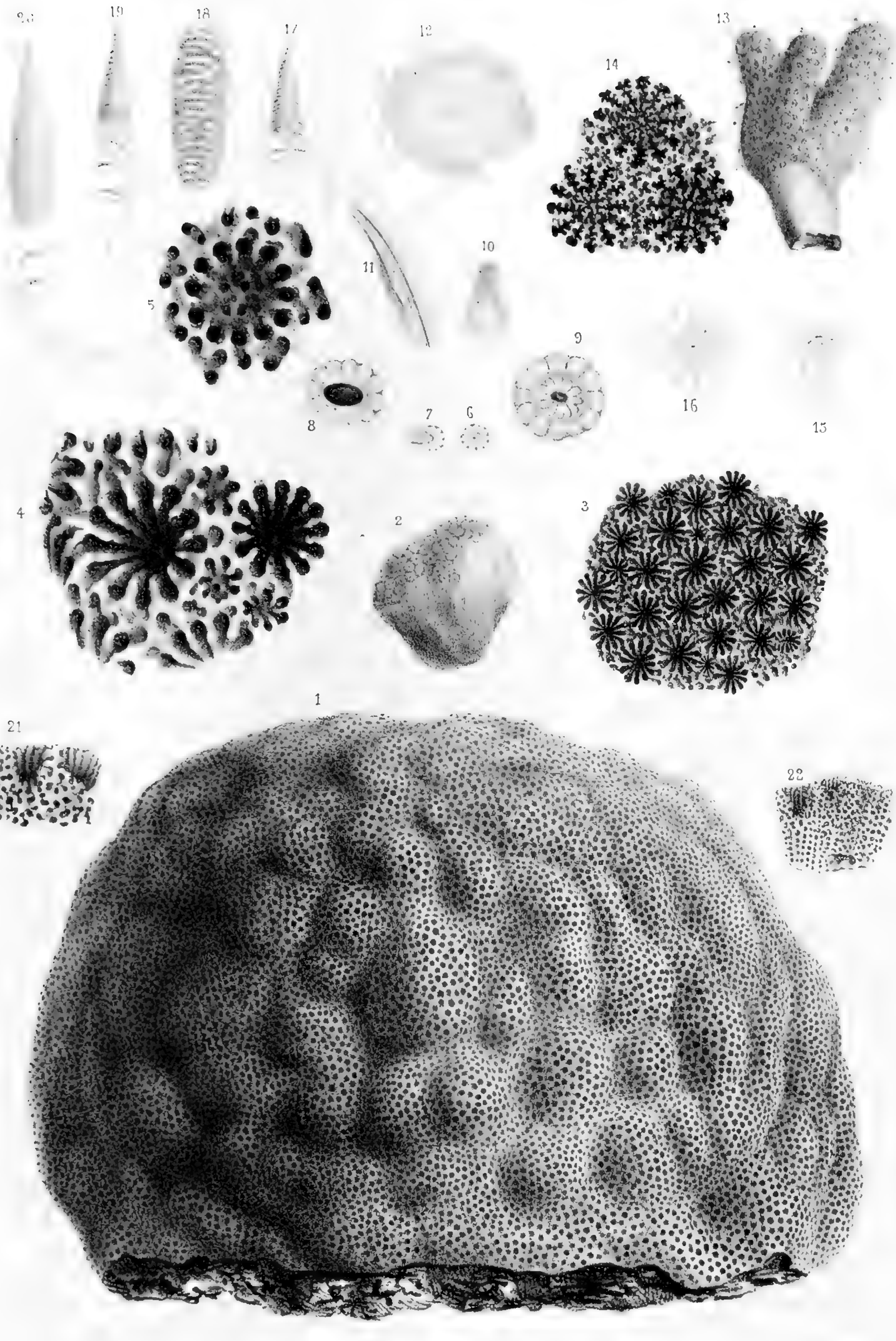

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PLATE XVII.

Fig. 1. Madrepora palmata Lamarck, small specimen, natural size.

Fig. 2. Madrepora palmata Lamarck, part of specimen magnified to show the differently shaped calicles.

Fig. 3. Madrepora palmata Lamarck, part of end of branch showing a terminal calicle, magnified.

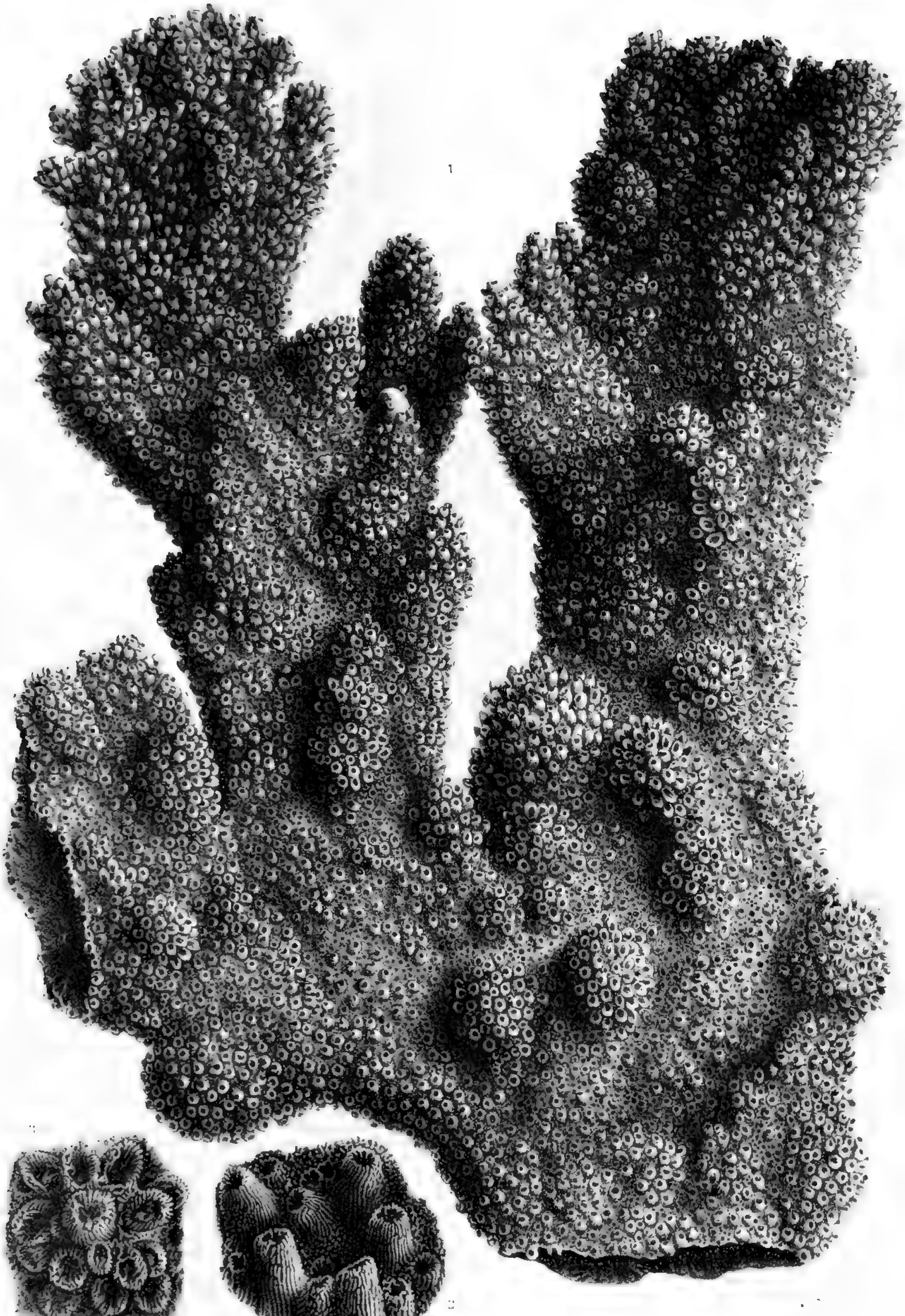

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PLATE XVIII.

Fig. 1. *Madrepora cervicornis* Lamarck, part of branch.

Fig. 2. *Madrepora cervicornis* Lamarck, section through branch near the tip, showing the terminal calicle in the centre.

Fig. 3. *Madrepora cervicornis* Lamarck, terminal calicle, magnified.

Fig. 4. *Madrepora cervicornis* Lamarck, terminal calicle from above, with surrounding lateral ones.

Fig. 5. *Madrepora cervicornis* Lamarck, outline of terminal polyp expanded, magnified.

Figs. 6, 7. *Madrepora cervicornis* Lamarck, outlines of expanded lateral polyps near the tip, magnified.

Fig. 8. *Madrepora cervicornis* Lamarck, base of a colony showing spreading mode of growth over a foreign body, with branches beginning to shoot up.

Fig. 9. *Madrepora cervicornis* Lamarck, calicles, magnified.

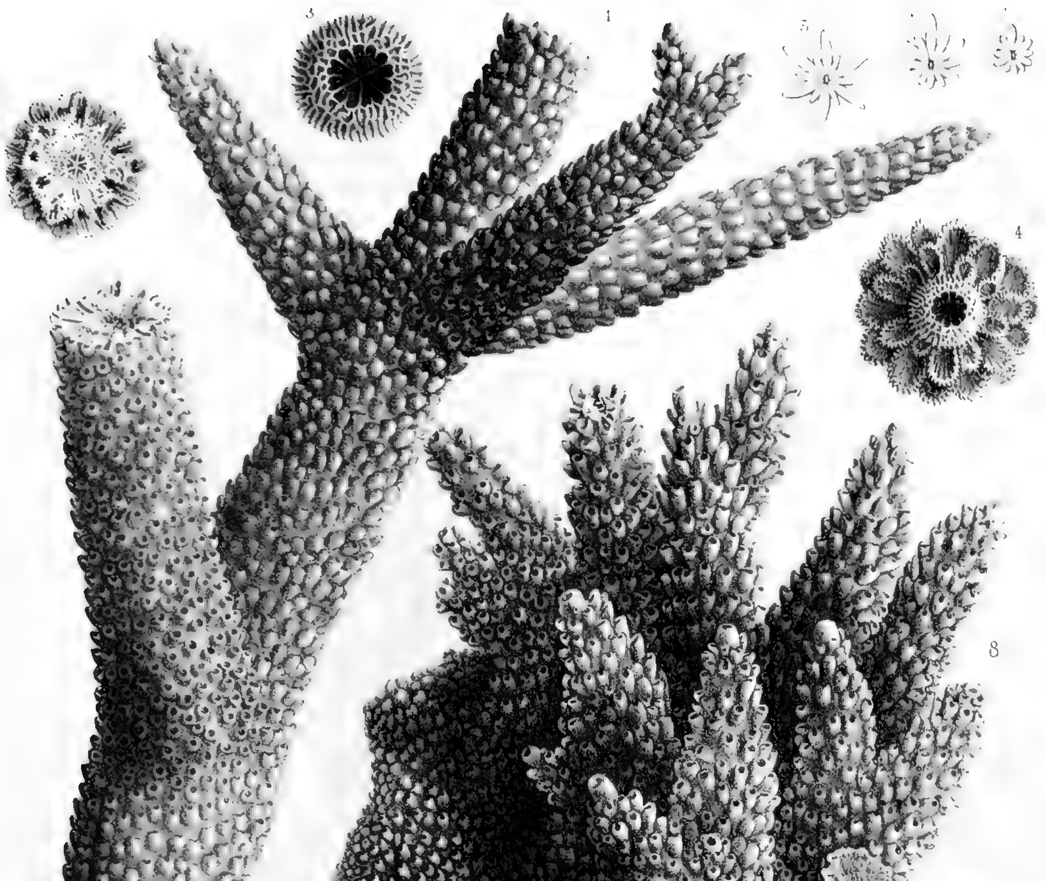

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PLATE XIX.

Fig. 1. Madrepora prolifera Lamarck, branch attached to a dead coral.
Fig. 2. Madrepora prolifera Lamarck, branchlets seen from above to show terminal calicles, natural size.
Figs. 3, 4. Madrepora prolifera Lamarck, end of branchlet magnified in profile and from above.
Fig. 5. Madrepora prolifera Lamarck, terminal calicle seen from above, magnified.
Fig. 6. Madrepora prolifera Lamarck, section through branch, magnified.
Fig. 7. Madrepora prolifera Lamarck, end of branch with polyps expanded.
Fig. 8. Madrepora prolifera Lamarck, lateral polyps, magnified.
Fig. 9. Madrepora prolifera Lamarck, young colony forming from an expanded base.

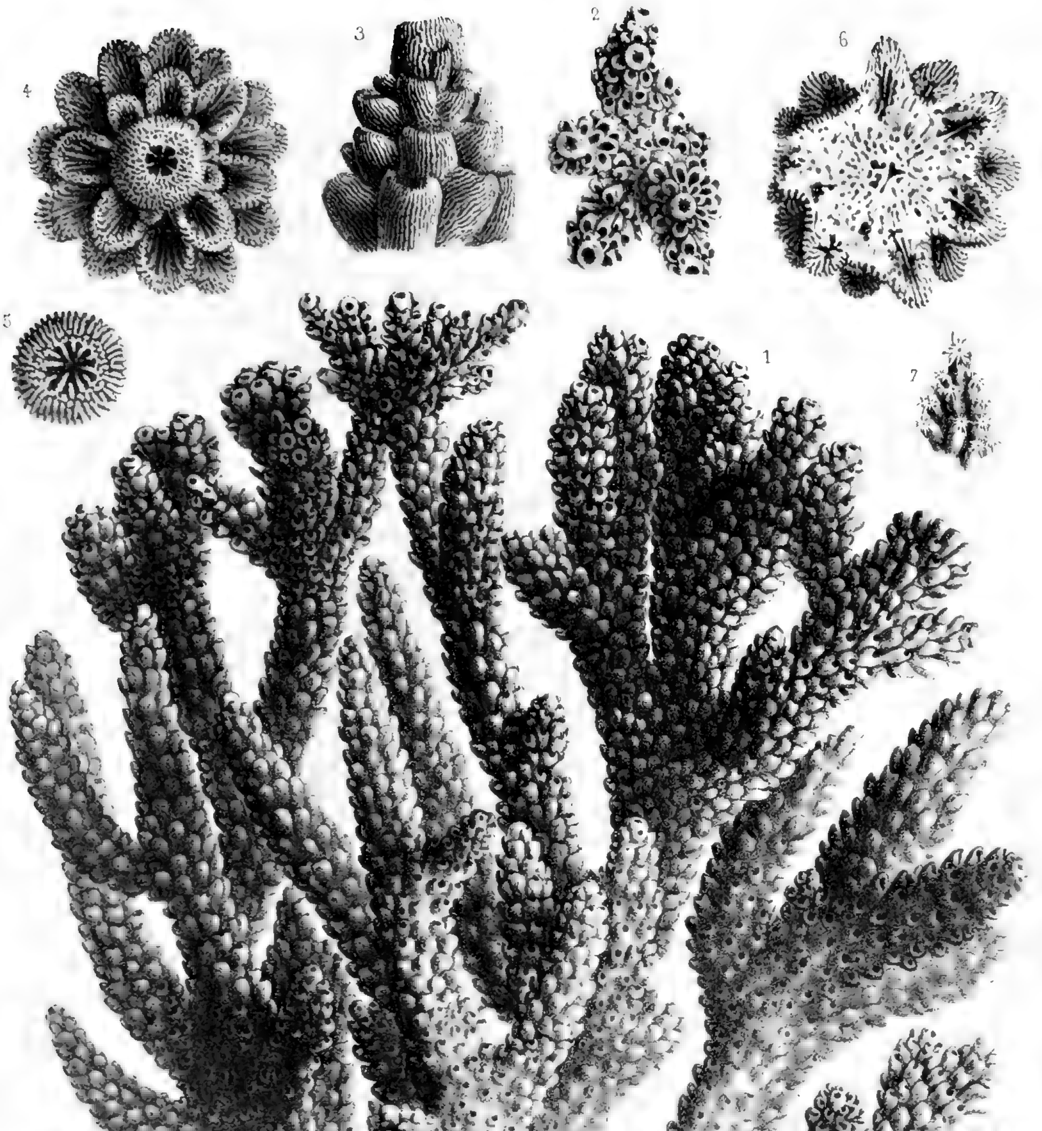

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PLATE XX.

Fig. 1. Millepora alcicornis Lamarck, natural size.

Fig. 2. Millepora alcicornis Lamarck, branchlet seen from above, natural size.

Fig. 3. Millepora alcicornis Lamarck, branchlet seen in profile.

Figs. 4, 5. Millepora alcicornis Lamarck, vertical and horizontal sections of corallum, showing the transverse floors (tabulæ) of the calicles.

Fig. 6. Millepora alcicornis Lamarck, surface magnified, showing the two kinds of calicles.

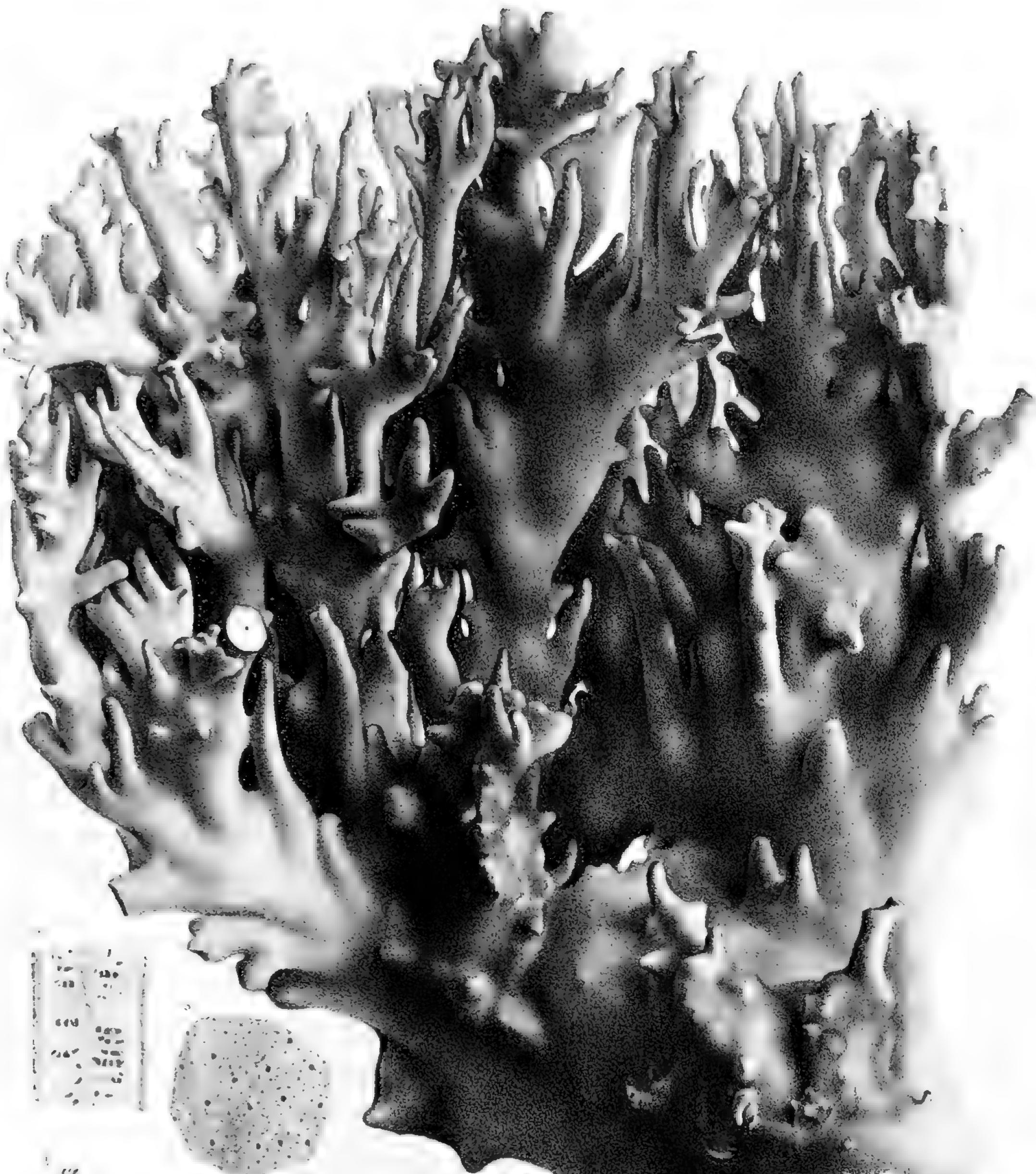

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PLATE XXI.

Fig. 1. Rhipidigorgia flabellum Valenciennes, reduced about one half.

Fig. 2, 4. Rhipidigorgia flabellum Valenciennes, magnified portions, showing the polyp-cells empty and dried.

Fig. 5. Rhipidigorgia flabellum Valenciennes, a planula, magnified (?). (No explanation of this figure could be found.)

Fig. 6. Rhipidigorgia flabellum Valenciennes, a small portion of the corallum, natural size, with partly expanded polyps.

Fig. 7. Rhipidigorgia flabellum Valenciennes, branchlet partly denuded of its cortical portion, and showing the horny axis.

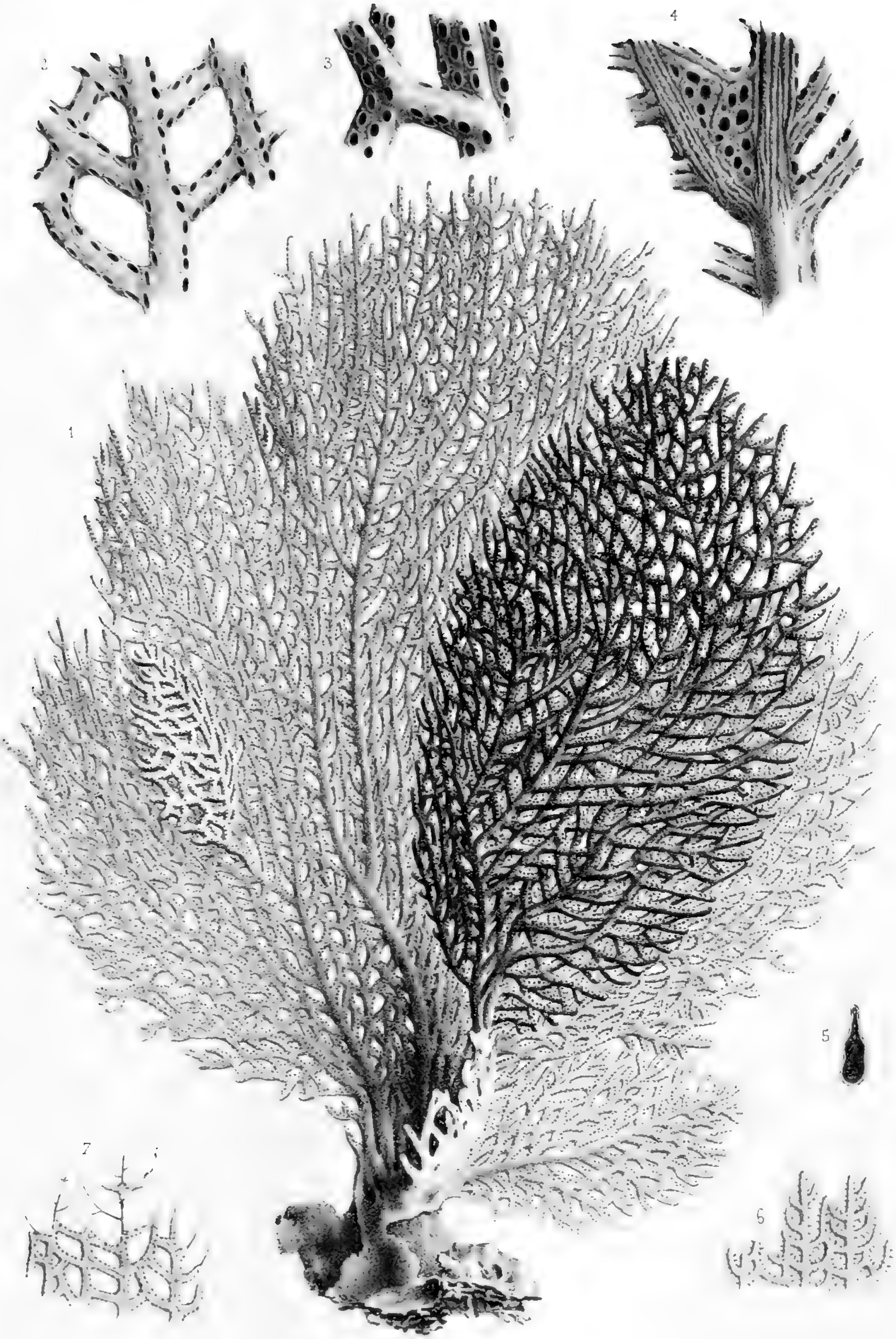

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PLATE XXII.

Fig. 1. Udotea flabellata Lamouroux, natural size.

Fig. 2. Udotea flabellata Lamouroux, edge of frond, magnified.

Fig. 3. Udotea flabellata Lamouroux, portion magnified.

Fig. 4. Udotea flabellata Lamouroux, surface of frond, magnified.

Fig. 5. Halimeda tridens var. incrassata Lamouroux, natural size.

Fig. 6. Halimeda tridens var. incrassata Lamouroux, profile view of terminal segments.

Fig. 7. Halimeda tridens var. incrassata Lamouroux, segments magnified.

Figs. 8, 9. Halimeda tridens var. incrassata Lamouroux, end view of terminal segments, magnified.

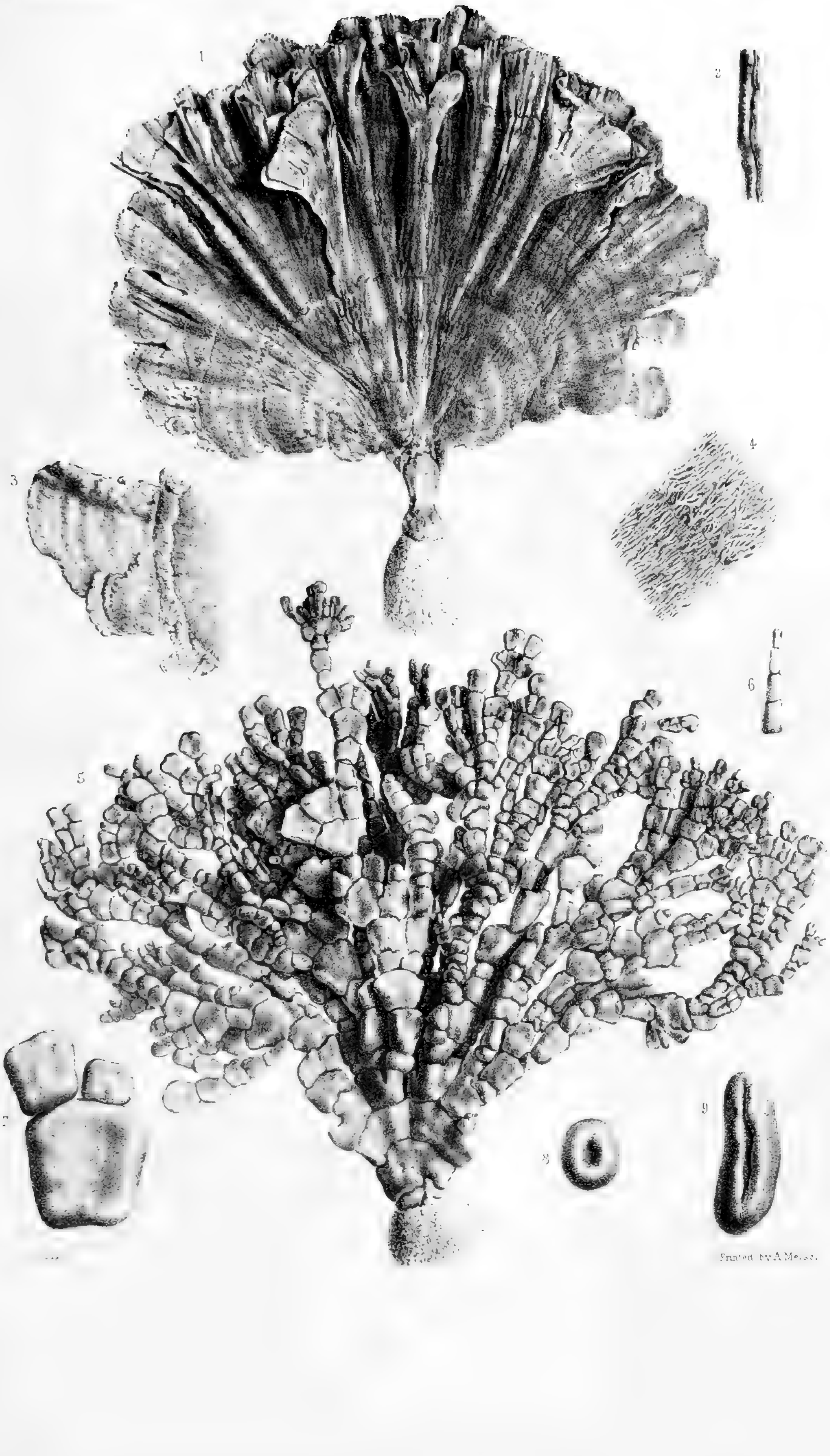

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PLATE XXIII.

Sketch map of Southern Florida, of the Keys and Reef, compiled from Coast Survey maps.

FLORIDA
Indian Hunting Grounds
GULF OF MEXICO
CUBA
STRAITS OF FLORIDA

Date Due