No. 13. — *Report upon Deep-Sea Dredgings in the Gulf Stream, during the Third Cruise of the U. S. Steamer Bibb, addressed to* Professor Benjamin Peirce, *Superintendent U. S. Coast Survey*, by Louis Agassiz.

(Communicated by Professor Peirce.)

The survey of the Gulf Stream, including soundings and dredgings in deep waters, had been going on for two years under your direction, when I was invited by you to join a third cruise. The surveying party this year, as before, was accommodated on board the United States Coast Survey steamer Bibb, master commanding Robert Platt, who had charge of the hydrographic survey, while Assistant L. F. Pourtales, who had hitherto superintended the dredging operations, still continued to direct the same work. The object of my own connection with the present cruise was to ascertain how far the last investigations covered the ground to be surveyed, and to what extent and in what direction further researches of the kind were desirable in the same region, and likely to furnish important information. The work of M. Pourtales had been so eminently successful, the results obtained in this short time so unexpected and of such high scientific value, that little more than a repetition, or perhaps, in some respects, a modification of his results could be expected from my participation in this year's operations. It is a pleasure for me to state that our cruise — extending farther to the east in the Gulf Stream, between Cuba and the Bahamas on one side and Florida on the other, than those of previous years — confirmed in every feature the conclusions already reached by M. Pourtales. His results may therefore be considered as settled facts, deserving the fullest confidence of the scientific world, and requiring only, in order to obtain the appreciation they deserve, that kind of publicity which illustrated descriptions and maps can give them. When thus made known, it will be seen that we owe to the Coast Survey the first broad and comprehensive basis for an exploration of the sea-bottom on a large scale, opening a new era in zoölogical and geological research. I speak thus emphatically, because the data hitherto obtained concerning the animals of the deep sea have been rather isolated, and not methodically connected with one

another, and with a study of the inhabitants of shallower waters, and the immediate seashore; nor have the previous collections been made over extensive areas, and so combined that every newly surveyed point was determined with reference to earlier investigations, as was the case with the dredgings of the last two years. In your recent surveys of the Gulf, the dredging operations have been pursued over an area so large as to preclude the possibility of any accidental and ill-considered conclusions. I should not speak in such terms of investigations in which I have had a share, had not the main results been secured by M. Pourtales before I joined the cruise.

There can be no doubt now that the area occupied by the reef which rises to the surface of the ocean has a peculiar, independent fauna, totally distinct from that of deeper waters. To this area belong those species of corals known as the true builders of coral-reefs, and to which, in a previous report to your predecessor, I gave, on that account, the name of reef-builders. The range of this fauna in depth is very limited; it does not extend below ten fathoms, and is mainly occupied by corals acquiring in their aggregate communities very large dimensions, such as *Madrepora palmata, cervicornis*, and *prolifera, Porites astræoides, Oculina diffusa, Eusmilia fastigiata, Astræa annularis* and *cavernosa, Isophyllia dipsacea, Manicina areolata, Colpophyllia gyrosa, Meandrina mammosa*, and other species of the genus, *Diploria cerebriformis, Siderastræa radians* and *siderea, Agaricia agaricites, Mycedium elephantotus, Millepora alcicornis*, the coarser and larger kinds of *Gorgonia*, and a host of animals of all classes living in and upon the reef, among which *Rhipidigorgia flabellum, Diadema antillarum*, and *Strombus gigas* are the most conspicuous. From this region (the only one of the kind which has been carefully surveyed by naturalists) I formerly secured those large and beautiful collections of corals which now adorn the Museum of Comparative Zoölogy.

Beyond this area, the width of which varies along the coast of Florida from a few miles, in the neighborhood of Cape Florida, to twelve, fifteen, or twenty miles and more off Cape Sable, we find another zone, rather sterile, or at all events not marked by that richness of animal and vegetable life which characterizes the reef range. The bottom of this second zone is a muddy mass of dead and broken shells, broken corals, and coarse coral-sand; it is chiefly inhabited by worms, and such shells as by their nature seek soil of this character.

with a few small species of living corals, some Halcyonarians, and a good many Algæ. From the nature of the bottom of this zone, especially at a depth of from twenty to forty fathoms, it is evident that a large number of dead Mollusks and Zoöphytes are scattered over its surface by the agency of the currents and tides, after they have been broken up.

I do not now enumerate the particular animals and plants found in this and the other submarine regions herein described, because the work of identification is as yet very incomplete; moreover, some of the most common and characteristic species are as yet neither described nor named, and would therefore be necessarily omitted in any list of the characteristic species of the Gulf Stream fauna. Indeed, for the present, such a list could only be an enumeration of species with which naturalists have become acquainted from specimens cast ashore, and would give no idea of the actual living faunæ in their natural habitat. On that account it is particularly desirable that the scientific harvest of these surveys should speedily be made known, accompanied by the fullest illustrations.*

A third region or zone, beginning at a depth of about fifty or sixty fathoms and extending to a depth of from two hundred to two hundred and fifty fathoms, constitutes a broad slanting table-land, beyond which the sea-bottom sinks abruptly into deeper waters. The floor of this zone is rocky; it is, in fact, a limestone conglomerate, a kind of lumachelle, composed entirely of the solid remains of organized beings, a true concretionary limestone, such as we might find in several levels of the Jurassic formation, and more especially in that horizon which geologists call "Coral Rag." We have here a plateau extending for more than a hundred miles, beginning off the Marquesas and stretching to Cape Florida, corresponding to Coral Rag. It varies from eight to ten, twelve, or twenty miles in width, — the greatest spread facing Sombrero, — and is built up entirely of animals now living upon its surface, and constantly increasing the thickness of the bed

* The corals found in the two earlier cruises are described by M. Pourtales, in Numbers 6 and 7 of the Bulletin, pp. 103 – 141. A preliminary report on the Echinoderms is printed in Number 9 of the Bulletin, pp. 253 – 361. As I have not enumerated the species therein described, it may not be out of place here to remark, that, though I have made some additions since, this report was prepared before Numbers 9, 10, 11, and 12 of the Bulletin had been handed in. The remarks upon the growth of corals were written immediately after my return from Florida, in May last.

by their accumulation. Large fragments of this rock were brought up by the dredge; so that its structure and characteristic remains of animals could be studied at leisure. I do not know that there is on record in the annals of our science a more direct illustration of the manner in which mountain masses of calcareous deposits have been accumulated on the bottom of the ocean. The animals inhabiting this plateau are innumerable, and as varied as those found along the shores most fertile in animal productions. A great variety of corals occur there, all of small size, and, strange to say, belonging to genera never known before from our sea-shores. Their aggregate affinity is indeed not with the living corals, but rather with the types of the tertiary and cretaceous periods. Echinoderms are equally numerous; they are also small as compared to those found nearer shore, and likewise recall, by their zoölogical affinities, the types characteristic of the cretaceous period. Salenoid and Discoidea-like forms, never known among living Echinoderms before, have been discovered on this plateau. Among mollusks I may mention one species, — the *Voluta Junonia*, hitherto considered the rarest shell from the southern coasts of the United States, and known only from a very few worn specimens. Of that species, which is particularly interesting on account of its close affinity with *Voluta Lamberti* of the Crag, and with *Voluta mutabilis* of the Miocene beds of Virginia and Maryland, quite a number of living specimens, young and old, have been brought up by the dredge. Two species of Brachiopods, — *Terebratula cubensis* Pourt. and *Waldheimia floridana* Pourt. — are extremely common, and contribute greatly to give this fauna an antique character. Most of the other mollusks have not yet been identified. Worms and crustacea abound also, and a few fishes unknown to me have also been obtained. All these are still undetermined.

The extraordinary richness, profusion, and variety of animal life displayed upon this table-land amazed me, not only on account of the peculiarity of the types, but from the vast number of individuals found together. The dredge coming up from such a depth, laden and crowded with all sorts of living creatures, as if it had been dragged in shoaler waters, was indeed a rare and startling sight for a naturalist. Such a result is the more unexpected, on account of the current impression, fostered by Edward Forbes's and Captain McAndrew's extensive dredging operations in the Ægean Sea, that as we descend below the surface of the ocean animal life gradually and steadily diminishes, till in deep waters

it entirely fades away. As we have already seen, this is not the case, and Captain McAndrew has himself lately helped to dispel the illusion. Nevertheless, it is true that a change is perceptible in the character and size of animals inhabiting respectively deeper and deeper waters, as compared with those of the shallow coast zone. It may very justly be said that we have in the sea something corresponding to the alpine and subalpine flora, when contrasting higher levels with the plains; only that our submarine deep-water flora, or rather fauna, consists mostly of creatures hitherto little known, or even entirely unknown.

It is a surprising fact that the variety of marine plants does not keep pace with the variety of animals; they make a poor show when compared with the many and diversified sea-weeds found in the littoral mud-flats and upon shoal rocky bottoms. The sponges, however, thrive in deep waters better than the ordinary algæ; but the large and valuable sponges now gathered in such quantity along the whole coast of Florida are found on the littoral shoals only. In deep water we find, with a variety of larger species, a great number of small species of the same type, and among them a diminutive *Hyalonema*.

Permit me a suggestion here. You have repeatedly commemorated the discovery, by officers of the Coast Survey, of some submarine ledge or ridge, or peculiar configuration of the sea-bottom, by associating their names with the field of their operations. It would be appropriate and just that this extensive coral plateau, the characteristic fauna of which M. Pourtales has so faithfully explored, should bear his name and be called the "Pourtales Plateau."

To the seaward of this coral table-land, the bottom sinks rapidly to a depth of four or five hundred fathoms, reaching even eight hundred fathoms and more, though our successive dredgings have hardly extended beyond seven hundred fathoms. Over the whole of this area, which properly constitutes the lower floor of the Gulf Stream, the sea-bottom presents a uniform accumulation of thick, adhesive mud,* in which animal life is much less profuse than upon the coral plateau. It cannot, however, be assumed that this diminution of life is owing

* When dried, this deep-sea mud, with its innumerable and characteristic Foraminifera, remarkably resembles the chalk-marls of the cretaceous formation. The green-sand formation I have not investigated myself, but it has been minutely studied by Mr. Pourtales, who has ascertained that it is the result of a peculiar alteration, disintegration, and final aggregation of Foraminifera.

to the depth and consequent pressure of the water, or to the absence of light, but rather to the nature of the soil; for we find in it many animals to which such a habitat is congenial, — a variety of worms, for instance, and such shells as seek muddy bottoms. I have not the least doubt that a rocky foundation at eight hundred or even a thousand and more fathoms would yield a large harvest of animals; unquestionably fewer than are found in shallower waters, but yet as varied and as numerous comparatively as are the Alpine plants on the very limits of perpetual snow, wherever, in various latitudes, that vegetation can be compared with the flora of lower levels. If we have not succeeded in finding such a fauna in the deepest waters of the Gulf Stream, I hold that the cause lies chiefly in the absence of rocky bottoms in the deepest parts of the basin through which the great current of our southern coast flows. The character of the mud in the channel of the Gulf Stream does not warrant the supposition that the mud deposits derived from the turbid waters of the Amazons and Orinoco have extended as far north as the Gulf of Mexico, even though the great equatorial current sweeps past the mouths of these rivers.

There is one subject of scientific research, the connection of which with deep-sea soundings cannot fail to lead to unexpected results. When attempting to explain the structure of the stratified rocks, and many other phenomena connected with the general appearance of the earth's surface, geologists have not hesitated to ascribe, in a general way, the facts under observation to the agency of water; but they have rarely entered into such specific details as would establish a causal connection between all these facts, and the cause appealed to. In proportion as the sea-bottom becomes more extensively known, and the character of the materials lying beneath the water and their mode of arrangement are ascertained with greater precision, more accurate comparisons, in consequence of which current views may have to undergo considerable modifications, will certainly be made between geological formations of past ages, including all their deposits of various kinds, and the materials at present scattered in special ways over the ocean floor.

From what I have seen of the deep-sea bottom, I am already led to infer that among the rocks forming the bulk of the stratified crust of our globe, from the oldest to the youngest formation, there are probably

none which have been formed in very deep waters. If this be so, we shall have to admit that the areas now respectively occupied by our continents, as circumscribed by the two hundred fathom curve or thereabout, and the oceans, at greater depth, have from the beginning retained their relative outline and position; the continents having at all times been areas of gradual upheaval with comparatively slight oscillations of rise and subsidence, and the oceans at all times areas of gradual depression with equally slight oscillations. Now that the geological constitution of our continent is satisfactorily known over the greatest part of its extent, it seems to me to afford the strongest evidence that this has been the case; while there is no support whatever for the assumption that any part of it has sunk again to any very great depth after its rise above the surface of the ocean. The fact that upon the American continent, east of the Rocky Mountains, the geological formations crop out, in their regular succession, from the oldest azoic and primordial deposits to the cretaceous formation, without the slightest indication of a great subsequent subsidence, seems to me the most complete and direct demonstration of my proposition. Of the western part of the continent I am not prepared to speak with the same confidence. Moreover, the position of the cretaceous and tertiary formations, along the low grounds east of the Alleghany range, is another indication of the permanence of the ocean trough, on the margin of which these more recent beds have been formed. I am well aware that in a comparatively recent period portions of Canada and the United States, which now stand six or seven hundred feet above the level of the sea, have been under water; but this has not changed the configuration of the continent, if we admit that the latter is in reality circumscribed by the two hundred fathom curve of depth.

Geologists have appealed very freely to oceanic currents as accounting for the presence of loose materials upon the surface of the earth. But now that the actual mode of distribution of such loose materials, under the action of extensive and powerful currents, begins to be known, those who explain the facts in this way are bound to show that their arrangement actually agrees with the effects of oceanic currents. I must confess that I have looked in vain, in the trough of the Gulf Stream, for traces of the characteristic mud which pours from the mouth of the Amazons in quantities sufficient to discolor the waters of the ocean for a great distance from shore; and yet the equatorial

current of the Atlantic is one of the greatest and most powerful of all known currents.

Another side of this subject is also immediately connected with deep-sea soundings. Geologists, and especially those of the school of Lyell, have again and again assumed the slow rising of extensive tracts of land from beneath the water, and taken all sorts of loose materials irregularly scattered over the surface of the land as evidence of its former submersion. But since the dredge has been applied to the exploration of the deep, and a great variety of animals, in a profusion rivalling that of shoal waters, have been brought up, not only from the immediate vicinity of the land, but at various distances, in increasing depth, from one to two and even many hundred fathoms, no observer is justified in considering extensive deposits of loose materials as marine in which no trace of marine organic remains are found. The very mud and sand of the deep teem with innumerable microscopic living beings, the solid parts of which are easily detected in the smallest samples of marine deposits, and may therefore afford a satisfactory test where larger animals or plants are wanting. Now, after surveying the whole width of our Western prairies, without finding anywhere a sign of marine animals or plants, I cannot see that there is any evidence of their marine origin, or of the influence of oceanic currents in accumulating or distributing the loose materials scattered over those vast plains. On the other hand, I have ascertained that the foundation rock, upon which these materials rest, is everywhere polished, grooved, and scratched in the same characteristic manner as the well-known glaciated surfaces, wherever exposed. I have seen such polished rocks in the valley of the River Platte, not far from Omaha, and am now satisfied that the whole extent of the country, between the Alleghanies and the Rocky Mountains, was one unbroken glacier bottom. The scratched pebbles found among the loose materials of the great prairies confirm this view. For similar reasons, I am satisfied that the valley of the Amazons has not been under the level of the ocean since the tertiary period.

The most perplexing feature disclosed to me by our deep-sea dredgings and by my observations of the sea-shores along the Gulf Stream, on the Florida and on the Cuba side, is the irregularity of the stratification of the Spanish banks as compared with the deposits on the American side.

Taken as a whole, the trough of the Gulf Stream, between Cuba and Florida, as well as farther east and north, presents features in its configuration widely different from the relief of any equally extensive area of the dry surface of our continents. The floor of this basin is gradually and slowly shelving from the Florida coast to greater and greater depth, while on the Cuban side it is rapidly rising again. The slope is, indeed, so rapid on the Spanish shore that, at a distance of less than two miles from the abrupt shore bluffs, the depth of the trough is generally from 3,000 to 4,000 feet, and here and there reaches 5,000 feet at a slightly greater distance. We have thus here a slope as steep as that of the steepest mountain ranges of that height, and even steeper; and, what is most surprising, the great inclination of this floor is not the result of uplifted and slanting beds of rock, but unmistakably the effect of the abrading action of the great current upon older coral formations, judging from the aspect of the shore bluffs, and their evident continuity with the general slope from the water-edge down to the greatest depth reached with the plumb-line and the dredge. This difference in the inclination of the slopes on the American and on the Cuban sides of the basin obtains for more than one hundred miles, — from the Tortugas to Cape Florida, — with the peculiarity only that in the direction of Salt Key Bank there rises, on the Cuban side, a low ridge from the deeper part of the trough, trending nearly parallel with the coast. Another remarkable feature of the edge of the great Florida reef consists in its having a less abrupt slope to the seaward than is ascribed to all the coral reefs of the Pacific Ocean. Nevertheless, the seaward slope of the reef is really steeper than the shoreward slope; and this is, it appears, an essential element in the growth and rise of all the coral reefs.

But while the great coral reef of Florida presents this exceptional character, the Bahamas and the reefs to the northeast of Cuba exhibit very abrupt slopes, and a great depth is reached close to the shores of these Banks; so that the Bahamas resemble the coral-reefs of the Pacific much more than the reefs of the coast of Florida.

The whole group of banks and keys embraced between Double-headed Shot Key, Salt Key, and Anguilla Key is a very instructive combination of the phenomena of building and destruction. The whole group is a flat bank covered by four or five and occasionally six fathoms of water, with fine sandy bottom; evidently corals reduced to

oölithes of various sizes, from fine powder to coarse sand, mingled with broken shells, among which a few living specimens are occasionally found. The margin of the bank is encircled on several points by rocky ridges of the most diversified appearance, and at others edged by sand-dunes. A close examination and comparison of the different keys show that these different formations are in fact linked together, and represent various stages of the accumulation, consolidation, and cementation of the same materials. On the flat top of the bank the loose materials are pounded down to fine sand; in course of time this sand is thrown up upon the shoalest portions of the bank, and it is curious to notice that these shoalest parts are its very edge, along which corals have formed reefs which have become the basis of the dry banks. The foundation rock, as far as tide, wind, and wave may carry the coarser materials, consists of a conglomeration of coarser oölithes, rounded fragments of corals, or broken shells, and even larger pieces of a variety of corals and conchs, all the species being those now found living upon the bank, among which *Strombus gigas* is the most common; beside that, *Astræa annularis*, *Siderastræa siderea*, and *Meandrina mammosa* prevail. The shells of Strombus are so common that they give great solidity and hardness to the rock. The stratification is somewhat irregular, the beds slanting towards the sea at an angle of about seven degrees. Upon this foundation rock immense masses of Strombus, dead shells, and corals have been thrown in banks, evidently the beginning of deposits similar to those already consolidated below; but there is this difference in their formation, namely, that while the foundation rock is slightly inclined, and never rises above the level of high water, the accumulation of loose materials above water-level forms steeper banks, varying from fifteen to twenty and thirty degrees. In some localities broken shells prevail; in other, coarse and fine sand; and the ridges thus formed, evidently by the action of high waves, rise to about twelve and fifteen feet. This is evidently the foundation for the accumulation of finer sand driven by the wind over these ridges and forming high sand-dunes, held together by a variety of plants, among which a trailing vine (*Batatas littoralis*), various grasses, and shrubs are the most conspicuous. These dunes rise to about twenty feet; on their lea side and almost to their summit grows a little palmetto. The sand of the dunes is still loose, but here and there shows a tendency to incrustation at the surface. The

slope of these dunes is rather steep, sometimes over thirty degrees, and steeper to the seaward than on the landward side.

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

Double-headed Shot Key is a long, crescent-shaped ridge of rounded knolls, not unlike "roches moutonnées," at intervals interrupted by breaks, so that the whole looks like a dismantled wall, broken down here and there to the water's edge. The whole ridge is composed of the finest oölithes, pretty regularly stratified, but here and there like torrential deposits; the stratification is more distinctly visible where the rocks have been weathered at the surface into those rugged and furrowed slopes familiarly known as "karren" in Switzerland. It is plain that we have here the same formation as on Salt Key, only older, with more thoroughly cemented materials. The uniformity of the minute oölithes leaves no doubt that the sand must have been blown up by the wind and accumulated in the form of high dunes before it became consolidated. The general aspect of Double-headed Shot Key is very different from that of Salt Key. The whole surface is barren, — not a tree, hardly a shrub, and the scantiest creeping vegetation. The rock is very hard, ringing under the hammer, and reminds one of the bald summits of the Jura, such as Tête de Rang, near La-Chaux-de-Fond. It is evident that what is beginning on Salt Key has here been not only completed, but is undergoing extensive disintegration in Double-headed Shot Key, both by the action of atmospheric agents over the surface and by the action of tides and winds against the base of the key.

Among these older oölithic deposits, forming the main range of Orange Key and of Double-headed Shot Key, we recognize formations of more recent date, occupying the cavities of ancient pot-holes, which have gradually been filled with materials identical with those of the older deposits. The pot-holes themselves show nothing very peculiar;

there are many such upon these keys, — some large ones many yards in diameter and others quite small, — evidently formed by the wearing action of loose pieces of harder coral rocks thrown upon the key by great waves, and only occasionally set in motion by the waters dashing over the key during heavy storms. The pot-holes nearest the water-edge are the most recent, and are mostly clean excavations, either entirely empty or containing sand and limestone pebbles lying loose at the bottom of the holes. Some of these excavations are circular, others oblong, still others have the form of winding caves opening towards the sea or upon the surface of the key. Beyond the reach of ordinary tides and of the waves raised by moderate winds, the pot-holes are generally lined with coatings of solid, compact, and hard limestone, varying from a thin layer to a deposit of several inches in thickness, and following all the sinuosities of the cavities in which they are accumulating. It is plain from their structure that these coatings are a subaerial formation, increasing by the successive accumulation of limestone particles left upon the older rock by the evaporation of water thrown upon the key when the ocean is so violently agitated as to dash over the whole key. Frequently the hollow of these coated pot-holes is further filled with consolidated oölithes ; or thin layers of minute oölithes alternate with a coat of compact limestone, throughout the excavation, which often has been filled again in this way up to the general level of the surrounding surface. Occasionally these regenerated surfaces are again hollowed out by the action of storms, and the result is a dismantled pot-hole, in which their structure and the mode of their filling is distinctly exhibited.

The stratification of the main mass of these keys is very peculiar. Though evidently the result of an accumulation of oölithes thrown up by high waves, the beds are pretty regular in themselves, but slant in every direction towards the sea, showing that they were deposited under the action of winds blowing at different times from every quarter. It is further noteworthy, that, while the thicker layers consist of oölithes readily distinguishable to the naked eye, there are at intervals thin layers of very hard, compact limestone, alternating with the oölithic strata, which have no doubt been formed in the same manner as the coating of the pot-holes.

As in their general aspect the coral formations of the Cuban side of the Gulf Stream differ from those of the American side, so do also the

rocks of the latter differ from the rocks observed upon the banks of Salt Key, Double-headed Shot Key, and Orange Key. We find upon the Florida reefs, as well as between the innumerable keys stretching along the American coast, and upon the coral plateau sloping towards the main trough of the Gulf Stream, extensive beds of regularly stratified rocks of various kinds. I have already described the limestone conglomerate of the Pourtales plateau, p. 365. Such a formation exists nowhere else within the range of the Gulf Stream, unless it should be hereafter ascertained that a similar deposit extends along the submarine border of our continent, edging the American wall of the deeper part of the Atlantic trough. But in the shoal waters intervening between the coast of the peninsula of Florida and the keys and reefs there exist various deposits of an entirely different structure, the accumulation and increase of which is constantly going on. The most extensive of these formations is a regularly stratified oölithic rock, the grains of which vary from imperceptible granules to larger and larger oölithes, approaching the dimensions of pisolithes, and cemented together by an amorphous mass of limestone mud. The oölithes themselves are formed in the manner first described by Leopold von Buch. Hard particles of the most heterogeneous materials, reduced to the smallest dimensions, and tossed to and fro in water charged with lime, are gradually coated with a thin film of limestone, and then another and another, until it sinks to the bottom, to be further rolled up and down the sloping shore bottom until it becomes cemented with other similar grains, and forms part of the growing limestone bed. Of course the finer oölithes are seen nearest the shore line, and it is instructive to see at low tide the little ripples of successive larger oölithes left dry as the water subsides. Naturally these materials are frequently thrown up along the beaches in layers of varying thickness, and in course of time become cemented, and are transformed into solid rock, over which crusts of hard, compact limestone are in the end formed by the evaporation of calcareous water dashed upon the dry surfaces.

In very shallow waters, which are not powerfully affected by tidal movements, and upon the bottom of which no oölithes are forming, we find extensive beds of a dull amorphous limestone, formed of lime-mud, alternating with seams of a more compact, hard limestone, in which a few oölithes may occasionally be seen that were floated over the flats in which such formations are going on. These deposits resemble

the marly limestone of the Oxford beds. Of course these different rocks may alternate with one another, as, owing to the increase of the whole formation, the conditions for the deposition of one kind of rock may be followed by those favoring another combination. Again, in consequence of the changes in the direction of the currents, or as the result of a heavy gale, considerable deposits which have been going on regularly for a long time may suddenly be worn away and destroyed, giving rise in turn to the formation of conglomerates made up of limestone fragments of various structure, united together into very peculiar conglomeratic pudding-stone with angular materials. The compact limestones are frequently as hard as the hardest limestones of the secondary formation, have a conchoidal fracture like the most compact Muschelkalk of the Triasic period, and may ring under the hammer.

Most of the keys consist of broken corals thrown up by the waves, including fragments of shells, sea-urchins, and occasionally bones of sea-turtles and fishes. At the Dry Tortugas and at the Marquesas, however, some of the keys are entirely made up of the decomposed fragments of corallines cemented together. The crescent-shaped joints of a large species of Opuntia are most prominent among them.

Nowhere, within the range of the Gulf Stream and its borders, have I seen a rock which could be supposed to have been formed by the materials accumulating in the greater depth of its trough, such as I have described above, p. 367. And no rock in the whole Jurassic formation could have been formed out of the kind of materials which are found in the deeper parts of the Atlantic basin, along the American shores; I therefore do not believe that any of the rocks of the Jura and the Suabian Alp have been deposited in very deep waters.

The extensive area occupied by the keys and reefs of Florida, including the sloping coral plateau of the American side of the Gulf Stream bottom, may fairly be compared to the Jurassic formation, as it stretches across Central Europe and farther east in the direction of the Caucasus and Himalaya Mountains. Indeed, the Jurassic formation, as a whole, bears the same relation to the older deposits upon which it rests, as the modern American coral formation sustains to the older parts of the coast of our continent. During the geological middle ages, the Jurassic formation was the submarine margin of a growing continent, as the Pourtales plateau forms at present the southern margin of North America.

These facts have an immediate bearing upon the question of the origin of submarine basins as compared with the inequalities of the mainland. The configuration and relief of our continents, as far as they are not the result of later denudations, have been determined by uplifts and the gradual rise of the land above the level of the sea, and hence have arisen the fractured ridges of mountain ranges, with their upright crests; while the areas of the great oceanic basins are surfaces of depression or subsidence, upon which prominent inequalities would of necessity be wanting, from the very fact that the breaks, where any occurred, must be turned downward. If this view is correct, it naturally follows that the main outlines and circumscription of the continents and of the oceans must have been determined at the very beginning of the formation of inequalities upon the earth's surface, and remained essentially the same through all geological ages, varying only as to their relative height and depth, as well as to their respective extension.

Such considerations enable us now to raise the question of the age of the Gulf Stream. Our present knowledge of the atmospheric and oceanic currents justifies the assumption that, — owing to the rotation of the earth upon its axis, and taking for granted that the latter has never changed its poles, — the great equatorial currents, fostered by the trade-winds, must flow in an east-westerly direction and be fed by northerly and southerly polar currents slanting westwards towards the equator. As long as the chain of the Andes did not intercept the Atlantic equatorial current, it must have been continuous with the great Pacific current; and, as stated by A. Agassiz, in another report, p. 305, there is palæontological evidence that during the cretaceous period the through channel was still open. I may add that I have myself seen the evidence, along the base of the Rocky Mountains, and on the western borders of the Amazonian Valley, of the post-cretaceous elevation of the great mountain range which rises like a huge barrier on the western side of the North and South American Continents, dividing the Pacific water-shed from that which feeds the Atlantic. We are thus justified in assuming that, even during the cretaceous period, there existed a great North Atlantic current, flowing from the northeast in a southwest direction, and that the Gulf Stream has assumed its present course in the opposite direction since that period; that is, since the Rocky Mountains and Andes have joined hands across Central America. This

result adds greatly to the interest excited by the cretaceous and tertiary character of some of the animals discovered by M. Pourtales in the deeper parts of the Gulf Stream. The true significance of this fact is, however, too foreign to this report to justify a discussion of its bearing upon the question of the origin of the present faunæ.

It would be of the highest importance to ascertain, by actual observation, the whole extent of the range of the deep-sea fauna recently discovered in the Gulf Stream, between the coasts of Florida and Cuba. To secure this information a great amount of dredging must be done from the eastern shores of the United States to the deepest waters of the Atlantic Ocean, all along the coast from Florida to our Northern States. Until such a comprehensive survey has been carried out, we can only combine, as well as we may, the scanty data on hand, in our attempt to form any idea of the northerly extension of the animals now known to exist in that part of the Gulf Stream flowing between Florida, Cuba, and the Bahamas. Happily the English and the Scandinavian naturalists have already collected a vast amount of information concerning the marine faunæ of the coasts of Norway and the British Islands, and the recent expeditions undertaken by the Swedish and by the English governments, with a view of exploring the greatest depths of the Atlantic Ocean, cannot fail to afford the most valuable means of comparison between the faunæ of the two sides of the Atlantic in different latitudes. From the reports of the British Association for Advancement of Science, from the publications of Professor Sars, from the reports of Professors Carpenter, Thompson, and Jeffreys, and from the private communications received from Dr. Smitt and Mr. Ljungman, the naturalists of the Swedish man-of-war Josephine, which recently visited the harbor of Boston, we have been able to ascertain that some of the species of our deep-sea animals of Florida are found far to the north of the British Islands, on the western coast of Norway, and near the Azores, upon the newly discovered "Josephine Bank." Now all these stations lie in the course of the Gulf Stream, as it divides into a northern or Scandinavian and a southern or Lusitanic branch, after crossing obliquely the Atlantic Ocean from our own shores, in the direction of Ireland; and the question naturally arises, Is not this wide distribution of the Florida deep-sea fauna to be directly ascribed to the agency of the Gulf Stream? It can hardly be otherwise, at least within certain limits. But at the same time we must not forget that, in a comparatively recent period, the main motion

of the North Atlantic must have been in a north-southerly direction, and that to this day there is a great northern current of cold water sweeping past the eastern shores of the United States; while the southern branch of the Gulf Stream flows in a southerly direction, past the western shores of Southern Europe; so that we may expect a strange mixture of arctic and subtropical animals in the great unexplored depths of the Atlantic, between America and Europe. It is to be hoped that the zeal with which the exploration of the deep ocean has begun may not flag before the whole problem is solved.

One of the most important results of this year's cruise, though not exclusively derived from deep-sea soundings, deserves a special mention in this Report.

Taught by former investigations, upon other classes of animals, that in their affinities and relative standing organized beings exhibit direct relations not only to the changes they undergo while growing, but also to their succession in past ages, and to their present distribution upon the surface of the earth, I lost no opportunity of ascertaining to what extent these relations may also be traceable among the corals. From their simpler organization, and the less prominent differences which distinguish their numerous representatives, it seemed hardly probable that facts could be ascertained plainly bearing upon these questions; and yet, the moment I proceeded with the investigation, I perceived that there was before me a vast field, thus far entirely unexplored, from the survey of which much valuable information could be secured.

A fortunate circumstance unexpectedly favored my researches. In consequence of injuries to a breakwater adjoining Fort Taylor, a large number of granite blocks, which had been three years under water, were hauled up on shore, and I found them covered with a great number of specimens of different species of corals, in various stages of growth. The surfaces of the granite were still so clean that it was possible to detect the smallest young corals upon them, and to trace so many stages between them and larger ones as to leave no doubt of their specific identity. I made, with the assistance of M. Pourtales, a large collection of these young corals, which I afterwards leisurely compared with one another and with adult stocks of the same species. The result of this comparison I may express in few words: Corals undergo a succession of changes peculiarly their own, and yet hardly

less marked than the embryonic changes already known among many animals. If we combine into a series all the changes thus far observed among different families of corals, an unmistakable gradation appears among them, akin to the series which may be traced among other animals in their adult condition, when we take the complication of their structure as a standard of their arrangement. Combining the evidence obtained from adult coral stocks, and their young at various stages of growth, it becomes evident that the representatives of the class of Polyps do not stand upon the same structural level with one another; but that there are higher and lower types among them, recognizable without the aid of embryological data, even though it was the study of the young which led me to the recognition of their relative standing. This is not the place for a discussion of the principles of classification of Polyps. I will only state, what I trust I shall be able to prove hereafter, that the Actinians proper stand lowest; next to them the Madreporarians, and highest the Halcyonarians. And as the Madreporarians form the most prominent feature in the coral reefs, I may add that among them the Turbinolians stand lowest, the Fungians next, then the Astræans, and highest the Madreporians. Now it is a most interesting fact that the successive changes which any representative of these different groups exhibit during their growth recall the characteristic features of the groups immediately below. For instance, young Astræans, before assuming their solid frame, are Actinia-like; their first coral frame is Turbinolia-like; and from that stage they pass into Fungia-like condition, before they assume their characteristic Astræan features.

I will only describe a few cases, in order to establish this correspondence of growth and relative standing of adults upon a firm scientific basis. Besides multiplying through eggs, Actiniæ increase also by budding, and this takes place by a spreading of their base of attachment (abactinal area), from the margin of which new individuals arise and finally detach themselves. Such a mode of enlargement or spreading of a simple individual, by a widening of its base of attachment, I have observed in many genera among Fungians, Astræans, Oculines, and Madrepores. If we take, for instance, a *Siderastræa*, which, by the way, is a Fungian, and not an Astræan, as is shown by the structure of its tentacles, as well as of its coral stock, we find that the large rounded masses formed by these corals are at first thin, spreading

disks, which only increase in thickness at a later time. The genus *Mycedium*, which, even in its perfect condition, constitutes a thin, spreading blade, may be compared, making allowance for the generic differences, to a young spreading stock of *Siderastræa*. In Mycedium the mode of growth is very plain. A series of specimens collected by M. Pourtales shows the beginning of such a coral community to be a single individual, the margin of which gradually spreads; from this spreading edge are developed additional individuals in the trend of the radiating partitions of the parent individual, spreading in their turn, while they remain connected with one another and with the central individual; this process going on until the coral stock has assumed its ordinary dimensions. Let us now conceive that the individual Polpys, united as a coral-stock in *Mycedium*, should increase vertically, as well as spread and multiply horizontally, the process of elevation beginning in the centre, we should have a *Siderastræa*. It is worth noticing, further, that the original central individual, from which the Mycedium community arises, is a diminutive Fungia, up to the time when new individuals arise around its margin. I have before me such young Mycediums, which might be mistaken for small specimens of Fungiæ, such as have been figured by Stuchbury and Milne Edwards. We are therefore justified in considering the genus *Fungia* as an embryonic form of the type of Fungians, when we compare it to *Mycedium*, *Agaricia*, or *Siderastræa;* and the propriety of assigning to Fungia proper a lower position in a natural system than that belonging to the compound types of the family must be obvious to all. The genus *Zoopilus* is only a Mycedium in which the individuals of the community are more intimately blended together than in *Halomitra*, thus forming a transition to Fungia proper. I have had an opportunity of examining also the growth of *Agaricia*. With the exception of generic differences in its structure, it exhibits in its growth the same features as Mycedium. The very youngest Mycediums exhibit Turbinolian affinities, inasmuch as the interseptal chambers are open from top to bottom and exhibit neither traverses nor synapticules.

Among Astræans the early growth of a community takes place in the same manner as among Fungians. Naturalists are accustomed to consider the formation of the hemispheric masses of these corals as arising from the formation of vertical buds around and between those

which preceded. This mode of enlargement of the communities obtains really in later periods of their growth; but it is not in that way that the foundation of the community is laid. *Astræa annularis*, the most common species among the Madreporarians of Florida, exhibits the formation of these stocks very plainly. The vast number of young stocks of this species which I have collected in every stage of growth leaves no doubt upon the subject. A simple individual Polyp spreads by the elongation of its radiating partition, Mycedium-like, in every direction, giving rise at appropriate distances to new centres or individuals around the first; and this goes on, without a marked vertical enlargement of the new individuals, until the community has acquired a diameter of several inches; just as in the cases of *Mycedium*, *Agaricia*, and *Siderastræa*. The appearance of this spreading margin of the young Astræa stock is so like that of a spreading Fungian, that, if detached from the well-defined circular individuals occupying the centre of the disk, it would unhesitatingly be taken for a fragment of a Fungian. It is only at a later time that in *Astræa annularis* the members of the community are developed in a vertical direction, and the community as a whole is enlarged by the interpolation of new individuals, to assume the form of a hemispheric mass. I have observed the same mode of growth in *Astræa cavernosa*, in *Manicinia*, in *Symphyllia*, in *Favia*, in *Colpophyllia* and in *Meandrina*. Of *Manicina* I possess a series of young still exhibiting their Turbinolian characteristics, with interseptal chambers open from top to bottom, and without a trace of traverses. The corals with undulating and meandering trenches arise also, like compound Fungians and compound circular Astræans, from single individuals, with circular outlines spreading from the margin, after the fashion of Fungians, just as much as Astræa proper. The peculiarities exhibited by each type cannot well be described without figures; I shall therefore not attempt here a detailed report of all the facts I have observed, reserving a fuller statement for a special memoir. But *Meandrina* exhibits some features so particularly interesting that I cannot pass on without giving some more special account of them. When the young spreading Meandrina has acquired the dimensions of about half an inch, still plainly exhibiting Fungian characteristics, its marginal extension gives rise to the formation of isolated clusters of rising radiating partitions, which stand distinct from one another, just like the characteristic hills of a *Hydnophora;* in fact, the

young Meandrina passes from a Fungian into an Hydnophora state, and in its farther extension, which takes place when the community has about two inches in diameter, when the trenches and walls begin to curve, while the margin is still spreading horizontally, the young Meandrina assumes the appearance of an *Aspidiscus*, a genus of the cretaceous period; in truth, it then resembles Aspidiscus and Hydnophora more than any adult representative of its own genus. We have here the highest complication of the Astræoid type, exhibiting successively Fungian characters, common Astræa characters, Hydnophora characters and Aspidiscus peculiarities, before it assumes its own prominent and permanent features. The Turbinolian stage I have had no opportunity of observing in Meandrina. This genus seems to grow more rapidly than other Astræans, and it was with difficulty I secured the earlier Astræan and Fungian stages of its growth.

Zoölogists are so accustomed to consider the *Oculinidæ* and *Madreporaidæ* as branching corals, that they may be surprised at the announcement that these families, like the Astræans, have their spreading Fungian-like stage of growth, — and yet I have before me a complete series of Oculina stocks, among which small clusters of individuals in simple juxtaposition exhibit the earliest condition thus far observed; others consist of flat spreading disks, several inches in diameter, without a vertical branch; while in others the branches seem to rise as small knobs and then begin to assume the ramified forms under which the Oculinas are generally represented in our museums. Even our most branching Madrepores, such as *Madrepora prolifera* and *cervicornis*, form spreading disks before they rise into branching stocks. *Madrepora palmata* is, as it were, an overgrown embryonic condition of the ramified species.

This summary of the facts concerning the growth of our coral-stocks can leave no doubt respecting the correspondence of the phases of growth of the Polyps and the gradation which may be recognized in full-grown communities of these animals. If we extend these comparisons to the representation of the class in earlier geological periods, down to the present time, we cannot fail to perceive that the series exhibiting their succession in time coincides also with that of their relative standing and that of their growth. In order to make this plain it would be necessary to enter into a discussion upon the real affinities of corals, for which this is not the place. I would state, however, that the knowledge I have

acquired of the Fungian affinities of Siderastræa leaves no doubt in my mind that a large number of corals, among the representatives of the Oölithic series generally referred to the family of Astræans, are genuine Fungians; thus showing a preponderance of the Fungian type at a period anterior to that in which the Astræans became more numerous. That the genuine Madreporians are of still later date in geological history has long been known. I would state also that from an examination of the soft parts of several representatives of the family of *Eupsammidæ*, I have satisfied myself that they are not allied to the true Madrepores, as Milne Edwards and Haime supposed, but belong in the neighborhood of the Turbinolians. If we now remember that the Acalephian affinities of the *Tabulata* are unquestionable, and that, with them, the *Rugosa* must be removed from the class of Polyps and referred to that of the Acalephs; and if we further take into consideration the fact that *Palæodiscus* belongs to the type of Rugosa, and not to the family of Fungians, it becomes evident that in their order of succession from the Mesozoic era, in which they make their first appearance, the great types of the class of Polyps have succeeded one another in the following order: first Turbinolians, next Fungians, next Astræans, and last Madrepores; in exactly the sequence in which these types stand to one another, as far as their structural gradation is concerned, and in exactly the same order in which, during their growth, these corals pass from one stage to another.

If we now turn our attention to the distribution of these animals in the ocean at different depths, it is equally unquestionable that the lowest types — Turbinolians and Eupsammidæ — range in the greatest depths, and form there the principal feature of the coral population. It is equally apparent, from the facts ascertained by the dredgings of M. Pourtales, that the various types of Astræans, including Stylaster, Oculina, and Parasmilia, appear next, the Stylasterians and Oculinians as the lowest ranging deepest, and that Astræa proper, Manicina, Meandrina, and Colpophylia, with Porites, are already types of shallower waters, while the Madrepores are, of all the genuine corals, those which have the most limited bathymetric range. I have not yet sufficient data upon the relative standing of the different types of Halcyonaria to extend this comparison to that order of Polyps. The results enumerated above are, however, already sufficient to show that, in the relations animals exhibit among themselves and to the elements

in which they live, there are other connections to be traced besides those arising from descent or the struggle for existence.

I have reasons for supposing that the investigation of the Gulf Stream, as presented in former Reports of the Coast Survey, has not yet reached its easternmost boundary. It was natural that the earlier explorations should have stopped where the great current no longer exhibits its characteristic peculiarities, and that its eastern range should have been traced with less minuteness than its alternate streaks of warm and cold water nearer shore. But now that the influence of the Gulf Stream upon the geographical distribution of organized beings appears distinctly as one of its most characteristic, though least suspected features, it will be necessary to extend the survey farther out into the Atlantic Ocean.

For the present I would suggest the following lines for soundings and dredgings: —

1°. One line from the Atlantic coast in Georgia or South Carolina to deep water, outside the range of the Gulf Stream, chiefly with a view of tracing the northern limits of the fauna of Florida.

2°. One line from the Atlantic coast in North Carolina or Virginia to the Bermudas and beyond; with the special view of connecting the deep-water fauna of the Gulf Stream with the shore fauna of these islands and that of our own coast, upon which Cape Hatteras marks the limits between two natural zoölogical littoral provinces.

3°. One line from Cape Cod or from the coast of Maine, in a south-east direction, across the Gulf Stream, with the special view of ascertaining the boundaries between the shore fauna and that of the Gulf Stream at this latitude. This line would afford the means of extensive comparisons with our Acadian fauna, which has already been carefully explored as far as Grand Manan by Dr. Stimpson, Prof. Verrill, and myself. Shorter lines from Sandy Hook to the trough of the Gulf Stream would add much value to the results obtained by dredgings from the coast of Massachusetts or Maine across the Gulf Stream.

I would also recommend one line across the Caribbean Sea, from Cumana or LaGuayra to Porto Rico, and one outside of the Small Antilles from the mouth of the Orinoco to Antigua; with the special view of ascertaining the area over which the mud deposits of the Orinoco spread, and how far they affect the Caribbean Sea.

But the most important line beyond our immediate shores, connected with the past history of the Gulf Stream, would be one from Panama westward into the deepest waters of the Pacific; for dredgings in that direction may prove that the deep-sea fauna is identical on both sides of the Isthmus, and that therefore, at a comparatively recent epoch, the great equatorial current of the Atlantic extended without serious obstructions over parts of Central America to the Pacific Ocean.

CAMBRIDGE, November 16, 1869.