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Bulletin of the Museum of Comparative Zoology

AT HARVARD COLLEGE.

VOL. XXVI. No. 1.

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A RECONNOISSANCE OF THE BAHAMAS AND OF THE  
ELEVATED REEFS OF CUBA IN THE STEAM YACHT  
"WILD DUCK," JANUARY TO APRIL, 1893.

BY ALEXANDER AGASSIZ.

WITH FORTY-SEVEN PLATES.

CAMBRIDGE, MASS., U. S. A.:  
PRINTED FOR THE MUSEUM.

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est hills of the Bahamas. We then skirted Cat Island along its western face, rounded the southern extremity, and made for Riding Rocks on the western side of Watling Island. We circumnavigated Watling, passed over to Rum Cay, then to the northern part of Long Island, visiting Clarence Harbor; we next crossed to Fortune Island, rounded the southern extremity, and passed to the east side, near the northern end of the island, on the Crooked Island Bank. Leaving the bank by the same track, we skirted its southern face, and steamed to Caicos Bank, crossing that bank from French Cay to Long Island, passed by Cockburn Harbor, and ended our eastern route at Turk's Island. From Turk's Island we made Cape Maysi, skirting the southern shore of Cuba as far as Santiago de Cuba.

After coaling there we visited Inagua, and next steamed to Hogsty Reef, a regular horseshoe-shaped atoll with two small cays at the western entrance, where we passed three days studying the atoll. This to me was an entirely novel experience; we were at anchor in three fathoms of water, surrounded by a wall of heavy breakers pounding upon the narrow annular reef which sheltered us, forty-five miles from any land, with a depth of nine hundred fathoms only three miles outside our quiet harbor. I made some soundings in the lagoon and of the slope of the reef outside. From Hogsty Reef we returned to Crooked Island Bank, to the westward of which I also made some soundings to determine its slope. Next we again visited Long Island, taking in the southern and northern ends, which I had not before examined. From there we passed to Great Exuma, stopping at Exuma Harbor and sounding into deep water on our way out. We skirted the line of cays fringing Exuma Sound to Conch Cut, where we entered the bank and sailed west, crossing to Green Cay. From there we made the southwest end of New Providence, and returned to Nassau.

On our first cruise we were fortunate enough to strike Cape Maysi a short time after daylight, and thus had a capital chance to observe the magnificent elevated terraces and raised coral reef which skirt the whole of the southern shore of Cuba from Cape Maysi to Cape Cruz, and make so prominent a part of the landscape as seen from the sea. We were never more than three miles from shore, and had ample opportunity to trace the course of some of the terraces as far as Santiago, and to note the great changes in the aspect of the shores as we passed westward, due to the greater denudation and erosion of the limestone hills and terraces to the west of Cape Maysi, which seems to be the only point where five terraces are distinctly to be seen. The height of the hills back of

Point Caleta, where the terraces are most clearly defined, I should estimate at nine hundred to one thousand feet ; though the hills behind the terraces, which, judging from their faces, are also limestone, reach a somewhat greater height, perhaps eleven to twelve hundred feet.

During our second cruise we steamed from Nassau for Harvey Cay, crossing the bank from north to south as far as Flamingo Cay, and from there passing to the westward of Seal Cay, Nurse Cay, etc. to Great Ragged Island, from which we took our departure for Baracoa.

At Baracoa I hoped to be able to ascend the Yunque ; unfortunately, the trip was given up, owing to the desperate condition of the roads. From Baracoa we steamed to the westward close to the shore, touching at Banes, Padre, Cay Confites, Sagua, Cay Frances, Cardenas, Matanzas, and finally ending at Havana. On this trip we continued the observations made on the south coast of Cuba, and thus traced the gradual disappearance of the terraces from Baracoa to Nuevitas, and their reappearance from Matanzas to Havana, from the same causes which evidently influenced their state of preservation from Cape Maysi west. We obtained a pretty clear idea of the mode of formation of the flask-shaped harbors found not only on the northern coast of Cuba to the eastward of Nuevitas, but all along the southern coast, and between Matanzas and the Colorado Reefs. They give us in part the explanation of the mode of formation of the extensive system of cays reaching from Nuevitas to Cardenas, and which find their parallel on the south coast of Cuba from Cape Cruz to Cape Corrientes, only upon a much wider plateau, and in the chain of cays stretching towards the western extremity of Cuba behind the Colorado Reefs.

From Havana we steamed to Cay Sal Bank, visited Cay Sal, the Double Headed Shot Cays, and the Anguila Islands, and then crossed the nearest point of the Great Bahama Bank. The bottom of this bank is of a most uniform level, three and three and a half fathoms for miles, sloping very gradually towards the west shore of Andros, so that we anchored nearly six miles from Wide Opening of the central part of Andros which we visited. The bottom consists of a white marl, resembling when brought up in the dredge newly mixed plaster of Paris, and having about its consistency just as it begins to set. The same bottom extends to the shore, and the land itself, which is low where we landed (Wide Opening), not more than ten to fifteen inches above high-water mark, is made up of the same material, and feels under foot as if one were treading upon a sheet of soft India-rubber. Of course on shore the marl is drier, and has the consistency of very thick dough. It appears to be made up

islands of the group. After the formation of the islands came an extensive gradual subsidence, which can be estimated at about three hundred feet, and during this subsidence the sea has little by little worn away the æolian hills, leaving only here and there narrow strips of land in the shape of the present islands. Inagua and Little Inagua are still in the original condition in which I imagine such banks as the Crooked Island, Caicos, and the Turk's Islands Banks, and other parts of the Bahamas, to have been ; while the process of disintegration going on at the western side of Andros still shows a broad island, which will in time leave only the narrow eastern strip of higher æolian hills on the western edge of the Tongue of the Ocean. Such is also the structure of Salt Cay Bank; it owes its shape to the same conditions as those which have given the Bahamas their present configuration. My reason for assigning a subsidence of three hundred feet is that some of the deep ocean-holes on the bank have been sounded to a depth of thirty-four fathoms, and I take them to be submarine blow-holes or cañons in the æolian limestone of the Bahama hills when they were at a greater elevation than now.<sup>1</sup> Subsidence explains satisfactorily the present configuration of the Bahamas, but teaches us nothing in regard to the substratum upon which the Bahamas were built. Indeed, the present reefs form but an insignificant part of the topography of the islands, and they have taken only a secondary part in filling here and there a bight or a cove with more modern reef rock, thrown up against the shores so as to form coral reef beaches such as we find in the Florida Reef.

We steamed in the "Wild Duck" nearly forty-five hundred miles among the Bahamas, visiting all the more important points, and made an extensive collection of the rocks of the group.

I had on board a Tanner sounding machine, kindly lent me for this trip by Colonel McDonald of the Fish Commission, and some deep-sea

<sup>1</sup> Dr. John L. Northrop, ("Notes on the Geology of the Bahamas," Trans. N. Y. Acad. of Sci., Oct. 13, 1890,) who passed considerable time in New Providence and in Andros, has given an excellent account of the characteristic features of Andros. He considers the evidence he has collected as conclusive of the recent elevation of Andros and of New Providence. During my extended examination of the Bahamas I did not meet anywhere with deposits either of corals or of mollusks, the position of which could not be satisfactorily accounted for as resulting from the action of winds and waves, or hurricanes. On the contrary, the very facts Dr. Northrop brings forth regarding the configuration of the western coast of Andros seem to me to lead to the opposite conclusions from those arrived at by him. All the evidence I have shows that the Bahamas owe their present configuration to subsidence and erosion, and that they are not rising.

thermometers were also supplied by him and by Professor Mendenhall, the Superintendent of the United States Coast Survey. I provided myself with a number of self-closing Tanner deep-sea tow-nets, with a supply of dredges and surface tow-nets, and carried on board a Yale and Towne patent winch for winding the wire rope used in dredging and towing in deep water. The yacht was provided with a steam capstan; by increasing its diameter with lagging we found no difficulty in hauling in our wire rope at the rate of a hundred fathoms in eight minutes. We carried six hundred fathoms of steel wire dredging rope of the same dimensions which I had used on the "Blake," and which has also been adopted on the "Albatross."

Both on going into Havana and on leaving we spent the greater part of a day in towing with the Tanner net. I thought I could not select a better spot for finally settling the vertical distribution of pelagic life than off Havana, which is in deep water — nine hundred fathoms — close to land, on the track of a great oceanic current, the Gulf Stream, noted for the mass of pelagic life it carries along its course. We towed in one hundred, one hundred and fifty, two hundred and fifty, and three hundred fathoms, and on the surface at or near the same locality, and I have found nothing to cause me to change the views expressed in the Preliminary Reports of the "Albatross" expedition of 1891.<sup>1</sup> At no depth did I obtain with the Tanner net any species which were not also at some time found at the surface. Even at one hundred fathoms the amount of animal life was much less than in the belt from the surface to that depth. At one hundred and fifty fathoms there was still less, and at two hundred and fifty fathoms and three hundred fathoms the closed part of the Tanner net contained *nothing*.<sup>2</sup> At each of these depths we towed fully as long as was required to bring the net to the surface again. Thus we insured, before the messenger was sent to close

<sup>1</sup> Alexander Agassiz: General Sketch of the Expedition of the "Albatross," from February to May, 1891. Bull. Mus. Comp. Zoöl., Vol. XXIII. No. 1, 1892.

<sup>2</sup> This is fully in accordance with the observations of the Plankton Expedition, as far as they have been published by Apstein, Ortmann, Giesbrecht, and others, relative to the bathymetrical range of the pelagic fauna. The diminution and final disappearance at sea of pelagic animal and vegetable life below a comparatively narrow limit seems general. That there are local conditions near shore, or in comparatively closed or shallow areas, or in districts adjoining submarine banks near the 500 fathom line, which modify these conclusions, I have already stated. Many of the observations which form the basis of statements proving the indefinite extension in depth of the pelagic fauna and flora, are of little value, owing to the imperfect working of the apparatus in use.



the lower part of the bag of the Tanner net, as long a haul through water as the open part of the net would have to travel till it reached the surface. This gave for comparison of their respective richness the fauna of a horizontal column of water obtained in the closed part of the Tanner net at one hundred, one hundred and fifty, two hundred and fifty, and three hundred fathoms, of the same or of greater length than the fauna of a vertical column from those points to the surface obtained in the sweep of the open part of the Tanner net.

In all our tows with the deep-sea self-closing Tanner net we took the usual precautions of carefully filtering the sea water into which the contents of the closed part of the net were emptied. We also made some slight modifications in the construction of the Tanner net. Iron rods were substituted for the rope guides of the pulleys, and one side was loaded so as to cant the net while it was towed. Off Clifton, New Providence, we made some trials in the Tongue of the Ocean, at a distance of not more than a mile from the edge of the bank, the depth being seven hundred fathoms. We towed at 9.30 A. M. in from one hundred to one hundred and ten fathoms for about twenty minutes: the net closed successfully. Only one Copepod was brought up from that depth, while in the open part of the net we obtained several specimens of Euclope, many bells of Diphyes, numerous Copepods, Alciope, Schizopods, larvæ of Brachiurans, Macrurans, Doliolum, Appendicularia, Gasteropod larvæ, and Collozoum. A fine Rhyzophysa came up attached to the wire after hauling in forty fathoms. At 10.30 we took a second tow at three hundred fathoms; the closed part of the net contained nothing, and a preliminary examination of the contents of the open part of the net, which remained open from three hundred fathoms to the surface, showed that it contained nothing we had not obtained from the shallower depths between the surface and one hundred fathoms.

In a haul with the deep-sea Tanner net, made at 1.50 P. M., five miles off Havana, in a depth of seven hundred fathoms, we towed for twenty minutes at a depth of three hundred fathoms. There was nothing found in the closed part of the net. There was a strong southeast breeze, so that we obtained comparatively little in the surface tow-net except a few pelagic algæ, Diphyes bells, and Copepods, while in the part of the tow-net which remained open all the way from the 300 fathom line to the surface we brought up a mass of pelagic stuff, consisting of Ctenophores (probably species of *Idyopsis* and *Eucharis*), of two species of Diphyes, of floats and tasters of Rhyzophysa, of masses of Copepods, of Schizopods, three species of Salpæ, many specimens of Doliolum, a few



Alciopæ, annelid and crustacean larvæ, Brachiurans, as well as Macrurans, and several species of Pteropods, the whole tow mixed in a broth of pelagic algæ, in striking contrast with the paucity of the pelagic fauna and flora at the very surface.

On another day, at 2.10 P. M., we made some hauls near the same locality, off Morro Castle, in seven hundred and forty-nine fathoms. We towed at two hundred and fifty fathoms for twenty minutes. The open part of the net contained many Sagittæ, Copepods, bells of Diphyes, pelagic algæ, Thysanopoda, Hyperiæ, Limacina, and crustacean larvæ. There was neither animal nor vegetable life in the lower closed part of the net. The water was smooth, a very light wind only having slightly ruffled the surface. The surface tow-net contained many fragments of Ctenophores, masses of Copepods, of Schizopods, of Macrurans and Macruran larvæ, as well as annelid larvæ, Sagittæ, Salpæ, Doliolum, Autolytus, Collozoum, and great numbers of pelagic algæ.

A second haul was made about an hour later at the same locality. We towed for twenty minutes at a depth of one hundred and fifty fathoms. This time the closed part of the net contained a few annelid larvæ, some Schizopods and Copepods, all of the same species we had found on the surface. It also contained specimens of Limacina and Styliola. None of these were in the surface tow-net, but they had been obtained from the surface on another occasion. In the open part of the net, which had remained open from one hundred and fifty fathoms to the surface, we obtained the same Pteropods which were found in the closed part of the net ; also the same Copepods and Schizopods, as well as the same annelid larvæ. In addition, the open part of the net contained bells of Diphyes, fragments of Ctenophores, Salpæ, Doliolum, crustacean larvæ, Collozoum colonies, and pelagic algæ.

On comparing the amount of material obtained in the closed part of the bag from towing twenty minutes at a depth of one hundred and fifty fathoms with the amount obtained at the surface in a tow-net dragged during the same length of time, we cannot fail to be struck with the poverty of the deeper haul as compared with the abundance of the haul made at the surface. After hauling in about thirty fathoms of the wire, we brought up a fine specimen of Rhizophysa. At six in the afternoon we towed the Tanner net for twenty-five minutes in one hundred fathoms near the same locality. The wind had sprung up somewhat, so that the surface tow-net contained practically nothing ; everything had been driven from the surface. In the closed part of the bag (towed at one hundred fathoms) we found Doliolum, Copepods, Sagitta, and Schizo-

Pods, all of species identical with those collected in the open part of the bag dragged through the belt extending from one hundred fathoms to the surface. It contained in addition some large Schizopods and Sagittæ, Tomopteris, Salpæ, Diphyes, Pteropods, tasters of Rhizophysa, and crustacean larvæ.

We hoped also to have made a large number of deep-sea soundings; unfortunately the trades were unusually heavy during the greater part of our visit to the Bahamas, greatly interfering with such work on a vessel no larger than the "Wild Duck," — one hundred and twenty-seven feet on the water line. For the same reason, the number of deep-water pelagic hauls was also much smaller than we had expected to make, as in a heavy sea the apparatus would have been greatly endangered. This was something of a disappointment, as the yacht was specially equipped for this work, and I had hoped, with the assistance of such skilled draughtsmen as were my assistants on this trip, Messrs. J. H. Emerton and A. G. Mayer, to accumulate a large series of sketches of pelagic types. It is a very different thing working at sea in a small yacht like the "Wild Duck," from working in such vessels as the "Blake" and the "Albatross," fitted up with every possible requirement for deep-sea work. The "Wild Duck," on the other hand, was admirably adapted for cruising on the Bahama Banks, her light draught enabling her to go to every point of interest, and to cross and recross the banks where a larger vessel could not follow. I am under the greatest obligations to my friend, Mr. John M. Forbes, for having so kindly placed his yacht at my disposal for this exploration.

The Bahamas (Plates I., VIII., IX., and X.) naturally divide themselves, first, into sunken banks like the Navidad, Silver, and Mouchoir Banks; next, islands occupying the whole or nearly the whole summit of the banks from which they rise, like Watling, Rum Cay, Conception, Samana, Marignana, the Plana Cays, Inagua, Little Inagua, and the atoll of Hogsty; then, banks having the semblance of atolls, like the Crooked Island and Caicos Banks, which are fringed by low islands forming a crescent with an open lagoon or flat between its horns; next, Salt Cay Bank, which from its structure holds a position intermediate between the group of sunken banks like Navidad and that resembling the Caicos Bank; and finally, such composite banks as the Little Bahama and Great Bahama Banks, with the characteristics of a combination of banks resembling all the others.

Darwin, in his account of the reefs of the West Indies,<sup>1</sup> assumes "that

<sup>1</sup> Coral Reefs, 3d edition, London, 1889, Appendix, p. 266.

large accumulations of sediment are in progress on the West Indian shores, . . . especially of the portion north<sup>1</sup> of a line joining Yucatan and Florida. The area of deposition seems less intimately connected with the *débouchement* of the great rivers than with the course of the sea currents, as is evident from the vast extension of the banks from the promontories of Yucatan and Mosquito." Darwin considers the isolated banks, such as the Misteriosa Bank, the bank off the northern point of Old Providence, Thunder Knoll, and others of various dimensions, to be "composed of sand firmly agglutinated, with little or no coral." He considers their steep slopes as characteristic of similar banks "in all parts of the world where sediment is accumulating, . . . the banks shelving very gently far out to sea, and then terminate abruptly. . . . The form and composition of the banks in the middle parts of the West Indian sea clearly show that their origin must be chiefly attributed to the accumulation of sediment; and the only obvious explanation of their isolated position is the presence of a nucleus round which the currents have collected fine drift matter." Further he says, "There cannot be any doubt that the Mosquito Bank has been formed by the accumulation of sediment round the promontory of the same name." And, finally, he says that the origin of the Bahama banks "is easily explained by the elevation of banks fringed on their windward side by coral reefs." But he modifies this assertion by stating that the Bahamas, as well as many of the submerged banks of the West Indian sea, "have been worn down by the currents and waves of the sea during their elevation."

From what we have learned of the geology of the West Indian seashores, there is nothing to confirm Darwin's views of the formation of great accumulations of sediment against the promontories of Yucatan or of Mosquito. The great submarine plateaus off those coasts consist of the seaward continuation of their shore strata, and not of accumulations of sediment. Whatever loose particles compose the bottom on these plateaus are due to the remains of the animals and plants thriving upon them, and flourishing to an unusual degree from the mass of pelagic life brought to serve them as food by the prevailing currents and winds. The currents, while they bear but little sediment in suspension, on the contrary carry along a pelagic fauna and flora unsurpassed in richness, but which supplies a comparatively small amount of material towards the building up of the submerged West Indian banks compared to that furnished by the carcasses of the animals and plants fed by this pelagic material, and the remains of which supply the great bulk of the deposits which go to build up these banks.

<sup>1</sup> This must be a misprint for "east."

Substituting older limestones in place of the oceanic deposits which Darwin imagines to have been made on the shores of the West Indian sea, and it seems to me that he has himself in his account of the coral reefs of the West Indies, the substance of which I have quoted above, given an admirable summary of the possible condition of the substructure of coral reefs in areas where it did not appear that his theory furnished a satisfactory explanation of the facts.

The following report must decide how far the explanation given by me satisfies the conditions of the coral reefs existing in Cuba, the Bahamas, Florida, the Bermudas, and other West Indian areas.

The plateau upon which the Bahama Islands are situated is connected with the shore plateau (the "Blake Plateau") of the east coast of the United States, extending in a triangular shape from Cape Hatteras to the Little Bahama Bank.<sup>1</sup> Its western face is separated by comparatively shallow straits from Florida; these become deeper as we proceed south, and their depth increases regularly towards the westward to the deepest points between Cape San Antonio and Yucatan.

The Bahama Plateau is separated from Cuba by the Old Bahama Channel. It gradually increases in depth eastward as we go from three hundred fathoms off Cay Frances to its greatest depth, over one thousand fathoms, off Diamond Point, between it and Boca Guajaba. (Plates I. and VIII.) The plateau itself slopes to the eastward at its northern termination, as is well shown also from the line of soundings to the north of the Little Bahama Bank parallel with it, and along the axis of the Northwest Providence Channel separating it from the Great Bahama Bank.

The relations of the banks to the eastward of the Great Bahama Bank are best seen from an examination of the hydrographic sections on Plates IV. and V., and of the charts, Plates I. and VIII.

In attempting to explain the formation of the Straits of Florida, we should remember that, in addition to whatever part the Gulf Stream may have played in cutting them out, on the Florida<sup>2</sup> side of the straits the land was nearly stationary during the time of the formation of the Florida reefs, while on the Cuban side the coral reefs have been elevated, and on the Bahamas the reefs now flourishing are in a region where there has been considerable subsidence, increasing as we pass eastward. If these movements of the Bahama Banks and of the land on their sides

<sup>1</sup> See charts, Figures 56 and 176, "Three Cruises of the Blake"

<sup>2</sup> See Suess, *Antlitz der Erde*, Vols. I. and II., Chapters X. and XVII.

were synchronous, they must have produced considerable warping of the surfaces enclosed within the area explored by the "Wild Duck."

—Mr. William H. Tillinghast has published some "Notes"<sup>1</sup> on the historical hydrography of the Handkerchief Shoal, "thinking that an examination of old maps might reveal a change of condition in the shoals since the time of the discovery of the Bahamas. . . . They throw more light on the condition of the cartography of the West Indies than on any physical changes among the islands."

An examination of the earliest charts of the Mouchoir Bank enumerated in the "Notes" which Mr. Tillinghast was kind enough to make with me at once showed the impossibility of their having been based upon actual surveys. On the chart of Thomas Jeffreys (1775), the Windward Passage from the east end of Cuba and the north part of Saint Domingo, there is a legend regarding the Banc du Mouchoir Quarre: "This bank is very little known. The soundings are taken from an English chart." It contains nine islands. On writing to Captain W. J. Whariton, R. N., Hydrographer of the Admiralty, regarding this English chart, I was kindly informed by Staff Commander Tizard that there appeared to be no earlier chart at the Hydrographic Office than that of 1775 by Thomas Jeffreys.

It is most natural that in those days, when computations for longitude were comparatively inaccurate, that in a region where the currents are most variable and often quite strong, the positions assigned to shoals and islands should be very inaccurate.

Even at the present time it is most difficult, owing to the varying strength of the currents, to pick up the position of well known banks, and still more difficult to find banks like that on which the "Superb" and "Severn" anchored, the position of which never was accurately fixed. But little importance can be attached to islands as shown on an old chart. On banks like those to the eastward of Turk's Islands (Mouchoir and Silver Banks), where there are many rocks awash, it is not impossible that patches of rocks awash should have been mistaken for islands by ordinary observers, and so marked on the charts.

But when we come to actual surveys, such as those of Count de Chastenot-Puységur (1787), who cruised over the Silver Bank and Mouchoir Quarre and took a number of soundings, we get a fairly accurate account of the aspect of the shifting bottom, of the rocks awash, and a series of quite characteristic soundings, but no islands are reported or plotted on the shoals.

<sup>1</sup> Library of Harvard University, Bibliographical Contributions, No. 14, 1881



With the exception of the changes in the distribution of the sand bores there are only some unimportant modifications of the topography of the islands recorded. Since the careful surveys of 1834, no changes of any consequence have been detected in the configuration of the land ; so that we are warranted in assuming that the configuration of the Bahamas as we now know them does not differ materially from that of the *Y<sup>as</sup>* de los Lucayos as they were first discovered by Columbus. The character of the forests alone has been greatly modified since the advent of Europeans.

The large scale charts of the region we explored in the "Wild Duck" are the British Admiralty Charts, Nos. 393, 659, 1256, 2579, and 2580, and the five Charts of the Bahamas, Nos. 399, 1496, 2009, 2075, and 2077. The deep-sea soundings are in the main those taken by the officers of the United States Coast Survey and United States Fish Commission, in addition to a few lines derived from soundings taken by the United States Navy Department and the steamers of private companies engaged in the laying of submarine cables.

The charts of the United States Hydrographic Bureau covering the same field are Nos. 373, 944, 946, and 947, and for the Bahamas, Nos. 26 a, b, c, d. Also the United States Coast Survey Chart of the Atlantic Coast from Cape Hatteras to Key West, scale  $\frac{1}{1,200,000}$ , as well as the charts of the Florida Reefs, Nos. 166, 167, 168, and 169. For the smaller charts and plans, and other charts of the West Indian and Caribbean districts, referred to in this Report, see the Index, and the chapters on the Hydrography of the Bahamas, page 139, and on the Coral Reefs and Banks of the West Indian and Caribbean, pages 145 and 160.



## THE GREAT BAHAMA BANK.

### Plate I.

THE Great Bahama Bank, by far the largest of the group, is irregularly V-shaped; it extends four hundred miles from northwest to southeast, and its greatest width is about two hundred and fifty miles. The western face, swept by the Gulf Stream, is slightly convex, and curves round to the southeast and south, forming the northern edge of the Old Bahama Channel. It then forms the edge of a great bay at the eastern extremity of the channel, extending northward and eastward, and terminating in a blunt projection, the Columbus Bank. From the eastern extremity of this bank the edge of the Great Bank runs north, and is protected by a line of low islands making a sweep which terminates in the southern point of Long Island. The island is the easternmost projection to the west of Exuma Sound, a deep gulf separating the eastern face of Great Bahama from the edge of the bank which extends northward from Great Exuma to the western spit of the southern part of Eleuthera.

The northern face of the western shank of the Great Bahama Bank runs nearly east from the Gulf Stream. It has, like the western side, but few fringing islands. Upon the eastern edge of the western shank of the bank are the Berry Islands. From their southern line the edge of the bank runs in a curve to the west edged by the Joulter Cays, which run into the northern extremity of Andros. This island, the largest of the Bahamas, forms the western edge of the Tongue of the Ocean, which separates the eastern and western shanks of the bank. On the eastern edge of the Tongue of the Ocean there are no islands except Green Cay and a few insignificant islets. The Tongue of the Ocean is a deep pocket; the extension of its eastern shore forms a sharp angle at New Providence, running slightly north of east to the extremity of Eleuthera. This edge of the bank is flanked by New Providence and a series of narrow islands which separate the Northeast Providence Channel from the inner bank. Eleuthera forms the northern part of the eastern face of the Great Bahama Bank; its southeastern spit is united to Little San



Salvador by a shallow narrow bank, which in its turn is connected with the northern extremity of Cat Island. The latter island forms the eastern side of Exuma Sound and the most easterly point of the Great Bahama Bank. We may now proceed with the description of the islands, beginning at New Providence and taking the eastern shank of the Great Bahama Bank first.

### New Providence.

Plate X. Figs. 2, 3; Plates XV. to XX.

Although the island of New Providence is not one of the largest of the Bahamas, yet the character of its surface varies greatly, and it is of sufficient size to give an excellent epitome of the features which probably characterized the land which once must have covered the greater part of the Great Bahama and Little Bahama Banks.

New Providence occupies the northwest corner of that part of the bank lying between the Tongue of the Ocean and Exuma Sound, its western extremity probably extending nearly as far out toward the edge of the bank, as is indicated by the outlying islands to the west, which were perhaps once a part of it. The sea has encroached but little upon its northern shore, except near the entrance to Nassau Harbor, where a few small islands to the west of the entrance show its former northern extension, and indicate that the same causes, together with the subsidence of the bank, have separated it from Hog Island.

The 100 fathom line is quite close to the north shore of the island, as well as to the western extremity, a depth of one hundred and fifty fathoms being reached within five hundred feet from the southwestern extremity of the island.

Hog Island, Athol, and Rose Island to the east, as well as the small outlying islands to the west of the entrance of Nassau, constitute the outer line of æolian hills which were separated from the ridge upon which Nassau is built by a valley, now the harbor of Nassau. It is evident, from an examination of the Nassau ridge, that it is of æolian formation, consisting of sand dunes closely packed together and heaped up one upon another. The outer hill, called Hog Island, the land which makes the breakwater of Nassau Harbor, is much lower, and runs parallel with this in a general way. The valley which separated the two outer ranges now forms Nassau Harbor, and its continuation to the eastward is the channel which leads to Cochrane Anchorage and to the parts of the Great Bank lying between Nassau and Eleuthera. The

harbor owes its existence in part to the general subsidence of this part of the Bahamas, which has sunk the valley between Hog Island and Nassau Hill as much as seventeen feet below low-water mark ; while the Grantstown plain to the south of Nassau Hill (Plate XVI.), extending to the next range, is still a few feet above high-water mark. A slight subsidence would separate Nassau Hill from the rest of New Providence and form a second range like Hog Island to the north of a large bay (Grantstown plain), cutting off the southern part of the island.

This ridge extends westward beyond Fort Charlotte from the point on which Fort Montague is built. From the Caves to the western entrance of Nassau Harbor the north shore of New Providence is formed by a line of hills running nearly parallel with it, and making the north side of the basin of Lake Cunningham. A broad valley stretches between it and the range of hills extending from Fort Charlotte to Fort Montague, the valley gradually opening out as we go westward from the Cave Point. The shore line itself is a long series of æolian rock sand beaches (Plate XVIII.), separated by an occasional rocky projection forming low cliffs.

The part of the island adjoining the north shore is covered principally by shrubs and trees. The flats at the foot of the hills are cultivated, and covered with sisal or cocoanut plantations.

The Queen's Stairway presents one of the finest sections of the æolian rocks of Nassau (Plate XV.) ; not only does the road leading up to its base pass through cuts of æolian rocks ranging from five to fifteen feet, but the so called Stairway itself is a succession of walls showing an exposure of fully sixty feet of æolian rock. This æolian rock when first exposed to the air is comparatively soft, but becomes quite hard after exposure to the action of the atmosphere.

Immediately behind the Queen's Stairway, on the southern slope of the Nassau Range, there is a fine quarry, one of a series which begins at Nassau Street and runs along the top of the range to the eastward of the Stairway. About one third of the way up the hill there is also a large abandoned quarry, showing the structure of the æolian rock. A few smaller abandoned quarries are found near the base of the hill, in which the exposed faces differ in no wise in character from those of the other parts of the hill. The same was found to be the case in the street leading from the main street to the Queen's Quarry, the nature of the exposed faces being everywhere the same.

The æolian rock faces as exposed in the quarries are in striking contrast with the harder rock surfaces exposed in the low ground between

the Nassau Range and the next range on the Grantstown road. There we find the æolian rocks of the surface coated with a hard ringing layer, and modified to a great extent by the intercalation of amygdulæ of red earth, which give to the rocks the appearance of an indistinct conglomerate.

At the foot of Nassau Street, twelve to fifteen feet above high-water mark, the vertical wall (ten feet high) of the back of the quarry also plainly showed lines of æolian deposit. On the way up the street there are other quarries which have been abandoned, and excavations for buildings showing the same structure. The quarries at the top of Nassau Street are being worked, and fine vertical faces could be examined there fully twenty feet in height, which showed on the whole face the same æolian structure so plainly seen at the foot of the same street, and at some other points of a still lower level, below high-water mark. The whole of the ridge forming the first hill back of the harbor of Nassau is evidently of æolian formation. Its highest point is about one hundred feet.

To the eastward of Fort Fincastle there are other old quarries, the exposures showing the irregular lines of wind-blown deposits. Wherever streets have been cut through the hillside as trenches, the same lines are visible on the faces of the side slopes. The æolian rock is used as building material throughout the Bahama Islands. It is either quarried from the surface in rough blocks from accessible faces, or regularly quarried, as at Nassau and Green Turtle Cay, by cutting narrow vertical channels five to six feet in the face of the vertical cliff exposures. A similar cut is made parallel to the face. The blocks thus laid off are then sawed in columns, and these in their turn sawed into blocks of the size wanted for building purposes. Imbedded in the rock faces of this quarry, and in the fragments scattered about, we found a number of land shells, quite similar to those still living. Mr. Dall has kindly prepared for the Bulletin a short account of the species collected.

Through the mass of the exposures tubes were scattered irregularly, formed from the decayed roots of bushes, grasses, and other plants which covered parts of the sand dunes while they were forming.

To the westward of Nassau the shore of New Providence is marked by a succession of beaches and æolian rock outcrops, and outlying cays, which once must have been short lines of hills more or less parallel to the principal hills on the north side of New Providence. They were separated from one another by low wooded flats, very similar to those now stretching at the base of the existing hills, but which by subsidence

and erosion have been changed into the narrow channels separating the outlying cays from the main island of New Providence. In some instances there has been an accumulation of recent shore coral rocks, flanking the hills and overlying the lower part of the older æolian rocks. Beyond the shore flat we cross Prospect Hill, then a second and third range of low æolian hills, and then we come upon the sink which forms Lake Cunningham (Plate X. Fig. 3). This lake fills a long valley, with its sides flanked by mangroves and with a few mangrove islands scattered on its surface. The water is slightly brackish. The vegetation outside of the mangrove belt runs into the characteristic Bahamian plants, most conspicuous among which is the so called grape tree (Plate XX.).

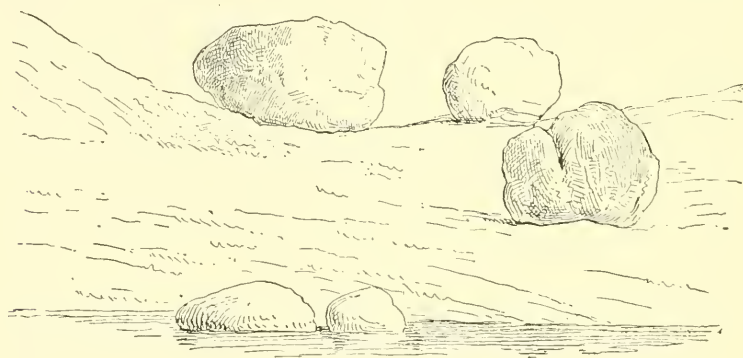
After passing the range of Prospect Hill, we come upon large tracts of pines, and in the hollows and valleys between the hills, where there is more moisture, we find a richer soil, there being more red earth in the decayed amygduloidal æolian rocks. In these low marshes and flats we find a peculiar flora, — a mixture of pines and groves of palmettos quite similar in character to the woods in some parts of Florida (Plate XIX.). In fact, with the exception that the country is more rolling, one might imagine the scene, by its clusters of palmettos and tall pines, to be laid there; while in the more open spaces, where the forests have been burned off, whole tracts are covered with bayonet palms and magnificent brushes of young pines.

The road running west as far as Cave Point is more or less parallel with the coast, and is flanked on each side with low bushes; but the principal shrub is the grape tree. Further inland the slopes of the hills are covered with larger growths, and on the flats between the prolongation of the hills, especially in the space formed by the extension of the valley in which Lake Cunningham lies, we meet fine clusters of palmettos and tracts of pine.

The spurs of the shore hills extending in a northwesterly direction form more or less prominent spits nearly perpendicular to the shore line, according to the hardness of the rocks and their exposure to the action of the sea. The cave from which Cave Point derives its name is an old vertical cliff, which is now separated from the shore by a narrow belt of coral shore rocks which have been thrown against the æolian cliffs, and have formed also the small flat flanking the southerly extension of the spur of which Cave Point is the northern end. The cave differs in no way from the many similar caves which exist throughout the Bahamas. The cave is from twenty to twenty-five feet wide, and perhaps ten to fifteen deep in places.

From the top of Cave Point, about twenty feet above high-water mark, a road leads at right angles to the shore line to Lake Killarney (Plate X. Fig. 2). The road runs nearly level the whole way to the lake; the country is covered with pines and clumps of palmettos until we strike the mangrove swamp which forms the edge of the lake. Lake Killarney is full of mangrove islands, forming very pretty vistas between their headlands, and occupies a shallow sink between two short ranges of æolian hills, similar to the one forming Lake Cunningham.

The bluffs at Clifton, which form the vertical cliffs of the southwestern extremity of the island, are the termination of the æolian range of hills extending nearly parallel to the south shore. This range gradually recedes from the shore, and the cliffs die out and are replaced by a long beach line, which extends nearly unbroken to the southeastern end of



COW AND BULL.

the island. At Clifton these cliffs are eaten in more or less by caverns and fissures both to the east and west of Moss Hill, and are admirable examples of the effect of the action of the sea upon æolian rock. The constant pounding of the ordinary swell breaks off large blocks, which in their turn break into smaller blocks and are thrown up in the season of the hurricanes above high-water mark, forming a stone wall along the coast line similar to those to be seen in other parts of the Bahamas.

Along this part of the shore there are many sea-holes and pot-holes, extending from the surface to low-water mark, or even below. Many of these irregular wells or caverns are from twenty to twenty-five feet deep, and when occurring in high cliffs, or hillsides farther inland, as on Long Island, from a hundred and fifty to two hundred or more feet in height.

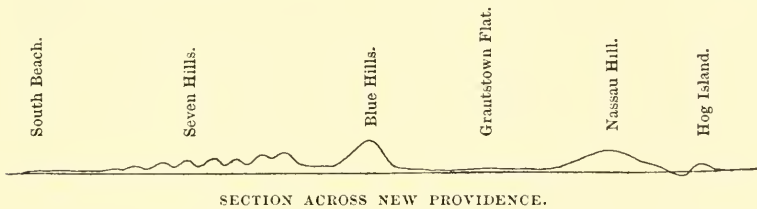


would readily account for the deep ocean-holes, one of which has been sounded to a depth of thirty-eight fathoms. These caverns would, if the islands sank to their full height, appear like ocean-holes in the general levels of the bank.

Moss Hill Bluff shows also the manner in which huge isolated rocks, sometimes twenty to thirty feet in height, like Cow and Bull on Eleuthera, near the Glass Window, may be left as fragments of hills formerly much higher, but gradually eaten away on the sides where parts of the rocks are not protected on the surface by a coating somewhat harder than that of the surface rock immediately surrounding them.

There are two bluffs to the north of Moss Hill, which now stand out like rounded knobs above the surrounding country, and which in time may appear almost like erratic boulders left high and dry, or like huge masses thrown up perhaps during a great hurricane.

The æolian rock sand from the bottom where we anchored is coarse and of a grayish color.



A section of the island of New Providence in a nearly north and south line from Nassau to the south shore is most instructive.

Leaving the shore at Nassau, we follow up Nassau Street, and at the quarries cross the crest of the ridge. The slope falls rapidly to the level of the extensive plain of Grantstown, which separates the shore range from the Blue Hills range. On the flat the exposed æolian rocks are greatly honeycombed and weather-worn, the whole surface occupied by pits, banana-holes, pot-holes, and cavities of all sizes, which have formed in the more or less rotten rocks of the Grantstown flat. On both sides of the road there are marshes and pools filling the depressions. It would require but slightly deeper depression to change the greater part of the mangrove marshes of this flat into lakes like Killarney, Cunningham, and other ponds which lie in deeper sinks. The greater part of the Grantstown flat is covered by low bushes (Plate XVI.), with here and there patches of mangroves.

At the foot of the Blue Hills we come upon the more or less amygd-

loidal rocks which usually characterize the æolian rocks a little inland, away from the immediate action of the sea, where the red earth which once filled the cavities has become a part of the rock itself. As we rise we pass into the regular stratified æolian rocks, still retaining their original structures, and only coated with a thin ringing crust at the surface. On reaching the summit and descending the hills, we come upon a low flat,<sup>1</sup> which separates the Blue Hills from the undulating plateau district known as the Seven Hills. These are six or seven irregular ranges, slight undulations merely, running more or less parallel with the Blue Hill range, which occupy the country between it and the south shore. These hills follow in rapid succession, and are perhaps twenty to twenty-five feet above the general line of the slope, which ends in the low flat behind the south beach. These hills become less and less prominent as we go south, and the last scarcely rises above the flat just referred to. The shore plateau immediately behind the beach is low and swampy, filled with clusters of mangroves, and when we reach the beach there are extensive mangrove flats extending some distance out (for about half a mile) from the shore line, and islets of mangroves running parallel with the line of the beach (Plate XVII.). This must evidently have been formerly a mangrove swamp similar to the one to the rear of the beach, which occupied undoubtedly a position similar to it at the foot of a low æolian hill in the valley between it and the next range, or between it and the old shore line, which by subsidence and erosion has been brought to its present level. All the way from the Blue Hills to the mangrove swamp the vegetation consisted of small pines thickly crowded together. In the more open spaces young pine shoots were starting up in all directions, and in the lower and more swampy districts between the successive ranges of hills groves of palmettos of all sizes varied somewhat the monotony of the pine barrens. Intermingling with the pines and palmettos are large tracts covered by bushes, and near the shore often prominent patches of larger trees. The pines and palmettos are affected by the proximity of the sea, being of a smaller size and growing less vigorously; while on the beach itself, and immediately behind it, we come upon the common plants characteristic of the shore line of the Bahamas.

<sup>1</sup> The rock exposed upon this flat resembles the more or less rotten æolian rock characteristic of Grantstown Flat.

## New Providence to Northern Eleuthera.

Plate X. Figs. 2, 3 ; Plate XI. Fig. 5 ; Plate XXXII.

On passing out of Nassau Harbor, making toward Douglas Channel, we obtained the first view of the peculiar aspect presented by the low æolian hill ranges forming the outer islands of the Bahama Bank. As we passed to the seaward of Hog Island we obtained an excellent view also of the sand beaches which form the western part of the island. Similar longer or shorter sand beaches extend throughout the Bahamas on the sea faces of such islands as are more or less protected by outside rocks, outlying islets, or banks or bars, from which the material for the inner beaches is worn away by the action of the sea and thrown up on the surface of the inner island. The sand beaches may also be formed from the disintegration of the more gentle slopes on the sea face of the æolian rocks of the inner islands.

As seen from the sea, the outline of the outer islands is most characteristic. Seen slightly obliquely, such an island as Rose Island, for instance, seems made up of a series of solidified dunes falling one over another. Rose Island is a long narrow island, the highest point of which is not more than thirty to forty feet above the sea level, of about twelve miles in length. One might readily imagine from the distant outline that the whole mass of the island was moving bodily to the westward, in a series of low sand waves, under the influence of the prevailing winds. Rose Island is parallel to the range of islands of which Hog Island may be called the centre. Long Cay and North Cay form the western extension, while Athol Island makes the eastern extension. Parallel to Rose Island are Salt Cay to the west and Booby Island to the east, — the remains, perhaps, of the range of æolian hills which formed the very edge of the northern part of the bank to the eastward of Nassau, very much as Egg and Royal Islands are the remnants of the ranges of the north-eastern points of the bank.

Rose Island is perhaps one of the most characteristic of the Bahama Islands. It consists of a single narrow ridge of æolian rocks, extending for twelve miles along the edge of the bank. In continuation of it, on the other side of Douglas Channel, is Booby Island, a very similar ridge. Rose Island is a low range of æolian hills, similar to those now running across New Providence ; it has become isolated by the subsidence, erosion, and destruction of the land of which it once formed a



part, little of which is left. At the eastern end of the island, where it is wider, a salt pond exists.

Passing into Douglas Channel, Booby Island (Plate XXXII.), a long barren line of rocks, is seen to the eastward, presenting very much the same appearance as Rose Island, with low æolian hills, but without a beach to either the sea face or the bank side of the range. The contrast of the appearance of Booby Island, as seen from the bank or from the northern side, is most characteristic. On the sea face it is one series of æolian hill slopes, piled one on top of another, while on the bank side the steeper slope of the hills has been cut away from the base nearly to the summit, leaving only a series of rounded tops on the horizontal line of the summits of the vertical shore cliffs. Booby Island is bare, with rounded summit, the whole surface of the island honeycombed more or less by the action of the sea. On both sides of the island the waves have made greater or less inroads, and have cut away the lower parts of the island, especially on the southeastern face, leaving round them a shallow bank formed of disintegrated æolian rock, on which animal life is not plentiful — having on it a few patches of Gorgonians and of coral-line algae — either on the sea or the bank face of the shoal. But as we go into deeper water, four to six fathoms, toward the steep edge of the bank, in the direction of the Providence Channel, we come upon more or less extensive patches of coral heads, separated by clear sand, which form an irregular belt of corals to twelve or to sixteen fathoms in depth along the sea face of the bank, from its northeastern extremity to the western end of New Providence.

Samphire and Upper Samphire Cays have the same general structure as Booby Island. There is perhaps a little more low vegetation on these rocks, and they appear a little greener. They are the remnants of cays which were undoubtedly similar to Hog, Rose, and Booby Islands, and which once formed long narrow æolian ranges on that part of the bank. The disintegrating action of the sea has, however, left only parts of these ranges, either as low cays like the Samphires, or the patches of small banks rising nearly to the surface on the two sides of the Fleeming Channel. In the distance we passed the western end of Current Island, a low point covered by a few trees. The point is formed of low undulating hills, of about the same height as Hog Island, and presenting the same structural features.

On our way to the Little Bahama Bank we passed again over the bank lying between Nassau and the Fleeming Channel. Through this we passed, and steered for our anchorage on the northwestern extremity of

Northern Eleuthera off Current Cut. The Six Shilling Cays and other rocks forming the northwestern edge of the bank to the eastward of Nassau are all low, bare, eaten away at the base (the remnant of the Eleuthera-Nassau land), formed of æolian rocks greatly weathered and worn; Fleeming as well as Douglas Channel being formed by the subsidence of the bank, of which the islets and cays and rocks are the higher summits and the channels the lower parts of the intervening space. As we came up to Pimlico Cay we saw an extensive belt of angular æolian rocks thrown up along the north shore of the cay above high-water mark. The north face of the cays between Fleeming Channel and Current Cut has been greatly eroded, and the rocks rounded and honeycombed by the action of the sea.

From Pimlico Cay to Egg Island round to Bridge Point there are a number of cays which have formed an outside line as it were upon the triangular extension of the bank to the northwest of Eleuthera. These cays are the outliers of the former Eleuthera land, having become disconnected from the main island. Of these cays we examined Egg Island, Northern Eleuthera, and the north end of Current Island adjacent to Current Cut. The constitution of the islands was everywhere the same, of æolian origin. The bottom on the bank where we anchored was made up of fine coral sand, with many broken shells, mainly bivalves. A strong current sweeps north or south through Current Cut according to the stage of the tides.

From the western face of Egg Island an extensive reef runs parallel to Royal and Russell Islands, from two to three miles distant, as far as Bridge Point on Eleuthera, where it sweeps across the northern extremity of Eleuthera and skirts the cays as far as the southern end of Harbor Island. The 100 fathom line runs so near the bluffs of Eleuthera, near the Glass Window, that the reef is interrupted, but reappears near James Point. From there it skirts the eastern face of Eleuthera as a fringing and barrier reef, and it extends south to meet the reef which connects Eleuthera, Little San Salvador, and Cat Island. From Eleuthera Point it extends on the west coast, but rather irregularly, as far as Bamboo Point. It appears again in patches on the west side of Powell Point Channel, to the south of the Schooner Cays, on the northern edge of the Exuma Sound Bank. From Ship Channel Cay to Wide Opening the corals on the edge of the bank are in from three to five fathoms of water, and the gaps between the cays are one mass of coral heads, with such passages as Ship Channel, Highborn Cut, Wax Cay Cut, and Wide Opening leading from Exuma Sound on to the bank.

In the passages — such as Douglas Channel and Fleeming Channel — leading from the Northeast Providence Channel on to the bank, we find that coral heads extend into three to four fathoms, and may be found even at less depth. But the heads are not vigorous, and do not compare with those growing on the sea face of the banks. They occur everywhere on the banks in proximity to the open waters of the deep channels, forming more or less extensive patches, such as are known near Nassau, between Hog and Athol, as the Marine Gardens.

On striking the open bank itself, beyond the influence of the fringing cays, one cannot fail to be struck with the poverty of the fauna and flora upon this great expanse of disintegrated æolian rocks. ' We found almost nothing upon the bank in the line extending in a general way parallel to the northern edge, from Douglas Channel to the Glass Window on Eleuthera ; here and there were to be met patches of Millepores or of Gorgonians, or a few sponges, very few mollusks, small clusters of *Zostera* and of coralline algæ, and a few broken sea-urchins and shells, and here and there a Crustacean or a Holothurian. The bottom was plainly visible as we steamed along, the ground occupied by animal or vegetable life presenting a different coloration.

The long cays which are scattered upon the northeastern extremity of the Bahama Bank to the northwest of Eleuthera are edged, as seen coming from the north, by very low cliffs of æolian rocks breaking in here and there on the otherwise continuous shore line. The north line of cays are fairly sheltered from the violent action of the swell, owing to the width of the shallow bank which extends beyond them, and also by the line of the coral reef which fringes nearly the whole width of the bank from a depth of five or six fathoms to ten or fifteen ; so that the sea is eating away but slowly the base of the shore hills of these cays.

Egg Island, on which we landed, does not differ from the typical Bahama cay. The base of the æolian hills on the south face has been beaten into diminutive vertical cliffs, which pass gradually into the rounded hill slopes of the cay. The surface of the rocks is more or less water worn, according to its distance from high-water mark and its exposure to the action of the sea.

### Eleuthera.

**Plate I.; Plate X. Fig. 2; Plates XXVII. to XXX.**

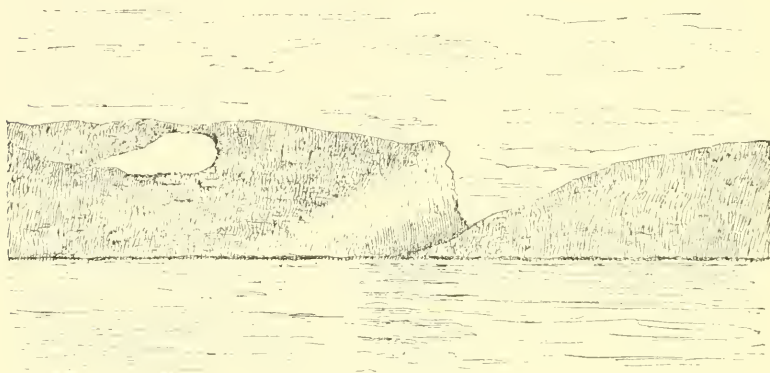
On both sides of the passage separating Northern Eleuthera from Eleuthera the island is so narrow that the whole surface is washed by the spray from both the eastern and western sides. The surface is free from vegetable growth, and the incessant action of the sea-water and of the rains has honeycombed the rocks from the water up to the highest ridge of the cliffs forming the eastern edge of the island. These cliffs are perpendicular, the heavy trade swells having broken off large masses of the eastern sides of the æolian hills and gradually washed them off into deep water, the 100 fathom line not being more than about a mile from the shore, and often much less, except at three or four points where the island must formerly have extended from five to six miles farther eastward, as off Savannah Sound, James Point, and the northeast bank to the eastward of Man Island. These perpendicular cliffs extend northward and southward, and form the sea face of Eleuthera. There is no shelf of any width at the base, and only along those stretches of the island where the coast shelf has any width do we find extensive patches of coral reefs forming a sort of barrier reef; as, for instance, at irregular intervals all the way between Eleuthera Point, Savannah Sound, and James Point, and again from Harbor Island to Egg Island, on the northeast and northern faces of the outside bank.

The photographs (Plates XXVIII., XXX.) will give a better idea than could any detailed description of the honeycombed surface extending north and south of the Glass Window Passage. In some cases the height of these little Gothic pinnacles is nearly three feet, and walking along the surface is very difficult. We met with similarly eroded surfaces at many other places in the Bahamas where the islands are narrow and their surface subjected to the action of the spray or surf, in addition to that of the rains in districts with a scant vegetable growth.

In the hollows formed by the disintegration of the surrounding surface there are accumulations of red earth, and there a few isolated stunted bushes begin to make their appearance. They gradually pass into larger patches as we come to wider parts of the islands not influenced by the action of the spray, where the decomposition of the surface rocks has been limited to the action of the rains. From three quarters of a mile to a mile both north and south of this barren tract, which looks more like an area covered with volcanic scoriae, the vegetation begins

again, and going south we soon pass into regions thickly covered with the same underbrush which is so characteristic of the shores of all the Bahama Islands; and inland we get patches of aloes, of palmettos, and of the forest trees characteristic of the Bahamas.

The arch of the Glass Window was evidently formed by the undermining action of the sea, which little by little disintegrated the underlying rock; finally the overlying arch gave way in part, leaving an opening known as the Glass Window, and remnants of the rocks forming the arch lining the western sides of the opening.



THE GLASS WINDOW.

Both the northeast and northwest winds act upon the southern shores of Northern Eleuthera, and are gradually eating away the outer shore shelf, forming low vertical cliffs, and leaving here and there numerous isolated rocks in from two to three feet of water, more or less water worn, and eroded or diminutive islets formed by the general subsidence and by erosion, which will gradually disappear and finally leave only the uniform flat level of the parts of the bank adjacent to the islands. An examination of the large-scaled charts of the Bahamas will show a large number of such islets and islands anywhere in this group, either on the windward or lee faces of the larger islands (see Plates IX., XII.). These different islets are now prominent, according to the height of the original hills of which they once made a part, or form shallow portions of the principal banks. The long island to the south of Savannah Sound, on the east face of Eleuthera, is an excellent example of such sloughing off (Plate X. Fig. 2).

The west face of Northern Eleuthera, as seen from our anchorage off

the Glass Window, is very much eaten away into low perpendicular cliffs behind a nearly flat area of considerable extent, eastward of which rise the hills forming the eastern face of the island. As we proceed south, the western cliffs become somewhat higher (Plate XXVII.), as the western hills composing that part of the island, instead of being cut away at the base like the northern hills, have been cut away at a considerable distance inland. To the eastward of the outer western range are piled three to four, or even five, irregular rows of æolian hills, the sides of which eneroach one upon another, and form more or less irregular ranges of hills according to the width of the island.

Even a casual examination of Eleuthera and of the adjacent islands to the northward and westward cannot fail to give one a very fair impression of the forces which have been at work on the Bahamas to bring them to their present condition.

Northern Eleuthera is nearly disconnected from Eleuthera by the gap forming the passage to the south of the Glass Window. Through this the sea breaks at high tide, and during a heavy swell the wash covers the path leading to Rock Harbor. The æolian hills which form the westward limits of the bay are protected from the sea by Harbor Island and Man Island. They are the inner range of hills which was once separated by a low flat from the outer range of which these islands are the remnants. With the general subsidence this flat has been changed to the shallow bay forming Harbor Island Bay. The action of the sea coupled with subsidence has in its turn formed the passage between these islands, as well as between Current Island and the western spit of Eleuthera. Similarly, George, Russell, Royal, and Egg Islands, with the adjoining rocks and islets, have become separated, and are left as the outcrops of a greater Northern Eleuthera which occupied in comparatively recent times perhaps the whole of the northeastern extremity of the Great Bahama Bank.

The action of the northwesterly and southwesterly winds along the western face of the islands has completely washed away the western ranges of hills which undoubtedly once formed a part of Eleuthera proper. The more southerly extensions now forming that part of the island from Palmetto Point to Eleuthera Point are the remnants of these ranges, the more prominent being the hills extending from Eleuthera Point to Powell Point, the outlyers to the eastward of which are the Schooner Cays, Finlay Cay, and the great sandbere bank to the eastward of the so called Middle Ground. This shifting bank we can readily reconstruct as a part of the greater Eleuthera, New Providence Island, to which I have already referred.



The condition of the western face of Eleuthera shows admirably the method of erosion, disintegration, and denudation which has taken place on the inner face of an island facing the great bank of which the part now worn away must once have been the summit surface.

Going south from the Glass Window, we keep sufficiently within sight of the land to read, as we pass along, its former history. About two miles south from the "Cove," where we anchored, begin a series of vertical cliffs, which continue almost uninterruptedly as far as Hatchet Point. They are full of holes and of small caverns, ribbed with stalactites, giving the face of the cliffs, not only here but everywhere nearly in the Bahamas, the appearance of basaltic rocks, more or less eaten away at the base. The cliffs are the remnants of the headlands, which have been worn away first, leaving only here and there a slope reaching from the inner hills to the shore. All along the west coast there is excellent sponging and fishing for large conchs. We found conch-shells and fragments of corals thrown up fully twenty-five feet above high-water mark, and lighter fragments of shells and dried stems of *Gorgonians* blown by the winds to the highest points of the hills on each side of the Glass Window.

Dana describes the surface of Metia, an elevated coral island which presents, I should say, much the same honeycombed appearance so characteristic of the more exposed and weathered islands and islets of the Bahamas, especially as seen at the Glass Window (see Plate XXX.). Its shore cliffs and rounded summits present a striking resemblance to some of the Bahamas. Compare the figure given by Dana (*Corals and Coral Islands*, page 193) with the figures I have given of the Bahama æolian hills and cliffs.

All the way from Hatchet Point to Governor Harbor (Plate X. Fig. 2) the same succession of vertical cliffs continues, with the same undulating, rolling æolian hills, perhaps a little lower behind the shore cliffs than farther north. To the south of Governor Harbor the ground falls off a good deal to Savanna Sound, and there are fewer vertical cliffs along the rest of the shore of Eleuthera extending to Powell Point. While coasting along Eleuthera we were taken at a good rate by a fresh northwester, which stirred up the bottom very extensively, and the whole sea was one mass of milky water carrying a very perceptible amount of particles of lime in suspension, derived both from the bottom and from the shores. There is to the westward of the island extending from the Cove to a few miles north of Tarpon Point a marked depression in the general level of the bank, varying from four to six fathoms in depth, with an average

width of more than eight miles (Plate X. Fig. 2). This must at some time in the history of the bank have formed an extensive lagoon or flat very similar to the lakes and flats now existing on a smaller scale at New Providence.

Although from abreast of Savanna Sound to Powell Point the general aspect of the island continues the same, yet from the altered trend of the shore its outline is greatly changed, and the island widens out between Powell Point and Eleuthera Point and extends eastward to form a long, irregular triangle, deeply indented by Tarpon Bay and Rock Harbor anchorage. The low spit forming the outer barrier of the harbor seems to be of recent shore sand origin, and not to be the remnant of some wider promontory. It is similar in structure to the few beaches and spits of recent origin which here and there have been thrown up to form small lagoons or barriers across headlands in favorable localities, where they are exposed to any length of reach of wind, as this point is to the north-west winds, which often blow here with great violence.

We leave the bank by a shifting channel leading from Tarpon Point by the sand spit to the north of Powell Point, to the westward of which lie an extensive flat formed by sand bars, and a few low isolated cays, like the Schooner Cays (Plate X. Fig. 2). This flat separates Exuma Sound from the deeper water on the bank to the northward of the sound. The shifting character of this channel is well shown from the fact that, drawing eight feet of water, we passed safely over a bar marked one foot on the chart as corrected to 1882. This extensive flat, filled with numerous dry sand bores, extending from Schooner Cays on the east to Finley Cay on the north and the Sail Rocks on the south, may mark the position once occupied by the westward extension of Eleuthera Island.

Entering Exuma Sound we skirted the Sound shore of Eleuthera past Bamboo Point to Eleuthera Point. The whole of this face of the island is low, the æolian hills not rising more than twenty-five or thirty feet in height. Near Eleuthera Point the rolling hills become slightly higher, some of them reaching forty to forty-five feet, — as Miller Hill, for instance, which is noted on the charts as forty-five feet high. There are numerous disconnected beaches on the Sound face of Eleuthera. The 100 fathom line is not more than two miles distant from the shore line, falling abruptly from the 10 to the 15 fathom line. Between Powell Point and Bamboo Point it is less than a mile off shore. The eastern extremity of Eleuthera Island at Eleuthera Point shows admirably the action of the sea in breaking through the long and narrow spit which



once must have connected Little San Salvador with Eleuthera Island, and gradually reducing it to the bank which now alone forms the connecting link, after having worn away the islands first formed, the remnants of which still exist as a series of isolated islets and rocks extending to the line of breakers to the east of Eleuthera Point, while here and there a single rock may still be detected standing in the breakers.

### Little San Salvador and Cat Island.

#### Plates I. and XXXIV.

Little San Salvador, and the islets and islands between it and the northern end of Cat Island, are the last vestiges of the former land extension of Cat Island, when it must have covered nearly all the space now limited by the 10 fathom line to the eastward of the island, from Hawk's Nest Point to Little San Salvador. Little San Salvador will eventually disappear. It is now low, not more than twenty feet high, and a long beach broken by six or seven rocky bluffs forms its easterly face.

Cat Island, where we anchored off Orange Creek, is interesting as having the highest land of any of the islands of the Bahamas. The



HIGHEST HILLS OF CAT ISLAND.

æolian hills to the north of Orange Creek are marked on the charts of the islands as being nearly four hundred feet high. Dunes of this height are not unknown; there are at the present day in many parts of the world high dunes covering extensive tracts, as along the Atlantic coast of the United States, both inland and along the sea border. They often rise to heights fully as great as those observed in the Bahamas, and that from comparatively narrow beaches. On the coast of the Baltic there are long stretches of unbroken dunes for many miles, the crest of which averages from ninety to one hundred and fifty feet in height, the summits rising to one hundred and eighty feet. On the west coast of Africa, near Cape Bojador, sand dunes are said to reach a height of over five hundred feet.

The west face of Cat Island is a series of low bluffs and beaches. The

hills become lower as we proceed south, and then rise again to form the rectangular shank of Cat Island extending from Hawk's Nest to Columbus Point. The highest hills of this part of the island are to the northwest of Columbus Point, on the western shore, near Fernandez Cay. There are a few isolated patches of reefs on the northeastern extremity of Cat Island, but none along the narrow bank formed by the 100 fathom line, extending from there to Columbus Point. To the eastward of Hawk's Nest there are patches and stretches of coral heads, forming an excellent reef harbor, Port Howe, between the Devil's Point and the Bluff.

### Nassau to Harvey Cay.

Plate I.; Plate X. Fig. 2; Plate XXXVI.

Passing out from Nassau to the eastward, Potter Cay divides the main channel into two parts, one of which is quite shallow. The æolian character of the low hills forming the base of the promontory at the extremity of which stands Fort Montague is well marked, and as we steam out we can see their continuation to East Point. On the other side of the channel we pass a series of low islands,<sup>1</sup> Hog, Salt Cay, and Athol, on the last of which stands the lighthouse. Their southern face is formed of low vertical cliffs; the vegetation upon these islands is scanty.

Dredging occasionally beyond the eastern channel, we brought up nothing except algæ and corallines; we passed a few patches of coral heads and of Gorgonians, generally opposite to openings between outlying islands which give a freer access to the water from Providence Channel. Our course lay southeast from the Porgee Rocks, and for a considerable distance we passed over a bottom nearly barren of animal and vegetable life; it consisted mainly of clean sand, with here and there a coral patch or a cluster of Gorgonians; but the farther south we steamed on the

<sup>1</sup> It seems to me that the explanation given by Dr. Northrop (Trans. New York Acad. of Sci., Oct. 13, 1890) regarding the formation of the cays north of Nassau Harbor is not the correct one. They owe their existence, not to the coral sand which has been thrown up from the outlying coral reef, but to the denudation and erosion of an outer line of æolian hills parallel to the Nassau range which forms their basement. It is true that upon their sea face coral sand has been heaped up between the headlands of the æolian hills composing the cays, and sometimes blown to a considerable height to form broad and high beaches, as on the sea face of Hog Island, but the æolian rock underlying them crops out in all directions, especially on the south side of the cays.

bank, the less numerous they became. The same was the case also when we crossed the bank from Nassau to the Glass Window; the patches of Gorgonians were more numerous as long as we kept in the vicinity of the line of cays extending from New Providence toward the Fleeming Channel.

On reaching the so called Middle Ground (Plate X. Fig. 2), we came upon a mass of Gorgonians and coral heads, through which our pilot picked his way by sight. This stretch of coral and Gorgonia ground did not extend far; we soon passed out of it and were back again upon the usual sand bottom, nearly bare of animal and vegetable life, with only an occasional patch of corals or Gorgonians. We next came upon the line of cays extending south of the Ship Channel, and were in plain sight of the æolian hills and cliffs of Saddle Cay and Norman Cay. The bank as we go south continues bare of animal life, no patches even of Gorgonians or clusters of heads of coral to be seen in any direction. Later we could see the vertical faces so characteristic of the western sides of the cays in the vicinity of Conch Cut, and to the south of that the æolian hills belonging to the chain of cays to the north of Harvey Cay.

Coming upon Harvey Cay, Bitter Guana Cay, and Great Guana Cay from the west, we were able to form an excellent idea of the character of the shores of the larger cays which are somewhat protected from the action of the trade wind swells. Their structure is the more striking in contrast with the outlying small low and water-worn cays which characterize Conch Cut and Rudder Cut. These low islets are mere ledges of rocks rising but a few feet above the water line, and likely to stand but a comparatively short time as a barrier to the inroads of the sea upon the larger inner cays.

Harvey Cay is itself greatly disintegrated; it is attacked by the spray and rain. There is but little vegetation upon it, and the limit of action of the sea upon its eastern face is very plain, at many places bare rocks extending close to the top of the cay. The east face of the cay is pitted from the action of the sea as far as it can reach. The cliffs of the lee shore are full of cavities and caverns, which have been exposed by the gradual inroads of the sea on the base of the æolian hills. As we steamed south, we could see the breakers throwing the sea over many of the smaller outer islets, or dashing its spray high above the summits of the high cays of the outer chain on the eastern edge of the bank. On Harvey Cay a little wild sisal grows; the more sheltered parts are covered with hard-wood shrubs, and the ordinary plants are found near the shore line. The bottom where we anchored was composed of a

kind of sticky marl, — greatly decomposed æolian sand. The nature of the bottom is accurately noted on the charts, and from the examination of the many samples collected it will be quite possible to give an excellent account of its characteristics.

On our way south we attempted to reach some of the ocean-holes marked as existing near Blossom Channel. Unfortunately the sea was too rough, and it was impossible in the disturbed condition of the bottom to recognize their position.

Harvey Cay is connected with the outer cays to the south of it by a number of small low cays, half eaten away by the action of the sea, which reach to Exuma Sound. They form a series of narrow parallel lines of rocks, with passages like those of Rudder Cut between some of the cays. These islets are in every respect similar to the numerous small islets we saw as we passed through Conch Cut (Plate XXXVI.). They extend across the passage between Harvey Cay and Great Guana Cay.

#### From Harvey Cay to Great Ragged Island and Columbus Bank.—The Sand Bores of the Bank.

**Plate I.; Plate XI. Figs. 3, 5; Plate XII. Figs. 1, 2, 4; Plate XXXV.**

The passage round Galliot Bank gave us an excellent idea of the alternating channels which exist between the different sand ridges running in a westerly direction from Galliot Island to the Barracouta Rocks. The navigation is entirely by the eye, and the boat is forced across the deepest part of a terminal ridge or of a lateral spur into the nearest channel. To the windward and leeward we could see on each side three or four additional bores, parallel in a general way to the two between which we were steaming. The channels and their probable depth were fairly indicated by the color of the band of water separating them. This bank is very similar to the bores to be seen on many other parts of the bank. The sand bores and sand spits separating the channels are plainly indicated by the light emerald-green color of the water, which is in marked contrast to the darker purplish color of the belts of deeper water forming the navigable channels.

Of course, where there is such constant disturbance over the bottom, and shifting of these large sand masses in accordance with the action of the winds prevailing for any length of time, as on the Galliot Bank, we were not surprised at finding the bottom bare of all animal or vegetable life.

Some of the shallower parts of the bank are practically impassable even for the smallest boats, owing to the existence of extensive stretches covered by shifting sand bores more or less exposed at low water, when they drift like æolian sand in the direction of the prevailing winds, or are run into more or less broken ridges parallel with the direction of the short seas breaking over the flats. Such tracts on the Great Bahama Bank are formed on the northeast part of the bank extending ten miles to the westward of the Berry Islands, where we find the water on the bank varying from a quarter fathom to a fathom to the westward of the cays, and extending to a line running diagonally across the bank from the Northwest Channel to Great Stirrup Cay (Plate XII. Fig. 4). Another track extends to the north and northwest of Andros, about fifteen miles to the westward of the Joulter Cays (Plate XI. Fig. 3). A similar small patch runs parallel with the southeast end of Andros for a distance of nearly ten miles, extending westward from Curley Cut Cays and rising from the great sand flat, which increases very gradually in depth as we go west, having a depth of only two fathoms fifteen miles southwest of the cays and three fathoms at a distance of twenty miles in the same direction. Extensive bores also occur to the eastward of the Beminis, and a belt of sand bores varying in width from one to five miles extends from eastward of Gum Cay to South Riding Rock, a distance of more than twenty-five miles.

There are also a number of such bores on the Mackie Bank, to the eastward of the Beminis (Plate XII. Fig. 2), and between that and the Northwest Passage another extensive tract, forming a bank of about ten miles by eight, traversed by numerous sand ridges, carrying from one and three quarters to two fathoms and from two and a half to three fathoms between them. From Orange Cay in a northerly direction as far as the latitude of the Beminis we find a number of isolated patches or banks of sand, held together by the masses of a species of *Thalassia* growing upon them. About twenty-five miles to the south of Orange Cay there is a narrow belt of sand ridges running nearly parallel with the 100 fathom line for a length of about eighteen miles. These banks and bores are limited to the area north of the great marl deposit to the west of Andros, which extends from a line running west a few miles north of Billy Island to from five to ten miles south of South Bight, the western limit of which varies from three to five miles from the 100 fathom line. Outside of these limits we again find the æolian sand, more or less modified by the fragments of coralline algæ or of Invertebrates which once lived upon the banks. Algæ also flourish upon the white clay or marl

district; but the number of species is not so varied as upon the other kinds of bottom.

By far the most striking of the sand bore districts is the one which forms the great sweep of the southern *cul-de-sac* of the Tongue of the Ocean (Plate XII. Fig. 1). South of the cays to the southward of Washerwoman's Cut (Plate XI. Fig. 3) is a tract of about ten by fifteen miles which is a mass of sand bores, many of them dry. To the eastward for a distance of thirty-five miles they run in a southwesterly direction, at a sharp angle with the course of the 100 fathom line. In this part of the bank they are broad ridges, more or less undulating, some of them half a mile in width and sometimes twelve miles in length, often nearly dry in places, and with from one to three fathoms on the ridges, separated by broad channels with from four to six fathoms of water. Some of the wider of these channels are regularly used as approaches to the interior of the bank, and are known as Queen's, Blossom, Thunder, and Lark Channels, through which vessels bound for Cuba cross the bank, coming out either through the Man-of-War Channel, south of Flamingo Cay, or running west of the Ragged Islands and crossing the Columbus Bank. The eastern extremity of these sand bores is formed by a tract of narrow sand ridges, with deep water between them, extending some fifteen miles along the edge of the bank on the eastern face of the Tongue of the Ocean.

To the eastward of Hawk's Bill Rock there is a line of sand bores to the south of the line of small cays reaching to the centre of the west shore of Great Exuma. To the west of the north end of Great Exuma occur a series of dry sand bores, with from one to two fathoms of water between them. They trend in a westerly direction, and run north, where they join the southern bores of the Galliot Bank. An extensive series of sand bores, many of them dry, runs east from Green Cay across the bank to within about ten miles of Conch Cut. During one whole day's sailing from Harvey Cay south nearly to our anchorage off Flamingo Cay we did not come across any patches of Gorgonians or of coral heads.

The Brigantine Cays, the Barraconta Rocks, and Hawk's Bill Rocks, low cays and patches of æolian rock, are the fragments of the western extension of the northern extremity of Great Exuma.

When we reached our anchorage off Flamingo Cay, we found the bottom a mass of broken shells, of fragments of corals and Gorgonians, and covered by Nullipores. As we approached Flamingo Cay we came in sight of some of the small islands forming a part of the chain of cays



which extends in an easterly direction from Flamingo Cay along the eastern curve of the bank towards the western extension of the central spit of Long Island. These cays are well rounded and weathered, presenting the usual features of cays forming the broken wall which now denotes the former extension of the Ragged Cay and Flamingo Land to the westward till it perhaps once formed part of the Andros, Lobos, Orange, and Bemini Land.

Some of the cliffs of the western face of Flamingo are high, separated by small coral and æolian sand beaches. The high coral sand beach opposite our anchorage formed the sea-wall of a small lagoon. The southern end of the beach was formed by fragments of conchs of all sizes up to nearly perfect shells, cemented together with æolian sand, fragments of corals, and broken shells, forming a splendid breccia. The shells in the lagoon of Flamingo Cay were very much smaller than specimens of the same species thrown up on the sea face of the beach.

After passing Hawk's Bill Bank we came upon patches of corals and Gorgonians, which became more extensive as we approached Flamingo Cay, the water at the same time becoming somewhat deeper and clearer, the bottom being less affected by the action of the seas due to the prevailing winds.

Flamingo Cay (Plate XXXV.) is comparatively well covered by vegetation; there are many wild guava bushes and shrubs. The æolian rocks, as seen on the two sides of the landing beach, are greatly eroded by the action of both fresh and salt water, the whole surface of the rounded æolian hills being pitted and honeycombed. The æolian rocks of Flamingo Cay are much harder than is usually the case with the æolian rocks so close to the sea-shore. The cays to the south of Flamingo are excellent specimens of æolian cays, with rounded summits almost bare of vegetation, and with surfaces pitted and worn by the action of the sea and rain upon them. Heavy seas could be seen breaking over those nearest the outer edge of the bank. The vertical cliffs of Flamingo were riddled with cavities and fissures, as were also the cliffs of the islands to the south of Flamingo, between it and Man-of-War Channel.

Steaming south from Flamingo Cay, we cross a series of bars running apparently at right angles to the trend of the cays, having from two to two and a half fathoms over the ridges, with numerous patches of coral heads and of Gorgonians. Some of the cays to the south of Man-of-War Channel were formerly inhabited; but since the destruction of the salt trade on Great Ragged Cay they have been abandoned. All except



Nurse Cay, which is quite fertile, are bare, or support at best a very scanty vegetation.

From Nurse Channel the chain of cays continues toward the Great Ragged Cays. We pass the white cliffs of Nurse Cay, with its low æolian hills forming a slightly undulating line on the horizon, separated by a narrow channel from Buenavista Cay. Next come Racoon Cay and Double-breasted Cay, all very bare of vegetation, with here and there a long coral sand beach separating the low cliffs formed by the eating away of the base of the æolian hills which form this chain of cays.

The disintegration of the formerly existing land masses, and their breaking up into smaller masses or islands or islets, and finally rocks and sunken banks, is also in great part a process not entirely due to the mechanical action of the waves. Both the æolian and coral shore rocks become most friable when saturated with sea water, so that large masses are constantly sloughed off from the base of the hills which project into the sea. These fragments of greater or less size are themselves rapidly disintegrated by the same process, resulting in a coarse sand consisting of æolian or shore coral sand, which helps to form the small beaches so frequently separating indistinct headlands marked by vertical cliffs. By this process, beaches, small bights, or diminutive harbors may be formed in the midst of faces of high or low cliffs, parts of which have been affected more than others by the action of salt water.

### Ocean-Holes.

#### Plate III.

May we not to a great extent measure the amount of subsidence which must have taken place at certain points of the Bahamas by the depth attained in some of the so called ocean-holes, as marked on the charts? Of course we assume that they were due in the æolian strata to the same process which has on the shores of many islands formed pot-holes, boiling holes, banana-holes, sea-holes, caverns, caves, sinks, cavities, blow-holes, and other openings in the æolian rocks. They are all due more or less to the action of rain percolating through the æolian rocks and becoming charged with carbonic acid, or rendered acid by the fermentation of decomposed vegetable or animal matter or by the action upon the limestone of sea water or spray under the most varying conditions of elevation and of exposure. None of them have their upper openings below low-water mark, though some of them may reach many

feet below low-water level. Ocean-holes were formed in a similar way at a time when that part of the bank where they exist was above high-water mark, and at a sufficient height above that point to include its deepest part. The subsidence of the bank has carried the level of the mouth and of the bottom of the hole below high-water mark.

From the description of the strata which crop out upon the banks in the vicinity of some of the ocean-holes at Blue Hole Point, there seems to be little doubt that the stratification characteristic of the æolian rocks has been observed.

The principal ocean-holes, Blue Holes, are the following: one five to six miles from Hawk's Bill Rock; three, of eighteen, twenty-four, and thirteen fathoms, a little east of north of Blue Hole Point, each about five miles apart on a northerly line; and two, of seventeen and thirty-eight fathoms, in the extension of the line of Blossom Channel leading from the Tongue of the Ocean upon the bank.

I am able, thanks to the kindness of Captain Wharton, the Hydrographer to the Admiralty, to give three sketches of these Blue Holes, showing the character of the soundings around them (Plate III.). They are such as we should expect to obtain from any part of the cays where there are many light-holes, if sunken below the level of the sea.

At other places on the banks ocean-holes are said to exist. Among those not on the charts, I may mention a fifteen fathom hole at High Point, Andros, and a twenty fathom hole in the Middle Bight, between Gibson Cay and Big Wood Cay. Dr. Northrop has examined some of the ocean-holes of Andros, and has given a description of those he visited.<sup>1</sup>

Except in the case of some wells at Nassau, there has been no observation of æolian rocks at any great depth below the surface. At the Bermudas the æolian rocks have been traced *in situ* during the building of the dry dock to a depth of over fifty feet. The presence there of trunks of trees would indicate the invasion of sand dunes at some time, much as they invade the gardens of the Bermudas at the present day.

From the description of the Bermudas given by Rein, Thomson, Fewkes, and Heilprin, there appears to me little doubt that we have there repeated on the bank of the Bermudas the identical processes which have been described in this paper, and that the Bermudas and the Bahamas owe their present configuration to the same process of waste which has been going on during their subsidence; that the so called diminutive lagoons we find there are not lagoons in the ordinary

<sup>1</sup> Trans. N. Y. Acad. of Sci., Oct., 1890.

sense of atoll lagoons, but are merely small pot-holes or former banana-holes which have come to be below high-water mark. Certainly there seems to have been nothing written to prove that the present configuration of the so called Bermuda atoll is directly due to the formation of the coral reefs which are still growing upon the bank, and their increase in thickness owing to the subsidence of the bank. I shall return to this subject in the description of my visit to the Bermudas.

In the shallower places on the Bahama Bank the whole body of water was discolored by the presence of sand stirred up by the action of the waves, and it is only natural that in all those parts of the banks where the water is constantly rendered turbid by moderate winds we should meet with so little animal life; for Gorgonians and corals can only flourish in clear water, and even corallines cannot obtain a foothold where the ripple-marks are too frequently changed or the bottom sand is in constant motion. Between Nurse Cut and Racoon Cut very little animal life was to be seen on the bank. After passing Racoon Cut we came upon a good many patches of coral heads and Gorgonians. At the same time the water was gradually deepening to the westward, and we seemed, steaming parallel with the general trend of the cays, to be cutting across a number of sand spits about at right angles to the shore line of the cays, and trending in the general direction of the prevailing winds.

### Great Ragged Island.

#### Plate XI. Fig. 5.

Great Ragged Island, the most southerly of the cays on the Great Bahama Bank, does not differ in structure or appearance from the other cays of the group. The rocks are æolian, hard, full of caverns and cavities in the cliffs of the west side, with here and there fine sand beaches between the spits of projecting rocks. At our anchorage the coral sand was much coarser. After leaving the anchorage we passed Hobson's Breakers, to the south of Ragged Island, which are all that is left of what must once have been an island of considerable size.

### Columbus Bank.

Columbus Bank, which lies to the southeast of Ragged Island, is fully exposed to the swell of the prevailing trades. Whatever cays once existed upon it have disappeared, with the exception of Cay Verde and Cay

San Domingo. The depth of water upon this bank is considerably greater than upon similar stretches of the Bahamas. Here and there patches of shallow water are dotted over its surface, but the average depth varies from seven to eleven fathoms. The sea at the time we crossed it was quite rough, and the action of the heavy swell upon that part of the bank must be quite effective.

### Long Island.

Plate X. Fig. 6; Plate XI. Fig. 2.

From the southwestern side of Exuma Sound extends Long Island, which projects far out from the angle of the bank. The eastern shore of Long Island is made up of a series of æolian hills, with more or less steep faces to the sea. Its highest point is one hundred and fifty feet. The island is narrow, often not more than a mile in width, varying from that to little more than three. It flanks the eastern face of the most easterly extension of the Great Bahama Bank. The 100 fathom line is generally within two miles or so of the eastern shore line. South of Clarence Harbor the island forms a long narrow spit, running southeast with the 100 fathom line within a couple of miles on



ÆOLIAN HILLS, CLARENCE HARBOR.

both sides, while off the eastern face of the northern part of the island an extensive flat, with less than three fathoms, connects Long Island with the chain of the Exumas. This flat is the continuation of the great flat which extends to the westward of the Exumas and the line of innumerable small cays forming the western bank of Exuma Sound. On the west side of the island, opposite Clarence Harbor, the bank makes a great sweep, the outer edge, protected by the Junientos Cays, forming a half-circle nearly to Ragged Island and the northern edge of Columbus Bank. A few small salt ponds, formed in the valleys of the æolian hills, are found near Clarence Harbor. The general trend of the æolian hills, both north and south of our anchorage, could be readily traced till the low hills disappeared below the horizon. Patches of coral are growing in the harbor, which is protected by small cays from the prevailing winds.

From Clarence Harbor we crossed to the west shore of the island. The salt ponds near Clarence Harbor are separated from the sea by an outer range of æolian hills. From the level of the ponds we gradually rose to the top of the second range, perhaps eighty feet above the sea level, and then gradually passed down the sea face of the slope of the last æolian range to the low western shore. Here we found a long, narrow lagoon, Salina Flat, formed by the throwing up of a low outer bank of æolian sand recently washed up and inclined at a slight angle to the sea. The lagoon, which skirts the western shore of the southern part of Long Island, is about twenty-five miles in length, extending to the southern extremity of the island. To the northward, what is now a flat must have been a wide lagoon; only a part of the southern end of the bank which once separated it from the sea is now left. In fact, as will be shown later, Long Island, with the string of islands extending north of Exuma as far as Ship Channel at the north end of Exuma Sound, and the line of cays forming the curve of the southeastern face of the Great Bahama Bank as far as Columbus Bank, are the remnants of what must once have been an extensive island. This island gradually became separated, first into a series of islands closely packed together, and later, by greater subsidence, into the innumerable islands now forming the eastern edge of the Great Bank, the islands and the Great Bank itself being all that now attest the existence of the island or islands which must once have covered the bank inside the 10 fathom limit.

Long Island is noted for its many caverns. On the road across from Clarence Harbor to the west shore we could not fail to be struck with the many pot-holes, banana-holes, sinks, and other signs of the extensive denudation to which the æolian limestone rocks forming the hills had been subjected. The accumulations of red earth here and there add their testimony to the extensive action of rains, which must have carried off the surface of the hills as they percolated through the fissures of the rocks and forced their way, little by little, through the porous mass, to form the numerous and often extensive caverns which are met with in every direction.<sup>1</sup>

In many parts of the island we passed through forests with trees of quite a respectable size, such as *lignum-vitæ*, pidgeon plum, tamarinds, and the like, giving us an idea of the fine forests which must have covered some of the islands at the time of their discovery by Columbus,

<sup>1</sup> Perhaps the most extensive caves of the Bahamas are those of East Caicos, described by Sharples (Proc. Boston Soc.-Nat Hist., XXII. 247, 1883).



and in marked contrast to the pine-covered cays of Andros, New Providence, and the Little Bahama Bank.<sup>1</sup>

From Cape Verd north the coast of Long Island is formed by low rounded æolian hills with gentle slopes to the eastward ; it then passes



ÆOLIAN HILLS AND CLIFFS, SOUTHERN PART OF LONG ISLAND.

into much higher hills, the base of which is formed by vertical cliffs of æolian rock, extending to the southern extremity of the opening of Clarence Harbor. To the north æolian hills of varying heights succeed one another, flanked to the eastward for almost the whole length of the island to its northern extremity by vertical cliffs full of holes and caverns. At a short distance south of Cape Santa Maria these eroded cliffs are quite striking.



ÆOLIAN CLIFFS SOUTH OF CAPE SANTA MARIA.

At the landing place the shores of Clarence Harbor consist of recent coral sand strata, dipping slightly to the sea. The summit of the ridge of one of the islands forming the outer barrier of the harbor, say twenty-five feet above high water, was formed of æolian rocks ; on the inside, round the base of it, shore coral deposits had collected, which were exposed in the flats between the æolian hills forming the outer line of the harbor and the shore of the island. On the summit of the outlying islands we observed many huge angular blocks similar to those which are thrown up by hurricanes and line the outer shores of so many of the islands of the Bahamas.

We were able on this island easily to observe how the sea undermines the æolian rocks. Huge rocks are thus broken off from the sea face, fall into the sea, and are in turn broken into smaller blocks, either as they crumble from the fall, or by the subsequent action of the sea as they lie piled up just as if the base of the hill had been blasted ; and subsequently, at times of violent storms or of hurricanes, these huge

<sup>1</sup> See List of Plants collected in the Bahamas by A. S. Hitchcock (4th Ann. Rep. Mo. Bot. Garden, 1893).

masses are hurled inland and deposited far above the ordinary high-water mark. All the way along the sea face of Long Island we passed large masses of gulf-weed, many of these patches more than twice the size of the yacht.

The difference in the aspect of the vertical cliffs in different parts of the Bahamas is very marked. If formed at the base of the gentle windward slope of the æolian hills, they are low and of very uniform height, especially if that face is the bank face of the island; but where the lee face of the hills — lee when formed — is also the sea face, the cliffs are on the steeper slope of the æolian hills, are far more irregular, and their height varies greatly, according to the height of the hill which is attacked and the distance inland to which the action of the sea has reached.

The corals do not form a regular reef off the east face of Long Island.

### The Exuma Islands.

Plate X. Fig. 5; Plate XI. Fig. 1.

To the west of Cape Santa Maria, Long Island has disappeared, leaving only a shallow bank flanking it for its whole length and connecting it with the Exuma Islands. From the central part of the western line of these islands extends a long, narrow spit, the only mark of the former extension of Long Island in that direction. It must have been a continuous shore, forming a great curve, indicated now by the row of islets and rocks which flank that part of the bank, extending in an unbroken line to Flamingo Cay, and from there by Seal Cay and the islets running to the north of Columbus Bank from the Ragged Cays as far as Nurse Channel.

Great Exuma is the largest fragment remaining of the land which once formed the eastern edge of the bank flanking the west side of Exuma Sound. Like the many islands, islets, and rocks extending northward as far as Ship Channel, it is built up of æolian rocks. Georgetown, the principal port of Exuma, lies upon a long inland sound studded with islands, and sheltered from the outer sound by a series of low outlying islands which form a barrier against the force of the trade swell, which gains considerable force over the forty miles or more of sea-way from the eastern side of Exuma Sound. These outlying islands are themselves gradually being eaten away, and were once also a part of the greater Exuma land, which has little by little become dismembered by the action of the sea upon the subsiding æolian hills. In the inner sound, which extends



for many miles southward and northward of Exuma Harbor, and forms one of the prettiest stretches in the Bahamas, there are many diminutive cays, isolated rocks of all sizes, with rounded ridges undermined at the water's edge and ready to topple over and disappear. The æolian rock, kept constantly wet, becomes soft and readily crumbles, and is washed into æolian rock sand. The whole floor of the harbor is covered with fine sand of this kind, and the harbor is gradually filling with material derived from the wash of the windward row of outer islands. Off Exuma, between it and the northern end of Long Island, the edge of the bank is comparatively wide. The British Admiralty Chart, No. 393, shows admirably the gradual wasting of the land which has taken place to form the inner sound.<sup>1</sup> There was comparatively little animal or vegetable life on the floor of the harbor where we examined it. On leaving Exuma we sounded at short intervals, and found the sea slope of the bank much less steep and more gradual than that of other faces we had explored.

### From Conch Cut to Green Cay.

#### Plate XXXVI.

From Exuma Harbor we steamed northward to Conch Cut, keeping as close as was prudent to the outer line of cays, which all showed indications of great erosion. On the northern extremity of Great Exuma the æolian hills are closely packed, and reach a height of one hundred and fifty feet. The islands of Lee Stocking and Great Guana present the usual features of æolian hills attacked by the sea at the base of the longer slope. The smaller cays are bare, while even on Exuma and the larger cays the vegetation is far less luxuriant than we might expect from the size of the islands.

Passing through Conch Cut to enter upon the bank on our way to Green Cay, we were struck with the number of small islets, which form a wide protecting belt against the encroachments of the sea. The islets are all exposed on the lesser slope of the æolian hills to the action of the trade swells, while the steeper face has been attacked by the shorter, sharper waves reaching across the bank, and undermining the western faces of the islets to an extraordinary degree. The solvent action of the sea water has also undoubtedly played an important part in producing the fantastic shapes which some of the islets and isolated rocks have assumed; so that by this combined action a wide shallow bank

<sup>1</sup> See also U. S. Hydrographical Charts, Nos. 26<sup>b</sup> and 26<sup>c</sup>.

has been formed which connects all these islets together, leaving only such entrances as Conch Cut, Wide Opening, and Wax Cay Cut for the passage of craft of shallow draft. The light green color of the bank



WATER-WORN ISLET, CONCH CUT.

connecting the islands indicates very markedly its position as contrasted with the deeper waters of the passages and of the outer sea edge of the bank. The larger cays are flanked on the western face by white sand beaches, formed by the rapid disintegration of that side of the cays.

All the way across the bank, from Conch Cut to Green Cay, we found but little life upon the bottom; there were no patches of weeds or of Gorgonians, the bottom being everywhere composed of coarse æolian sand. But when about two to three miles off Green Cay, patches of coral heads and of Gorgonians begin to appear, and become more numerous as we approach the western edge of the bank forming the eastern side of the Tongue of the Ocean. The absence of animal and vegetable life upon the bottom of the interior of the banks is undoubtedly due to the constant shifting of the coral sand from the action of the sea. At moderate depths of one to three fathoms we could everywhere see that action plainly indicated by the presence of ripple marks. In the shallower parts of the banks this action forms great sand bores, which, exposed to the action of the winds, also tends to increase them in size in the direction of the prevailing winds. To the eastward of Green Cay we could see such a great sand bore, seven feet high, forming as it were a cay consisting of nothing but a constantly shifting tract. In many localities on the banks these great sand bores have assumed quite definite positions, which they retain, merely shifting north or south or advancing eastward or westward within narrow limits. At our anchorage off Green Cay the bottom consisted of fine hard coral sand, fairly well covered with coralline algæ.

### Green Cay.

#### Plate XXII.

The western extremity of Green Cay itself is the termination of one of these shifting bores, and its frequent changes of position and dimen-

sion are known to every skipper who anchors off its shores. Green Cay has been extended by this sand bore to the very edge of the plane where the sudden drop in depth beyond the 20 fathom line takes place. The æolian rocks of Green Cay crop out at the eastern edge of this sand bore. Against these outcrops the bore rests, and in some places has completely overwhelmed them. At the eastern extremity of the western spit a mass of blocks of æolian rock has been piled up by some hurricane. On Green Cay we find the same pupæ so characteristic of all the Bahamas. The vegetation reminds us of that found on Eleuthera along the shore line. The principal mass of Green Cay, which rises to a height of sixty feet, is of æolian origin; but the extent of the cay is greatly modified by its being a buttress for the sand bores which extend from it both to the westward and eastward. Green Cay is marked among the Bahamas for the combination it presents of sand bores and æolian rocks, and shows how some parts of the banks themselves may have been formed of movable bores at certain stages of their subsidence, when masses of sand large enough to become affected in their movements by the action of the sea and of the winds had accumulated from the disintegration of fixed nuclei of æolian rocks. It is very easy to imagine such a process as we saw going on at Green Cay to have been an important factor in connecting adjoining hills or in filling low valleys between neighboring islets. Green Cay is the only cay left to indicate the former existence of the land which once extended round the edge of the Tongue of the Ocean all the way from New Providence to the islets to the south of Andros, parallel with the line of the 100 fathom soundings, which now alone indicate its probable original outline.

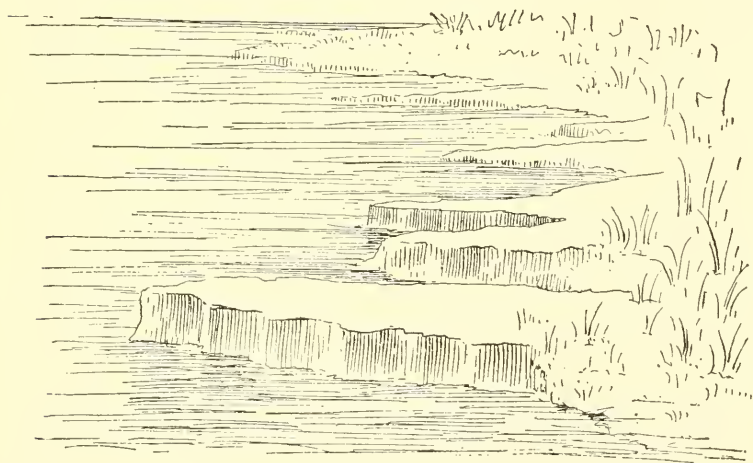
### Andros and the Western Part of Great Bahama Bank.

Plate XI, Figs. 1, 3; Plate XII, Fig. 3; Plate XXXIII.

From Anguila Island we crossed the Santaren Channel during the night and made for Wide Opening early in the morning. When in sight of Andros we made a haul for a specimen of the bottom, and obtained our first sample of the so called "white marl," which is marked on the charts as extending many miles west of the Wide Opening of Andros, as well as to the north and south, forming a huge triangular patch characterized by this peculiar bottom. It consists of a very fine chalky ooze, resembling plaster of Paris which has just been mixed for setting.

From our anchorage to the shore of Andros at the mouth of Wide

Opening, a distance of about eight miles, we found the bottom sloping gradually, with here and there a few blades of *Thalassia*. It was everywhere composed of the same marly substance, and sustained but little animal life. A few *Lupas*, a couple of small sharks, and the holes of a *Squilla* seemed to be the limit of the fauna and flora of this marly waste. On reaching the shore, we found the land, as far as we examined it, to consist of the same white marl as the bottom, but still sufficiently solidified to enable us to walk upon it. It was somewhat elastic, giving us the sensation of walking upon a sheet of India-rubber. In some places the marl was covered with a black alga, forming a thin crust, or it was often coated with a harder material composed of minute fragments of shells and of sand, giving the surface a gray appearance. On digging into the soil, we found the same white marl, more or less mixed with vegetable matter. The shore upon which we landed was at no point more than from twelve to fourteen inches above the high-water



WEST SHORE OF ANDROS, WIDE OPENING.

mark. The country inland seemed well covered with low vegetation, and mangroves flourished in every direction. Here and there a ridge of sand had been blown up, composed of fragments of shells and of crabs. These ridges, rising a few inches higher than the general dead level around them, formed the high ground, as it were, upon which was growing a somewhat richer vegetation, composed mainly of the same

plants so characteristic of the shore lines of all the Bahamas. Upon these sand ridges also flourished small groves of palmettos.<sup>1</sup>

As we steamed northward, the low, dark line of Andros stood out in marked contrast with the intensely light-green water, extending as far as the eye could reach over the shallow bank to the westward of the island. Here and there the low line was broken by a high mangrove tree looming up like a cliff in the distance, or was interrupted by a stray line of high palmettos on some sand ridge near the shore. The edge of the island near Wide Opening is occupied by a lagoon inside the shore line, and the deep bights which characterize the island show clearly how it has little by little been eroded, then cut into halves and thirds, next into smaller cays, and finally, wearing away having commenced, has left here and there a small cay (Plate XII. Fig. 3, and U. S. Hydrographical Chart, No. 26\*) to the westward of the main island. As the water is quite shallow all along the west shore of Andros, its action is most feeble, and it must have triturated and ground very slowly all the shore material into the very fine and minute particles composing the "white marl" covering so large an area of the bank between the island and the Santaren Channel. This white marl looks almost like deep-sea chalky ooze; it has about the same consistency, is made up of the same nearly impalpable fine particles, and is of the same whitish color. A similar white marl deposit is also found, only on a most limited scale, in protected pools exposed to the very lightest wash of the sea in the recesses of the shore line.

The shores of the inner lagoons, and in many places the main shore of the island, is lined with mangroves, many of which are large, and form the most prominent landmarks available in the navigation off the west shore of Andros.

As far as Williams Island, about twenty-five miles to the northwest of Wide Opening, the bottom on the bank is composed of the same white marl. All the way to Billy Island we found no change in the character of the bottom, which seemed fully as barren of animal life as it proved while rowing to the shore of Wide Opening from our anchorage. On our way north from Wide Opening we steamed in water so shallow that we left in our wake a broad belt of white water, stirring up the white marl with the wash of the screw.

On going ashore at Billy Island we found it to consist of the same finely triturated æolian rocks. The shores were formed by miniature

<sup>1</sup> See Northrop's description of the "Swash" ("The West Coast of Andros," Trans. N. Y. Acad. of Sci., Oct., 1890).

vertical cliffs of about eighteen inches in height, presenting all the appearances of water action so characteristic of the higher limestone cliffs on other islands of the Bahamas. The diminutive seas had eaten out small bays, formed promontories, and indented the coast in a man-



YOUNG MANGROVES, WIDE OPENING.

ner no less characteristic than the shore lines of higher islands when exposed to the full action of the trades. Masses of dead shells are found blown up or thrown up on the diminutive beaches of the recesses cut out of the shore line. Billy and Williams Islands must at one time have formed a part of the northwestern extension of Andros. There is no part of the Bahama Bank which is so instructive as that now occupied by Andros. Nowhere else do we find so large an island undergoing all the processes of disintegration, division, and erosion which have on other parts of the bank ended in forming the submarine shoals, and leaving here and there traces of the former extension of the larger islands of which the bank was composed. Andros still occupies a comparatively large part of the Great Bahama Bank to the west of the Tongue of the Ocean; yet it is cut into three islands by the so called bights which connect the Tongue of the Ocean with the shallow waters of the bank to the westward of Andros. Its former southern extension is marked by the numerous small islands, isolated rocks, sand banks, and ridges reaching southward and eastward from the southern end of Andros. Its former western



extension, perhaps close to the edge of the Santaren Channel, is well marked by the great belt of white marl, which we may see formed under our eyes on the shores of Wide Opening. The northern limit is marked by the spread westward and northward of the white marl, with here and there a remnant of the main island as an isolated cay, like Billy or Williams Island, reaching perhaps to the northern extremity of the bank, where the only traces of its former existence are the rocks, islets, and shallow bars extending from Great Isaac to Great Stirrup Cay, forming to the eastward of the northern extension of Andros a broad promontory, of which the Berry Islands and the Joulter Cays are the only remnants. On the west, along the line of the Old Bahama Channel, the Santaren Channel, and the Straits of Florida, we are reminded, by Lobos Cay, Guinchos Cay, and the disconnected flats and patches edging the channel as far as Orange Cay, of the western extension of Andros; while the Riding Rocks, Gun Cay, and the Bemini Islands, lying between Orange Cay and the Great Isaac, attest the former existence of the shore line of a large island — probably the west coast of Andros — along the eastern edge of the Gulf Stream.

The appearance of the east coast of Andros, the high æolian bluff of which flanks nearly the whole of the western edge of the Tongue of the Ocean, is in striking contrast to its low western shore. The east face of Andros is a series of alternating beaches and bluffs, extending from the northern extremity to High Point. The island is comparatively well wooded, large tracts being covered by pine and by hard-wood forests. To the south of Morgan's Bluff near the shore begins a magnificent coral reef, extending the whole length of the island, and running parallel with and distant from it half a mile to a mile and a quarter, with openings in the outer reef to allow the passage of spongers. This reef, though narrow, is one of the finest reefs I have seen, and the patches of corals and Gorgonians which flourish between the outer reef and the shore are not surpassed in beauty by the corals of any district known to me. These patches form an intricate network, rendering navigation inside the reef very difficult. In fact, it can be followed only by the eye. The inside patches of Gorgonians are in many places most luxuriant, while the outer reef is mainly made up of masses of *Astræans* and *Madrepores*; the patches between the outer reef and the shore consist of *Porites*, *Mæandrinae*, and *Millepores*, growing upon the æolian rocks. These corals, when broken up by the action of the sea, supplied the sand forming the beaches which cover the underlying æolian rocks. I saw but few stretches of the shore coral rock formation.



The vegetation of Andros consists mainly, as I was informed by Mr. Chamberlain, of pine, mahogany, mastic, and the heavy undergrowths.

The ridge which runs parallel or nearly so to the coast is followed by a second ridge from forty to sixty feet high, separated from the first by a wide flat plateau, beyond which we come, by a rapid descent about five miles inland, upon the low flat land which extends to the western edge of the island and forms the marl shores we visited at Wide Opening.

Morgan's Bluff (Plate XXXIII.) has the finest limestone cliffs on the eastern face of the island. The outlying islands and rocks and islets off the east coast of Andros, of which High Cay is a good example, as far as the South Bight, are all of æolian origin, and have been separated from the main island by the same agencies which have been at work in other parts of the group. The æolian rocks of Andros itself differ in no way from those of other islands. The eastern edge of Andros is separated from the deep water of the Tongue of the Ocean only by the narrow shelf of the bank of which the eastern edge is occupied by the long barrier reef which protects the eastern edge of Andros, leaving an excellent well protected inside channel for small boats along the whole length of the island.

### From Andros to Orange Cay.

From Billy Island we steamed across the northern end of the great white marl belt forming the southern edge of an excellent sponging ground which extends northward towards the edge of the Bahama Bank, south of the Northwest Providence Channel. The white marl, as we stopped to dredge or to sound, seemed very barren of animal life. Here and there an occasional sponge could be seen. On our way to Orange Cay we found that the white marl as we got farther west gradually contained more coral sand, which became coarser and more abundant as we approached the western edge of the bank, where the bottom was again composed of the characteristic coral and æolian sand found upon other parts of the Bahama Bank. With the increase of the coral sand we came upon a species of *Thalassia* with huge roots, by which it anchored in the fine marl. The great development of the roots is very characteristic of the coralline algae, which thrive upon the coral sand bottoms. A macroscopic examination of the marl from the shore of Billy Island showed that it contains a good deal of vegetable matter and a few Foraminifera, an indication most probably that the marl was formed in a lagoon with free access to the sea, perhaps a sink much

like those on Nassau and on other islands, in the shape of salt ponds. The presence of Foraminifera in this marl, so like deep-sea ooze, yet known to be formed only by the slow trituration of æolian rocks in very shallow waters, raises the question of the depth at which Radiolarian earth, as at the Barbados and elsewhere (Baracoa), may have been formed. It is no more difficult to imagine that the formations round the shores of such a shallow water lagoon have been elevated, than it is to believe the same of an elevated coral reef. In the Billy Island marl the presence of Lobulina and Globigerina would merely indicate that the open sea had free access to the lagoon. Similarly, the Radiolaria of the Barbados earth may have floated into the shallow waters in which it was formed, were it not that the presence of Cystechinus, by analogy with our recent species, indicates deep water. The marl of the shore of Billy Island contained Lobulinae and Globigerinae, while the marl from nearer the edge of the bank, in about four to five fathoms, and within four miles south of Orange Cay, which contained a greater percentage of coarse coral sand, also contained Lobulinae and Globigerinae, as well as fragments of silicious Radiolarians. When within five miles from the edge of the bank the bottom was quite clear of mud and marl, and was composed mainly of nicely rounded particles of coral sand.

### From Orange Cay to Great Isaac.

Plate I.; Plate XII. Fig. 2; Plates XXIV. to XXVI.

When approaching the western edge of the bank off the Racolas Rocks to the south of Orange Cay, we began to see bars of corals in from five to six fathoms of water. This had now become much clearer, and, compared to the water on the midway of the bank, apparently carried nothing in suspension. Still farther to the westward could be distinctly seen the dark blue line indicating the deep water of the Gulf Stream off the edge of the bank. After passing the Racolas Rocks, we came upon Orange Cay, a low ridge of æolian rocks absolutely bare, pitted and honeycombed over its whole surface. Vessels crossing the banks from Stirrup Cay sail an almost straight course from there to Orange Cay, and next strike Salt Cay Bank, thus avoiding a great part of the strength of the Gulf Stream, and making for Havana from off Matanzas close to the north shore of Cuba. From Orange Cay as far as Riding Rocks bars of corals run parallel to the edge of the bank on an approximate north and south line. The corals on these

bars are all flourishing, and consist mainly of heads of *Astræans* and of *Mæandrinæ*.

The shore lines of Orange Cay, as well as the adjoining isolated rocks, are all eaten away at the base, the surface being completely pitted and honeycombed; this small cay, with the scattered isolated rocks extending to Riding Rocks, being all that is left of the western part of the great Andros Island land. Riding Rocks are found, like Orange Cay, to be composed of the same kind of æolian rock. Masses of corals are flourishing, forming great patches more or less disconnected on the face of the bank towards the Gulf Stream, extending to fifteen or seventeen fathoms of water. *Astræans*, *Mæandrinæ*, *Millepores*, and *Madrepores* extend all the way to Gun Cay. Nowhere perhaps on the Bahamas is it more obvious that the existing bars of corals found along the sea face of the nearly continuous bank throughout the Bahamas have had nothing to do with the formation of the cays and rocks on the west side of the Andros Bank. The coral masses are merely surface growths as it were upon the banks, which owe their building up to entirely different causes and to a state of things which has long passed away.

From Riding Rocks to Gun Cay a series of isolated patches, rocks, and islets, all of the same character, sometimes in two or more parallel rows, run north on the edge of the bank; these are flanked on the westward by very flourishing patches of corals growing close together, and extending on the sea face of the bank into about seventeen fathoms of water. These rocks and islets are comparatively less barren as we go north. The remnants of the former land also increase in number as we approach Gun Cay, and become still more numerous and large with the *Bemini*s and the adjacent rocks and islets. On the southern end of South Cat Cay there is a considerable æolian hill, covered with vegetation similar to that of other islands on the east face of the bank. North Cat Cay has a grove of cocoanut palms and low bushes. The sea face shore lines of this and South Cat Cay are protected against the action of the sea by lines of outlying rocks, and are thus less affected by the wearing action of the prevailing winds. South Cat Cay is high enough to have, near the middle of the north end, a line of low vertical cliffs, both the Cat Cays being somewhat higher than Gun Cay.

## Gun Cay.

Plate XII. Fig. 2.

On the south point of Gun Cay a lot of loose rocks are thrown up well above high-water mark. The cliffs of the southern shore are eaten away, and on the western face of the cay the rocks up to the line



ÆOLIAN ROCKS THROWN UP ABOVE HIGH-WATER MARK, GUN CAY.

of scanty vegetation are deeply pitted and honeycombed. All along the west face of Gun Cay rectangular masses of rocks are thrown up close to the line of vegetation. These masses of rocks are the fragments of the shores torn off from the vertical cliffs by undermining, and then thrown up by the action of the heavy seas or hurricanes. Picket Rocks derive their name from such a mass of angular rocks thrown up on the very crest of the ridge of the cay, looking a little way off like an irregular picket fence. Holm Cay is another island of similar character, but smaller.

Running parallel with the line of outer rocks which make the extension of Gun Cay to the north, we crossed magnificent banks and patches of corals, some of which run close up to Gun Cay, as well as to the rocks in the vicinity. Off the little sandy reach inside of the north end of Gun Cay we brought up large masses of *Thalassia* in the dredge.

On the east face of Gun Cay the shore rocks are so eaten away as to form numerous caverns and cavities in the face of the shore line.

Going on shore, we found it composed of the ordinary æolian rock of the Bahamas, its character admirably shown in the cuts made for the boat landing and for the foundation of the derrick used in handling the supplies. The cay, wherever exposed to the strong waves of the Gulf Stream, is deeply pitted and honeycombed. We found a few speci-



GUN CAY.

mens of the same pupa so common on other islands of the group. The vegetation was very scanty, — a few scattered specimens of cactus, wild grape, wild geraniums, and verbena, — with the usual plants characteristic of the shore belt throughout the Bahamas. Among the most prominent rocks north of Gun Cay, between it and the Beminis, are Turtle Rocks, forming a low rocky æolian ridge.

### The Beminis.

#### Plate XII. Fig. 2.

The Gulf Stream skirts close to the western edge of the two Beminis. They are separated by a picturesque opening, forming an excellent harbor even for boats of a considerable size. At the south end of both South and North Bemini we find a long line of angular æolian rocks thrown up by hurricanes well above high-water mark, often fully twenty feet. From here to the northern end extends a long coral sand beach, disconnected in many places by extensive patches of shore built coral rocks, covering in many places the underlying æolian formation. The greater part of the shores of the Beminis is made up of this shore deposit, piled up above the older æolian rocks wherever they have been washed away, and forming small cliffs along the northern face of the western shore line of North Bemini. Here and there an occasional cliff of the older æolian is seen, but greatly weathered and worn, as near the northern extremity of North Bemini, some distance above the village. The sea has thrown up a high beach and formed a lagoon at that end, which is filled with mangroves and small mangrove islands. The outlying rocks of North Bemini are all æolian, the surface pitted

and honeycombed, and eaten away at the base. On the gulf side of the Beminis, and all the way north to Great Isaac, we meet fine patches of corals in from four to six fathoms of water. These patches and bars extend but little way eastward on the bank, and flourish most luxuriantly as we approach the Gulf Stream edge of the bank out to fifteen or sixteen fathoms, where they often cover extensive tracts separated by irregular sandy lanes.

### Great Isaac.

#### Plates XXIV. to XXVI.

Great Isaac, as it is approached from the south (Plate XXV.), reminds one of Double Headed Shot Cay, with its rounded outline and outlying islets and rocks presenting a most barren and desolate appearance. The southern faces of the island, and of its adjoining islets and rocks, are all cut off by low vertical cliffs, full of caverns and cavities. The surface of Great Isaac is an admirable example, perhaps one of the best, of the forces which have been at work during the subsidence of the Bahamas. The æolian structure of the rocks is everywhere most apparent. The action of the sea in undermining the shore slopes and forming low vertical cliffs by the breaking off and falling into the sea of huge angular masses of rocks is seen on all sides. The action of the sea during hurricanes in throwing up huge masses far above high-water mark is not better shown on any other island of the group. Finally, the action of the salt-water spray and waves, as well as of the tropical rains, in pitting and honeycombing the surface of the island, the former near the shores, the latter everywhere else over the cay, cannot fail to strike the eye of the most casual observer. As we passed the west end of Great Isaac we observed a number of huge isolated irregular rocks, left far above the high-water mark, passing into an irregular mass of angular blocks forming a rude broad wall, left as a witness of the fury of the hurricane of 1876. But on the north face of the island we come upon another tract covered by still larger blocks, thrown up by an older hurricane, the date of which is not known. Two of the largest of these blocks we measured, and found them to be, the one twelve feet eight inches long by four feet wide and six feet high, at a distance of one hundred and twenty-five feet from the shore and fully twenty-five feet above high-water mark; the other was fifteen feet six inches long eleven feet wide and six feet high, at least eighty feet from the shore and about eighteen feet above high-water mark (Plate XXIV.). On the highest



part of the island, to the eastward of the lighthouse, we found a number of fantastic isolated pinnacles of æolian rock left standing high above the present general level of the cay by the denuding action of the tropical rains. Many of these pinnacles were limestone tables of varying tops and heights, with a slender pedestal still attached to the ground. They owe their origin undoubtedly to the harder character of the surface limestone at certain points.

On the north side the slope of the island is very gentle. There are many pot-holes and sinks, as well as ocean-holes, on the northern face of the cay, and at the south side the sea has washed the cliffs into the most fantastic pinnacles (Plate XXVI.), some of them several feet in height, so that a part of this shore recalls very vividly the aspect of the surface of Eleuthera near the Glass Window. Only the most scanty vegetation is found at certain points of the island, not enough for the food of a goat. A cactus, a few stunted bushes and shore plants, compose the flora of this island. Gun Cay, the Beminis, Great Isaac, and the long line of rocks and sand bars to the eastward of it extending to the Berry Islands, such as North Rock, the East and West Brothers, and the Eastern Isaacs, are probably the remnants of the northern and western edges of a larger island, now only barely apparent above the level of the sea, perhaps itself formerly a part of Andros. Off Little Isaac the bottom samples became quite coarse, consisting principally of broken shells and masses of coral-line algae. When approaching Great Stirrup Cay, about thirty miles southeast of Great Isaac, the bottom was coral sand, with many broken shells, small whitish *Mellita hexapora*, and light brownish *Clypeaster*. In fact, the prevailing tone of the whole fauna of the banks proper is of light hue, except where coral patches are found close to the edge of the bank, and nothing is more apparent than the bleached aspect of the shells, echini, or coralline algae characteristic of the bank itself. The darker patches of sponges, corals, and Gorgonians alone apparently form an exception to the general monotony of color characteristic of the bottom on the inner parts of the banks.

### From Great Isaac to the Berry Islands.

Plate I.; Plate XII. Fig 4.

To the eastward of Great Isaac run a series of rocky ledges, the remnants of former cays, running parallel with the trend of the 100 fathom line, distant from it three to seven miles, known as the North-east Rock, the Brothers, Little, Middle, and East Isaacs, Rockawash, and



other rocky banks, ending with the Gingerbread Ground in the east. There we strike the extensive bight between it and Little Stirrup Cay, where the bank slopes most gradually from the 3 fathom line to the 12 or 15 fathom line, and then drops suddenly to the 100 fathom line, the ledges named above forming the northwestern edge of the bank.

### The Berry Islands.

Plate XII, Fig. 4.

We passed the islands to the westward of Great Stirrup Cay in the dark, but that island and those of the Berry Islands which we saw during the day were all of æolian rock. Great Stirrup Cay is full of pot-holes and sinks; it is comparatively well wooded, as well as many of the Berry Islands and of the islands to the northwest visible from our anchorage in Great Harbor.

All the way from Great Harbor south we found irregular patches and bars of corals on the shelf to the eastward of the Berry Islands, extending from three to four fathoms or less to fifteen or sixteen near the eastern edge of the bank. Coming from the west, I am informed that from Gingerbread Ground similar coral reefs extend as far as Great Harbor Cay, on the shelf of the banks, outside of the cays.

The islands, islets, and rocks known as the Berry Islands, extending along the Providence Channel and forming the northeastern edge of that part of the bank of which Andros is the principal land, are both as to number and size in marked contrast with the small and insignificant islets and rocks which occupy the edge of the bank flanked by the Gulf Stream. The principal cays of the Berry Islands, such as Haines Cay, Little Harbor Cay, Alder Cay, Bond's Cay, as far as Whale Cay, present no features of special interest. Their surface appears well pitted and honeycombed, as their eastern face gets the full force of the northeast trades. Near their highest point they are covered by a very scanty vegetation. The outer line of cays protect a beautiful sheet of water of a brilliant light green.

They show the usual variation in height of from twenty-five to thirty feet, occasionally rising, as at Haines Bluff and Devil's Bluff, to fifty or sixty feet, their eastern faces presenting the ordinary variation of low vertical cliffs where the headlands have been cut off by the action of the sea, or the more or less extended coral sand beaches stretching between those promontories, with here and there extensive walls of æolian blocks thrown up above high-water mark, as on the Market Fish

Cays. The cays in this vicinity are more exposed to the action of the sea, the eastern shelf of the bank being quite narrow, and in many cases the eastern faces are formed by low vertical cliffs of æolian rocks, thirty to forty feet high, separated by short stretches of sand beaches. The



DEVIL'S BLUFF.

north end of Bond's Cay and the sea face of Alder Cay are both very much eaten by caverns, with rows and patches of loose angular blocks thrown up above high-water mark. There is but little vegetation on either Cay. Beaches and low cliffs alternate along the southern end of Bond's Cay. Along the whole length of the north end of Whale Cay the action of the sea is well marked in the undermining of the low cliffs forming the sea face of the cay.

The effect of the shallow wide shore shelf to the east of the Berry Islands is very marked on the swell, which is far less powerful than on the Atlantic or Gulf face of the bank, wherever deep water comes close to the sea face of the cays.

An extensive tract of sand bores, dry at low water, runs from the Northwest Channel to Great Harbor Cay. In the whole of the track to the eastward of them as far as the Berry Islands there is only a very limited area with a depth of one fathom. To the westward of the cays from Great Harbor Cay to Whale Cay the shores run into broad sand flats. The westward extension of these sand flats forms the southern edge of the bank from Whale Cay and the Chub Cays to the entrance of the Northwest Channel and to the Joulter Cays. From that edge of the bank extensive sand bores run diagonally across in the direction of Haines Cay. (Hydrographic Chart, No. 26<sup>a</sup>.)

Fine patches and bars of corals follow us south, with lanes of sand separating them and extending to the edge of the bank from three or four fathoms into fifteen or sixteen. Toward the outer edge the corals grow most vigorously. The same kind of bottom followed us as far as Whale Cay. Corals begin to grow in from three to four fathoms, where they are less disturbed by the constant movement of the coarse coral sand of the bank, and hence the corals have not assisted in building up the shores. Very few coral patches come close to the surface, as they do in the Florida Cays, where the corals play an important part in the formation of the outer ones.

From Whale Cay we crossed over to Mastic Point on Andros. As soon as we got into deep water after leaving the bank we began to encounter again flying fishes, not one of which we had seen while steaming on the outer shallow part of the bank.

## THE LITTLE BAHAMA BANK.

Plate I. ; Plate X. Fig. 1.

The Little Bahama Bank is dumbbell-shaped, one of its shanks running in a northwesterly direction, the other irregularly north and south. The northern edge of the bank from Walker Cay Channel to Elbow Cay, and the eastern edge from that point to Cherokee Sound, is skirted by numerous cays running nearly parallel with the 100 fathom line, at a distance varying from one to four miles. The rest of the southeastern edge of the bank is flanked by the high cliffs of Great Abaco as far as Hole in the Wall ; from that point the shore trends to the southwest, and extends northwest from Southwest Point to Rocky Point. Of the outer line of eastern cays the principal ones are Walker Cay, the Double Breasted Cays, Stranger, Carter, Fish, Pensacola, Spanish, Munjack, Green Turtle, Great Guana, Man-of-War, Elbow, Tilloo, and Lynyard Cays. A broken line of reef extends from Cherokee Sound along the eastern edge of the bank to Matanilla Reef. This reef becomes specially prominent north of Elbow Cay, leaving only here and there a passage through the reef for small boats to gain admittance into the large sheet of water, from two to six miles wide, and twelve feet deep, which separates the outer cays from the eastern shores of Great and Little Abaco. Large craft can enter this inner sheet of water through Man-of-War or Whale Channel Cay.

As far as we saw the outer line of cays from the Stranger Cays to Lynyard Cay, they are all low, generally bare, Green Turtle Cay being an exception. They probably represent the outer line of æolian rock hills which once formed the eastern shore of Great Abaco, but which, owing to the subsidence and to the wearing action of the sea, has separated these hills into numerous islets and formed the wide and navigable channel intervening between them and Great and Little Abaco.

In the vicinity of Little Harbor the outer range of æolian hills is still connected with the main island, Ocean Hill and the adjoining promon-

tories forming the southern edge of the harbor and the northern boundary of Cherokee Sound, while the promontory of Sweeting protects the northern side of Little Harbor. At Marsh Harbor settlement and at Black Point, both on Great Abaco, promontories nearly two miles in length are left as monuments of the former eastern extensions and connections of Abaco with the outer cays. In fact, very little more wearing away would separate the promontories forming Little Harbor from Abaco, and turn them into cays similar to the outer line, leaving perhaps at the same time a second inner row of cays like those now in formation off so many parts of the eastern shore of Abaco, traces of which farther north are seen in the numerous banks of all sizes and shapes which exist both to the westward and to the eastward of the outer cays, being parallel to them in a general way.

### Great Abaco Island.

Plate X. Fig. 1; Plate XL.

We made the lighthouse on Abaco Island at Hole in the Wall, the southern extremity of the Little Bahama Bank. That part of Abaco is low, with rounded outlines (Plate XL). The rocky surface is bare, all that part of the island being exposed to the full action of the prevailing trade winds and swell. In consequence the shore is formed of low cliffs, having the peculiar basaltic appearance so characteristic of the darker limestone cliffs of the Bahamas. The surface of the island within reach of the action of the sea is pitted, honeycombed, and full of pot-holes. This is specially seen on the east face of the Lighthouse Hill and the spit to the south of it.

A well marked narrow rocky promontory, covered near the shore by pinnacles, runs out from the southern end of the island, at the extremity of which are situated two islets undermined at the base. Near the



HOLE IN THE WALL.

extremity of this narrow promontory the sea has broken through and formed a large hole, which has given to the locality its name of Hole in the Wall. The outlying islands have perhaps been formed in part by

the same process which will in time separate the extremity of the promontory as a distinct islet, now connected with the inner part of it only by a comparatively thin arch. From its exposed position we naturally find many fragments of rock thrown up on the shore. A few at the base of the cliff leading to the lighthouse are quite large. The largest rock train is thrown up on the beach near the spit to the west of Abaco Lighthouse. The cliffs to the westward, to the eastward of Southwest Spit, are the remnants of a range of æolian hills existing at one time to the south of those which form the extension of Lighthouse Hill. These western hills must have reached very close to the edge of the bank before the general subsidence of the Bahamas had produced any marked change in the topography of the land. The valley which separated them from the northern range of hills is still well marked.

After turning the Southwest Spit we ran parallel to a long coral sand beach, the shore line of which was flanked at intervals by stretches of angular rocks thrown up by southeastern hurricanes or gales above high-water mark and extending inland. On landing we found rocks, sponges, Gorgonians, and large masses of corals, thrown up to a considerable distance on the lowland, forming an extensive plateau extending inland behind the beach. Soon after passing Southwest Spit we began to see fine stretches of pines, which are so characteristic a growth on the larger islands of the Little Bahamas.

The edge of the narrow bank flanking western Abaco is covered with fine coral heads, growing abundantly in from three to ten fathoms close towards the shore, and separated by wide lanes or patches of sand. On the western face of the Little Bahama Bank this edging of corals is nearly continuous, extending all the way from Southwest Spit on Abaco to Memory Rock, where we entered on the bank to cross it *en route* for Green Turtle Cay.

Great Abaco from Southwest Spit westward is low, and covered with a fine forest of pines, which extends into the interior. The Lighthouse Hill range gradually falls to the westward, but extends to the northeast of the lighthouse, and forms the eastern face of the island, which is edged by vertical cliffs from forty to one hundred and fifty feet in height, forming a nearly continuous wall, upon which pounds the heavy trade swell. These vertical cliffs extend north as far as Guineaman's Bay, where the outer row of rocks, islets, and cays begins, extending in a nearly unbroken breakwater off the main island from Cherokee Sound as far as Matanilla Reef. On the west side the lowland extends as far as Rocky Point, and then disappears to form the extensive shallow bank

which stretches to the southeastern extremity of Bahama Island on one side, and to Little Abaco on the other. On the interior of the bank the west face of Great Abaco runs at many points close to the eastern shore of the island, leaving only low, narrow ridges connecting the various parts of this singular island (Plate X. Fig. 1). On examining the chart, one cannot fail to be struck with the endless islets and passages which have been left on the east coast of Abaco as records of the subsidence of the bank, and the numerous cays which flank the western edge of the bank between Rocky Point and the southeastern end of Bahama Island, while the many cays found upon the shallow interior bank attest the former extension of the Abaco Bahama Island Land. The Little Bahamas are perhaps a finer example than even Andros can be of the former greater extension of the land, and of the causes which have resulted in the present configuration of the group.

The Abaco Bahama Island Land, which once covered the greater part of the Little Bahama Bank, and probably corresponded in outline approximately with the line of ten fathoms, was exposed at its north-western face to the violent action of the northers. They have eaten away the whole of the northern face of Bahama Island, leaving only Memory Rock and the banks to the north as witnesses of its former extension. On the north face of the Little Bahama Bank the patches forming Middle Shoal, Matanilla Reef, and the long line of outer cays, give us approximately the outline of the former Little Bahama Land, of which Little Abaco and the cays extending to the westward to the Centre of the World are remnants, these remnants being in turn the outliers of Great Abaco before it became disintegrated by the action of the northers, when it was perhaps only separated by a narrow channel from Bahama Island. Of course, as soon as a wide channel was formed to the north of Bahama Island or to the westward of Abaco, the action of the northeast trades also came into play to cut away the low shores of these islands, thus helping to increase rapidly the dimensions of the bank.

But what has made the shape of the banks such as they are, and what has shaped the outline of the old land in so absolute conformity to what we may reasonably assume to have been their original outline?

As far as the shape of the Windward Islands is concerned, we can still see the action of the volcanic forces which have elevated islands of very different shapes and different sizes above the bottom of the surrounding ocean, — islands which are separated one from the other by channels of very varying depths, and round which have been formed on one face or



the other narrow fringes of limestone by the reefs surrounding them. As we pass northwards from South America we find that these islands become larger, or rather that they are the summits of larger plateaus, forming banks of greater or less extent and separated by channels of various depths. We also see that on some of the banks there are no volcanic islands, the whole surface of the plateau being covered by coral sand, in part the remnants of limestone tracts which had a greater extension, or in part perhaps of limestone banks which during periods of great volcanic activity have gradually formed upon the folds of the bottom of the ocean. Even granting for the Bahamas the greatest possible subsidence as indicated by the deepest ocean-holes, the outlines of the banks at the time of their greatest elevation could hardly have been materially different from that of the present charts, as the whole change of level is taken to be well inside the 100 fathom line, at not more than fifty to sixty fathoms. Take the sea face slope as we find it to-day, it would not have changed materially the position of the coral reefs which must have been growing there, perhaps as barrier reefs exposed to the disintegrating action of the sea, and supplying by their own disintegration the material needed for the formation of the aeolian hills from which the Bahama Land was built. Or, more probably, these reefs existed as fringing reefs, much as they do in our days along some parts of the coast of the Sandwich Islands, and from them were formed the immense stretches of coral sand beaches which, swept alternately by the trades and the winds prevailing at other seasons, supplied the sand to build up the gigantic dunes of former days. These formed the highest hills of the Bahamas, and they in their turn have, from various causes mentioned in this account of the Bahamas, been reduced to their present limits.

### The Bank from Great Abaco to Bahama Island.

#### Plate X. Fig. 1.

Between Rocky Point (Great Abaco) and the southeastern extremity of Bahama Island only a few cays exist, — Gorda, Channel Cay, Black Rock, Lily, and Burrow Cays. The reef can be crossed at Burrow Cay and at Mores Island Channel. Between Burrow Cay and Bahama Island we found numerous sand bores extending five or six miles from the edge of the bank. Inside of Gorda Cay and to the east of Southern Cay and of Mores Island extends a great tract filled with banks and numerous sand ridges reaching towards the ill defined low

swampy shores of the western side of Great Abaco. These sand bores also extend in a northerly direction from Mores Island to the sand bores east of Burrow Cay. In crossing the bank from Mores Island to the Woollendean Cays, we carried from one and a half to two fathoms of water, and before reaching the cays had struck the territory of the so called marl of the Little Bahamas. It seems to have been formed under very much the same conditions as those which have formed the great white marl flats to the west of Andros; but the Woollendean Cays and the Joe Downer Cays being the remnant of a land rather higher than that on the west shore of Andros, this marl is not so pure, and contains a greater amount of vegetable matter derived from the decomposition of a larger amount of soil.

When off Rocky Point we could easily follow with the eye the changes which had perhaps taken place in the configuration of the west side of Abaco. To the east stretched the low coast of the island itself, covered with a dense forest of pines, and deeply indented by channels which seemed, as seen from the rigging, to cut the shore line into numerous islets. To the westward extends a low rocky spit, and still farther west rocky cays are found on the edge of the bank, — the outliers of the former Abaco. Gorda Cay, the summit of which is covered by a regular picket line of angular æolian rocks, attests the strength of the hurricanes which have gradually eaten away the greater part of the west shore of Abaco; while farther inland Mores Island and the Woollendean Cays, æolian islands rising upon the shallow interior bank, indicate the action which has gradually reduced the western part of Great Abaco to its present dimensions. Long Cay Rocks and other small cays south of Mores Island are bare, like Gorda Cay, though often topped here and there like the latter by a wall of loose rocks thrown up during the hurricane season. There is excellent sponging on the interior of the bank. The bank is entered by a good passage a little north of Mores Island, and in that way the west coast of Great Abaco can be reached. We anchored in Rock Harbor, on the west coast of Abaco, after having visited the Woollendean Islands and the marl district of the Little Bahamas.

Burrow Cay is low, not more than twenty feet in height, with vertical cliffs on the channel side. A long row of angular æolian blocks is thrown up on the western face of the island to a height of about fifteen feet above high-water mark. On the western extremity a small low rocky cay protects the northern shore of the island from the action of the northers. On the northern shore there is a short stretch of recent shore coral rock, masses of Nullipores, of Gorgonians, of corals, and

an immense accumulation of large conch shells covering an extensive flat, and also forming a wall of at least five feet in height above low-water mark. These conchs are of course of all sizes, and the fragments into which they have been broken are in all stages of wearing by the action of the sea. Such masses of conchs, forming almost as great an accumulation as might be due to an Indian shell heap, we have not found anywhere else in the Bahamas, although in many places we met with smaller heaps. All along the line of the bank, in from four to six fathoms of water, we found the continuation of the coral reef which we struck soon after reaching the lighthouse near Hole in the Wall.

Owing to threatening indications of a norther, we turned back, and passing in by Channel Cay entered on the Little Bahama Bank. We soon came upon the northern extremity of Mores Island, which can readily be distinguished by the greater height of the cay and the rounded hills of which it is formed. In this vicinity the bank is thickly covered with conchs, which are collected by the inhabitants and burned to make lime. Mores Island is composed of æolian rock, and is fairly



MORES ISLAND.

wooded. Here and there the promontories of some of the hills have been washed away by the sea, so that the shore is composed of patches of low limestone cliffs alternating with sandy beaches. On the west shore the modern coral sand beach formation hides from view the underlying æolian rock. From Mores Island towards the north end of Abaco there is excellent sponging ground, and all the way from Black Rock to Mores Island the bank is covered with extensive patches of sponges and Gorgonians. The extensive coral reef to the westward of Black Rock and Channel Cay reaches some little way over the bank, and shows special vigor in the vicinity of the Channel.

Off the northeast point of Mores Island the dredge came up filled with several species of coralline algæ and sponges. The bottom samples contained but few specimens of Foraminifera, and the sand at this point was already much finer and more sticky, as compared with the coarse coral sand of the entrance of the Channel. We found an abundant surface

fauna off Burrow Cay, — *Leptocephalus*, *Squillæ*, pelagic flounders, *Sagittæ*, *Doliolum*, *Diphyes*, *Copepods*, floating algæ, and many larvæ of Crustaceans. After we passed Mores Island the specimens of the bottom became more and more sticky, and contained a greater number of Foraminifera, changing also to a grayish color. As seen from the northwest, the northern extremity of Mores Island, with its rounded hill-tops, is very characteristic, and in striking contrast to the low æolian hills which form the southern part of the island. On the horizon to the south is seen the low line of Great Abaco, covered with its pine forests, and to the eastward the line of the two Woollendean Cays, the outliers of the former extension of Great Abaco to the west of the marls. These cays are partly rocky and partly sandy. The sea, although shallow, has evidently considerable force here, especially during the northers, and low walls of æolian rocks are thrown up here and there on these cays just at high-water mark. We landed on one of the cays to the north of Cambridge Harbor. It consisted of æolian rocks in an interesting stage of decomposition, nearly marl, the holes of the rocks full of red earth and of vegetable matter. The sand on the beaches was made up of the same material, a little less compact and quite marly. This stage of the æolian rock seemed to be the condition immediately preceding that of the locality which is marked "The Marls" on the charts extending from the Woollendean Cays to the eastward towards Abaco and to the northward to Little Abaco. The so called marl which we obtained just inside of the cays differed greatly in its darker color from the whitish marl west of Andros. It also differed materially in being made up of far coarser materials, though it seemed to be fully as tough and sticky as the white marl from Andros.

As we approached the northern extremity of Great Abaco, near Norman's Castle, we could see the æolian cliffs on the south of it, formed from the hill slopes cut away at the base. At many points huge blocks, eaten away at their base, had been broken off, and looked now like huge white sails scattered along the coast line. It is interesting to follow to the westward of Norman's Castle the continuation of the æolian hills, which as small cays extend in a line outside of the main shore of Abaco and form Rock Harbor, the lowland lying between them and the mainland having all been washed away. The rocks were, as at Woollendean Cays, nearly changed into marl, mixed with more or less vegetable matter and red earth, so that very little additional disintegration would change it into the sticky and half sandy bottom so characteristic of this part of the Little Bahama Bank.

The chain of small cays in the vicinity of Rock Harbor, to the westward of Great Abaco, affords one of the best examples of the evidence we have of the former continuity of the many cays scattered all over that part of the bank. The cliffs of the cays are eaten away at the base by the slow action of the sea, which here has a far more limited range than when acting upon the Woollendean Cays to the southward. The bottom here is sticky, and, though still of the characteristic gray color, is made up of much finer particles than the samples of bottom we obtained on our way to this point from Mores Island.

The few large pines still left upon some of the smaller islands near Rock Harbor indicate clearly their former connection with the pine forests which are seen upon the main island (Great Abaco) to the eastward. Rock Harbor Cay was interesting as showing us the remnants of the inner western line of hills which form the Black Point of Little Abaco, appear again on Randall's Cay and on Norman's Castle on Great Abaco, and which may have formed the line of hills connecting Great and Little Abaco.

Little Abaco is separated by a narrow shallow channel from Great Abaco, and is only a narrow spit, the remnant of a line of hills running westward from the northern extremity of Great Abaco.

Coming back to Channel Cay, we pushed rapidly north to Bahama Island, steaming all the way from Channel Cay over the fine coral reef which fringes the western edge of the bank in from four to ten fathoms. The reef is bare at many points, especially in the extension of some of the ledges of rocks or low cays in the channels formed between them. The western slope of the bank is often very steep; it was not an uncommon occurrence while steaming over the reef to see the patches of the great coral heads in from five to eight fathoms on one side of the yacht, while on the port side we could not see bottom. From Burrow Cay to Carrion Crow Harbor there is a continuous stretch of coral sand banks separated by shallow channels, leaving passages for small boats to enter the bank. In the channels, or flanking these sand banks or their extensions as rocky ledges, thriving patches of large heads of corals could be seen whenever we came near enough to the outer line of cays. A few miles north of Carrion Crow Harbor the line of the great barrier reef, which runs parallel with Bahama Island, makes a sharp angle. As we ran parallel with this beautiful reef, we could follow the spurs of the main reef striking toward the shore of the island, and becoming changed at many places for a short distance into a fringing reef.

## From Bahama Island to Memory Rock.

Plate X. Fig. 1; Plate XXXIX.

Bahama Island forms the southern face of the northwestern shank of the Little Bahama Bank. It is sixty-five miles in length, but not more than six to seven miles in width. It is low, covered with a thick forest of pine. It may be fifty to sixty feet at its highest point, to the east of High Rock. The high ridge runs close to the south shore, and on



HIGH ROCK, BAHAMA ISLAND.

crossing this we come upon the level stretch sloping gently north to the northern shore. Its southeastern extremity is broken into numerous low cays, and the north shore, which has not been surveyed, appears, as far as could be seen from the rigging, to be made up of innumerable low wooded (pine) cays running east of Settlement Point.

The highest cliffs we saw were at High Rock, where there is a small settlement, but even there the cliffs are not more than from twelve to twenty feet. In the vicinity of High Rock, to the eastward of Gold Rock, where we anchored, we had an excellent opportunity to see the barrier reef growing upon the submarine extension of the shore æolian rocks. The reef where we anchored is in about four fathoms of water. We dropped our anchor in an open space between patches of fine heads of *Porites*, of magnificent huge clusters of *Madrepora palmata* and colossal heads of *Meandrinae* and *Astræans*, many of them overgrown by splendid *Millepores*. Inside the reef, towards the shore, the sheltered waters were filled with patches of large *Gorgonians* and isolated coral heads. The distance from the 5 fathom line to the shore line is nearly a mile. Inside of this the coral heads were not very numerous, except in the lines where they formed spurs reaching to the shore of Bahama Island, constituting an incipient fringing reef. The shore æolian rocks are well protected, except at such places as High Rock, by the barrier reef running parallel with the shore line of the island. Back of the beach the highest point cannot be more than ten to twelve feet. The surface of the exposed rocks is more or less water-worn from the



combined action of the rain and sea. Behind the shore line of rocks extend vast flats, the pine barrens of the island. The æolian rocks are everywhere fully exposed, presenting the peculiar characteristics of the great expanses of level or nearly level surfaces which in other islands frequently separate parallel ranges of æolian hills. In the sinks and pot-holes, or depressions of greater dimensions, pools and ponds, often of considerable size, have accumulated, many of which are separated from the sea only by the narrow wall forming the low line of æolian hills immediately back of the shore.

The shores of Bahama Island, all the way from Carrion Crow Harbor to our anchorage at Turtle Reef near High Rock, have once been a succession of coral sand beaches and of low cliffs along the edge of the low line of hills, forming a sort of dam between the pine tract levels and the edge of the island. Beyond Turtle Reef the extension of this line of hills forms a few insignificant cays to the west of Gold Rock. The reef is outside of this line of cays, which represents a part of the ancient shore line of Bahama Island. The reef dies out at Southwest Point, where the shore is clear close up to the beach. Beyond Southwest Point, at Barnard's Point, the low shore hills with vertical cliffs are again characteristic of the shore line, the pine barren plains appearing to be from one half to three quarters of a mile behind the beach mound. Wherever there is any outcropping of rocks between the stretches of coral sand beaches, many blocks of æolian rock are thrown up above high-water mark. There are a number of these rocky outcrops, and as we go north past Southwest Point the sandy beaches become shorter and are much more frequently interrupted by considerable lengths of outcrops. Hawk's Bill Creek is an estuary which has cut Bahama Island in two, and which comes out on the north side. The shore line of cliffs leaves a wide opening flanked with mangroves and shrubs; in the distance are the pine barrens about one mile inland. Soon after leaving Hawk's Bill Creek the pine barrens recede farther from the shore, and towards the narrower part of the northern extremity of the island the pines diminish gradually in size and in thickness, becoming quite scattered. The low range of shore hills increases in width, extending farther inland. The continuation of the northern extremity of the island consists of four or five small cays, the remains of the former northern extension of Bahama Island. These small cays are of the usual type; the rocks are æolian, with vertical faces more or less undermined, and the surface of the islets pitted and honey-combed. As the pines diminish north of Hawk's Bill Creek, their

place is taken by scrub vegetation. The island becomes quite flat; there are but few rock exposures, and longer reaches of sand beaches. We still find flourishing patches of coral heads all along the coast, but they are disconnected, and the patches are often far apart. When off the northern extremity of Bahama Island we could see from the rigging the east shore of the island cut up into numerous small islands, many of which are still well covered with pines, far better than is the western part of the northern extremity of the island. These numerous cays and estuaries are not marked on the charts; in fact, the eastern and northern coasts of Bahama Island have not as yet been thoroughly examined and mapped out. Here and there on the west coast, close to the shore, are left a few pine trees, and the mangroves are in many places large and most flourishing.

All along Bahama Island, as well as along Andros, where the barrier reefs are perhaps better developed than elsewhere along the sea face of the bank, wherever there are breaks in the barrier reef so that the shore line is not protected by it from the action of the sea, we find stretches of sand beaches corresponding to the openings left in the barrier reef; while opposite the unbroken reaches of the barrier reef the shores are rocky, exposing in full view the underlying æolian rocks, which are not covered up in part by the reef sand, as in the shore opposite the breaks.

After leaving Settlement Point we came upon Indian and Wood Cays, the rocky remnants of the western side of Bahama Island. Sandy Cay is low, not more than fourteen feet in height, with no exposed trace of the underlying æolian rock of the bank.

Memory Rock (Plate XXXIX.), close to which we passed as we turned eastward to cross the bank, is perhaps one of the most characteristic of the outlying sentinels of what once formed a part of the greater Little Bahama Land. The gradual disappearance of this land as we pass north is most characteristic. We can as it were follow the disintegration which has taken place about the northern part of Bahama Island, the character of which changes radically as we leave the pine barren flats and pass to the bare rounded rocky hills, pitted, honeycombed, and worn, which form its western end, and to the numerous cays extending eastward, thickly wooded, covered with pines, which are the continuation northward of the pine barrens of the main island.

Nearer the western edge of the bank, Indian and Wood Cays are more or less exposed to the same agencies which have acted upon the Bahama Islands in so uniform a manner. On Wood Cay we find large

blocks of æolian rock thrown up above high-water mark, and above this belt it is covered with low shrubs. When we finally come to Memory Rock, we find nothing but a few pinnacles of æolian rocks, pitted and honeycombed, and worn into fantastic shapes, the only land still visible of the northern part of the older Bahama Abaco Land.

The northwestern extremity of the bank is fringed by patches of coral reefs and sand bars. The reef which extends nearly unbroken from Southwest Point on Great Abaco along the western face of the Little Bahama Bank beyond Memory Rock runs to within about fifteen miles from Matanilla Shoal, the northernmost coral patch on the bank.

### From Memory Rock to Green Turtle Cay.

Plate X. Fig. 1: Plate XXI.

The character of the bottom on the bank from Memory Rock for about thirty miles eastward is that of grayish coral sand, rather finer than the bottom samples near the edge of the bank, which are clear coral sand and broken shells. At each haul of the dredge masses of *Thalassia* were brought up.

The Barracouta Rocks, five to six isolated little rocky patches, twelve to fourteen feet high, are pitted and honeycombed, and water-worn at the base. The æolian lamination in some places is most distinct, dipping at times thirty-five to forty degrees. The cavities of these rocks were in part filled by very peculiar rounded lumps of a cellular mass of red earth, sometimes also arranged in ridges on the dividing edges of adjoining depressions.

Little Sale Cay rises about twenty feet above high-water mark, and is devoid of vegetation. It is, like the Barracouta Rocks, the remnant of a larger island, which must have covered the greater part of the bank to the north of the eastern end of Bahama Island. Little Sale



LITTLE SALE CAY ROCKS.

Cay, the Barracouta Rocks, and the Centre of the World, standing as they do as the outposts most exposed to the agency of the waves, are cays and patches of rocks the outlines of which have been far more affected by the action of the sea than the more eastern range of inner cays, which protect the eastern extremity of Little Abaco.

Grand, Double Breasted, Stranger, Carter, Fish, Pensacola, and the Hog Cays are, in the order named, the westernmost of the long line extending from Walker Cay Channel on the northern edge of the bank along its eastern edge as far as Cherokee Sound near the southeastern extremity of the bank. This line of cays protects the eastern face of Little Abaco and of Abaco from the action of the heavy trade wind swell which pounds upon the eastern face of the cays; they will in time disappear completely, as the intervening channels become wider, thus exposing their western face to the long reach of the sea, which has already removed nearly all traces of the former line of outer cays, islets, and sheltered cays which must once have formed the continuous Little Bahama Bank, — then a bank on which were many islands, and which was fringed on its sea face by cays of which no trace is now left except the shallower patches on the banks to indicate their former existence. The outer line of cays is flanked on the sea side by the narrow flat of the bank between them and the 18 or 20 fathom line, where the bank drops suddenly to a hundred or a hundred and twenty fathoms. On this flat coral reefs flourish, as more or less extended patches of heads or clusters of heads, in a depth of four to six fathoms. Inside of this line the corals do not flourish well, being too much exposed to the full force of the Atlantic swell. This belt of corals we crossed twice, on going off the bank at Green Turtle Cay, and again on attempting to enter Little Harbor.

The inner shore line of the outer row of cays is generally formed by low vertical cliffs, behind which rise the rounded summit lines of the cays, scarcely reaching at any point a greater height than fifty feet. All these islands are of æolian origin, the rocks composing them differing in no wise from those of the other parts of the Bahamas. The character of the bottom, however, changes somewhat after we approach the Barracouta Rocks. There it begins to be somewhat more marly, and soon after going eastward we enter a district the bottom of which is characterized on the charts as marly; finally, when we get off Green Turtle Cay, we find that the marl closely resembles the peculiar white ooze covering so great a part of the bank to the westward of Andros. This white marl fills the channel all the way from Little Abaco to Man-of-War Channel. The samples of the bottom taken off West End Rock of Little Abaco, in three fathoms of water, are fine marl of a light gray color, and of a consistency almost like plaster of Paris, but of a bluish tint. Off the eastern face of the outer cays the bottom is covered by the coarse sand formed of coral débris and of æolian rock,

or even of large pieces, according to the conditions due to the outer line of protecting reefs. The outer line of cays forms a sort of sieve through which the action of the sea outside due to the prevailing winds is greatly modified and tempered both upon the western face of the cays and the eastern channel face of the Abacos.

Steaming along in an easterly direction, keeping Little Abaco to the south, the island is covered with low growth, the cliffs of the eastern face are not prominent, and the æolian rocks can be seen at all exposed places on the sides of the cay which are bare of vegetation.

To the eastward are seen the outline of the low rounded hills of Spanish and Powell Cays, the latter about eighty feet in height, off Great Abaco. South of Spanish Cay the bottom consists of very fine marl, and is covered with sponges, coralline algæ, *Thalassia*, and several species of *Penicillus*.

After passing the spit at the north end of Great Abaco the island widens somewhat, so that we get two lines of æolian hills parallel to the shore. The western range, which is the highest, is covered with low vegetation. Nearer the shore the trees are taller, seemingly mastic and mahogany woods, while from the south the pines come in again, and the southern part of the island, which falls off rapidly to a low flat from Mango Hill, is covered with a thick pine forest, which extends unbroken to Rocky Point. About opposite Munjack Cay the shore æolian hills, which run south from Angel Fish Point, are not more than from four to six feet in height. Farther south they rise to twenty or twenty-five feet, and pass into the flats upon which the pine forest extends, as we could see when steaming from the Woollendean Cays on the inside of the bank towards the western shore of the island.

After Powell Cay comes the narrow line of Munjack Cay, and next Green Turtle Cay, the most important settlement of the Bahamas after Nassau. Seen from the west all the cays appear to be low æolian hills with rounded outlines. Green Turtle Cay is a little more than seventy feet in height. It is somewhat broader than any of the other outer cays. There is a fine bluff of white æolian rock at the southern extremity of the island. The base of the cliff is constantly eaten away by the action of the sea, and supplies the material from which is derived the whitish marly bottom which extends over the channel to the east of Great Abaco. No Name Cay protects the anchorage of Green Turtle Cay from the outside swell to the south, and Munjack and Crab Cays protect it from the north. Owing to the short distance between the outer cays and Great Abaco the sea in the channel acts upon its shores with little force.



An examination of the larger charts of this part of the Bahamas will show the effect which subsidence has had in forming a number of boat harbors and inlets on the shores of this cay. Some of them have twenty feet of water, and are more or less protected by the patches of coral reef growing between the cay and the edge of the bank. Upon these patches the sea beats violently, forming two or three lines of breakers, through which it is often impossible even for small boats to find their way out. Similar sinks exist upon many parts of the Bahamas, one of the most characteristic of which is Hurricane Hole, south of Andros (Plate XI. Fig. 4).

After leaving Green Turtle Cay, immediately along the sea face of the Little Bahama Bank on our way south, we passed through great masses of gulf-weed. There is little doubt that much of the Sargassum we meet with in the Bahamas comes from the shores of the cays. It is found in considerable profusion in many localities, and, while growing vigorously during the comparatively short season of calms, immense quantities are torn off during gales or heavy seas, so that a fresh stock of Sargassum must at all times be increasing the mass floating in the range of the Gulf Stream and of the northern extension of the equatorial set. How long it can thus float, and perhaps propagate by budding, is not known. It is, however, a well known fact, that Sargassum torn off from the rocks can be kept thriving for months in tanks or dishes.

The slopes of the low shore hills of Great Abaco, as seen extending southward from the anchorage at Green Turtle Cay, show in a most characteristic way their æolian structure. The base of these hills is cut off by low vertical cliffs which have been formed by the gradual wearing away of the rocks by the sea. We examined the shore of Great Abaco at Black Point, pulling round it and landing inside on the sand beach formed behind the spit. The rocks present the same æolian structure, and are greatly worn by the breakers. The material back of the beach is more in the amygduloid stage than in the marl stage. In three and a half fathoms off the beach the bottom is somewhat more sticky than the cleaner samples taken immediately on the beach.

In our way out through Whale Channel Cay we found all the islets and rocks rounded off on the summits, the surface pitted and honey-combed and eaten away at the base of the rocks.

From the summit of the white cliff to the eastward of the landing on Green Turtle Cay we could see the breakers on the outer coral reef, which extends more or less parallel with the edge of the bank all the way round its eastern edge in a nearly unbroken line.



### Whale Cay Channel and the Eastern Face of the Little Bahama Bank.

Plate X. Fig. 1; Plate XI. Fig. 7.

Passing out through the channel and crossing the opening left in the reef through the breakers, we had a fine exhibition of the skill and coolness of the pilot as he steered the "Wild Duck" into deep water.

Whale Cay Channel Rock is but a small outlier of a sunken patch. Whale Cay, as seen end on, shows the æolian hills to have their longest slope on the east face, and the same structure is admirably shown for Great Abaco. Great Guana Cay displays the same feature, though here and there short stretches of the base of the shore hills are eaten away into low vertical cliffs, probably opposite smaller or greater gaps in the belt of coral heads protecting the outer islands from the terrific pounding of the trade wind swell. Where not cut away the lower part of the shore hills is pretty well covered with coral sand torn off from the reef and thrown up on the shore. Great Guana Cay is covered by a most scanty vegetation near the shore, but is a little better wooded on the hill face near the summit.

Between Great Guana and Elbow Cays is a series of low cays, rocky or sandy, with very little vegetation near the summit ridge. The line of breakers forms a continuous wall with the islets whenever there is a heavy swell running, as was the case when we steamed past.

Man-of-War Cay has the same characteristics as Great Guana Cay. It has a high sandy beach with an occasional rocky outcrop covering the underlying rock, and the usual scanty vegetation just above high-water mark becoming somewhat thicker near the ridge of the island.

The succession of æolian hills piled up one by the side of another and sloping up to the westward is clearly seen in the line of Man-of-War Cay and of Elbow Cay. The settlement on Elbow Cay is protected by an outlying line of rocks, a part of the former eastern extension of that island, which now forms an outside line of islets connecting it with Man-of-War Cay.

As we steamed down towards the south end of Elbow Cay the face of the northern ridge above the settlement was seen to be white æolian rock cropping out between the bushes and scrub vegetation. All the way from Whale Cay we were running parallel with the belts of coral reef and the outer line of rocky cays. Near the south end of one of the small cays, between Tilloo Cay and Lynyard Cay, there is an accumulation of large

rocks opposite one of the gaps in the reef and in the outer line of rocky cays, giving the sea full swing to throw up the fragments of the æolian cliffs as they become broken off.

The east face of Lynyard Cay is low and worn into low cliffs. In the background can be seen the pine forests of Great Abaco rising behind Tilloo Cay Sound. The last of the outer islets we were near enough to examine made the northern spit of the entrance to Cherokee Sound, while Ocean Hill, a promontory of Great Abaco, formed the opening to Little Harbor to the south of Lynyard Cay. As we lost Great Abaco, the eastern face of which is no longer protected by outlying islands, we could see the comparatively high vertical cliffs extending southward in a nearly unbroken line to the point which we had seen on our first reaching the island north of the Hole in the Wall.

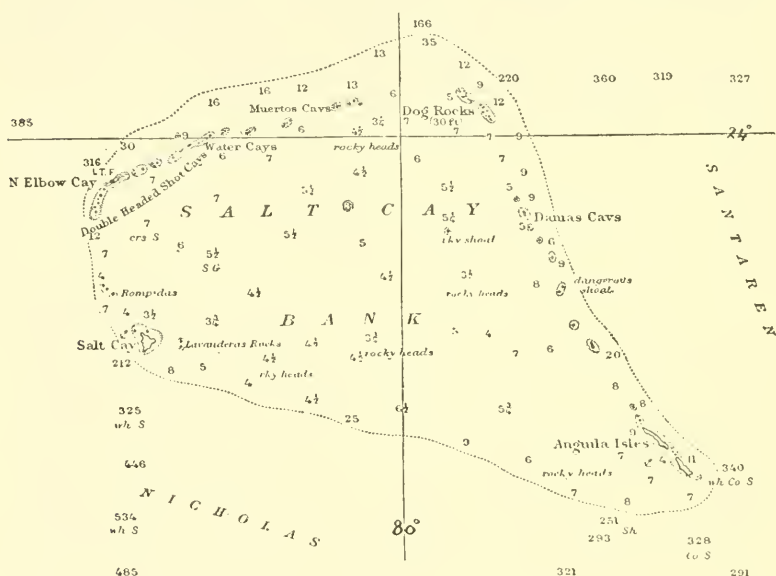
## SALT CAY BANK.

### Plates I. and XXXI.

Before describing the banks to the eastward of the Great Bahama Bank I will give a short account of Salt Cay Bank, the westernmost of the three banks lying on the eastern edge of the Gulf Stream. Salt Cay Bank is triangular, with rounded angles, its greatest width being about forty miles and its length nearly sixty. It lies at the western opening of the Old Bahama Channel, the forks of which, separating the bank from the Great Bahama Bank and Cuba, are known as the Santaren and the Nicholas Channels. In general, Salt Cay Bank resembles more the Crooked Island and Caicos Banks, and has reached a condition intermediate between them and the Mouchoir and Silver Banks. There remain on the edge of Salt Cay Bank fewer islets and rocks than along the Crooked Island and Caicos Banks, but they have not disappeared so as to leave mere rocks awash, as upon the edge of Mouchoir and Silver Banks.

Salt Cay Bank has been described by Professor Agassiz in his Report to the Superintendent of the United States Coast Survey for 1851, and republished in the *Memoirs of the Museum of Comparative Zoölogy*. Having visited the Florida Keys first and Salt Cay next, he naturally extended his explanation of the formation of the Florida Keys to all the cays of Salt Cay Bank. The structure of Salt Cay is, I believe, however, radically different from that of the other cays of the bank which I visited.

It is, like Cay Lobos, built of recent coral sand rock accumulated after the formation and disintegration of the cays of the bank. It is on the very edge of the bank, and owes its existence to the throwing up at that point of coral sand so as to make an island, the underlying base of which there is every reason to suppose does not differ from that of the other banks of the Bahamas. This we may safely infer after an examination of the remaining outcropping islands forming the Double Headed Shot Cays, the Muertos Cays, the isolated islets of the eastern edge of the Salt Cay Bank (Dog Rocks and Damas Cays, etc.), and the



Anguila Islands. The shores of Salt Cay are edged with strata inclined to the sea, composed of recent coral rock sand of different degrees of fineness, including in some cases excellent examples of coarse heavy breccia. At another point on the shore we found a mass of broken fragments of *Strombus* and *Turbo* of all sizes and shapes, rounded, elliptical, or angular, often more or less worn, forming a regular coarse conglomerate. Mixed with this are numerous pieces of bivalves. At other places the fragments of shells have been broken to very small pieces, forming a very fine breccia.

The Salt Lagoon, which was once the basis of a thriving industry, destroyed by the hurricane of 1866, is separated from the sea by a long

steep beach, the summit of which is from twelve to fifteen feet above the level of the sea. The sea face is not more than twenty to thirty feet wide, while on the lagoon side the beach is from three to five hundred feet wide. As has been noted by other observers, the water of the lagoon is intensely salt. We saw nothing living in it, but many dead conchs and the shells of other large mollusks, as well as those of innumerable smaller mollusks were found scattered all along the lagoon beach. These mollusks must have lived in the lagoon during a higher stage of water, when its salinity did not differ materially from that of the sea. It is surrounded by mangroves, many of which run far into the lagoon. The hills to the east are not more than twenty-five feet in height. I could not satisfy myself of their true character, and could not decide from what I observed whether the rocks composing them were æolian, or whether they had been thrown up during hurricanes, as was undoubtedly the case with a bluff which forms a part of the same low range separating the lagoon from the sea. This bluff was built up of large rectangular blocks of coral rock similar in structure to that of the inclined strata along the shores. Some of the blocks had been thrown up to a height of fully twenty-five feet above the level of the sea during the hurricane of 1866. At least our pilot says that is the general report.

Between Salt Cay and Double Headed Shot Cays as far as Rompidas Rocks we steamed on the edge of the bank in about seven to eight fathoms over masses of coral heads closely clustered together, separated by narrow sand bars consisting of *Astræans* and other corals. At our anchorage off Salt Cay the coral heads were growing luxuriantly in from three to five fathoms. The great abundance of living corals on the edge of the Salt Cay Bank fully accounts for the masses of fragments of corals in all stages of comminution which we found on the beach of Salt Cay, and for the formation of an island like Salt Cay, which is probably wholly of reef-rock sand origin, and not of æolian origin like the other cays on the northern and eastern edges of the bank. After making the shallower water of the bank, the coral heads are fewer, there are longer stretches of sand between the heads, and large spaces entirely devoid of corals.

Salt Cay Bank is, like the other banks of the Bahamas, a triangular plateau fringed on the eastern and northern edges with islands and islets or isolated rocks all of æolian structure, while on the western edge of the bank, with the exception of the Rompidas and Lavanderas Rocks, they have disappeared. The subsidence of the bank has probably been fully as great as that of many of the other banks, if we are to judge

by the condition of the Double Headed Shot Cays and of the Anguila Islands.

The Double Headed Shot Cays, as approached from the south, present one mass of isolated rocks, islets, and islands without vegetation. Elbow Cay (Plate XXXI.), the largest island of the group, is a splendid specimen of the transformations to which the æolian rocks of the Bahamas have been subjected. The surface of the island is deeply pitted and honeycombed in all directions. Near the edge there are many blow-holes, through which the spray is sent in all directions, and on the north side, where the water is deepest, the action of the northers must have been one of the principal causes of the wearing away of that part of the island. The æolian structure of the rocks of the island could be most plainly seen. At the landing to the south of the lighthouse, as well as in the deep channel for landing stores cut into the rock on the north side, the stratification so characteristic of æolian rocks was most distinct. Steaming across the bank towards the Anguila Islands we found the bottom on Salt Cay Bank much like that of the other Bahama Banks, with little animal life but many coralline algæ. We dredged a few times on the way, bringing up many fragments of shells and broken Clypeastroids showing the effect of the waves on this shallow plateau. The outlying rocks to the northwest of the Anguila Islands could plainly be seen to



ÆOLIAN CLIFFS, SOUTH ANGUILA.

be of æolian origin. The islands are comparatively low, the northern and southern extremities being somewhat higher than the central mass of the islands. The long stretches of low vertical cliffs forming the western shore of the islands are separated by sand beaches. The hills near the southern extremity on the west shore mark the highest part of the islands. Opposite our anchorage were fine æolian hills from forty to fifty feet in height, full of cavities and deeply honeycombed.

## THE EASTERN BAHAMA ISLANDS.

Plate I.; Plate VI. Figs. 1 to 4; Plate IX.

To the eastward and southeastward, and separated from the Great Bahama Bank by very deep channels, are a series of islands and banks extending from Watling Island to Navidad Bank, which in their turn rise sharply from the bottom of the ocean. These islands and banks are of all shapes, either elliptical, or circular, or more or less rectangular, or sometimes irregularly triangular. They are interesting as showing the different stages through which the Bahamas as a whole have passed, from the time when they covered a far greater area than that now indicated by the islands, which in some cases merely form the sea fringe of the banks of which they represent the summits. The former islands have been eroded and eaten away, and have wholly disappeared on the western faces of the banks, or have left only here and there a small island or isolated rock to testify to the former existence of the same æolian hills which form the summits of the present islands.

The smaller islands — like Watling, Conception, Rum Cay, Atwood Cay, the Plana Cays, Mariguana, and the Inaguas — still occupy nearly the whole area of the banks upon which they rise. The 100 fathom line of Great and Little Inagua, of Samana, and of Mariguana, is but a little distance beyond the shore line of these islands. On Rum Cay and Watling the 100 fathom line bank is somewhat larger, and Conception Island is a small part of the submerged bank upon which it rises. But except Conception these islands have at no time differed very materially from their present outline. When, however, we come to such banks as the Crooked Island Bank, Caicos Bank, and Turk's Islands, we find upon them a series of islands which have been greatly modified by the action of the sea. The islands, such as Crooked Island, Fortune Island, Bird Rock, the Fish Cays, Acklin, and Castle Island, which, with the exception of the westward face, nearly surround the Crooked Island Bank, are all that remain of the one large island which undoubtedly once occupied the whole of this bank even somewhat beyond the 10 fathom line. In fact, we may well imagine the time when the Crooked Island Bank presented much the same appearance as Great Inagua, when it had like the latter its fringing reef a short distance from the shore line at a depth of four to fifteen fathoms, and formed perhaps here and there a reef harbor like that of Alfred Sound at the northwest extremity of Inagua.



The æolian hills of the western face of the former Crooked Island land were probably quite low, and were soon eaten away. As the bank subsided, the great lagoon or flat occupying once the central part of the island, as at Inagua, sank below the level of the sea to become the bottom of the bank, while the low land to the westward was all washed away and disintegrated by the action of the sea and rains.

We can readily trace a similar course of events on Caicos Bank, and find no difficulty in reconstructing the Caicos Bank land. This is now split up into West Caicos, Providenciales, and North, Grand, and East Caicos, which form the northern and northwestern outline of the bank, while South Caicos, Long Cay, Ambergris Cays, and the Swimmer Rock fringe the eastern face of the bank, and Molasses Reef, French Cay, and West Sandspit are the remnants of the land fringing the southwest line of the Caicos Bank. Here and there on the southeastern part of the bank rise the Seal Cays, Pear Cay, White Cay, and the small rocks which were once a part of the greater Caicos land. The bank itself, like Crooked Island Bank, the Turk's Islands, in fact all the banks, not excepting the Great Bahama Bank, show a dip to the westward, and the same is the case with the sunken Mouchoir, Silver, and Navidad Banks. Great and Little Inagua evidently have not been subject to the same amount of subsidence which has so materially affected the islands and banks to the seaward.

In addition to these larger banks we have *Mira por vos* Bank with a few insignificant cays, Diana and Brown Banks, both of which are sunken, the one with ten, the other with nine fathoms in the shallowest part. To the southeast of Turk's Islands are Mouchoir and Silver Banks, on both of which there are rocks awash and coral heads on the northern faces of the banks, with a few isolated rocks irregularly scattered, the depths on their banks ranging from nine to twenty fathoms; and finally comes the last sunken bank to the eastward, Navidad Bank, with an average depth of about sixteen fathoms and a least depth of eleven fathoms.

### Watling Island.

Plate IX. Fig. 12; Plate XXIII.

Watling, as is seen from the chart, is twelve miles long and from five to seven wide. Its shores are but slightly indented. The greater part of the surface of the island is occupied by salt water lagoons of very irregular outline, formed in the valleys and sinks of the cross ranges

of æolian hills covering the island. These hills rise to a height of from a hundred to a hundred and forty feet, and are covered with woods.

An examination of the map of Watling Island is interesting as showing the great number of lagoons which occupy so large a part of its surface. On the western side is found the largest of these lagoons. It is quite shallow, the part we examined varying between one and a half and three feet in depth. An artificial cut has been made through a low ridge separating one of the western lagoons, about half a mile from Riding Rock beach, so as to make a boat passage to the larger lagoon and reach by water the vicinity of the lighthouse on the northeastern extremity of the island. The cut shows the same æolian structure of the rock so characteristic of the islands we had so far visited: In the distance, on the opposite side of the lagoon, could be seen rising the same solidified æolian hills which characterize the structure of all the islands on the larger banks. The examination of this side of Watling Island plainly shows its structure to be similar to that of the islands to the westward, and also shows that Watling owes its present configuration and the existence of its many lagoons to the subsidence which has caused the gradual disappearance of the extensive tracts of æolian land which once covered the greater part of the Bahama Banks.

The bottom of the great lagoon is thickly covered with algæ (*Aceabularia*), and the shores of its beaches are lined with diminutive specimens of the same species of shells found on the open sea beaches. The water of the lagoon is intensely salt. It connects evidently with the sea, as our guide mentioned several blow-holes through which the tide is forced into the lagoons.

The shores of the lagoon are lined with mangroves. Parts of the lagoon have been separated from the sea by a high narrow beach thrown up by the incessant Atlantic swell; but by far the greater number of the lagoons of Watling Island are due to the general subsidence of the island, forming drainage areas, and allowing the sea to cover the flats intervening between the ranges of æolian hills and then to the closing of these openings by coral sand beaches thrown up by the sea. Many of the ponds are disconnected, are salt, and are supplied by percolation through the barriers separating them from the sea, or by blow-holes connecting them directly with it. This is especially the case with some of the ponds only separated from the sea by narrow beaches. Many of the lagoons are in underground communication with the sea, and in some of them the position of the blow-holes through which the sea water is forced up can be traced by the commotion of the water of parts of the lagoon.

The subsidence and erosion of the island have formed an extensive harbor at the northeastern end, hemmed in on all sides by islands and islets, leaving a couple of passages to the northeast of Green Cay into Graham Harbor. Fringing this harbor, and following its outline in from three to six fathoms of water, extensive patches of corals are met with which form to the eastward a more or less continuous coral reef, with an inner protected passage for boats and smaller vessels along the whole of that face of the island. These independent patches of corals are also found on the west coast, as at Riding Rocks, but are not so continuous as on the east coast. The corals forming these patches are the common West Indian species of Madreporæ, Mæandrina, Astræans, and Orbicellas, with Flabellum as the most common of the Gorgonians. Sailing round Graham Harbor, we followed a course parallel to the eastern shore. The outer reef shelters the long sand beaches fairly well, and the former outline of the island was such that there are but few vertical bluffs on the windward side of the island. The highest hills are on this eastern side, one rising to the southward of the lighthouse, its sea face forming the white bluffs which, according to Captain Becher of the Royal Navy, flanked the beach where



LANDING PLACE OF COLUMBUS, ACCORDING TO CAPTAIN BECHER, R. N.

Columbus first landed, while the spurs from Fortune Hill nearer the southern end of the island extend to the sea and form the white cliffs which according to Sir Henry Blake flanked to the north of Columbus Bight the spot where Columbus first landed in the New World. The



LANDFALL OF COLUMBUS, ACCORDING TO SIR HENRY BLAKE.

beach at the northeast end of the island is so entirely shut out by patches of coral reefs that it would have been impossible for Columbus to have anchored at the spot which Becher assigns as his anchorage. Our pilot says no sponger ever dares to anchor there; while farther south, at Columbus Bight, the spot selected by Sir Henry Blake, there is a small reef harbor where boats of the size of the caravels could readily

find an anchorage, and from which the boats of the fleet might have rowed in safety to examine the "other side," and return the same day to their ships.

I may here quote from a translation, by Mr. H. L. Thomas of the U. S. State Department, of the Journal of Columbus,<sup>1</sup> the following points of interest regarding the so called barrier reef off the east face of Watling Island: "Went along the island, in a northeasterly direction, to see the other side, which was on the other side of the east. . . . I was afraid of a reef of rocks which entirely surrounds that island,<sup>2</sup> although there is within it depth enough and ample harbor for all the vessels of Christendom, but the entrance is very narrow. It is true that the interior of that belt contains some rocks, but the sea is there as still as the water in a well."

From Columbus Bight on the east coast there is an excellent boat passage inside the reef leading to Graham Harbor, and it is within this passage that the boats of Columbus probably rowed to explore the other side of the island. It is undoubtedly to this passage, sheltered by the reef, and to the reef harbor, that he refers as capable of holding the navies of the world. Such a wonder as a reef harbor or a passage inside a barrier reef could not fail to strike him, and it seems strange that it is not better described in his journal, and that so little is said by him of the striking contrast of the light green color of the water inside the barrier reef and in Graham Harbor with the dark blue of the ocean beyond the 100 fathom line.

The 100 fathom line extends about a mile beyond the reef. Inside the reef, the passage is on an average about a third of a mile wide. The 100 fathom line runs at a fairly uniform distance from the shore all round the island, except off the Hinchinbroke Rocks at the southeast end, where the bank extends seaward more than two miles, and comes in again along the south shore to Southwest Point. .

Along the west coast disconnected patches of coral heads extend from a depth of three or four fathoms towards the edge of the bank. We came to anchor that same day at Southwest Point on the steep slope of a sand beach. Here we also found, in from four to twelve fathoms of water, outside the action of the breakers, fine patches of Madrepores and other masses of corals furnishing material for the recent coral beaches which form a low plateau flanking the æolian hills. This plateau lies at intervals between headlands along the western face of the island.

<sup>1</sup> G. V. Fox, Appendix 18, U. S. Coast and Geodetic Survey, Report for 1880, p. 14.

<sup>2</sup> Not the west side.

## Rum Cay and Conception Island.

## Plate IX. Fig. 11.

From the southwest point of Watling Island we steamed to Rum Cay, the structure of which is very similar to that of Watling. The salt ponds are limited to two small areas, from which formerly a considerable amount of salt was exported.

On our passage from Watling Island to Rum Cay, and while sailing round it and on our way to Clarence Harbor, we passed through many streaks of gulf-weed.

The bank of which Rum Cay forms the summit extends northeast about five miles to the 100 fathom line. The bank is narrow on the west face. On the north side the 100 fathom line is not quite two miles from shore, and varies from three miles to three and a half on the west and south sides. On the eastern side the salt ponds are separated from the sea by æolian hills varying from fifty to ninety feet in height, and on the south by walls of recent coral sand. The northern and western ends of the island are also capped by æolian hillocks.

Rum Cay is about nine and a half miles in length by five in breadth at the east end and two at the west. The southern side of the cay is edged by a coral reef nearly a mile off shore, growing upon sunken patches of æolian rocks. A wide entrance through the reef forms Port Nelson inside the reef with four fathoms of water. There are patches of corals all along the north shore about half a mile from it. The corals are thriving, and consist, as far as we examined them, mainly of huge masses of *Astræans*, *Orbicellas*, *Madrepora palmata*, and *Millepores*.

The low southeastern part of the island is formed of débris of the reefs now growing on the southern edge of Port Nelson. A low bank of coral sand is thrown up, forming strata slightly inclined and protecting the coral sand flat extending inland to the base of the æolian hills. The north face is bold, steep, with low bluffs and no anchorage along it. The east face is flanked by low æolian hills. The highest hills are along the northern side near the northwest extremity of the island.

Conception Island we did not visit. The adjacent cays rise to one hundred and thirty feet above the circular bank, which carries from six to fourteen fathoms of water. Reefs extend in a nearly unbroken line round the southeastern and western edges of the bank. It is probable that the 1,000 fathom line connects Conception Island Bank with the southeastern side of Cat, and that Rum Cay also lies within that line.



### The Crooked Island Bank.

Plate IX. Figs. 1, 9; Plate X. Fig. 4; Plates XXXVII. and XXXVIII.

The most westerly of the smaller outlying banks of the Bahamas is the Crooked Island Bank, which is triangular in shape. Its northern side is about thirty miles long, its eastern face forty, and the western forty-eight miles. The bank slopes very gradually towards its western and southern edge. The 100 fathom line runs close to the edge of the bank along the sea face of both Crooked and Acklin Islands, as well as to the west face of Fortune. This and Caicos Bank are, as it were, epitomes of the Great Bahama Bank, representing on a small scale the characteristic physical features of the Bahamas. Fortune Island forms the western edge of the bank, Crooked Island the northern, and Acklin and Castle Island part of the northern and eastern face of the triangular bank, which is open to the sea for the greater part of its western side. The islands forming the outside edge of the bank are all narrow; both Crooked and Acklin Islands are somewhat wider than Fortune Island, spreading out on the northern and western sides very gradually, and passing into the shallow waters of the inner northeastern part of the bank. From the western extremity of Crooked Island extends a wide range of æolian hills, the Blue Hills, occupying the central line of the greater part of the island; the summits reach a height of about two hundred feet. Near the eastern end Mount Pisgah rises to two hundred feet close to the shore.

The whole northern face of the bank is edged by a coral reef extending from Northeast Breaker on Acklin Island to Bird Rock, where the reef forms a well sheltered basin. About a mile from the northwest point of Crooked Island is Portland Harbor, with three to four fathoms of water.

Acklin Island is separated from Crooked Island by a wide passage of about two miles, but very shallow. The eastern face of the island is skirted by a reef nearly continuous from Northeast Point to Castle Island, beyond the southern extremity of Acklin Island. Castle Island stands on the southern end of the Crooked Island Bank, and is about two miles in length. On the northern and eastern sides of Acklin Island are a series of æolian hills lying along the eastern face, which rise to a hundred and fifty or two hundred feet. Near the southern extremity they are somewhat higher than those of Fortune Island.

The west shore of Acklin, like the southern shore of Crooked Island,



is low, running into the shallow water of the bank. Nowhere, except near the southern end of Fortune Island and to the west of the Fish Cays, and a small patch to the eastward of them where there are two fathoms, is this shallow water of greater depth than one to one and a half fathoms, and a great stretch of the bank carries even less than that.

Acklin Island and Castle Island, as seen from the southeast, presented no features differing in any way from those of the other Bahama Islands. Vertical bluffs of æolian rock, of greater or less height, characterize their sea face. The trend and outline of the æolian hills of Acklin plainly indicate their origin.

Fortune Island is nine miles long, comma-shaped, barely a quarter of a mile wide at its northern extremity. Near the south end a hill rising to a hundred and ten feet slopes gradually towards it. Off the east coast near the south end there is a deeper belt of water running rapidly into six or seven fathoms. From the southwest end of Fortune Island a narrow reef extends along the whole western face, in from four to twelve or fifteen fathoms, towards the edge of the 100 fathom line bank, which drops off abruptly from the outer edge of the reef. The Fish Cays are the only remnants of the land once skirting the southern part of the western edge of the bank, or perhaps of the land which once covered the whole bank, and of which the larger islands are the vanishing tops. To the eastward they are surrounded by a series of sand bores which do not quite reach the surface at low water. Off the west coast of Fortune Island the 100 fathom line runs close to the shore, leaving but a narrow belt of soundings. This belt widens out somewhat about half-way north along the west shore, and from that point an irregular coral reef extends, in from three to five fathoms, almost to the northern end of Crooked Island. The western end of Crooked Island is cut up by narrow lagoons opening on the bank side. The inner one opens by two channels edged with mangroves into a large inland bay nearly ten miles across. The outer one is separated from the Crooked Island passage by a narrow band of recent coral sand. This gradually disappears as one goes farther on the bank, until finally the bottom is made up of the débris of æolian rocks mixed with fragments of shells, and other Invertebrates, the whole kept more or less in place by the numerous calcareous algæ which flourish on the limestone bottom.

On entering the bank off the southern extremity of Fortune Island we found the bottom to be dotted with coralline algæ, fine sand, and

with patches of the common West Indian Gorgonians. The corals on the bank exist in irregular patches, and do not extend any distance eastward. They flourish along a narrow belt on the edge of the bank, between three to six and fifteen or sixteen fathoms.

On the bank side of Fortune Island the slope of the hills runs insensibly into shallow water; but, steaming on the western face, the shores all the way from the South Spit of Fortune to its northern extremity are flanked by low æolian cliffs interrupted by steep coral sand beaches. Above the low cliffs extends for a considerable distance a line of angular rocks thrown up above high-water mark by an unusual swell or by hurricanes.

The lagoon which extends south from the settlement nearly to the southern end of Fortune Island is separated from the sea by a high steep coral sand beach (Plate X. Fig. 4). The beach becomes gradually much lower north of the settlement; it extends all the way to the northern extremity of Fortune Island, and is again seen on Crooked Island, being nearly unbroken along the whole shore line as far as Portland Harbor at the northern end of the island. Crooked Island is also built of æolian hills with gentle slopes to the west except near its northern spit, where the shores consist of low vertical cliffs.

From Bird Rock lighthouse the beautiful sweep of a coral reef connecting it with Crooked Island forms a fine bay sheltered from the northeast trades, the green waters of which stand out in marked contrast with the dark blue of the deep water off the bank, while the white wall of breakers marks the dividing line between it and the deep water to the east.

If Columbus visited Bird Rock, or Cape Beautiful, as some writers call the western end of Crooked Island, he could not have failed to notice a physical phenomenon so strange to him as that of a coral reef forming a bay well protected from the prevailing winds, nor could such a sharp observer have failed to describe at length, or to note at least, this peculiar feature of the sea.

To the westward of Castle Island is the *Mira por vos* Bank, with soundings near the edge of from five to nine fathoms. It is pear-shaped, with a cluster of low barren rocky cays, the highest of which is but thirty feet. At the north end they are connected by a reef; and there are several disconnected patches of corals, with three fathoms of water over them.

Two other small banks rise in the Crooked Island passage. Diana Bank, twenty miles to the west of Fortune Island, is about four miles

in length, in from nine to fifteen fathoms of water. The bank is said to consist of sand and of coral. South of Mira por vos Bank rises the peak of Brown Bank (Kansas Bank), which has from ten to twenty-three fathoms of water on it. Both these banks drop abruptly into deep water from the 100 fathom line, close to the soundings indicated.

A number of other small banks have also been reported, but their position is doubtful. They are Cuidado Bank, south of Mariguana, the Clarion Bank, south of Mathew Town (Inagua), the Fawn Shoal, south of Turk's Island, and the Severn Shoal, to the northeast of Silver Bank. It is not astonishing that, in a district where the currents are so strong and so variable, it should be difficult to find the position of reported shoals, the original positions of which are generally very inaccurate.

### Mariguana, the Plana Cays, and Samana.

Plate I.; Plate IX. Fig. 4.

On account of the strength of the trades we did not visit Mariguana, Samana Island, or the Plana Cays. The highest point of Mariguana is stated to be a hundred and one feet, and at the east end there are several hummocks of from forty to sixty feet. The hills, I am informed, consist of the regular Bahamian æolian rocks, and the same rocks also occur on the Plana Cays. The north shore of Mariguana is skirted for its whole length by a reef. The west shore is bold, and the 100 fathom line of the bank is close to the land. The south shore, with the exception of a reef which protects Abraham Bay, is clear; the bottom is covered with clean sand. At Southeast Point a reef of nearly nine miles in length extends to the easternmost extremity of the spit formed by the bank off the east-



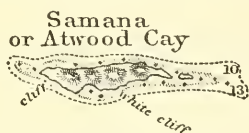
Lat.  $22^{\circ} 40' N.$ ; Long.  $73^{\circ} 34' W.$

ern face of the island. The reef is close to the 100 fathom line on the south side of the spit, but on the north side it is half a mile distant.

The eastern side of the West Plana Cay is fringed by a reef, while both the north and south sides of East Cay are skirted by a reef about a third of a mile from the shore, and extending nearly five miles off the east end.

The highest point of East Plana Cay is about seventy feet. On the north side of West Cay the bank limited by the 100 fathom line extends about two miles.

Samana Cay is nine miles long and about a mile and a half broad. Its surface is uneven, stated by Sir Henry Blake to be perfectly barren,



Lat.  $23^{\circ} 6' N.$ ; Long.  $73^{\circ} 40' W.$

and the most inhospitable looking of the islands. It attains a height of one hundred feet. The narrow cay running nearly due east and west is practically fringed by a coral reef, occasionally broken for its whole length both on the north and south shores.

### The Caicos Bank.

Plate I.; Plate IX. Fig. 2.

Caicos Bank is the largest of the eastern outlying Bahamas. Its outline is most irregular, extending sixty-four miles east and west and fifty-eight north and south. The northern and the greater part of the eastern face are edged with islands, all consisting of æolian rocks.

The wearing away of the Caicos Bank has taken place on a proportionally larger scale than on the Crooked Island Bank. The Caicos Bank is protected from the northeast trades by a line of islands extending from West Caicos east in a great curve, namely, the Providenciales, North Caicos, Grand Caicos, and East Caicos, South Caicos, Long Island, the Ambergris Cays, and Swimmer Rock, forming the only land on the east face of the bank. A few isolated patches of rocks of æolian origin rise a few feet above the surface on the southern spit of the bank, and on its west face French Cay and other shallow patches mark the outline of the former Caicos Land. On the sides facing the interior of the bank the shores of the northern islands are all low, passing into lowlands scarcely rising above the level of the sea, and thus forming most indistinct coast lines, which gradually pass into the shallow soundings characteristic of the northern part of the bank.

From the northern end of West Caicos as far as the south end of South Caicos there is on the outer edge of the bank a coral reef

extending nearly unbroken along its whole length in from three to twelve fathoms of water. The reef forms a wide belt between West Caicos and Providenciales, with a narrow passage of from two to five fathoms of clear water between the reef and Providenciales. It skirts, both as a fringing and as a barrier reef, the northern shore of Providenciales, with but a narrow channel between the barrier reef and the shore. It extends along North Caicos, at a distance varying from half a mile to two miles off shore. There is a break in the reef at Juniper Hole, between the North Caicos and Grand Caicos reef. The latter extends nearly unbroken along the north side of Grand Caicos and East Caicos to Cape Comete, and thence south along the east faces of East and South Caicos. Along Long Cay the 100 fathom line is close to its eastern face, from its southern extremity the reef runs in isolated patches towards Ambergris Cays. We were unable to observe its course along the southern edge of the bank. The edging reef reappears again about twenty miles southeast of West Sand Spit, extending all the way to that point and westerly to French Cay, beyond which it forms extensive and nearly continuous reefs along the edge of the bank, such as Molasses and the Southwest Reefs east of West Caicos.

A little to the south of French Cay we entered upon the bank, passing through an opening in the edging reef, and steamed nearly east across the bank, carrying from two and a half to three fathoms of water, to Long Cay, passing in sight of Middleton and Six Hill Cays, and out



SIX HILL CAY.

into Turk's Island Passage south of South Caicos. We were in sight of Ambergris Cays, beyond which are dotted the Seal Cays, running across the southern part of the bank. The highest point on the islands of the Caicos Bank are the hills on North Caicos and Ambergris, which are said to be one hundred feet high. West Caicos is about sixty feet high. North of the track we followed in crossing the bank, as the pilot informed me, the water shallowed very rapidly, while in the direction of the Seal Cays the water is deeper.

The peculiar light green tint assumed by the western edge of the bank follows the belt of the edging reef, and is in striking contrast to the white bottom inside of the reef and the adjacent dark blue color of the water outside of the 100 fathom line. This color, when reflected on the edge

of the clouds, is often seen at great distances ; it is known to the bank fishermen as the bank bliuk.

Our pilot informed me that in from six to ten fathoms of water on the southern part of the east face and the southern face of the bank there are large tracts covered by a species of *Thalassia*, judging from his description of the weed.

We examined the bottom on the Caicos Bank on our way across from French Cay to Long Cay. As we steamed along we came upon patches of Gorgonians and of large heads of corals (*Astræans*) separated by long irregular lanes of sand, or nearly choked by it. The coral belt of the western face of the bank was, where we followed it, in from four to ten fathoms, although limited in extent, of a rather more luxuriant growth than on the east face of the bank. At Molasses Reef it has reached the surface, and isolated patches are exposed at low tide. The bottom consisted mainly of broken shells and of æolian sand, more or less tied together by the roots of calcareous algæ.

On leaving Caicos Bank the fine white æolian cliffs of the southeast end of Long Cay formed a prominent landmark, and gave us an excellent idea of the extent of the disintegration of all that side of the Caicos Bank land. The Turk's Island Passage is remarkable for the abundance



LONG CAY.

of its pelagic life. In the first place, gulf-weed was most abundant ; Appendiculariæ in their houses swarmed ; a species of *Mertensia* was a common Ctenophore ; *Liriope*, annelid and crustacean larvæ, embryos of corals, *Pneumodermon*-like Pteropods, large and small *Arachnactis* ; — in fact, a finer display of pelagic types than we found anywhere in our cruise outside of the track of the Gulf Stream between the Cuban coast and Florida.

### Great Inagua.

Plates I. and VIII. ; Plate VI. Fig. 2 ; Plate IX. Fig. 3.

Inagua is about forty-five miles long ; its outline is most irregular, its greatest breadth being only eighteen miles. East Hill, the highest point on the island, stands on its east face, and is one hundred and thirty-two



feet high. North of East Hill a number of hills rather higher than those of the south shore extend to Northeast Point. A number of low hills from thirty to ninety feet in height skirt the southern face of the island; when approaching them from the south, as we did in coming from Cape Maysi, they appear like distinct islands. The hills are covered with stunted bushes and palmettos. The west shore is comparatively low, Mortimer Hill north of Mathew Town being its highest point. Beyond Alfred Sound on the north shore rises James Hill, about ninety feet high, the only elevation west of Carmichael Point; flanking Ocean Bight are a number of hills from seventy to ninety feet in height. The interior of the island is low, wooded, and intersected by many salt water lagoons. A recent coral sand beach, quite steep, is the landing place of Mathew Town to the north of the lighthouse. The material for the beach comes in part from the wearing of shore coral sand rocks which extend all the way along the coast from the Lighthouse Point northward, and in part also from the fragments of the belt of coral reef which grows upon the narrow coast shelf of the island. The low plain forming the greater part of Inagua Island apparently consists of shore coral rock rising but a few feet above high-water mark, which has been deposited in the sinks between the æolian hills flanking the northern and southern shores. The æolian hills rise from the northern and western ends of the island, and increase in height to the eastward. This plain is fairly covered with vegetation and with coarse grass, and affords excellent pasturage for cattle and horses, which run wild over the island.

The eastern face of the island is skirted by a reef from six hundred feet to half a mile from the shore, the 100 fathom line being about half a mile from the reef. Nearly the whole of the south shore is also similarly skirted by a reef, with the exception of a short distance round Southwest Point on the west coast. The coral growth is in patches, the water off shore being bold and the 100 fathom line close to the land.

Alfred Sound on the east side of Northwest Point in Inagua is an anchorage for small vessels, protected by a reef nearly dry at low water, which runs out from Palmetto Point at a distance of a mile and a half from the shore. Standing at the western opening of the reef harbor are two low cays covered by a little vegetation, and connected by a reef or patches of corals and *Gorgoniæ* growing in the shallower water. To the eastward a long spit extends, formed by a coral reef, inside of which no less than seven fathoms are found in places. At the east end of the spit the reef is quite awash, and the course of the reef is clearly indicated by the long horseshoe-shaped line of breakers. The reef which extends

east from Palmetto Point also skirts the western part of Ocean Bight. All along the shore from Palmetto Point to Northeast Point the bank formed by the 100 fathom line is very narrow. The coast is steep, and is exposed to the full action of the northerly winds.<sup>1</sup>

We did not visit Little Inagua. It is quadrangular in form, eight miles long by five miles broad (Plate IX. Fig. 3). Its highest point on the north side is sixty feet, and on the south side there are a few hills of nearly the same height. The northeast and northwest shores are bold, with a clear sandy bottom to a distance of about one third of a mile. There is a coral growth off the south and east sides; on the west side the bank to the 100 fathom line is perhaps a mile wide.

We may readily imagine the various banks on the Bahamas to have been somewhat in the condition of Inagua. An extensive and flourishing coral reef on the edge of the bank may have supplied the material for the formation of the great shallow bank which once existed at the foot of the æolian hills, which in their turn were formed from dry material, supplied from the shallower portions of the bank, blown into dunes and consolidated.

The outlying eastern islands, Samana, the Plana Cays, and Marignana, resemble in their structure Watling and Rum Cay, occupying nearly the whole of the bank of which they form a part.

Neither Inagua nor little Inagua has changed its outline greatly since the subsidence took place which so materially altered the face of the line of banks from Crooked Island to Navidad Bank. Judging from an examination of the charts, it appears that, as we pass eastward from the Crooked Island Bank, the banks have been worn away generally in proportion to their easterly position. The Crooked Island Bank has in proportion to its size a greater amount of dry land fringing its border than Caicos Bank, that in its turn more than the Turk's Islands Bank, while the Mouchoir, Silver, and Navidad Banks carry more water as we pass to the east.

<sup>1</sup> Dr. Henry Bryant visited Inagua in 1859, and gave a short account of the island in 1866. (Proc. Bost. Soc. Nat. Hist., Vol. XI. p. 63.) He considers the salt lake "the remains of the original lagoon which once occupied the greater part of the island, and which has been gradually filled up so evenly that the portion which still remains is nowhere more than a few feet in depth." As Dr. Bryant well says, the fertile plains are merely salt plains covered with a coarse grass dotted here and there with clumps of stunted trees, and scarcely elevated above the level of the salt lake. Dr. Bryant considered both Inagua and Watling Islands as "merely a narrow margin of an interior lagoon"; the plains as "the remains of lagoons formed by fringing reefs filled up by the action of the winds and waves."

It is worthy of notice that the position of all the important islands of the Great Bahama, Crooked Island, and Caicos Banks — as well as of Little Bahama Bank with the exception of Bahama Island — is on the weather side of the banks, either on the eastern or northern face. On the western side we find only small islets or rocks, the remnants of the western islands which were the first to disappear on the subsidence or the tilting of the western shore. This must have resulted in leaving the northwestern and eastern faces of the banks at a higher level, and must also have given to all the banks of the Bahamas a very gradual dip to the westward. This is found to be the case whether we examine the section of the bank from Andros to the Santaren Channel, or from Eleuthera to the Tongue of the Ocean, or from Long Island to the Old Bahama Channel, or that of the Little Bahama Bank from Great Abaco to Burrow Cay, or a line parallel to this from Spanish Cay to Memory Rock. The configuration of these wide shallow banks, flanked by islands on the windward face and by islets or rocks on the western face, plainly shows that the growth of the recent corals, which flourish in from three to fifteen or more fathoms almost around the whole outer face of the banks, has added very little to the amount of land, which consists wholly of æolian rock. It is only here and there that bights in the disintegrating islands have been filled as it were by the material thrown up from adjoining coral reefs, and thus coral sand flats have been formed abutting upon older æolian hills. These flats, however, form but an insignificant part of the land which remains, and play no important part in the configuration of the islands of the Bahamas.

While crossing the Caicos Bank we encountered large masses of gulf-weed.

### The Turk's Islands.

Plates I. and VIII.; Plate IX. Figs. 5, 6.

The easternmost of the Bahama Islands are the Turk's Islands, which rise from a narrow bank running about thirty-five miles in a north and south direction. From the middle of the bank a wide tongue extends for seven miles eastward, on which the soundings are from eight to ten fathoms. Grand Turk Island is five and a half miles long and about one mile broad. The eastern face is formed by a narrow ridge of æolian hills about seventy feet high, with their steep face on the east. The western slope of the ridge is flanked by recent shore coral rocks, which have formed the flats between the landing and the hills, and have iso-

lated the salt ponds once the source of a profitable industry for the inhabitants. On the west side of the island near the southern end the 100 fathom line is less than eight hundred feet from the shore, and the reef which skirts that part of the island forms an exceedingly narrow belt from the 4 or 5 fathom line to the 12 or 15 fathom line. It fringes the southeastern end of the island, and on the east face extends in a mass of disconnected heads irregularly scattered over the 3 fathom line reach which stretches eastward from the shore, gradually passing into the reef which flourishes along the 4 or 5 fathom line, and which extends from Northeast Reef to Tucker Rock, along the centre of Turk's Bank, connecting all the cays of that side. On the northern part of the west face the reef is broader and has a width of from an eighth to a quarter of a mile. It increases in width on the north side, and there connects with the broad reef on the east of the island. To the southwest of the southern spit of the island a reef runs for nearly four miles which protects Hawk's Nest Anchorage. The whole of the space included between Gibbs, Long, and East Cays on one side, and from the south spit of Turk's Island to Salt Cay on the other, is filled with huge heads of corals, some of which have been described as having attained an exceptional size.<sup>1</sup> I am more inclined to look upon these gigantic coral heads as coral blocks of the usual size growing upon isolated pinnacles of æolian rock such as are so common in the Bahamas and the Bermudas, and which here represent the remnants of the disintegrated greater Turk's Island, which has all disappeared towards Endymion Rock.

East Cay is the highest of the Turk's Islands, the æolian hills being ninety-six feet high. Cotton Cay and Salt Cay are both formed, as is Grand Turk Island, in part of shore coral rock and in part of æolian rock. Sand Cay, the southern of the Turk's Islands, also consists of æolian rock. A coral reef runs off from the island in a northerly direction for nearly two miles.

The southernmost trace of the former Turk's Islands land is Endymion Rock, which stands isolated near the southwestern spit of the Turk's Islands Bank. From Salt Cay to the southwest spit of the bank the soundings vary from six to thirteen fathoms. The whole bank has a remarkably uniform depth, and a very abrupt slope from ten or twelve fathoms to one hundred fathoms. The bank is covered with decomposed æolian rock sand, mixed here and there with corallines.

<sup>1</sup> See A. E. Verrill, *Proc. Bost. Soc. Nat. Hist.*, 1862.

### Navidad, Silver, and Mouchoir Banks.

Plate IX. Figs. 7, 8, 10.

The most southerly of the Bahama banks is Navidad Bank. It has a least depth of eleven fathoms near the southeastern extremity. From the soundings it appears to vary little in depth. The southeastern part of the bank slopes off to the 100 fathom line somewhat less abruptly than either the eastern or western face. The depth on the main body of the bank varies from eleven to seventeen fathoms. It is covered with æolian sand modified by Nullipores. Navidad Bank is oval-shaped, twenty-two miles long in a north and south direction, and in the centre about eleven miles wide.

Between Navidad and Silver Banks there are three small submarine banks rising to a depth of ten, twelve, and seventeen fathoms.

Silver Bank, the next bank to the westward, is an irregularly rectangular bank. Its eastern somewhat concave side is twenty-nine miles long. The northern side is thirty-eight miles. The central part of that side, at a distance of about eight miles from the southeastern extremity, is occupied by a triangular patch of coral heads which are awash and extend nearly five miles inland, towards the northwest angle of the bank.

The west side of the bank runs nearly north and south thirty-seven miles. Coral heads crop out only at one point of this side of the bank, and also on the western part of the southern line of the bank, which is twenty-four miles long.

The soundings on the bank vary from six to twenty fathoms. The deeper soundings occur nearer the western side of the bank.

The last of the larger submerged banks is Mouchoir Bank, the outline of which is more irregular than that of Silver Bank. Its greatest length from east to west is about thirty-one miles. Its breadth north and south varies greatly. The eastern face is twenty-five miles, extending into a long narrow spit. The depth on the bank varies from seven to fifteen fathoms. On the north side there are two large patches of coral heads awash, both extending some distance south on the bank.

From what I can learn, the coral heads on Mouchoir and Silver Banks are growing upon pinnacles of æolian rock.

### Hogsty Reef.

#### Plates I. and II.

Hogsty Reef is a small atoll, irregularly elliptical ; its longer axis is something more than five miles and its shorter about three at its widest part, measured approximately from the limits of the 20 fathom line. As will be seen from the deep soundings to the northwest and southwest of the reef, there is a depth of nine hundred and five fathoms not more than four miles and a quarter from the 100 fathom line to the northwest of Northwest Cay, and as great a depth as twelve hundred and eighty-one fathoms somewhat less than four miles to the south of Southwest Cay. The accompanying sketch of the reef (Plate II. Fig. 1) I owe to the kindness of Captain Wharton of the British Admiralty. It has been slightly modified from the soundings taken by the "Wild Duck" off the northeastern face of the reef. Quite an extensive plateau was developed on that side, extending the 100 fathom line more than a mile to the eastward from the position formerly assigned to it. With that exception, the shelf between the 3 fathom line and the 100 fathom line is quite narrow, and the slope most abrupt between seventeen and a hundred fathoms. It is only on the eastern edge that successive soundings were taken of ten, eleven, and twenty fathoms before reaching the 100 fathom line. Usually we might strike ten or twelve or perhaps fifteen fathoms, and the next sounding would show no bottom with the 50 fathom hand-line. The slope to the south of the atoll is slightly greater than 1 : 2.7, and that on the northern side not quite so steep, 1 : 3.1. (Plate II. Fig. 3.)

With the exception of the broad triangular shelf on the eastward side of the reef, where the corals extend out fully one mile from the breakers, the annular ring of growing corals is less than a thousand feet wide. In the lagoon itself no heads are growing except those which are found scattered between one and a half and two fathoms ; these grow more luxuriantly as they get within reach of the effects of the last inner line of breakers. Here and there a head is also found in the lagoon in somewhat deeper water, but none were seen inside at any distance from the shallower parts of the reef. On the eastern face there is a stretch of corals perhaps a hundred yards in width, of which here and there a mass is exposed to the air at low tide, but as a rule there is a foot to a foot and a half of water at low tide over the shallowest part of the reef. On this narrow shelf and on its lee side are thrown up fragments of corals,



or small heads, Nullipores, Gorgonians, and débris of Mollusks torn off from the outside of the reef by the incessant swell of the trade winds. Owing to the steepness of the weather shelf there are not more than two or three lines of breakers usually pounding on the reef. The corals growing to seaward are almost entirely made up of large masses of *As-træans* and of a few heads of *Madrepora palmata*. There was a greater variety of species on the lee side of the shelf, — *Madrepora cervicornis*, small heads of *Mæandrinæ*, *Manicina*, and clusters of *Millepora*, as well as large patches of Gorgonians. Nullipores are most abundant on the summit of the reef, growing upon the smaller fragments of broken corals, which they also often cement together, when they are forced inward into deeper parts of the lagoon, where the cemented masses frequently form heads of considerable size.

Longitudinal and cross sections of the lagoon show that its bottom is uniformly covered with coarse sand and broken shell material, or fine sand, according to the distance from the action of the breakers. Upon this looser material algæ and corallines thrive and grow abundantly, generally in large patches. As will be seen from the survey of the atoll (Plate II. Fig. 1) the annular ring of corals within the 3 fathom line is of nearly uniform width, except that on the northern edge the belt is slightly narrower. On the shelf of the atoll, both seaward and on the lagoon side, algæ, corallines, and Nullipores are most abundant. On the sandy bottom of the lagoon the patches of vegetation consisted mainly of masses of *Thalassia*, *Caulerpa*, *Penicillus*, *Halimeda*, and *Udotea*, while on the lagoon coral shelf are found masses of a species of *Sargassum*, of *Padina*, *Blodgettia*, *Laurencia*, *Digenea*, and several species of incrusting Nullipores.<sup>1</sup> The heads exposed at low tide are also more abundant on the eastern face of the atoll, where there are no boat passages, while on the south face, as well as on the northwestern face near Northwest Cay, there are a number of points where the reef can safely be crossed. There and on the spit to the west of South Cay the reef does not come as near the surface, that end of the reef being lower both on the north and south side of the atoll.

The entrance to the atoll is on the west side. It is flanked on the north side by Northwest Cay, and by the smaller South Cay about two

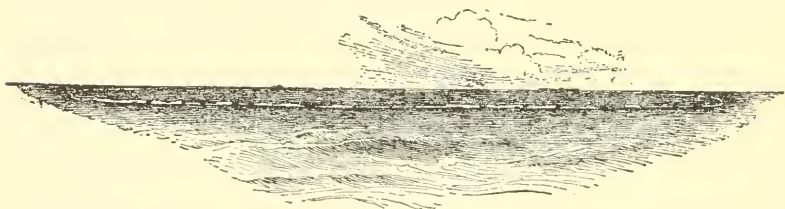
<sup>1</sup> For a list of the West Indian marine algæ, the greater number of which have been collected also at the Bahamas, see G. Dickie, "On the Marine Algæ of Barbadoes," Journ. Linn. Soc., Botany, Vol. XIV. p. 146; and "Contributions to the Botany of H. M. S. Challenger," communicated by Sir J. D. Hooker, "I. On the Marine Algæ of St. Thomas and the Bermudas," Ibid., p. 311.

miles off in a southeasterly direction. The entrance is steep to directly south of Northwest Cay, while a long sunken spit extends from South Cay to the northwest, encroaching upon nearly half the opening to the lagoon. Coral heads are scattered all the way across the entrance, in six to nine fathoms of water; they become quite abundant and luxuriant as we approach the Northwest Cay, and are continued in shallower water on the outer rim of the atoll all the way to the eastern face, seemingly finer and more thriving as they extend to the eastward.

The same is the case with the heads on the outer face of the southern and eastern face of the atoll; the coral heads increase in size and number as they extend towards the eastern extremity, and take their fullest development on the comparatively broad shelf stretching to the eastward. As far as I could ascertain with the water glass and lead the coral heads do not extend beyond eighteen or nineteen fathoms, but owing to the steepness of the outer slope of the atoll it was difficult to decide this. When we examined the eastern shelf the sea was too rough to enable me to detect the presence of heads beyond seventeen fathoms, and at that depth they were more distant, and frequently separated by large patches of coral sand, while towards the atoll they gradually became more numerous and more thickly crowded, attaining apparently their maximum of development in the belt inside of ten fathoms.

The poverty of the coral fauna of the interior of the lagoon is very striking. As I have stated above, the bottom is nearly level, sloping as seen in the longitudinal section (Plate II. Figs. 2, 4) very gradually from a depth of three fathoms to five and a half fathoms, when the slope increases more rapidly to seven, ten, and then suddenly drops down to over a hundred (140) fathoms. Transverse sections of the atoll show well its gradual deepening as we proceed from the inner eastern edge to the section across it near the western entrance of the lagoon. The floor of the lagoon is of a very uniform depth transversely, as all the sections taken from north to south readily show; but the depth increases as they are taken more to the westward (Plate II. Figs. 5-7), with the exception of one or two small shallower patches, on which some Gorgonians and algæ are growing. On the western face, the coral heads are more developed near the two little islets forming the gate posts as it were to the lagoon. They form a large broad patch, gradually passing on the one hand into the broad ring of scattered coral heads below the 10 fathom line on the western face of the atoll, and on the other hand into the two narrow belts of scattered coral heads and patches of Gorgonians found running along the interior of the lagoon more or less parallel

with the shallowest part of the reef. This belt of heads rarely extends to a greater depth than one and a half to two fathoms, and has a width of usually less than one hundred yards, thus leaving the whole interior of the lagoon free from coral heads. Judging from the descriptions of Dana, Darwin, and others of the growth of coral heads in the interior of other lagoons, their absence in a lagoon as open as that of Hogsty Reef seems to be an exception. This is the more remarkable as the position of this atoll is such that from its constant exposure to the action of the prevailing trades a great mass of fresh sea water is constantly poured into the lagoon for more than half its circumference. This mass of water of course washes constantly the scattered heads parallel to the line of least depth, but also throws into the inner lagoon water loaded with particles of sand, which cover its floor and leave apparently no chance for the growth of anything except algæ and corallines in the main basin of the lagoon. It is quite evident, when watching the



HOGSTY REEF.

huge trade wind breakers following one another in rapid succession, that they must act as a very efficient force pump in driving an immense quantity of water to the westward, thus constantly changing the water in the lagoon, and rapidly removing the carbonate of lime it holds both in solution and in suspension.<sup>1</sup> It is only when we reach the western part of the atoll, where the depth increases, that a great part of the water forced into the lagoon by the breakers finds its way out in part through passages both on the north and south faces, but mainly through the wide western entrance of the lagoon. The entrance is nearly a mile wide between the 3 fathom lines of opposite sides, and the section across it shows a greater depth (five, six, and seven fathoms) than at any other section of the lagoon. A strong westerly current is always running out, probably due to the mass of water incessantly piled up by the breakers into the eastern half of the comparatively closed portion of the lagoon.

<sup>1</sup> Murray and Irvine, Proc. Roy. Soc. of Edinburgh, 1889, p. 79.

The action of the water on the bottom of the lagoon is clearly seen in all the patches of clear sand by well defined ripple marks, showing the unstable condition of the sand even at depths of six to seven fathoms.

Owing to the steepness of the edge of the Hogsty bank, the 100 fathom line represents very closely the width of the growing belt of corals. The approximate centre of the inner line of breakers is within one hundred yards of the inner 3 fathom line. I was informed by our pilot that both Northwest and South Cays had increased in size, the former in length on the northerly face, the latter on both its east and west faces. Northwest Cay is mainly built up of the broken fragments of corals thrown up on its northern faces derived from coral heads to the eastward and westward of the cay, and South Cay from the heads growing either on the spit to the northwest or to the eastward on the southern face of the atoll. The cays are nearly flat, with steep shores about fifteen feet high, their surfaces covered with fragments of broken shells and corals, and with here and there small patches of vegetation consisting mainly of the different plants so characteristic of the shore line of the Bahama Islands. On parts of the shores of the cays the recent coral rock forming the underlying base of the islets can be seen sloping seawards. The cays at the time of our visit were occupied by a rookery of boobies.

One cannot fail to be struck with the fact that on Hogsty Reef the most luxurious growth of corals is from a depth of five or six fathoms to ten or twelve, and that below that point, while still flourishing, the heads are not clustered as closely together as in shallower water, while the heads similarly diminish rapidly in number as they reach the line of breakers. Contrary to the observations of Bourne<sup>1</sup> and Hickson, who lay great stress on the growth of corals inside of the lagoons of the atolls they have examined, in our atoll their growth is practically limited to a very narrow belt close to the line of breakers, of not more than one hundred to one hundred and fifty yards from the principal line of the corals awash. The slope from the ring of the atoll to about ten or fifteen fathoms is quite moderate, while beyond that it drops very fast. It is on that edge, as has been observed by others, and as is specially marked

<sup>1</sup> Bourne states (Proc. Royal Society, March 22, 1888, p. 440) that corals thrive remarkably and most vigorously in that part of the Diego Garcia Atoll which is most remote from the influence of currents, and he attributes to corals a greater capacity as vegetable feeders than has been supposed. But no decayed vegetable masses derived from the shores of the lagoon are found in either of the atolls I have examined, Alacran or Hogsty. In these atolls there is nothing else for the corals to feed upon except what is brought by the currents of the sea.

everywhere in the Bahamas, that the coral heads flourish best. The ring of coral heads is generally from one hundred and fifty to four hundred yards wide, except at the eastern face, where the width of the reef is nearly a mile and a quarter.

There is of course nothing to show that the substructure of Hogsty Reef differs in any way from that of the other banks of the Bahamas. It is fair to assume that, like them, it was built up of æolian rocks which have gradually been worn away by the action of the sea, so that between erosion and subsidence nothing has been left to indicate the existence of the former Hogsty land beyond the growth of corals which now flourishes upon the underlying æolian strata, and which they completely cover.

That the corals grow in a more or less circular belt I have attempted to explain by the action of the breakers pounding upon the surface of the bank, thus forming a gigantic pot-hole. Finally the water breaks through this pot-hole on its lee side, forms an opening, and changes it into a lagoon. This explanation of the formation of Hogsty Reef had occurred to me before I had seen the so called Serpulæ Reefs of the Bermudas, of the structure and mode of formation of which I gave a short account in the June number of the American Journal of Science for 1894. I shall in my report on the Bermudas further consider this subject.

## THE COAST OF CUBA.

Plates I., XIII., XIV., XLI. to XLVII.

We were fortunate enough, both in going to Santiago de Cuba and in leaving it for Hogsty Reef, to run along the south shore of Cuba, to and from Cape Maysi, in daylight. This gave us an admirable opportunity to obtain an excellent impression of the terraces and the elevated reef extending along that coast, forming so prominent a feature of Cuba at intervals all the way from Cape Cruz to Cape Maysi, and similarly all along the northern coast, past Baracoa, Gibara, Matanzas, Havana, and Mariel. But while we thus obtained an excellent idea of their extent, so superficial an examination could only give me data for the most general conclusions regarding the part these elevated limestones and the reefs had played in the geological history of Cuba, far less for any views regarding their mode of origin.

The white honeycombed limestone cliffs which are so characteristic of the whole coast of Cuba are known locally as "soboruco," the name applied by the natives to the honeycombed limestone rock forming the



elevated terraces, though originally applied only to the elevated coral reef forming the first terrace. These terraces are striking features on certain reaches of the coast, and are so noted in the descriptions of the coast pilots that they often serve to distinguish special points.

During my trip along the north coast of Cuba I became satisfied that I had misinterpreted the nature of the elevated terraced limestones of the shores of the island. With other naturalists, I had been led to think from a first examination, made many years ago, that these elevated limestones were coral reef rock limestones representing coral reefs of perhaps twelve to fifteen hundred feet in thickness. The true character of the coral reef rock, which has in general been elevated to a height of not more than twenty-five or thirty feet, is readily made out. The exposed surface of the platform of the first terrace is often one mass of coral heads, and it requires but little effort to reconstruct this into a recent living reef. When we come, however, to the flats of the second and third terraces, the problem is not so simple. It is evident that the limestones are of older age than those of the raised coral reefs flanking the shores. They underlie the elevated reefs, and, while greatly altered, yet contain an occasional mass of coral belonging to the reef-building species, but so few in number that we can hardly call the stone of which they form a part a coral reef limestone. These questions were brought to mind vividly at Santiago, while exploring the limestone terraces; also at Saboney, at Baracoa, where the thickness of the elevated reef is not more than thirty-five feet, at Banes, at Matanzas, and at Havana. It became important to determine exactly the age of the limestones forming the second, third, and higher terraces, and to ascertain how far the presence in older limestones of an occasional mass of a species of reef-building coral, at different heights all the way up to two hundred and fifty or even to over four hundred feet from the level of the first terrace, justified the conclusion that these deposits of older limestones belong to the group of coral reef limestones. Such an inference from the presence of a few corals in the older limestones seems to me no more reasonable than to speak of a few isolated heads of reef-building species found along the shore lines of any coast or island as constituting a recent coral reef.

My observations are here given as noted during the cruise of the "Wild Duck." Not having myself the time to make the necessary explorations, I gladly accepted the proposition of Professor Robert T. Hill, of the United States Geological Survey, to carry on this exploration, and to determine the character of the elevated terraced limestones, and their relation to the overlying elevated coral reef, as well as the greatest alti-

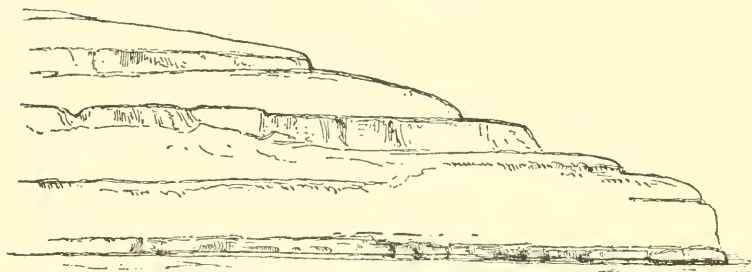


tude to which true coral reef rocks could be traced. His Report will be printed in the Museum Bulletin, and I shall refer to this paper for such illustration as will supplement the observations of Professor Hill.<sup>1</sup>

### Cape Maysi to Santiago de Cuba.

Plate I.; Plate XIV. Fig. 5; Plate XLVII.

From the westward of Cape Maysi to Caleta Point there are four very distinct terraces, and signs of a fifth, the summit of the hill forming Caleta Point being probably nearly twelve hundred feet in height. The accompanying sketch will give better than any description of mine an idea of the appearance of the shore as seen from the yacht's deck. As



TERRACES AT CALETA POINT.

we go westward these terraces become more and more indistinct. They are no longer continuous, as we saw them for a long stretch to the eastward of Caleta Point. There has been great erosive action, and many valleys have been cut from the shore through the limestone hills back to the older formations upon which the shore hills rest. During the erosion, the hills parallel to the coast line have been cut into disconnected patches, and often reduced to a height less than that of the second or third terrace on the shore line near Caleta Point. In the process the lines of the terraces have also frequently been obliterated, so that it is impossible to detect their continuity. Here and there isolated remnants, generally of the third terrace judging from their comparative altitude, can be traced at intervals all along the shore line to Santiago de Cuba. The first terrace formed by the line of the elevated shore reef is most persistent; it can often be traced for miles where the

<sup>1</sup> A preliminary note on the Geology of Cuba, by Professor R. T. Hill, will be found in the September number of the American Journal of Science, 1894, p. 196.

existence of the others cannot be detected. The faces of the terrace show the exposed limestone to be greatly honeycombed. It is often columnar in appearance, and large caverns and cavities of all sizes open into the exposed vertical faces of the terraces. Some of the ravines running westward from the shore line expose, in their section of the shore hills, high cliffs of limestone similar in structure to those of the terraces. This is particularly well shown in two of the ravines beyond Caleta Point. Some of the hills near the shore, which as seen from the ship seemed to be limestone, must have reached an elevation of at least eleven or twelve hundred feet. To the west of Jauco River the hills in the rear rise to at least sixteen or perhaps eighteen hundred feet, but no shore limestone hills could be detected of a probable height greater than one thousand to twelve hundred feet, judging from the exposures visible in the ravines.

Near Imia Bay another great ravine has cut through the coast range limestone hills. The second terrace is obliterated by the talus of the third terrace, and the hill behind this rises to about the height of the fourth terrace. This part of the coast must have jutted out somewhat, and that portion of the shore which formerly formed the first and second terraces has been washed into the sea, and left only the steep cliffs forming the base of the third terrace, which was further inland.

Between Sabana la Mar and Baitiqueri there are traces of the second terrace, the third terrace is specially well marked, and indications perhaps of the fourth are visible near the summit of the shore hill.

To the eastward of Port Escondido the shore hills show the lines of at least four of the terraces. But the breaks in continuity of the terraces due to the elevation of the coast are, as I have stated, very numerous, and by far the greater mass of the shore limestone hills must have been carried into the sea. Formerly their characteristic terraces undoubtedly extended at intervals, if not continuously, all along the southern shore, and probably were as well marked as we have seen them to the eastward near Caleta Point.

When we come to the entrance of the harbor of Guantanamo, the shore hills show still more plainly the effects of the great erosion which has taken place all along the southern coast. We find this erosion to be greater in proportion as we go northwestward from Cape Maysi. To the westward of the harbor of Guantanamo we have fragments of the first and second terraces. To the east of the harbor the shore is flanked by low more or less conical hills, which from their shape completely conceal the terraces of which they are only the remnants.

From Guantanamo the shore hills are not terraced, and to the eastward of Hatibonico the first shore terrace again becomes prominent. From the pier to the westward of Morillo Chico the shore limestone hills are again seen. They rise there to six hundred or eight hundred feet perhaps, and behind and above them are seen the dioritic mountains upon the flanks of which the shore limestone ranges have been deposited and have been raised during the periods of elevation. Near Baitiqueri River an isolated shore limestone hill shows plainly four terraces.

Guantanamo (Plate XIV. Fig. 5), like Santiago de Cuba and Port Escondido, is a flask-shaped harbor which has been formed by erosion in the limestone during the elevation of the belt which flanks the whole of the southern shore of Cuba from Cape Maysi to Cape Cruz. The same formation is said to extend to Cape San Antonio from Cape Cruz. Its limits on the south shore are not known to me, but I have followed it from Cape Maysi to Cape San Antonio on the north shore. The harbors of the north shore from Baracoa to Bahia Honda, like Livisa, Banes (Plate XIV. Fig. 6), Padre (Plate XIV. Fig. 7), Nuevitas, Matanzas, Havana, and others of a similar character, have all been formed by the erosion of their drainage area across the shore limestone hills during the rising of the shore line.

### Santiago to Saboney.

During a trip we made to the Juragua iron mines I was able to examine more in detail a considerable stretch of the shore limestone hills and of the elevated reef. The narrow gage railroad which runs from the dock of the company in the harbor of Santiago de Cuba rises rapidly upon the hills which surround the bay, and attains a height of about two hundred and fifty feet. It then drops gradually to the shore, and runs for a distance of about ten miles, to Saboney, along the shore line, keeping all the way on the top of the first terrace, the surface of the elevated reef. At the greatest height reached by the railroad behind Santiago, in the cut about three kilometers from the company's wharf, we found a number of fossil shells, embedded in a sort of marl formed of the decomposed limestone of which all the exposures of the hills consist. So much is this the character of the limestone in the vicinity of the harbor of Santiago that nowhere except in some of the cuts to the eastward of the city, and after passing over the sea face of the hills, are we able to obtain characteristic specimens of the limestone rock of the shore hills.

According to Mr. Dall, who has been kind enough to examine these fossils, they "are of old Miocene age, the same as the age of Bowden in Jamaica and those of the Isthmus of Panama. They are also represented in Florida by what has been called the Chipola epoch, to which the beds of Ballast Point, Tampa Bay, belong. Some of them appear identical with fossils from the Chipola River, Florida. Fossils of the same age were obtained on the Cuban coast by Professor R. T. Hill and Dr. J. W. Spencer at various points."

After passing the summit and descending to a point a hundred and sixty feet above the level of the sea, we came upon a cut in the road, where we found hard limestone and a small isolated head of a fine *Astræa*, but no coral rock. From there down, the rock is hard limestone greatly honeycombed, as are all the faces of the terraces along the coast parallel to which the railroad runs. The first terrace, upon which the railroad runs, is about twenty feet above the level of the sea. It is nowhere more than three hundred feet wide, and forms an ideal railroad bed. At Saboney the road enters into a gap of the shore hills and soon passes out of the region of the limestone shore hills to meet the dioritic rocks which compose the second range of mountains. At the gap of Saboney, and thence to the westward, the second and third terraces are very prominent. The second terrace is about fifty feet above the first, and the third not more than sixty feet above that. The third terrace is often obliterated by erosion. The first terrace in spots has been carried away by the sea, and cliffs have been formed which reach the height of the second or even of the third terrace.

We were indebted to the courtesy of Mr. Shuman, the agent of the Juragua mines, for an excellent opportunity to examine a part of this elevated coral reef, forming the surface of the first terrace at Saboney, — the old surface of the shore reef. We made good collections of specimens of *Mæandrina*, two species of *Astræans*, a large *Colpophyllia*, and a fine *Allopora*, all belonging to species now found living.<sup>1</sup> The corals were clustered very closely, much as they would now be found growing on a living coral reef, and quite as thickly packed.

The examination of the terraces along the line of the Juragua Railroad shows plainly that the vertical distance between the second and third

<sup>1</sup> The species of corals characteristic of the elevated reef (the "soboruco") belong to the following genera: *Colpophyllia*, *Orbicella*, *Porites*, *Mæandrina*, *Agaricia*, *Favia*, *Stephanocenia*, *Manicina*, *Madrepora*, *Isophyllia*, and *Siderastrea*; wherever thus far collected in the Caribbean, they all belong to recent species of reef builders characteristic of the West Indian fauna.

terraces, not being more than fifty to sixty feet, is not of greater height than the depth at which corals would readily grow up from a new base. The flat surface which forms the upper part of the elevated reef, the first terrace, is covered with several species of corals apparently killed *in situ* by the gradual elevation of the base upon which they were growing, and of which they formed the living top at the time the elevation began. The lower portions of the reef have grown up at greater depths, and, as they died or were covered by more flourishing or by growing corals, have formed the base upon which the newer crop built their way little by little to the surface. The terraces as we see them form a series of steps, each of considerable width, so that the fifth terrace, for instance, might be fully twelve to fifteen hundred feet horizontally removed from the shore line. Of course the first terrace may have been much wider than where I measured it, and much of its sea face may have been worn away. Still, as the depth off the south shore of Cuba is very great, and the limit of coral reef builders is at almost every point of the coast reached within a comparatively short distance, it is not probable that the width of the first terrace was very considerable. The examination which I made does not settle the question that each of the terraces corresponds to a separate growth of corals laterally; it neither proves or disproves the former continuity of the coral reef, nor its division through the agency of the waves into perhaps one or more distinct terraces. I can only say that the character of the rock exposed on the faces of the second and third terraces showed quite plainly that they consisted of older rocks with very marked differences, — differences which would indicate a greater age in the face of the second terrace than in the first, and a still greater age in the third, but not necessarily, as the terraces may have been cut successively in limestone of the same age. The condition of the fossil corals was specially marked, and the differences noted in fossilization quite agreed with the different conditions of the limestones of the second and third terraces as contrasted with each other, or as compared with that of the first and youngest elevated coral reef terrace. We may conclude that at Saboney at least the first terrace only is composed of an elevated coral reef, while the limestones of the second and third terraces are much older, and, although containing a few corals, yet are not coral reef limestones.

It may be that the isolated corals identical in species with those now living or with those of the elevated reef forming the first terrace, which are found on the second and third terraces near Santiago, at Baracoa, and to heights of nearly five hundred feet near Banes, are the remnants of



the former extension of the veneer of coral reef which covered the shore of Cuba during the time of elevation of each terrace; that is, there probably existed at the time when the older terraces were formed a fringing reef, much like the present elevated fringing reef forming the first terrace, each reef corresponding to its terrace and forming on the sea face of the older underlying limestones a veneer of about the thickness of the present "soboruco" reef, say twenty-five to thirty feet. The patches or isolated heads upon the faces of the older limestones are probably the remnant of these successive reefs, the one upon the first terrace being the youngest. The existence of these scattered patches has led many observers to assume that the elevated limestones are of the same age as the elevated reef (the first terrace).

The sheet of coral, which may have extended to a height of nearly five hundred feet along some parts of the Cuban shore, has been eroded and swept away by the same agencies which have formed the peculiarly shaped limestone hills of the shore line. This erosion has been very extensive; with the exception of the first terraco, where the coral reef is nearly continuous, it has left only an occasional patch of coral reef or an isolated head here and there, at varying altitudes, to testify to the former existence of the coral reef sheet, the higher inland parts of the reef having all been eroded from the sides of the underlying older tertiary rocks. Yet it is strange that no patch of recent reef rock of any extent should have been met with thus far, unless we except the elevated reef of Matanzas, where, according to Professor Hill, it reaches a height at least of a hundred feet.

A similar coral sheet, resting upon oceanic beds and the so called Scotland beds, has been carefully described by Harrison and Jukes-Browne<sup>1</sup> as extending at the Barbados from the sea level to nearly eleven hundred feet. This sheet consists of a series of "platforms built up one around the other as the island slowly rose from the sea," and this I imagine to have been the case with the successive elevated reefs of the Cuban coast. The erosion at the Barbados seems to have been much less than along the Cuban coast, leaving the bases of the successive platforms of coral reef continuous. According to Browne and Harrison,<sup>2</sup> there are six distinct terraces between the sea level and a height of five hundred feet, and between that height and one thousand feet they indi-

<sup>1</sup> The Geology of Barbados, by J. B. Harrison and A. J. Jukes-Browne. Published by Authority of the Barbadian Legislature, 1890.

<sup>2</sup> The Geology of Barbados, by A. J. Jukes-Browne and J. B. Harrison. Quart. Journ. Geol. Soc., XLVII. 197.



cate at least five additional terraces. They say that there are not many places where the thickness of the coral rock is greater than two hundred feet. In some places it appears to reach two hundred and thirty feet, and in one place two hundred and sixty feet.

Guppy<sup>1</sup> describes the elevated reefs of the Solomon Islands, where extensive degradation of the surface has also taken place, as being of very moderate thickness. This agrees with the structure and thickness of the elevated reefs of Barbados and of Cuba, as I imagine them to have been.

Professor Dana says: "The atoll of the Tortugas, and others in the West Indies, are regarded by Mr. Agassiz as having a basement up to the coral growing limit of pelagic limestone or of some other material. It may be so; but there is as yet no proof of it."<sup>2</sup> Surely the extension of the miocene rocks of the peninsula of Florida south under the district of the belt where coral reefs are found may fairly be assumed. The existence of the modern limestone of the Pourtales Plateau has been proved by dredging to run close to the seaward limit of the coral reefs. The Alacran atoll, as well as all the coral reefs of the Yucatan Plateau, are underlain by a marine basement (not composed of corals), into the extension of which one can penetrate nearly three hundred feet in depth. And, finally, the recent explorations of Professor Hill and myself along the northern coast of Cuba have proved beyond doubt the existence of a miocene basement underlying the elevated coral reefs.

While not denying that subsidence is necessary to account in many cases for the formation of deep lagoons and deep channels, it must be left to others to prove that these depressions and channels have been cut through the thickness of the coral reefs, and not through that of the basement. It is quite possible to imagine lagoons to be formed hereafter in some of the Bahamas and in the Bermudas by subsidence, which might have a depth of nearly sixty fathoms and yet have a thickness of corals of not more than a few feet on the upper margin, extending along the inner and outer slopes to a depth of not more than twelve or fifteen fathoms.

The vertical distance between the lower terraces near Saboney was far less than between those observed at Caleta Point. It is quite possible that at the eastern extremity of the island the terraces which are still so plainly marked are not the only terraces once existing. The erosion which made, as we have seen, such great changes in the physical aspect

<sup>1</sup> The Solomon Islands, by H. P. Guppy. London, 1887.

<sup>2</sup> Corals and Coral Islands, p. 292.

of the shore line to the west may also have acted there to a less extent, but perhaps quite enough to have obliterated the lines of some of the terraces intermediate between those which at Caleta Point have been designated as one to five. From the Juragua mines one gets an excellent distant view of the shore limestone hills stretching to the west and east, and well separated from the inner range which forms a part of the mass of Gran Piedra. At Saboney, and at several places on the way from Santiago along the outside of the line of the railroad, small boat harbors have been formed on a diminutive scale by erosion, very similar to the larger ones so characteristic of the Cuban coast, and of which Guantanamo (Plate XIV. Fig. 5) and Santiago are the two finest examples on the southern coast. Many bights on the coast have been produced in a similar way. Neither at Santiago nor at Guantanamo do we find any trace of terraces along the sides of the eroded limestone hills which surround these harbors. They have been obliterated by the wash along their sides into the drainage basin fringing the bays. On our way east from Santiago we so timed our start as to see by daylight that part of the coast near Santiago which we had passed after dark. To the westward of the entrance of Santiago the terraces are most indistinct, the third terrace being alone fairly defined, while to the eastward a fine line of terraces can be seen from the sea. We were able to get a distant view of the second and third terraces running along the hill slopes above the first terrace, forming the road-bed of the railroad leading from Santiago to Saboney. Through the gap at Saboney we could see the line of the Juragua mines on the foothills of the Gran



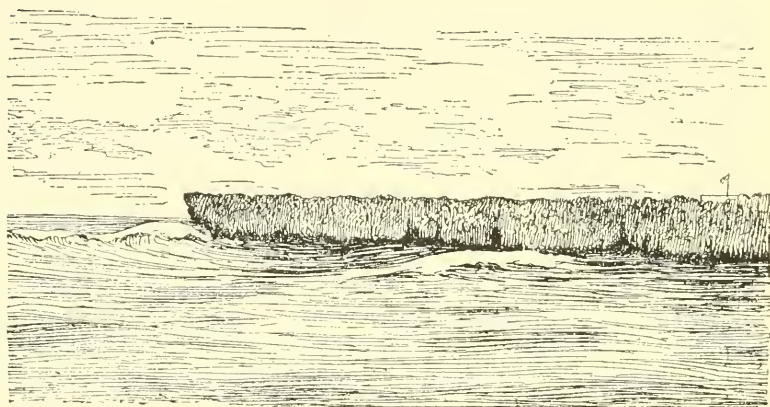
GRAN PIEDRA AND TERRACES NEAR SABONEY.

Piedra. To the eastward of the Saboney Gap, before reaching the pier of the Spanish American Mining Company, one of the foothills shows four terraces quite plainly, the same number which on our way to Santiago we had seen on the isolated hill near Baitiqueri River.

### Baracoa to Banes.

Plate I.; Plate XIV. Figs. 3, 6; Plate XLI.

We reconnoitred the north shore of Cuba from Baracoa to Havana, reaching the former place from Ragged Island. Baracoa is a small harbor, eroded out of the first terrace in a gap of the shore hills caused by the drainage of the country behind it (Plate XIV. Fig. 3). The entrance is narrow, flanked on either side by well worn and honeycombed



ELEVATED REEF (SOBORUCO), ENTRANCE OF BARACOA.

reef rocks. To the south of the entrance the platform of the first terrace extends for nearly a mile, and upon the inner edge, at the foot of the cliffs of the second terrace, around Miel Bay, the town of Baracoa is situated. The second and third terraces can be seen plainly, and the small fort which commands the harbor is built upon the second terrace. Traces of the third terrace can also be seen on the hill to the north of the entrance to the harbor. A river is banked off from the bay by a beach thrown up by surf, so that it does not empty directly into the bay, but runs parallel with the shore for the greater part of its circumference, emptying finally into the southeast corner of the port, where it is protected from the swell of the sea.

The first terrace of the elevated reef of Baracoa presented the same features which had so greatly interested us when examining the reef at Saboney. We found huge masses of *Astræans*, of *Mæandrinæ*, of *Madrepores*, of *Allopora*, apparently all in place as they grew, and likewise

we found in the section of the terrace on the harbor side the same species of corals composing the bulk of the reef rock. On going up to the flat of the second terrace, we found isolated masses of corals and shells, which evidently form a considerable part of the limestone of the cliff extending from the first to the second terrace. To the south of the fort one can reach the base of the cliffs of the third terrace, in which we found again isolated corals of species characterizing the limestone of the second terrace. On the second terrace we found considerable red earth. The whole thickness of the first terrace of the elevated reef at Baracoa, of not more than thirty-five to forty feet, wherever there was a section showing its character, proved to be one mass of heads of corals closely packed together, — huge masses of *Astræans*, of *Allopora*, of *Mæandrinæ*, etc., all cemented together just as they must have grown on the surface of the reef when it was living.

Not more than five miles from us in a straight line rose Yunque, an elevated mass of limestone underlaid, according to Professor O. W. Crosby, by older metamorphic rocks, and stated by him to be one continuous mass of solid reef rock,<sup>1</sup> the upper part perhaps being of a greater age than the lower limestone cliffs. Unfortunately the condition of the roads was such as to make it impossible for us to reach the mountain, which I was most anxious to visit in order to ascertain whether in this great mass of limestone any trace of the successive terraces of the coast reefs could be found. Judging from what could be seen of the base of the mountain from the sea, the talus at its foot, built up of the disintegrated limestone which for years has been falling from the upper layers, must make it wellnigh impossible to ascertain the thickness of the successive terraces which compose the Yunque. Still more difficult would it be to determine their number, and whether they were caused by the erosive action of the sea or were built out successively seaward during the different periods of elevation which must have followed one another with (geologically) considerable rapidity in order to bring about such a succession of terraces as can still be recognized to the south of Baracoa. The apparent columnar structure of the flanks of Yunque, especially as they approach the summit, due to the breaking away of huge masses of limestone, gives no great hope that we shall ever be able to make out the history and succession of the terraces of which this mass of limestone is the monument (Plate XLI.).

Passing to the westward, the ranges of shore hills show markedly the

<sup>1</sup> Professor Hill in his report to me distinctly states that the Yunque limestone is not a coral reef limestone.

effect of the extensive erosion to which they have been subjected. The terraces become indistinct after we pass the first point beyond Baracoa. The vegetation is very dense, and nothing can be seen from the sea indicating the successive lines of former elevation. But the shape of the hills — worn into saddles, into peaks, into isolated cones, forming indistinct ranges more or less parallel to the coast — sufficiently shows how great has been the effect of the erosion on the limestone hills. Between Baracoa and Mangle Point the whole country is broken up into disconnected bits of hills, those nearest the shore being from six hundred to nine hundred feet high. A careful study of the cross breaks of the shore hills might reveal some limestone faces, and throw light on the age and succession of the limestone belt which covers so great a part of the coast of Cuba from Baracoa to Cape San Antonio. Here and there along the coast we may recognize — as, for instance, near the Saddle of Bay, in the range of hills nearest the shore — the second and third terraces. To the west of the Sierra de Moa, near Cayo Grande de Moa, begins a series of saddles and peaks culminating in the Cuchillas del



CUCHILLAS DEL PINAL.

Pinal, which seem, as seen from the sea, a series of gigantic ant-heaps and disconnected saddle-like ridges, showing the great effect of erosion in this district. We could see the eroded shore hills flanking the Sierra de Cristal, and the low shore extending past the ports of Cabonico, Livisa, and Nipe, all fine examples of the flask-shaped harbors of Cuba. To the eastward of Livisa indistinct traces of the third terrace could be seen.



TERRACES AND ENTRANCE TO NIPE.

It was not till we faced the entrance to Nipe that we once more clearly traced in the spit to the westward the first, second, and third terraces. To the eastward of the entrance the second terrace was well defined.

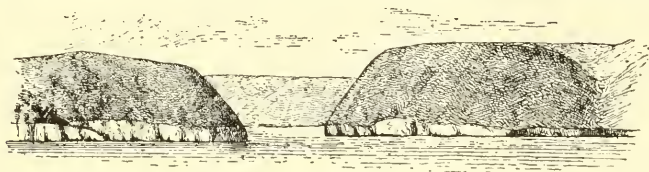


## Banes to Padre.

## Plate I.; Plate XIV. Figs. 6 and 7.

On each side of the entrance to Banes the second terrace could be seen, towards Mulas Point the third can be indistinctly followed for a considerable stretch, and towards the Sama hills there appear to be four, if not five terraces. The winding cañon forming the entrance to Banes is a fine example of the passages, more or less tortuous, leading into the flask-shaped harbors so characteristic of the Cuban coast, — harbors due to the gradual cutting away of the drainage area of which they are the sinks during the elevation of the coast. From the wharf of the banana plantation of the Messrs. Dubois we went inland to the village, to a height of fifty-five meters above the level of the sea and a distance of six kilometers, passing through a region of limestone similar in structure to that of the rocks through which the cañon forming the entrance of Banes had been cut. We drove up to the summit of a hill about eighty-eight meters higher than the village, say one hundred and forty-three meters above the level of the sea. The top of this hill was probably a part of the fourth terrace. We found on its highest ridge, forming a nearly level saddle, a species of *Astræa in situ*. The rock in place here, and lower along the slope of the hill, is everywhere the same limestone, greatly disintegrated, so that the lines of the terraces are nearly everywhere obliterated.

Having become acquainted with the entrance to Banes (Plate XIV. Fig. 6), we had, on leaving the port, an excellent opportunity to see the



OUTLET OF PORT BANES.

cañon through which we passed out, and to note the deep cuts, from seventy-five to one hundred feet in height, forming the nearly vertical sides of the main channel. The channel carries from four to six fathoms, is long enough and tortuous enough to make a perfectly land-locked harbor, which opens out after a little over a mile into a broad bay with deep water, from five to six fathoms, close to the shore. The



shores of the bay are low, consisting mainly of decomposed limestone and of red earth, making an exceedingly fertile soil. Harbors like Nipe, Banes, Padre, and the like, which are so common on the north coast of Cuba, were of little use before the days of steamers. Their entrances, facing the full force of the prevailing trades, make it nearly impossible for a sailing craft to weather the shores and get an offing. It was simple enough to sail in, to tack out against the trades was quite another matter.

After passing Point Lucrecia four terraces can be distinguished between it and Point Sama, but owing to the extensive denudation and erosion of the district only isolated parts of the several terraces are left, and it is often difficult to determine to which terrace they belong. Port Sama is an indentation formed by a break in the shore hills. To the westward of the port a long ridge extends, at the extremity of which the four terraces composing it stand out very clearly; and here we have an excellent guide for the determination of the terrace to which the isolated saddles of the country both east and west belong. We then come upon a stretch of shore eastward of Naranjo crowded with isolated



LIMESTONE HILLS BACK OF NARANJO.

saddles and peaks, giving a peculiar aspect to that part of the coast. All the way to Gibara the shore hills are eroded into the most fantastic shapes, leaving no trace of any of the higher terraces. Thus the limestone hills appear from the sea to be one continuous mass from the base to the summit. A careful examination of the slopes and valleys would however probably reveal in favorable localities the lines of the old terraces. To the westward of Gibara the high limestone hills, so characteristic of the shore line all the way from Baracoa to Gibara, recede from the coast, and we now only find low shore hills, the highest point of which can scarcely be as high as the fourth terrace.

The coast as seen from the sea is now low as far as Sagna la Grande, where the Sierra Morenas approaches the coast again. The spurs of the main range which receded from the coast westward of Gibara are again within sight from the sea, and continue to form the principal part of the background of the shore line past Cardenas and Matanzas, and well towards Havana.

### Padre to Nuevitas.

**Plate I.; Plate XIII. Fig. 1; Plate XIV. Fig. 7.**

The entrance to Padre is very wide, fully a third of a mile. It is straight, and has all the appearance of being the mouth of a great river. After about two miles it opens into a Y-shaped channel formed by islands lying opposite its western end, and then spreads into a bay (Plate XIV. Fig. 7). The shores behind the beaches are low, and wherever there are any rock exposures the same reef rock is found which occurs all along the coast, and the same limestone half-way up the low hills to the westward of the town. There is a great deal of red earth, and the soil is very rich.

The shores on both sides of the channel are flanked with low mangrove islands. We find here the beginning of the extensive system of cays which runs uninterruptedly from Nuevitas to Cardenas; but to the south of Nuevitas the channel which separates the cays from the mainland is not as yet cut through the space separating consecutive harbors to the north of Padre. With little more erosion the condition of things existing to the north of Nuevitas would be extended as far as Padre. To the westward of Padre are a number of low mangrove islands within the reef which extends from the western side of the entrance. South of Padre an extensive reef with coral heads awash extends from Herradura Point to the entrance of the harbor. The shore line of the first terrace is now frequently obliterated by the sand formed from the débris of the reef outside and constantly thrown against the shores by the prevailing winds. The remnants of the second and third terraces form the hills west of Manati, which may be about two hundred feet in height, and are the only high land in this vicinity.

### The Cays from Nuevitas to Cardenas.

**Plate I.; Plate XIII. Figs. 1 to 5; Plate XIV. Figs. 1, 2.**

The entrance to Nuevitas is very similar to that of Padre. A coral reef has formed a prominent spit to the south of the entrance, enclosing a shallow lagoon open to the north. Such elongated patches or spits, like the reef at Padre, are found all the way from Mangle Point, and north of Nuevitas they form a nearly continuous living reef to the westward outside of the cays, with here and there a break or passage for boats

and shallow draft vessels. After passing Nuevitas the clusters of gulf-weed became more and more numerous.

The long, low cays which extend westward beyond Maternillos Point are separated from the shore by a shallow lagoon, forming a continuous passage for small boats between them and the mainland all the way to Cardenas. The highest point on any of the cays is on Cay Romano, the hills on the northern extremity of which are marked on the charts as being about two hundred and thirty feet high. The monotony of this low shore along which we skirted after passing Maternillos Light was relieved by the hills of Cay Guajaba, ninety feet in height perhaps.

While we could make out the reef rock of the immediate shore line of Cay Sabinal, Cay Guajaba, and Cay Romano, we could also see how great a part of the beaches concealing it was made up of sand formed from the decomposition both of the soboruco and the fragments of the outlying living coral reef. After passing Boca Guajaba, the plateau to the eastward of Cay Romano widens greatly, and upon its eastern edge are Cay Verde, Cay Confites, Cay Cruz, Caiman and Anton Cays, and Paredon Grande, which must undoubtedly once have formed a part of Cay Romano, but have been separated from it by the extensive erosion which has taken place all along this coast, and which has swept away between Nuevitas and Cardenas nearly all traces of the second and third terraces, and perhaps others, and in the majority of the cays has reduced the area once occupied by them even below the level of the first terrace.

### Cay Confites.

Plate I.; Plate XIII. Fig. 2; Plate XIV. Fig. 2.

The rock of which Cay Confites is composed showed this clearly. We anchored for the night to the westward of the cay, and had an opportunity of examining its structure. It is on the very edge of the Old Bahama Channel, holding to it on the west very much the same relation which Cay Lobos holds to it on the east. Those parts of the cay not hidden by sand are all made up of coral reef rock of the first terrace. We collected here, as we had at so many other places, specimens of *Astræa*, *Mæandrina*, and *Madrepora* identical with those collected at Baracoa from the reef rock of the first terrace. Between the spits of the older reef rock were stratified beaches of coral sand dipping to the sea, and formed from the débris of the living reef spit extending to the south of Cay Confites, parallel to the edge of the Old Bahama Channel. On the

beaches were thrown up some of the largest specimens of *Madrepora palmata* I have seen. The branches were from twenty to twenty-eight inches wide, fully eighteen inches thick, and some of the pieces were as long as eight feet, and many were over six.<sup>1</sup>

Cay Confites is just on the edge of the bank (Plate XIV. Fig. 2). The northern end of its slope off the cay is steep, leaving no space for an extended reef. The cay is situated at the narrowest part of the Old Bahama Channel, where the trade wind drives into a deep funnel all that comes floating along the equatorial drift from the northern shores of the larger West India Islands and from the Virgin and Windward Islands, so that, besides the blocks of recent corals thrown up by heavy surf on the surface of the cay, there are found logs and twigs of all sizes and of many species of wood, beans, calabashes, sugar-cane, bamboo, and cocoanuts. With a fertile soil many of the waifs thus thrown upon this island would soon get a foothold, and it would be interesting to make a list of the species of plants which are thus carried by the trades and the currents far from their origin. On the poor soil so characteristic of all reef rock land we found growing mainly such plants as are characteristic of the immediate shore line in the Bahamas and other West India Islands. The Pupa so common on the Bahamas was also found on Cay Confites.

### Cay Lobos.

Plate I.

Cay Lobos, on the opposite side of the old Bahama Channel, is a recent coral island, at least the exposed surface was entirely made up of fragments of recent corals which conceal the foundation æolian rock upon which the lighthouse has been built.

### Paredon Grande to Cay Frances.

Plate I.; Plate XIII. Fig. 2.

The island of Paredon Grande is composed of low, rocky bluffs, remaining from the disintegration of the second terrace, the sea front of

<sup>1</sup> On Enderbury's Island similar large Madrepores with the mode of growth of *M. palmata* extend over areas of twelve to fifteen feet in diameter. These vie in size with the huge masses of *Porites* one meets with on the reef flat near Honolulu. They are nearly as large as those found in the rock of the inner reef of Tongatabu, stated by Dana (Corals and Coral Islands, p. 186) to measure twenty-five feet in diameter, or as the *Astræans* and *Mæandrinæ* both there and at the Feejees measuring from twelve to fifteen feet (Ibid., p. 146).

which in many places is changed into extensive sand beaches. On the mainland in the distance can be seen the outline of Mount Gunagua. After passing Cay Coco, which only at Coco Point rises above the first terrace, we sailed along a series of disconnected patches of reef rock, the remnants of larger cays undoubtedly, like Cay Coco, Paredon Grande, and the like. Along the face of Cay Guillermo are here and there short stretches of low cliffs, parts of the first terrace, separated by low rounded hills. The low hills of Triguano Island are now faintly seen in the background. The plateau formed by the system of low cays we are describing is widest in the region from Cay Verde to Cay Frances. The terraces here were probably of great width, as the hills of



PATCHES OF SOBORUCO, CAY FRANCES.

older rocks upon which they flank do not in this part of Cuba come near the coast line, as is the case from Santiago to Cape Maysi, and as far west as Gibara.

On the cays to the eastward of Santa Maria Cay, as far as Cay Frances, the reef rock cliffs are separated by sandy beaches, and the hills are so eroded that it is impossible to determine the terraces of which they once formed a part. Upon the outer edge of the plateau, in from four to ten fathoms of water, an extensive nearly unbroken reef runs from Nuevitas to Cardenas, and is the source from which are formed the long sand beaches that reach between the low cliffs of reef rock forming the sea faces of the line of cays. There are patches of living corals often extending close to low-water mark, with heads awash at low tide. From these sand beaches, exposed to the full force of the trade winds, patches of recent æolian rock have occasionally formed on this line of cays. Such a patch was observed at Cay Frances. The inner cays, many of them extending toward the shores of the mainland, are composed of limestone, and have been washed away below the level of the sea and converted into regular mangrove islands. Cay Frances is really the first break admitting vessels of any depth inside the cay reef plateau, and forming a channel leading to the main passage running parallel to the coast. Between this and Sagua there are two others, the principal and deepest one leading to Sagua la Grande.



The Fragoso Cays are low, and protected on the face of the inner channel by innumerable small cays. Here and there we find cays with a low reef rock bluff or point, but generally they are bordered by sand beaches. Passing Tocinero Point, we come to a wide bay, a passage for small boats making for the mainland, and soon opened upon the mainland an isolated saddle similar to those so frequently seen farther to the eastward, the remnant probably of limestones belonging to the third terrace.

To the eastward of Vela Cay there is also a wide passage, leading from the outside of the cays to the interior channel along the main shore of the island. We next come to the Lanzanillo Channel, a similar break between the outer cays. To the westward of this extend Lanzanillo Cay, the Jutias Cays, Cay Cañete, and Cay Cristo, separated by the Boca de Marillanes. All these low cays are eroded parts of the second terrace, with low reef rock bluffs separated here and there by long stretches of coral sand beaches derived from the outlying living reefs of the edge of the shore plateau.

### Sagua la Grande.

Plate I.; Plate XIII. Fig. 4; Plate XIV. Fig. 1.

We now reach the entrance to Sagua, a wide channel not less than eleven miles long, carrying nineteen feet of water, fringed on all sides with low mangrove islands. To the northwest of the anchorage opposite the town stretches out a wide, shallow bay, the outer edge of which is protected by the continuation of the numerous cays on the north of the entrance to Sagua (Plate XIII. Fig. 4; Plate XIV. Fig. 1). In the distance behind Sagua rise the Sierra Morenas, and to the eastward the Lomas de Sagua la Grande. Sagua is built on piles on the highest part of a mangrove island, which can hardly be called a part of the mainland. A causeway of limestone brought from the neighboring highlands forms the main street and the sidings of the railroad station. To the westward of Sagua and of Bahía de Cadiz extends an archipelago of low mangrove cays, reaching to the entrance of Cardenas Bay (Plate XIII. Fig. 4). Cay Piedras, the most westerly of the islands on the Nuevitas-Cardenas plateau, shows a ledge of low bluffs of the usual reef rock. In the background of the cays the Limonar range becomes a prominent feature of the landscape. The hills approach the shore of the mainland again, and we soon make out indistinct traces of some of the higher terraces in the horizontal lines of the saddle-like hills seen



in the distance. To the eastward the Pan de Matanzas rises above the horizon, and the hills which surround it to the eastward and westward make part of the shore line itself. The Bay of Cardenas is easily entered, and we anchored close to the town. There is no rock in place at Cardenas, but the rocks brought for building purposes from the neighborhood are older limestones. All the way east from Cardenas to the inner southern extremity of Cay Romano there is an excellent water way for small boats. The inland navigation is protected the whole way by an almost unbroken line of cays. The distance between the outer cays and the cays forming part of the immediate shore of the mainland is often considerable, though the depth of water is not great. This wide inland sea-way, and also the channels separating the cays on the wider passages, like Boca de Cañete, Boca de Marcos, the entrances to Buenavista Bay, Cardenas, Sagua, Caybarien, and others, are undoubtedly due to mechanical agency. The rock washed by the greater or smaller waves of the outer sea or of the inner bays is readily changed to sand, and thus great stretches of the low cays are converted into flats, and the finer particles washed away, increasing little by little the depth of the water upon them; the currents deepen the channels between the cays, or form the still deeper passages, giving egress to much of the disintegrated reef rock.

### Cardenas to Matanzas.

Plate I.; Plate XIII. Fig. 4.

The peninsula of Icacos, which forms the western protection of the harbor of Cardenas, is low, fairly wooded in parts, and opposite Diana Cay there is a fine cliff of older limestones; other outcroppings occur also on the peninsula, farther out from Cardenas, and nearer its eastern point.

After rounding Cay Piedras and passing Monito Cay we followed the low coast making the continuation of the peninsula of Icacos and stretching toward Matanzas. This is flanked on the sea face by low reef rock cliffs, which become higher as we proceed westward; behind them rise a low range of well rounded limestone hills, perhaps two to three hundred feet in height. In the background, to the eastward, the Limonar range passes into the Santa Clara hills, and they in their turn are connected by a low range of hills (the Camarioeca Paps) with the Pan de Matanzas lying to the westward of the entrance to the Bay of Matanzas.

## Matanzas.

Plates I., XLII., and XLIII.

As one approaches the entrance of Matanzas harbor the eroded hills gradually pass into distinct terraces to the eastward of the mouth of the bay. The low elevated coral reef forming the first terrace comes into prominence, and next the line of the second can be distinctly traced, while on the opposite shore near Sabanilla Point three of the terraces are plainly marked. A part of the Bay of Matanzas and the Yumuri Valley have undoubtedly been formed by erosion during the elevation of the surrounding country. The extent of this erosion is seen on all sides of Matanzas, from the terraces of the eastern and western sides of the harbor to the gently sloping hills rising to Bellamar, or to the conical paps of Camarioca, or to the rolling foothills rising to the massive Pan



PAN DE MATANZAS.

de Matanzas, or to the vertical limestone cliffs nearly as high as the Pan itself to the westward of it. The caves of Bellamar are the finest examples of the many caverns found in the limestone district of Cuba. Their opening is on a comparatively level plateau from three hundred and fifty to four hundred feet above the harbor; but to which one of the terraces the plateau corresponds it is difficult to say. With the exception of the terrace (perhaps the second) indicated in the railroad cutting as we ascend from the bay, there are no traces of other terraces. A few isolated corals are found on the level of the entrance to the caves. The first terrace follows the line of the road, which runs round the bay on the east side. At all cuts of the first terrace we find several species of corals, apparently in place in the reef rock. From Montserrat one gets a beautiful view of the Yumuri Valley. I found no corals anywhere in the limestone on the way up, but a good many shells are embedded in the limestone at an elevation of four hundred to four hundred and fifty feet. The wide valley of Yumuri, with its terraces to the north, is shut in by low ranges of hills, which are cut through immediately back of

Matanzas by a deep gorge. This gorge must at one time have been the entrance to a flask-shaped harbor very similar to such harbors as Nipe, Padre, and the like, which once opened through this cañon into the Bay of Matanzas, but the bottom of which has been elevated above the present level of the bay.

We had an excellent opportunity, on going out of Matanzas on our way to Havana, to observe the plainly marked first and second terraces inside of Sabanilla Point, just beyond the pilot station. Before reaching Guanós Point the base of the second terrace is seen to be dis-



TERRACES, GUANÓS POINT, MATANZAS.

tinctly undermined, the limestone sloping very gently to the low bluff of the first terrace. After passing Guanós Point the sea has encroached upon the first and second terraces, leaving vertical bluffs which probably represent the summit of the third terrace. The fourth terrace may be seen indistinctly to the east of Guanós Point, at a height of from five hundred to six hundred feet. In the background there are indications of the fifth terrace.

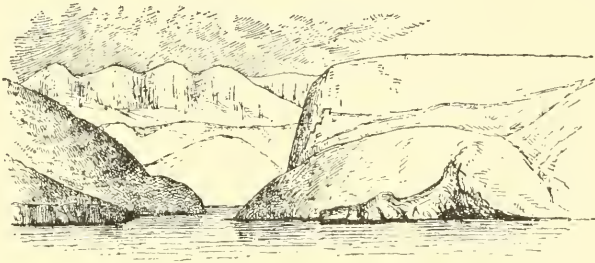
### Matanzas to Havana.

#### Plate I. and Plates XLIV. to XLVI.

On leaving Matanzas we come upon a stretch of coast line which is in marked contrast with the configuration of the island to the eastward. The line of shore, protected by outlying cays, which extends from Cardenas to Nuevitas, is now replaced by a nearly continuous vertical bluff, representing probably the summit of the third terrace, which extends to about opposite the Managua Paps. This low shore line belt of the third terrace is cut through by valleys following the course of the small rivers which empty on this part of the north shore between Matanzas and Havana; as, for instance, the Rio Canasi, the Santa Cruz valley, and the Jaruco River. An examination of some of the cuts made by the rivers on this part of the coast might throw important light on the history of the limestone forming the different

terraces of the shore line. The height of the bluffs of the shore line, or of the hills corresponding to the third terrace, is about three hundred and fifty feet. Seen from the mouth of Canasi River Gap the limestone hills through which the river has cut its way remind one of the flat hills apparently damming the course of a river in the anthracite region of Pennsylvania.

In the background, after passing westward of the gap, the Jaruco hills come into view. They are greatly eroded as seen from the sea, and present the characteristic erosion of the vertical cliffs of the limestone hills on the eastern extremity of Cuba. The same seems also to be the case with the hills to the rear of the Santa Cruz cut. Inland behind the



SANTA CRUZ GAP.

third terrace, where it can be traced near Santa Cruz, the general level of the land appears lower than the terrace in front of it. There seems to have been an extensive valley, parallel with the coast, formed by erosion to the rear of the shore hills. The range of hills extending to the westward towards Havana is the continuation of the Sierras de Jaruco. It seems to trend somewhat away from the coast, and also to be considerably lower. The Managua Paps are marked on the chart as not more than seven hundred and thirty-two feet high. In the vicinity of Havana the second row of hills is not of greater height than that of the third terrace. To the westward of the Jaruco River entrance there are large isolated blocks, the remnants of the soboruco after the general disintegration of the first terrace. These indicate clearly the extent of the erosion which has taken place, and which has here widened the reach of the slope of the first terrace towards the base of the cliffs or of the hills forming a part of the second terrace. Professor Dana<sup>1</sup> has called attention to the existence of similar huge masses of reef rock upon the shore platform of coral islands.

<sup>1</sup> Corals and Coral Islands, p. 179.

To the westward of the Jaruco River the shore hills gradually become lower; they are not above four to five hundred feet in height, with rounded slopes, from which all traces of the terraces have been obliterated. Only here and there can we trace the first terrace. As we approach Havana from the eastward the shore hills continue to diminish in height, showing greater marks of erosion. They are not above two hundred or two hundred and fifty feet, and when the Morro comes in sight they are about a hundred to a hundred and twenty feet. It is only near the Morro that the terraces are again discernible. The first terrace is most prominent to the westward of the entrance of the harbor, while some of the hills which surround the port can readily be recognized as parts of the second and third. The higher hills to the southeast of Havana show no traces of terraces. To the westward the table-land of Mariel consists of several terraces, the steps of which are plainly visible on entering the harbor of Havana. The reef rock of the first terrace (Plate XLV.), extending westward from the Castle de la Punta to the San Lorenzo quarries, is full of fine specimens of corals, of the same species which have characterized the first terrace of the elevated reef wherever we have examined it, whether at such distant points as Saboney, Baracoa, and Cay Confites, or at Matanzas or Havana.

To the westward of Havana the coast hills are low. They are flanked by the line of the first terrace, and cut through here and there by the valleys of the small rivers taking their rise in the Mariel table-land, and in the broken range extending westward to the Sierras de los Organos. Mariel, Cabañas, and Bahia Honda are the only flask-shaped harbors found between Havana and the eastern extremity of the Colorado Reef. The Colorado Reef forms the edge of a plateau extending outside of the shore line from Bahia Honda to Cape San Antonio; there are on it comparatively few cays (Plate XIII. Fig. 5). That part of the coast resembles only in a general way the cay protected shore of Cuba extending from Cardenas to Nuevitas.

On leaving Havana for Cay Sal we kept farther out to sea than when steaming from Matanzas west. We were thus able to get a better view of the inner range of hills rising behind the low shore hill range.



## THE CORAL REEFS OF CUBA.

Plates I. and XIII.; Plate XIV. Fig. 2; Plates XLIV. to XLVII.

Outside of the elevated coral reef which may be said to flank nearly the whole coast of Cuba is found the growing reef, extending to ten or twelve fathoms or more wherever there is an insular platform of any width between the elevated reef and the 100 fathom line. This living reef is most irregular, occurring often merely as patches, or as spits forming small boat harbors, or as either short barrier or fringing reefs. But in many localities the general line of the reef is interrupted, either from the shifting bottom of coral sand on the sea face of the elevated reef, or from the great steepness of the shore slope, as along the south coast of Cuba from Cape Cruz to Cape Maysi, and nearly as far north as Nuevitas. Here, and along the face of the cays protecting the main shore of the island as far as Cardenas, the continental platform is much wider, and forms a coast shelf of considerable width, upon which corals flourish, principally in from three to seven fathoms of water, though they extend into depths of ten or twelve fathoms, or even more. From Cardenas to the eastern extremity of the Colorado Reef corals do not flourish, except on the Jarueco Bank, probably from the same causes which influence their distribution on the south coast. Inside the Colorado Reef as far as San Antonio exist a series of cays similar to those on the submarine bank to the eastward of Cardenas, but on a smaller scale. On the south shore, from the Isle of Pines to Cape Cruz, we have an extensive archipelago of similar structure upon a wide platform the edge of which is fringed with corals. On this plateau are, to the east of Trinidad, the Great Bank of Buena Esperanza, the Manzanillo and the Laberinto de Doce Leguas Banks, and innumerable cays dotted over its surface. The reefs between Cape Cruz, the Isle of Pines, and Cape Corrientes I have not examined, and know them only from the description of the Coast Pilot. The Colorado Reef I have only seen at two points.

On the south coast, between Cape Maysi and Cape Cruz, the prominent stretches of reefs are those to the eastward of Jucaro Anchorage, on each side of Damas Cay, and the belt extending eastward from Brava Point, where the reefs extend to the foot of the Ojo del Toro and form a sheltered reef harbor. A small patch of corals also stretches to the westward of Cape Cruz. In addition to the many cays which stud the banks between Cape Cruz and the Isle of Pines, many parts



of this region are "thickly covered with mushroom-shaped coral shoals, which suddenly rise from soundings of five to eleven fathoms to just awash." These coral heads are said to be especially thick in the vicinity of Boca Grande, and extend towards the mainland. A prominent reef extends all the way from Breton Cay north of Boca Grande as far as Zarza de Fuera Cay. From that point the reef is limited to a short stretch of patches to the eastward of Trinidad. The coast there is flanked by steep rocky cliffs. The 100 fathom line is close to the shore as far as Cochinos Bay, the western shore of which is sandy, and terminates in Piedras Cay, whence a bank extends to the westward which connects with the Jardinillos Bank. The reef encircling this bank starts from Diego Perez Cay in Cazones Bay, and extends on the east face to East Guano Cay, the most easterly extremity of the bank. The southern face of the bank is "skirted by a chain of reefs," broken to form Rosario Channel. Beyond the channel a "formidable barrier coral reef" runs on the prolongation of the bank out towards Dry Shingle, to the eastern end of the Isle of Pines. Within Dry Shingle, the Calapatch Melhagon Reef is one mass of corals just awash.

The south coast of the Isle of Pines is skirted by a reef. On the western side of the island there are, as on the shores of many of the cays of the banks between Cape Cruz and Cape Corrientes, extensive patches of "soboruco," parts of the first terrace or elevated reef of Cuba. A coral reef closely skirts the whole west coast of the Isle of Pines. The Isle of Pines is by far the largest of the islands and cays which are dotted over the greater part of the wide banks off the southern coast of Cuba. The eastern extension of the Isle of Pines Bank reaches to Rosario Channel, and the western extension to Cape Frances. The coral reef skirting the west coast of the island stretches to the westward, bordering the San Felipe Cays, and from there to Cape Frances there are patches of coral reefs. From Mangle Point, near Cape Frances, to Cape Corrientes the coast is flanked by soboruco, with here and there a short stretch of coral reef.

On the north shore the Colorado Reefs extend nearly all the way from Cape San Antonio to Cabañas. There are a number of openings through the reef, with an inside channel navigable for small vessels (Plate XIII. Fig. 5). To the east of Cape San Antonio the reef is at a considerable distance from the coast line, extending across the mouth of the wide bay formed between it and Buena Vista Opening. From here the great barrier reef runs parallel with the coast, and is separated from it by an irregular belt of low cays, not many in number, compared

with the endless chain of cays extending eastward from Cardenas as far as Nuevitas.

The entrances to the flask-shaped harbors of Bahia Honda, Cabañas, and Mariel are made by breaks through the extension of the barrier reef, which from the Manimar Opening to Cabañas has become almost a fringing reef. Beyond Cabañas, and as far east as Matanzas, there are but few patches of corals, one to the westward of Mariel, another off Mangles Point to the westward of Havana, and we find corals again on the Jarnco Bank and off Maya Point on the eastern side of the entrance to Matanzas. The absence of corals is undoubtedly due to the great depth immediately off shore along that whole stretch of coast line.

From Cardenas to Nuevitas extends a shore platform varying in width from five to twenty-five miles. The outer edge of this coast shelf is edged for nearly its whole distance by a narrow coral reef extending from three to seven fathoms in depth, or perhaps more. A belt of cays, many of them of great size, like Cay Coco, Cay Romano, and Cay Sabinal (Plate XIII. Figs. 1, 2), lie between the edging reef and the shore, leaving large bays or channels navigable for small boats between their western shores and the main island. Between Cardenas and Cay Coco the cays are smaller, and are either scattered in clusters over the shore platform, forming small archipelagos like those off Santa Clara Bay, Sagua la Grande, and Caybarien, or else form a belt more or less parallel with the 100 fathom line (Plate XIII. Figs. 3, 4).

These cays are the result of erosion combined with the wearing action of the sea. On their sea face we find patches of soboruco elevated to a height of from five to fifteen feet. The first terrace, formed mainly of soboruco, has been greatly eroded in the district between Cardenas and Nuevitas, and in many cases only small patches of the soboruco are left.

To the eastward of Cay Confites the edging reef little by little trends toward the shore as the shore platform becomes narrower, and to the east of Nuevitas the reef becomes a fringing reef, forming disconnected patches separated by sandy banks between Maternillos Point and Herradura Point. At some places, as off the entrance of Padre and of Nuevitas, the reefs form small reef harbors off the shore, similar to that of Alfred Sound on Inagua. They are readily distinguished, even at a considerable distance from the land, by the exquisite emerald color of the enclosed waters.

The Jaragua anchorage is an excellent example of the formation of an anchorage behind a coral reef caused by the breaking through of a channel opposite the mouth of a river. (Hydrographic Chart, No. 518<sup>a</sup>.)

Opposite the river Moa the coral reef which stretches across the port of Cayo Moa is interrupted, and the break forms the entrance to Cayo Moa Bay. A still better example is perhaps that of the anchorages of Yamanigüey and Cañete, where the outlying coral reef is broken through in two places, opposite each of the rivers which gives the anchorage its name. These lead into an elongated bay, the northern end of which is the Bay of Cañete and the southern the Bay of Yamanigüey.

Between Herradura Point and Cape Maysi we find only here and there patches and short stretches of fringing and edging coral reefs, or small reef harbors, as between Gibara and Sama Point, and south of Mulas Point to Banes, and between the entrances of Nipe and Port Canova. From that point the shore platform becomes wider and the reef more continuous to off Cayo Moa; it runs close to the shore from Mangle Point to Jaragua. From this place to Cape Maysi corals grow outside of the elevated soborucó reef only where the deep water does not come too close to the sea face of the elevated reef. But the living coral reefs of this part of the coast, all the way from Cape Maysi to Nuevitas on the west, and to Cape Cruz on the south coast, are of little importance.

## DISTRIBUTION OF CORALS IN THE BAHAMAS.

### Plate I. and Plates IX. to XII.

It is interesting to follow the distribution of corals upon the banks. Excluding the edging reefs of the Great and Little Bahama Banks, as well as those of the outer edge of the smaller outlying eastern banks which have been referred to elsewhere, we find that upon the interior of the Great Bahama Bank reef corals are limited to a wide belt running east from New Providence as far as Current Island, and extending in a southerly direction. Between New Providence and the Ship Channel another extensive tract, known as the Middle Ground, is full of coral heads. It is separated from the New Providence ground by a barren area, and a similar area separates it on the south from another great patch of coral heads to the westward of Norman Cay. On examining the chart, it will be found that these areas of reef corals are in a position to be swept by the clear water of the Tongue of the Ocean and of the Northeast Providence Channel in regions where the bottom is not in constant turmoil from the action of the sea. In fact they probably grow upon the isolated patches of æolian rock, which afford the corals a solid foundation. With the

exception of the edging reef on the west side of the Great Bahama Bank, on the east face of the Gulf Stream, we find the bank wholly bare of coral heads. It is one wide expanse of marl and of coral or coralline sand to the west of Andros, and to the north or northwest as well as west of the line from Andros Island to Cay Lobos. To the southeast of the termination of the Tongue of the Ocean the whole surface of the bank is dotted over with an innumerable mass of rocky heads, forming a wide field of æolian rock ledges, separated by narrow channels of from two to three fathoms of water or less, through which only small boats can navigate. This field extends almost to Nurse Channel on the south, and occupies a large triangular area reaching to the southern edge of the Jumentos Cays. Many of the heads are covered with coral growth. There are similar but more widely separated patches of rocky heads on Columbus Bank, and another extensive area flanking the southern edge of the bank from north of Blue Hole Point to Lobos Cay. In the district to the north of the line from Blue Hole Point to Diamond Point these patches are met with nearly forty miles from the edge of the bank. Another important patch of coral heads is found to the west of the southern end of the Tongue of the Ocean, south of Andros.

In addition to the Middle Ground southeast of New Providence, there is a band of rocky heads occupying the centre of the bank to the west of Norman Cay, and extending south till it reaches the sand bores to the east of Green Cay. Over the greater part of the rest of the bank the disintegration and reduction of the heads and islands and islets have been so complete as to leave the surface covered only with æolian sand and fragments in various stages of destruction, from the finest impalpable powder to fine sand, coarse sand, and flakes of coralline algae from an eighth to a quarter of an inch in length.

On the smaller banks, the western and northern edge of Little Bahama Bank north of Bahama Island is occupied in part by heads, and the edge between Settlement Point on Great Abaco and Carrion Crow Harbor is fairly covered with heads between the few islands and islets reaching the surface. On the eastern edge of the bank the heads are interspersed between the cays, and nowhere form such a peculiar ground as the Middle Ground of the Great Bahama Bank. On Crooked Island and Caicos Banks the sunken heads are limited to a comparatively small area; in the former to the west side of the bank between Fish Cays and Castle Island, and in the latter to the area of the bank south of Ambergris Cays to South Rock and Swimmer Rock, and along the western edge of the bank. On Mouchoir and Silver Banks there is but a small area where coral heads are found.

But perhaps the most characteristic of the Bahama banks, showing the disintegration of the larger æolian islands into small isolated heads, is the Turk's Islands Bank, where the whole area to the south and west of Grand Turk Island, as far as Salt Cay on the one side and East Cay on the other, is one maze of heads with deep channels between them (Plate IX. Figs. 5, 6).

The "coral heads" described by Mr. J. A. Whipple<sup>1</sup> in his Journal, referred to by Professor Dana<sup>2</sup> as standing in fifty feet near Turk's Island, are not coral heads in the strict sense of the word. They are mushroom-shaped rocks of æolian structure, veneered with coral growth. Similar mushroom-shaped rocks of volcanic origin covered with corals occur in Kaneohe Bay, on the weather side of Oahu in the Sandwich Islands, and are common in the Bahamas and Bermudas.

These tracts of coral heads are seen to be in areas accessible to the prevailing winds, and to the food supply swept upon the banks by them and the prevailing currents. These patches, forming the Middle Ground or "coral heads" region, are without doubt clusters of æolian rock, which have not become entirely disintegrated, and which rise to very varying heights above the bottom of the bank. Upon these in many places corals and Gorgonians have obtained a foothold. Upon the smaller banks, closed on one or more sides, the corals or coral heads extend only a short distance upon the side open to the action of the prevailing winds.

Upon Little Bahama Bank we find no extensive tract of coral heads outside of those areas which may be called edging or fringing reefs, or, as on the southern face of Bahama Island, their extension a short distance upon the bank. The edging reefs may in general be said to exist along the margin of all the Bahama banks in from three to ten, or even fifteen to eighteen fathoms of water.

There seems to be nothing in the distribution of the coral reefs upon the Bahamas to show that they form anything more than comparatively thin layers of corals overlying the æolian rocks which constitute the substructure of the islands and the smaller sunken patches, and the foundation of the banks. What their thickness or extent must have been in order to form the extensive beaches which supplied the material which was blown into the dunes of the Bahama æolian land, is another ques-

<sup>1</sup> "The trunk which made up two thirds of its height was only fifteen feet in diameter along its upper half, and it supported above a great tabular mass one hundred feet in diameter, whose top was bare at low tide."

<sup>2</sup> Corals and Coral Islands, p. 133.



tion. It may not be far out of the way to assume that their thickness was no greater than that of the elevated reef of the Cuban coast on the opposite side of the Old Bahama Channel.

The difference in the formation of the coral reefs of Florida, the Bahamas, and Cuba is most striking. The coast of Cuba is characterized by the elevated reef terrace which surrounds it. In the Bahamas the corals are scattered over wide areas, either on the interior of the banks or lining their margins; they have played no part in the building up of the Bahamas. In Florida the corals have not only built up the outer keys, but also the inner line of islands, and the outer reef reaches the surface at many points. In the Bahamas the reefs are subsiding, in Florida they are stationary, and in Cuba they have been elevated.

## HYDROGRAPHY OF THE BAHAMAS.

Plates I.-VIII., and Plate X. Figs. 4, 5.

This brief sketch of the Hydrography of the Bahamas, of the Windward Islands, and of the Caribbean, will serve to show the relation of the coral reefs to the great banks upon which they are found. The Contour Map of the Caribbean (Plate VIII.) was prepared for my Reports on the "Three Cruises of the Blake," at the Hydrographic Office, through the kindness of Commander J. R. Bartlett, U. S. N., Hydrographer, and it is for the sake of convenient reference reproduced in this Report. For the chart of the Bahamas (Plate I.) I am indebted to Commander C. D. Sigsbee, U. S. N., the present Hydrographer of the Navy Department.

The sea face of the Bahamas indicates depths and steep slopes "fully as remarkable as any yet observed in the Pacific, even among its equatorial islands,"<sup>1</sup> and which are in great contrast to the more gentle slopes off the Florida Reefs.<sup>2</sup>

The character of the slope of the bottom off the Florida Reefs has been well described by Pourtalès<sup>3</sup> in the Introduction to his Monograph on

<sup>1</sup> Dana, Corals and Coral Islands, p. 216.

<sup>2</sup> See Langenbeck, *loc. cit.*, p. 28. I am surprised to find that Dr. Langenbeck questions this. A comparison of the West Indian and Equatorial Pacific Hydrographic Charts leaves no doubt on this point.

<sup>3</sup> Deep-Sea Corals, by L. F. de Pourtalès, Ill. Cat. Mus. Comp. Zoöl., No. IV., 1871. See also Pourtalès, in *Peterm. Geog. Mittheilungen*, 1870, Heft XI.; and A. Agassiz, The Tortugas and Florida Reefs, *Mem. Am. Acad.*, XI. 107, 1882.



Deep-Sea Corals. He has called attention to the great width (comparatively speaking), varying from three to six miles, of the slope covered by calcareous mud extending from the outer reef to the 100 fathom line. This is in marked contrast with the narrow plateau found outside of any reef on the Bahamas between it and the 100 fathom line. This plateau is nearly always a mere narrow shelf, sometimes less than a hundred feet, and rarely more than a mile in width at its greatest breadth.

An examination of the sections given on Plate IV. Figs. 1-3, and Plate V. Fig. 16, will readily show the character of the slope of the bottom off the Florida Keys, and the striking contrast of this slope with the steep, almost vertical sides of the sea faces of the edges of the coral reef banks of the Bahamas (Plate IV. Figs. 4, 5, 6, Plate V. Figs. 10, 15). Along the Florida Reef, after passing the 100 fathom line, we find a rocky belt of limestone built up of organic fragments of all kinds of Invertebrates, which extends very gradually to the 250 or 300 fathom line, and has a greatest breadth of about eighteen miles off Sombbrero Light. Beyond this rocky belt, the Pourtales Plateau, the slope becomes steeper towards the trough of the Gulf Stream. Off Cuba the rocky slope is very abrupt (Plate V. Fig. 16), and this abrupt slope is characteristic of the whole line of the Cuban coast, both north and south, except along the face of the Old Bahama Channel. Figure 16 of Plate V. is a section from Sand Key to Havana; Figure 14 is a section from Coffin's Patches to Elbow Cay on Salt Cay Bank. This shows with great clearness the gentle slope off the reef to two hundred and thirty fathoms, and the abrupt pitch of the Salt Cay Bank off Elbow Cay.

The character of the sections across the trough of the Gulf Stream becomes more clearly indicated in the sections from Fowey Rocks to Gun Cay (Plate IV. Fig. 3), from Hillsboro Inlet towards the North-west Providence Channel (Plate IV. Fig. 2), and from Jupiter Inlet to Memory Rock (Plate IV. Fig. 1). The abrupt slope on the Bahama Bank side characterizes all the sections.

The sections of the two branches of the Old Bahama Channel passing into the Straits of Florida on the two sides of Salt Cay Bank (Plate IV. Fig. 5) show a more abrupt slope on the Cuban side than on the opposite side off Salt Cay (Plate V. Figs. 13-15), where the slope is more gentle; while the section from Anguila to the opposite bank (Plate IV. Fig. 6) shows its steepest slope off Anguila as compared with the Bahama Bank slope.

As we proceed eastward, the section from the Santa Maria Cays to the

opposite shore of the Great Bahama Bank indicates that beyond the 100 fathom line the extension of the wide plateau off the main island takes a more gentle slope to the central part of the trough, while the bank slope is quite abrupt. (Plate V. Fig. 1.) It is the opposite in a section from Paredon Grande to Guinchos Cay, the Cuban slope being the more abrupt. (Plate V. Fig. 2.) In a section from Cay Lobos at right angles to the channel across to Romano Cay, the two slopes are equally abrupt. (Plate V. Fig. 3.) The same is also the case in the deeper section from Cay Romano to Diamond Point, though the Cuban slope is slightly less abrupt. (Plate V. Fig. 4.) As we go eastward the sections across the approaches to the Old Bahama Channel become deeper; in that from Maternillos Point (Cay Sabinal) to Blue Hole Point, the Cuban slope is the steeper. (Plate V. Fig. 5.) The contrary is the case in the section from Sama Point to Cay San Domingo and Ragged Island. (Plate V. Fig. 6.) The section from Cape Maysi (Point Azules) to Inagua (Plate V. Fig. 7) shows the first eight hundred fathoms to be steeper, followed by a gentler slope to the deepest part of the channel, while the Inagua slope is more uniformly steep beyond the 200 fathom line. Off Haiti in a line from Cape Isabella to Turk's Islands the Haitian slope is seen to be steeper than that of the Turk's Islands Bank. (Plate V. Fig. 8.) The sections across the Straits of Florida and across the Old Bahama Channel (Plate IV. Figs. 1-3, Plate V. Figs. 1-9) show the depths of the troughs which separate the Bahama Banks from Florida and from Cuba. The extension of some of these sections across the banks to the Atlantic give us an idea of their great expanse, and of the deep channels which cut into the banks. First, the Providence Channels, which separate the Little Bahama Bank from the Great Bank (Plate IV. Figs. 2, 3); others, like the Tongue of the Ocean or Exuma Sound (Plate IV. Figs. 4-6), which form deep bays into the bank itself; and finally the deep passages that separate the smaller banks and connect the Atlantic directly with the deep valley forming the approaches to the Old Bahama Channel.

A section run from Jupiter Inlet to Memory Rock (Plate IV. Fig. 1), across the bank to Great Sale Cay, and running off the Little Bahama Bank outside of Pensacola Cay, shows that the soundings on the bank between Great Sale Cay and Memory Rock are slightly deeper than those to the eastward towards Pensacola Cay. There seems to be little difference perceptible in the steepness of the Atlantic slope of the bank from the 10 fathom line to about three hundred fathoms, as compared with the slope off Memory Rock into the channel of the Gulf Stream. A section from Hillsboro Inlet across the Northwest Providence Channel

(Plate IV. Fig. 2) shows the southerly extension of the Little Bahama Bank separating the Gulf Stream channel and the Atlantic bight of the Northwest Providence Channel. This line runs across the bank from Mores Island to Great Abaco, and shows a much steeper sea face off Little Harbor on the Atlantic than off Mores on the Providence Channel slope. The section from No Name Cay south of Green Turtle Cay (Plate VI. Fig. 4) is interesting as showing the line of the outer ridge of cays and patches, often rising to the surface, and joining the disconnected parts of the outer reef with the belt of deeper water between it and the inner line of cays of which Green Turtle Cay is one.

The section from Fowey Rocks to Gun Cay (Plate IV. Fig. 3) across the northern part of the Great Bahama Bank to the Berry Islands shows a much steeper slope off these islands into the Northeast Providence Channel than the western slope off Gun Cay in the direction of the trough of the Gulf Stream. The line across the bank from Royal Island to the Atlantic face of Eleuthera indicates a very abrupt slope both on the channel side and on the Atlantic side, these two slopes being as steep as the slope east of the Berry Islands.

A section made somewhat farther south (Plate IV. Fig. 4), from Orange Cay across the northern extremity of Andros, the Tongue of the Ocean, Nassau, and that part of the bank lying between it and Eleuthera, shows the same features as the more northern section. The Orange Cay slope is less abrupt than the east and west slopes of the Tongue of the Ocean off Andros and off Nassau. The Atlantic slope off Eleuthera is somewhat less steep than the slope farther north. A section from Salt Cay Bank (Plate IV. Fig. 5) across to the southern part of Andros, to Green Cay, to Harvey Cay, and across Exuma Sound to Cat Island, shows a less abrupt slope on both faces of the Tongue of the Ocean, though steeper than the Santaren slope of the bank. Off Harvey Cay the slope into Exuma Sound is far less abrupt than either, and the slope from the 1,000 fathom line to the 500 fathom line off the west side of Cat Island is nearly as flat as that on the west side of the Straits of Florida. From the 500 fathom line the west face of Cat Island is as abrupt as the east face. The two slopes of Cat Island are, however, both equally abrupt, and as steep as the slopes of the outer Atlantic faces of the bank elsewhere.

A cross section somewhat farther south (Plate IV. Fig. 6), from the latitude of Anguila Island on Salt Cay Bank across the Hurricane Flats, the southern part of the Tongue of the Ocean over to Exuma Island across Exuma Sound, Conception Island, and Watling Island, shows the peak of Conception Island to be one of a ridge in continuation of Cat Island, and

of which Rum Cay is another summit. The eastern slope of the 'Tongue of the Ocean is less steep than the western face, and the slope off Exuma is far less abrupt than that of the peaks forming Conception Island and Watling Island, both of which rise abruptly from a narrow base at a depth of over twelve hundred fathoms, and finally on the line from Cape Cabron (Haiti) to Navidad Bank the slope is equally abrupt on the two sides of the deep valley which separates these points. (Plate V. Fig. 9.) A line from Acklin to Hogsty Reef (Plate V. Fig. 10) and thence to Inagua shows very abrupt slopes in the deep channel separating Acklin from Hogsty (over one thousand fathoms) and that between Hogsty and Inagua, which is more than fourteen hundred fathoms deep. The extension of that line to the eastward of Inagua runs into over seventeen hundred fathoms, and cuts somewhat diagonally across the slope of the northern face of the deep channel to the north of Haiti.

There are unfortunately no soundings on the Atlantic face of the lines between Crooked Island Bank, Mariguana, the Caicos, Turk's Islands, Mouchoir, Silver, and Navidad Banks, to show definitely how far these banks are separate elevations, or how many may be connected together. (See Plates I. and VIII.) On the western slope the soundings seem to indicate that Turk's Islands and the banks to the eastward may be the summit of a greater bank connecting them all, and that Mariguana, Plana Cays, and Caicos and Crooked Island Banks are the summits of distinct banks separated by deep channels, much as Crooked Island Bank is separated from Long Island by the Crooked Island Passage, with nearly thirteen hundred fathoms in the deepest part. But perhaps the Plana Cays, Mariguana, the Turk's Islands, and the other banks may hold to one another much the same relation which the *Mira por vos* Bank summit holds to Castle Island (Plate V. Fig. 11) and the Crooked Island Bank, being separated from the last by a channel of more than nine hundred fathoms in depth and from Cay Verde by a channel with a depth of nearly fifteen hundred fathoms.

The soundings parallel to Turk's Islands Bank would seem to indicate a deep channel of perhaps a thousand fathoms between it and the Caicos Bank and the extension of the slope of Mouchoir Bank to the eastward south of Turk's Islands Bank.

We made a line of soundings to three hundred fathoms at right angles to Crooked Island Bank (Plate VI. Fig. 2) about one mile south of Southwest Point on Fortune Island. The bottom from three to five fathoms was coarse nullipore and coral sand; at from six to fifteen fathoms it became quite fine; at one hundred and eighteen it was still finer; and

as no specimen was collected at either of the soundings beyond that, it must have been rocky bottom. On steaming back to our starting point for dredging, as we reached seventeen fathoms we found a few coral heads, with large patches of fine white sand between them.

On the line of soundings we ran at right angles to the bank off Exuma Harbor (Plate VI. Fig. 3) we brought up as far as seventeen fathoms the coarse sand of the banks; at eighty fathoms we found rather finer coral sand and a few broken shells; at one hundred and forty-two fathoms the bottom was composed of fine nummulitic and coral sand; the bottom was rocky at one hundred and fifty-seven and two hundred and forty-two fathoms, and at two hundred and sixty-six fathoms we struck fine coral ooze.

Neither of these slopes differs materially from the northerly slope of Hogsty Reef. Off the reef the 900 fathom line (Plate II. Fig. 1) is about four miles from the 100 fathom line. Off Fortune Island it is at about the same distance, and off Exuma Harbor the 800 fathom line is four miles from the 300 fathom line. (Plate IV. Fig. 6.) The sudden drop of these banks to the 100 fathom line occurs from the 15 to the 20 fathom line, the distance to the 100 fathom line varying from one sixth to three fifths of a mile from these soundings, or even less at other points on the banks, as off Green Cay, where it is not more than five hundred feet. Off the coast of Florida the 100 fathom line is from four to nine miles distant from the 10 fathom line, the line of the reef. (Plate IV. Figs. 1-3, Plate V. Fig. 16.)

Off the Mosquito Bank, south of Rosalind Bank, the 600 fathom line is nearly thirty miles from the 100 fathom line, and between the Rosalind and Pedro Banks the slopes east and west from each bank are fully as flat as that. (Plate IV. Fig. 7.) Off the northeastern edge of the Yucatan Bank the slope is even less, the 600 fathom line being more than thirty-five miles from the 100 fathom line. (Plate VI. Fig. 5, Plate VIII.)

The west face of the banks of the Windward Islands is often much the steeper. Off Saba the 600 fathom line is about twelve miles distant. (Plate VII. Fig. 3.) The slope of the bank at the east end of Santa Cruz is about the same. (Plate VIII.) Off the west side of Barbados the 800 fathom line is over twelve miles distant. (Plate VII. Fig. 7.) At some points of the Grenadines Bank (Plate VII. Fig. 7, Plate VIII.) the 1,000 fathom line is within fifteen miles of the 100 fathom line. The eastern end of the Virgin Island Bank is steep on the sea faces; the 1,000 fathom line is in many places less than ten miles distant. (Plate VII. Fig. 1.)



An examination of the sections across Martinique (Plate VII. Fig. 5), Grenada (Plate VII. Fig. 6), the Grenadines (Plate VII. Fig. 7), Dominica (Plate VII. Fig. 8), and St. Lucia (Plate VII. Fig. 9), will show the same character of the western slope of the islands. Off the Montserrat and Antigua Bank (Plate VII. Fig. 4) this does not hold, the eastern slope being the steepest; nor is it the case with the ridge of which Barbados is the summit, the eastern face being the steeper (Plate VII. Figs. 7, 9). A section from north to south across the Virgin Island Bank (Plate VII. Fig. 2) shows a steeper slope on the southern face within the 500 fathom line.

That is, the continental slopes, or the slopes of such straits as the Florida Straits, are less steep than the ocean slopes within the area of the limestone banks.

## THE CORAL REEFS AND BANKS OF THE CARIBBEAN DISTRICT.

### Plate VIII.

The following notes on the reefs and banks of the Windward Islands and of the Greater Antilles were made during my connection with the expeditions of the "Blake" from 1877 to 1880. As they bear upon the general theory of the coral reefs, they are now published more in detail than in the general account of the "Three Cruises of the Blake." The statements concerning the reefs of the north coast of Cuba, and of the south shore from Cape Maysi to Santiago de Cuba, are based upon personal examination, as well as those on the Florida reefs and the Yucatan Bank. In making up my notes I was obliged to consult nearly all the recently published charts of the Caribbean. This has led me to add a short account of the distribution of the coral reefs of the north coast of South America from Trinidad to Costa Rica, and also along the Mosquito, Nicaragua, and Honduras coasts, as far as Cape Catoche on the Yucatan Bank. With the exception of the coast near Aspinwall I have not examined any of the reefs or the outlying banks off the Mosquito coast, off Honduras, or those between Jamaica and the Mosquito Bank. Neither have I visited the line of shoals extending from Cayman Brac to Misteriosa Bank.

The reefs of the Windward Islands are almost without exception on their weather side, and on Saba Bank. off Anegada, and on the bank east



of Santa Cruz we have horseshoe-shaped reefs following the outline of the banks at depths of from six to ten fathoms. In the majority of these cases we might look upon these curved reefs as atolls. They vary greatly in outline, following closely the depths at which they best thrive, and have usually taken from the shape of the basis upon which they have developed the outline of a more or less circular belt. The summits which have risen above the sea level are many of them more or less circular or irregularly elliptical, like St. Vincent, Grenada, and Dominica. Others are greatly indented, like the Grenadines, Martinique, Guadeloupe, and St. Martin; while among the northern islands we find, as among the smaller Grenadines, many irregularly shaped islands, as Santa Cruz, Anguilla, St. Thomas, Cat Island, and the like, along the shores of which we also find lines of irregular broken reefs.

The 100 fathom line of the banks on the west face of the Windward Islands is comparatively close to the shore, the sea face is quite abrupt, and the mass of volcanic mud and other material which is washed down during the rainy season is quite sufficient to prevent the growth of fringing reefs, which are so flourishing on the weather side. Were the banks of the Windward Islands fringed only by low, narrow islands, like the Bahama Banks, we might expect to find reefs growing on their western edge, forming thus a number of atoll-like banks, such as Crooked Island, Caicos, and Hogsty Reef.

Horseshoe-shaped or semicircular reefs exist on isolated banks in the Caribbean, as for instance on the Morant Cays, Serranilla, Serrana, and Quita Sueño Banks. There are also curved reefs simulating semi-atolls on the Mosquito and Yucatan Banks, such as Edinburgh Reef, Half-Moon Reef, and the Hobbies on the former, and the Triangles, Sisal, and Cay Arenas Reefs on the latter, besides the Alacran atoll.

Finally, off Belize we have the isolated banks of Chinchorro, Turneffe, Lighthouse Reef, and Glover Bank, all more or less irregularly elliptical, and rising from deep water beyond the 100 fathom line and inside the five hundred fathom limit, the east face of the last running rapidly into a depth of one thousand fathoms, while the slope of the Chinchorro Bank is comparatively less steep, the 1,000 fathom line being at least twenty-five miles to the eastward. Nearly the whole length of the coast off Belize, from Ambergris Point to Cape Three Points, is protected by a reef which lines the edge of the bank inside of Turneffe Island.

Let us now examine the banks of the Windward Islands formed by the 100 fathom line and compare them with the Banks of the Bahamas.

Beginning with the Grenadines Bank and throwing out of account the

broad continental shelf formed by the 100 fathom line outside of Tobago and Blanca Islands, we find the bank to extend from Bequia in a south-westerly direction, forming a curved elongated plateau concave towards the west, with Bequia and Grenada as its principal islands, the latter rising to a height of over twenty-seven hundred feet, and other volcanic summits such as Carriacou, Caunouan, and a number of smaller ones scarcely rising above the level of the water. Corals flourish on the Atlantic face of the bank, forming fringing reefs or barrier reefs, or often coral ridges connecting the smaller islets. Round St. Vincent (Hydrographic Chart No. 1279, Admiralty Charts Nos. 791, 956), St. Lucia (Hydrographic Chart No. 1261, Admiralty Charts Nos. 956, 1273), Dominica (Hydrographic Chart No. 1318, Admiralty Charts Nos. 697, 956), and Martinique the 100 fathom line forms comparatively small banks. Only a narrow belt on the northern and western face of St. Vincent and St. Lucia, and a somewhat wider plateau on the eastern face of Martinique, are studded within the 20 fathom line with coral reef patches existing either as barrier reefs or as fringing reefs. No elevated reefs have been observed on Martinique, St. Lucia, or the Grenadines, while Barbados, which rises to over eleven hundred feet, is surrounded with elevated reefs forming a series of terraces round the island. These have been carefully studied by Harrison and J. Jukes-Browne. Barbados itself is the summit of an extensive elliptical bank above the 500 fathom line, the greater part extending northward nearly to the latitude of the northern extremity of St. Lucia.

The northeast coast of Barbados (Hydrographic Chart No. 1010, Admiralty Charts Nos. 956, 2485), is skirted by a coral reef from a quarter to half a mile from shore, which encircles almost the whole island. Off Palmetto Bay the reef is more than a mile off shore, but off the south-east coast a barrier reef is found, known as Cobbler Reef, extending from Kitridge Point to South Point, with a channel varying from one half to three and a half fathoms, and from a quarter to half a mile in width, with two to eight feet of water; and parallel with this is a narrow sunken reef with from seven to ten fathoms of water, separated from Cobbler Reef by a belt of water from one quarter to three quarters of a mile wide, with soundings close to the outer reef ranging from fourteen to twenty-seven fathoms. To the seaward the 100 fathom line is not more than two miles off.

Grenada (Hydrographic Chart No. 1316, Admiralty Charts Nos. 956, 2821) attains a height of from twenty-three to twenty-seven hundred feet. It is volcanic, and rises from a bank on which are the Grenadines

(Hydrographic Chart No. 357, Admiralty Chart No. 2872). The 100 fathom line is about seven miles from the east coast. The bank has twenty-seven fathoms on the east edge, diminishing to twenty about half a mile from the shore. On the western side of the island the edge of the bank is not more than two thirds of a mile from the shore.

The eastern and southern shores of Grenada are skirted by wide fringing coral reefs, following the deep indentations which characterize that part of Grenada. Between the island and the 100 fathom line a number of irregular banks rise from the main bank, with from seventeen to eighteen fathoms upon them, from near the 20 or 30 fathom line, the summits probably of islets and islands no longer reaching the surface.

The Grenadines consist of about one hundred islands and rocks extending for sixty miles between Grenada and St. Vincent, none of them attaining a height of more than eleven hundred feet. The smaller islets and islands are many of them fringed with reefs, or protected on the eastern faces by barrier reefs.

Carriacou<sup>1</sup> (Hydrographic Chart No. 357, Admiralty Chart No. 2872), Little Martinique, Little St. Vincent, Union, and Prune Islands are protected on their eastern faces by curved barrier reefs with deep water between the reef and the shore (one to seven fathoms), or by fringing reefs. The Tobago Cays are the centre of a complicated system of coral reefs, forming the fringing reefs of Tobago and of the smaller adjacent cays; between the islands extend broad patches of coral heads. The Tobago Cays (Hydrographic Chart No. 357, Admiralty Chart No. 2872) are in the centre of a great narrow horseshoe-shaped barrier reef, the horns of which are nearly two and a half miles apart. Outside to the eastward are the isolated reef patches known as Egg Reef and World End Reef, which rise within the 6 fathom line and are similar to the isolated reefs so common upon the bank, but most of which are covered with coralline and coral sand too deep for the vigorous growth of corals.

Cannouan (Hydrographic Chart 357, Admiralty Chart No. 2872) is flanked on the east face by a barrier reef with a belt of water from one to six fathoms inside of it. On the islands to the north the coral reefs are less vigorous. From Moustique to Carriacou there are a series of narrow, elongated ridges with from fifteen to twenty fathoms of water upon them, rising from the 20 to the 30 fathom line and following in general the 100 fathom curve.

The ridge of which the Grenadines, St. Lucia, and other Windward Islands form the summits broadens out gradually as we pass northward

<sup>1</sup> The largest of the Grenadines, rising to a height of nearly one thousand feet.

from Grenada. It becomes materially wider north of Martinique. This is indicated by the two small banks lying northeastward of Martinique between it and Dominica. North of Dominica, Marie Galante, and Guadeloupe with its outliers of Desirade and Petite Terre, occupy nearly the whole width of the ridge to the 500 fathom line on either side. It again increases in width at the line from Nevis to Barbuda, and attains its greatest lateral dimensions on the line from the western edge of Saba Bank to the edge of the bank east of St. Martin, one fold of the ridge extending from Saba Bank to Santa Cruz and another to Sombrero, the valley between them falling off rapidly to the Anegada Passage.

The northwest end of St. Vincent rises abruptly to three thousand feet. On the east side of Calliaqua Bay there is a lagoon protected by a reef.

The Pitons of St. Lucia are between three and four thousand feet high. At Laboise the shore is skirted by a reef.

The depths of the passages between the banks of the Windward Islands are quite moderate. Only in the channels between Dominica, and Martinique and between Martinique and St. Lucia do we get a depth of more than five hundred fathoms (in one case 548 fathoms, in the other 575), the 500 fathom line joining St. Lucia and St. Vincent to the Grenadines Bank, and the 500 fathom line uniting Dominica with all the banks to the south of Sombrero with the exception of Santa Cruz and the two submarine banks between it and Sombrero.

Dominica (Hydrographic Chart No. 1318), which rises to over forty-seven hundred feet, is, like Martinique, flanked on the east by a plateau of considerable width limited by the 100 fathom line. Between it and Martinique to the eastward rises a small bank, with a depth of forty fathoms. The northeast end rises less abruptly from the sea, the soundings off the coast showing a continuation of this gradual slope, the 100 fathom line being three and a half miles off shore. It is interesting to compare the submarine slopes of Dominica, Martinique, St. Lucia, and St. Vincent with the steep slopes of the Bahama Banks, which have been considered by many writers as due to the continuous growth of coral reefs during subsidence, so as eventually to form walls of limestone rising abruptly from nearly two thousand fathoms in depth. It is surprising to find that it is the western faces of these islands which give us the abrupt slopes, while the eastern faces, on which the coral reefs are found growing upon a limestone bank of considerable width, show a comparatively gentle slope.

The 100 fathom line surrounding Guadeloupe does not include within its limits the volcanic summits of the Saintes, or the elevated limestone

islands of Desirade, Petite Terre, and Marie Galante. They are separated from Guadeloupe by narrow but deep channels, having a depth of more than two hundred fathoms.

The western part of Guadeloupe (Hydrographic Chart No. 363, Admiralty Charts Nos. 885, 956) is volcanic, and rises to a height of nearly five thousand feet. Grande Terre, the eastern division of Guadeloupe, is almost a level plain. A part of the northern coast of the island is skirted by reefs with channels through it. A coral bank extends along the southern part of the northeast coast of Grande Terre and of the eastern side of Guadeloupe.

The Saintes rise to more than one thousand feet, and are skirted with patches of reefs. Marie Galante is of moderate elevation, its general appearance being flat and low. It rises gradually from south to north. The east and northeast coasts are dangerous, and skirted by coral reefs. Desirade and Petite Terre are joined by a ten-fathom bank of coral reef, the south and east sides fringed by corals.

The French surveys of Martinique (Hydrographic Chart No. 1009, Admiralty Charts Nos. 371, 956) show that the eastern face of the island from Point Laboussaye is bordered by a nearly continuous fringing reef, following the many indentations of its shores and of the small islets off the coast. Outside of this, at a distance of from one to two miles from the coast, extend a series of elongated coral banks, most of them awash, rising from the 7 to the 10 fathom line, and forming a disconnected barrier reef with wide passages between them varying in depth from four to fifteen fathoms, reaching from Caracoli Point on the north to the Vauclin Channel on the south. Martinique rises to a height of nearly four thousand feet.

St. Eustatius (Hydrographic Chart No. 1011, Admiralty Charts Nos. 487, 2600) is volcanic, and rises to a height of over nineteen hundred feet. The greater part of the eastern coast is fringed with corals; on the southeast coast coral patches are found. Saba, also volcanic, rises perpendicularly more than twenty-eight hundred feet from the sea. The 100 fathom line is not more than half a mile from the west side, and only three cables from the west face. It is so abrupt that no corals grow upon its sides.

The eastern edge of Saba Bank (Admiralty Charts Nos. 130, 487, Hydrographic Chart No. 1002) is fringed with a narrow ledge of corals nearly thirty miles in length, with six to ten fathoms of water. The bank is about thirty by twenty miles. To the westward of the coral reef, with the exception of a few coral patches, there are nine to ten



fathoms of water; the bottom is clean white calcareous sand, with a depth of from twelve to fifteen or twenty fathoms, gradually increasing to thirty fathoms, where the slope becomes very abrupt.

St. Bartholomew is nearly one thousand feet high, and rises from a flat bank of considerable extent, composed chiefly of broken shells, white sand, and corallines.

St. Martin, and also the smaller islets near St. Bartholomew (Hydrographic Charts No. 1002, Admiralty Chart Nos. 130, 2038), are fringed with reefs on the eastern and greater part of the northern faces. On the shores of St. Bartholomew itself there are but few coral patches. St. Martin is nearly thirteen hundred feet high. Tintammare is bordered on all sides except the west by coral reefs extending one quarter of a mile from shore.

A small inverted-comma-shaped bank is formed by the 100 fathom line uniting Montserrat (Hydrographic Chart No. 1011, Admiralty Chart No. 254) and Redonda, both of which are volcanic rocks. The isolated peaks of Montserrat rise to three thousand feet above the sea. It is fringed here and there with corals on the east end. Redonda reaches a height of six hundred feet.

The volcanic island of Saba (Admiralty Charts Nos. 130, 487, Hydrographic Chart No. 1002) stands by itself, and to the westward of it rises within the 100 fathom line the Saba Bank, on the southern and eastern face of which a belt of coral reef is found.

An elongated bank is formed by the 100 fathom line uniting Nevis, St. Kitts, and Eustatius.

Nevis (Admiralty Chart No. 487, Hydrographic Chart No. 1011) is also volcanic, and over thirty-five hundred feet above the sea. With St. Kitts and St. Eustatius (Hydrographic Chart No. 1011, Admiralty Charts Nos. 487, 2600), it stands upon a bank entirely detached from the adjoining islands, separated by channels of more than two hundred fathoms in depth. From the south end of the bank a remarkable coral ledge about a mile in breadth extends along its southwest edge for a distance of five miles, and has from eight to ten fathoms on it, with deeper water within. Except on the west side, the shore is fringed with a coral reef extending three quarters of a mile out to a depth of ten fathoms.

St. Kitts (Admiralty Chart No. 487) rises to a still greater height, viz. over forty-three hundred feet; a great part of the eastern face of the island is flanked by a fringing reef.

Antigua (Hydrographic Chart No. 1004, Admiralty Charts Nos. 917, 2600), which rises to a height of thirteen hundred feet, is near the



southern extremity of a bank formed by the 100 fathom line, at the northeastern end of which is placed Barbuda, an island composed of limestone, rising to a height of two hundred feet. The shores of Antigua are deeply indented, especially the northern and eastern faces of the island. It lies upon the middle of the eastern edge of the same bank as Barbuda, the general depth of which is from seven to eleven fathoms, with a coralline and coral sand bottom. It is surrounded by many small islands and islets, and edged on the east, south, and north sides with fringing and barrier reefs, leaving only intricate passages leading into the deep sounds of the island. From the entrance to North Sound the patches of reefs and banks extend in an arc to the westward as far as Diamond Bank, the most westerly of these coral reefs. The Highlands are apparently composed of three terraces, the highest of which is two hundred feet.

From the southeast end of the eastern shore of Barbuda (Hydrographic Chart No. 367, Admiralty Charts Nos. 1997, 2600) a coral ledge skirts the shore at a distance of half a mile; a reef also extends one and a half miles off the north shore, the depth being thirty fathoms within a mile of it; and reefs run off the south coast nearly seven miles in a southwest direction. Barbuda is connected with Antigua by a bank with seven to thirty fathoms of water.

Between Antigua and Guadeloupe an isolated bank rises to a depth of forty-three fathoms, and a similar bank is found to the southeast of the bank limited by the 100 fathom line, of which the principal summits are St. Bartholomew (992 feet), St. Martin (1360 feet), and Anguilla (213 feet). With the exception of Anguilla, they are volcanic summits. They are surrounded by a number of smaller islets of the same structure.

Sombrero is steep and rises to forty feet from a small bank about four miles long. It is composed of recent limestone (Julien), very much honey-combed, and rises abruptly within the 500 fathom line. In a line between it and Santa Cruz rise two submarine banks, the one with a minimum depth of three hundred and seventy-six fathoms, the other with a depth of three hundred and eighty-three fathoms.

Anguilla (Admiralty Charts Nos. 130, 2038, Hydrographic Chart No. 1002) is not more than two hundred and thirteen feet high. The south shore and the eastern end of the north shore are fringed with coral reefs. An extensive reef runs westward from Scrub Island within the 10 fathom line for over twenty miles, with passages to the west of the Pear Cays and eastward of Dog Island.

**Santa Cruz, the Virgin Islands, and the Greater Antilles.<sup>1</sup>**

Santa Cruz is the broad summit of the bank which extends east of the island for a distance of nearly twelve miles, and forms a narrow belt round it. With the exception of a small part of the western end of the north shore and of the western side, Santa Cruz is fringed along its whole coast with corals, forming either fringing or barrier reefs off the north side, and a broad belt of fringing and barrier reefs skirting the south side, of the island. Round the eastern extremity of the bank to the east of the island an extensive reef (Lang Bank) follows the outline of the 100 fathom curve. On this we find six to nine fathoms. It extends on the south face of the bank from the east end to opposite the eastern point of Santa Cruz (Admiralty Charts Nos. 130, 485, and Hydrographic Chart No. 1002).

The Virgin Island Bank, which includes within the 100 fathom line the Virgin Islands and Porto Rico, is separated from the banks to the south-east of it by a deep cañon of over one thousand fathoms, connecting the Atlantic with the Santa Cruz deep of more than two thousand fathoms, separating that island from the Virgin Islands. Porto Rico is the easternmost of the greater West India Islands, and occupies nearly the whole width of the western end of the Virgin Island Bank.

The Virgin Island Bank (Admiralty Charts Nos. 106, a, b, c, 130, and Hydrographic Charts Nos. 1002, 2008) presents very much the same characteristics as the Grenadines Bank. It is the summit of an elongated bank seventy-five miles in length, reaching from Porto Rico to Anegada, and from twenty-three to thirty miles wide. Some of the larger islands which crop out upon the southern edge of the bank, like Crab Island, Tortola, Culebra, St. Thomas, and Virgin Gorda, attain a height of more than fifteen hundred feet, while there are a great number of smaller islands, islets, and rocks barely reaching the surface, all of which are of volcanic origin, Anegada alone being composed of recent reef limestones.

The sea face of Anegada (Admiralty Chart No. 130, Hydrographic Charts Nos. 1002, 2008) is fringed with a coral reef extending to a depth of about thirteen fathoms. Off the east point the reef spreads out upon a broad bank over three miles in width, which also extends along the western face of the island and is studded with coral heads. A wide band of coral heads extends from East Point, known as the Horseshoe Reef, following in a general way the line of the 100 fathom curve. The

<sup>1</sup> The reefs of Cuba have already been described in a separate chapter.

reef is broken to form the Necker Island Passage, and opposite Virgin Gorda a long narrow belt of corals extends nearly the length of the bank as far as Crab Island, with from twelve to seventeen fathoms of water, forming a regular wall with a belt of deeper water on the inside of from twenty to thirty fathoms, and from two to five miles wide.

Nearly all the islands of the Virgin Bank are skirted on their eastern and southern faces with patches and stretches of coral heads, often forming extensive fringing reefs. This is the case with Virgin Gorda, Tortola, St. John, St. Thomas, Culebra, and the eastern end of Crab Island.

The Virgin Islands lie on the southern edge of a vast bank of soundings extending from Porto Rico, which rises to a height of thirty-seven hundred feet, to the east of Anegada, which has an elevation of not more than thirty feet. The contrast between the soundings off the north and the south face of the bank is quite marked. The southern edge of the bank is not more than seven miles from the cays, while the northern edge extends nearly thirty miles to the north of the islands. The general depth of the bank varies from seven to thirty fathoms. Tortola rises to a height of nearly thirteen hundred feet, and Virgin Gorda to a little less. St. Thomas (Admiralty Charts Nos. 130, 2183, Hydrographic Chart No. 1002) rises to a height of over fifteen hundred feet, and is surrounded by many small islands and cays fringed with corals.

The 500 fathom line forms an elongated bank round Aves or Bird Island, which is the summit of a wide fold at less than one thousand fathoms running nearly north and south from Saba Bank to Bird Island in the direction of Venezuela to about the latitude of Bequia, a bay with a minimum depth of two thousand fathoms running between it and the Windward Islands to the latitude of the southern extremity of Dominica.

Aves Island (Hydrographic Chart No. 40, Admiralty Chart No. 2600) is only ten feet above the level of the sea; it is composed of coral rock skirted all round by a reef except on the west side. The islet rises from a bank of considerable extent, which has not been defined by soundings.

The south shore of Porto Rico (Admiralty Charts Nos. 130, 2600, Hydrographic Chart No. 40) is fringed with reefs about four miles off shore. Mona Island is formed of white perpendicular cliffs about one hundred and seventy-five feet high full of holes, with numbers of grottoes and caves.

A part of the east coast of San Domingo (see General Charts of the West Indies, Hydrographic Charts Nos. 40, 373, Admiralty Chart No.

393) is formed of remarkable limestone cliffs from one hundred and fifty to two hundred feet high. The projecting parts of the island in the vicinity of Aquin Bay consist of very remarkable bold white cliffs and hills resembling chalk, which occur both on the south and on the north coasts. There are coral reefs all along the shores of the island. The 100 fathom line adds but little to the extent of San Domingo, which is separated from Porto Rico by a channel, the greatest depth of which is only two hundred and sixty fathoms. The area of Jamaica would be greatly extended on its southern face by the addition of the plateau formed by the 100 fathom line. Extensive areas of elevated tertiary limestones have been traced along the coasts of Jamaica and of San Domingo.

Between the eastern point of Haiti and Jamaica are the small island of Navassa and the Formigas Bank. Navassa (Hydrographic Chart No. 379, Admiralty Charts Nos. 461, 486) is about three hundred feet high. It rises from a small bank of soundings one third to three quarters of a mile broad. There is a patch of corals on the north end of the island. Formigas Bank (Hydrographic Chart No. 373, Admiralty Chart No. 486) is eight miles in length; the bottom is rocky, with a general depth of from five to seven fathoms. There are narrow veins of sand near the edge, in from nine to eighteen fathoms.

To the southeast of Jamaica are the Morant Cays, a group of small cays seven to ten feet high, forming with the adjacent reefs a crescent bank convex to the southeast of about three by one and a half miles wide. These cays rise from an elongated bank about twelve miles by four within the 100 fathom line, with depths close to it ranging outside of the reef from seven to eighteen fathoms, and thirty to fifty near the edge of the bank. A terrace is said to rise seventy-five feet all round the island, composed of ringing and honeycombed limestone. The Albacross Bank lies to the northeast of the Morant Cays, and is a similar bank; it carries, however, from nineteen to thirty fathoms close to the 100 fathom line, and is marked on the charts as coral sand.

Fringing and detached reefs abound on the south shores of Jamaica. They are especially numerous from Morant Point to the west of Kingston Harbor as far as Portland Point, although they extend, irregularly distributed in favorable localities, to the western extremity of the island off Alligator Point, and from Pedro Bay to St. John's Point (Admiralty Chart No. 255, Hydrographic Charts Nos. 347, 373).

### The Banks of the Caribbean Sea.

Between Jamaica and Honduras and off the Mosquito Bank rise a number of banks, the most easterly of which is the Pedro Bank (Hydrographic Chart No. 373, Admiralty Charts Nos. 450, 486), which rises abruptly from depths of three hundred and fifty to five hundred fathoms. It is irregular in shape, nearly a hundred miles long east and west, quite narrow at the eastern end, not more than nine miles, while at the western end it is fifty-five miles broad. The surface of the bank is level, ranging from nine to fifteen fathoms except near the eastern and the southeastern edge of the bank, where there are many shoals and cays said to consist of white limestone. The bottom on the bank is generally white sand and fragments of corals, but there are patches of coral heads and of coralline algæ. Portland Rock is thirty-two feet high; Plover Rock is two to three feet high. Off the Pedro Cays, about twelve feet high, reefs extend parallel with the 100 fathom line between the cays. Banner Reef is just awash.

Next comes to the westward the Rosalind Bank (Hydrographic Charts Nos. 373, 394). It is pear-shaped, nearly sixty-three miles long, and ranging in width from fifteen to thirty-five miles. The only shallow ground upon it is near the southeast end, where there is a wide coral belt nearly three miles wide, and trending in a northeasterly direction for fourteen miles, with depths upon it varying from four to ten fathoms. On the eastern face there is also a second ledge about thirteen miles north of the first, eight by four miles, on which we find eight fathoms. The general depths on the bank vary little from ten to twenty fathoms; the bottom is coarse coral, coralline sand, and broken shells.

Between Rosalind and Mosquito Bank lies a narrow bank, thirty-seven miles long, not more than ten miles wide, with from thirteen to thirty-five fathoms close to the 100 fathom line. This bank is separated from the Mosquito Bank by a narrow channel with a depth of about one hundred and seventy-five fathoms, and by a somewhat deeper channel from the Rosalind Bank.

To the south of Pedro Bank rises the small, isolated Bajo Nuevo Bank (Hydrographic Chart No. 379, Admiralty Chart No. 391) on which there are two remarkable hook and bow shaped coral reefs rising from the 5 fathom line on the eastern and southern face of the bank. On the bank the soundings vary from six to fifteen fathoms close to the 100 fathom line.

To the south of Rosalind are the smaller banks, the most northerly of



which is the Serranilla Bank. It is somewhat circular in outline, and about twenty-four miles in greatest length. There is a general depth of from five to fifteen fathoms upon it; the bottom on the bank is coarse coralline and coral sand. The bank is steep, the slope increasing rapidly in depth from twenty to one hundred fathoms and more. On the east face of the bank there are three small cays, from which extensive reefs run along the eastern face more or less parallel with the 100 fathom curve from Northeast Breaker to Beacon Cay. Farther south, east of the Mosquito coast, are the Serrana and Roncador Banks to the eastward; half-way between them and the Mosquito Bank comes the line of the Quita Sueño Bank, of Old Providence, of St. Andrews, and of the Courtown and Albuquerque Cays (Admiralty Charts Nos. 379, 1498, Hydrographic Charts Nos. 373, 394).

Both Old Providence (Hydrographic Charts Nos. 395, 1372, Admiralty Chart No. 1334) and St. Andrews (Hydrographic Charts Nos. 391, 945, Admiralty Chart No. 1511) resemble in their general features, but on a smaller scale, some of the volcanic Windward Islands, upon the weather side of which coral reefs flourish. The greatest height of the volcanic peaks of Old Providence is nearly twelve hundred feet; from the central peaks spurs run off terminating in shore peaks of from three to seven hundred feet in height. Besides the main island, there are upon its bank the small island of Santa Catalina and a couple of smaller cays; the bank carries from two to ten fathoms of water. A barrier and fringing reef extends round the island, and a long reef stretches out north. St. Andrews is only three hundred feet high. A few small cays are scattered upon its bank; its northeastern end is flanked by a reef. Upon Courtown Bank (Hydrographic Charts Nos. 391, 945, Admiralty Chart No. 1511) a barrier reef extends across it from the northern end to within half a mile of the southern extremity. The northern and eastern sides of Albuquerque Cays Bank are skirted by a reef.

The eastern face of Quita Sueño Bank (Hydrographic Chart Nos. 394, 945) is flanked by a reef for twenty-five miles, leaving only a small part of the bank clear at each end. The north and east edges of Roncador Bank (Hydrographic Charts Nos. 373, 395, 945, 1374, Admiralty Chart No. 1478) are fringed by a coral reef. The cays upon it are composed of broken coral blocks and coral sand.

The extreme east end of Serrana Bank presents a solid crescent-shaped reef. The space within the horns is crowded with detached shoals, with from five to ten fathoms alongside. The east face of the bank is abrupt, no bottom at one hundred fathoms one quarter of a mile from the 10 fathom line; the south edge of the bank is edged by a reef.



Misteriosa Bank (Hydrographic Chart No. 966) is the western extremity of a submarine chain flanking the northern side of Bartlett Deep to the east of Cape Cruz, of which Cayman Brac and Little and Grand Cayman are the summits, and to the north of which the isolated Pickle Bank rises, upon which are from ten to forty fathoms of water, with a coral sand bottom. Misteriosa Bank is twenty-four miles long, oval in shape, with general depths of from ten to twelve fathoms and a coral bottom. To the south of it are four other small banks with from thirteen to nineteen fathoms of water. Still farther south are the Swan Islands, but the limits of the bank from which they rise have not been determined. The islands are separated by a coral reef; they are flat, sixty feet in height, and bounded by a bold, rocky shore. The soundings upon the bank are from six to thirteen fathoms, increasing rapidly to forty fathoms on the western side of the islands.

Grand Cayman (Hydrographic Charts Nos. 43, 373, 947, Admiralty Chart No. 462) is about forty feet high. At the southwest end a reef runs out half a mile. All but the west side is skirted by a fringing or barrier reef, which is steep to for a distance of a quarter of a mile to a mile. At the east end it forms a solid barrier for the distance of a mile; on the south side there are several small cuts through the reef. At the western end there is a large circular lagoon, Great Sound, with from one to two fathoms, and a passage leading through the reef with from two to two and a half fathoms. Cayman Bank, about ten miles west of Grand Cayman, is a ridge of coral five miles long and half a mile broad, with a depth of from fifteen to twenty fathoms. The edge drops very suddenly to more than one hundred fathoms.

The highest point of Little Cayman (Hydrographic Charts Nos. 43, 373, 947, Admiralty Chart No. 462) is forty-eight feet. The south coast is skirted by a fringing and barrier reef with a wide passage on that side. The north coast is only fringed in part. The 100 fathom line of the bank is generally half a mile from the shore.

Cayman Brac (Hydrographic Charts Nos. 43, 947, Admiralty Chart No. 462) rises to fully one hundred and thirty feet. The north and south coasts are skirted by a broken reef; the 100 fathom line is about half a mile off.

### The Coral Reefs along the North Shore of South America.

Along the north shore of South America (Hydrographic Charts Nos. 40, 964, Admiralty Charts, West India Sheets VIII. to XI., Nos. 394,

395, 396) and the adjacent islands there are many points where coral reefs take a great development. With the exception of the central part of the north coast of Tobago, which rises from a bank of about forty fathoms, the island is fringed with disconnected fringing and barrier reefs, growing most luxuriantly off the northeast end of the island and near the southwest extremity (see Hydrographic Chart No. 354, Admiralty Chart No. 505). The Testigos are surrounded by coral reefs on the eastern face of the bank from which they rise; they are within the broad belt of the 100 fathom line, and carry from twenty-three to thirty-eight fathoms near them. Detached patches of coral reefs extend along the coast from the Gulf of Paria to the Gulf of Cariaco. Margarita Island is flanked by fringing and barrier reefs on the eastern and western coasts, as well as along its whole southern shore. The islands of Cubagua and Coche, which lie between it and the mainland, are likewise skirted on the eastern faces with reefs. Orchila is low and flat, surrounded by reefs on the eastern face. Los Roques are a group of cays rising from a bank of twenty-three miles in length; the greater part of it is covered by coral heads, and its sea face is edged by coral reefs. The Islas de Aves are banks similar to Los Roques. Buen Ayre Island is fringed by a reef on the eastern and northwestern extremities of the island. Little Curaçoa is a coral islet with steep sides. The south side of Curaçoa is bordered by a bank of coral reefs.

From Cape Codera to Cape St. Roman the coast is fringed with long stretches of coral reefs, from Codera to Caracas, and on both sides of Punta Tucacas, east of Zamuro Point. The whole eastern face of the peninsula of Paraguana is fringed by corals. West of the Gulf of Venezuela, with the exception of the fringing reefs along the eastern and northern coasts of the Guajira peninsula, the reefs along the north shore of South America as far as the Mulatas archipelago are limited in extent, occurring on comparatively short stretches of shore interrupted by long reaches of sand beaches (Hydrographic Chart No. 964). The Mulatas archipelago, a number of islets and islands from two to ten miles off shore, extends from Pajaros Island to off Point San Blas, a distance of eighty miles: they are fringed by reefs rising from seven to ten fathoms of water (Hydrographic Chart No. 945). The north shore of the coast of Panama and of Costa Rica is, with that exception, free of exterior reefs. The north side of the interior of Chiriqui Lagoon is thickly studded with detached shoals of corals and coral patches.

### The Coral Reefs and Banks of the West Coast of the Caribbean Sea.<sup>1</sup>

It is to be noted that on the western Florida Bank, as well as on the Yucatan Bank, where the conditions of depth would seem to be most favorable for the growth of corals, in the one case the coral reefs are limited to a few isolated patches like Arenas Cays (Hydrographic Charts Nos. 403, 1233, Admiralty Chart No. 1209), Sisal Reef (Hydrographic Charts Nos. 403, 1235, Admiralty Chart No. 1206), Madagascar Reef (Hydrographic Chart No. 1235), the Triangles (Hydrographic Charts Nos. 403, 1239), Obispo Shoals (Hydrographic Charts Nos. 403, 1239, Admiralty Chart No. 1830), the Arcas Cays (Hydrographic Charts Nos. 403, 1234, Admiralty Chart No. 1829), and the Alacran atoll (Hydrographic Charts Nos. 403, 966, 1234, 1235, 1240, Admiralty Chart No. 1203); while in the other case they form a narrow thread parallel with the course of the Gulf Stream outside of the Florida Keys from north of Key Biscayne to the Tortugas.<sup>2</sup>

Along the west coast of the Gulf of Mexico (see Coast Survey Chart of Gulf of Mexico,  $\frac{1}{250,000}$ ) the corals are wanting, with the exception of a few isolated patches of coral reefs off Vera Cruz coming up from sixteen fathoms of water (Hydrographic Chart No. 967, Admiralty Chart No. 523), which, although noted in the Admiralty West Indian Pilot,

<sup>1</sup> The reefs of Cuba have been described in a separate chapter.

<sup>2</sup> Since my explorations of the Bahamas and Bermudas I am convinced that a more detailed examination is needed to ascertain how far south the older miocene rocks of Florida extend, and to what depth they are covered by the recent coral growths from Key Biscayne to the Tortugas. An exploration of the inner line of keys may show perhaps how far the configuration of the western part of the Florida Bank to the south of Cape Sable may be due to a slight subsidence, and how far this has been concealed by the growth of corals to form the outer reef, and by the deposition upon these older rocks of coral material which has formed the inner line of cays, or how far erosion has been the main factor in shaping the topography of the submerged southern part of Florida and of the adjacent keys. Borings alone can determine this question, owing to the quantity of coral silt which has been deposited upon the mud flats north of the keys, unless we may succeed in finding somewhere among the inner keys an outcrop of the older miocene or perhaps later tertiary rocks.

For an account of the Florida Reefs see L. Agassiz, *Ann. Rep. U. S. Coast Survey*, 1851, *Mem. Mus. Comp. Zool.*, Vol. VII. No. 1, 1880; A. Agassiz, *The Tortugas and Florida Reefs*, *Mem. Am. Acad.*, Vol. XI., 1882; *Three Cruises of the "Blake," Bull. Mus. Comp. Zool.*, Vol. XIV., 1888; and *Coast Survey Charts*, Nos. 166, 167, 168, 169.

had failed to come to the notice of scientific men, have been described by Professor Heilprin.<sup>1</sup> Is their absence due to the limited amount of food brought by the current across the Yucatan Bank, sweeping as it does northward towards the Tortugas and washing the shores of the Florida Keys? The exposure of the coast of British Honduras and of the Yucatan and Mosquito Banks to the influence of the prevailing winds and currents, bringing with them a vast supply of pelagic food, is probably the principal cause for the abundant growth of coral reefs in all favorable localities on the Yucatan and Mosquito Banks and along the British Honduras coast, as well as upon the weather faces of the Serrana and Quita Sueño Banks, the Roncador Reef, Old Providence, St. Andrews, and the Courtown and the Albuquerque Cays.

### The Reefs of the Yucatan Bank.

On the Yucatan Bank (Hydrographic Charts Nos. 1234, 1235), with the exception of the Alacran atoll, the reefs are merely more or less irregularly shaped patches, either surrounding the cays wholly, or reaching out from them, and rising generally from the 3 to 5 fathom line of the bank itself. This is the case with the Arcas Cays and the Triangles (Hydrographic Chart No. 1239). The Obispo Shoals (Hydrographic Charts Nos. 403, 1239, Admiralty Chart No. 1830) and the Sisal Reefs are small irregular patches rising from the 5 or 6 fathom line, while Madagascar Reef is a narrow coral ridge about two miles long, rising from the 7 to 11 fathom line with from one and a half to three fathoms of water upon it. On the extension of the Yucatan Bank plateau to the westward there are also a few patches of reefs off the Barra de Tuxpan and scattered patches off Champoton, but neither these nor the reefs off Vera Cruz, along the inshore edge of the narrow shore platform of the west coast of the Gulf of Mexico, can be considered as reefs of any importance. And indeed they are so unimportant that it was not unnatural for Darwin and Dana to speak of the Mexican coast of the Gulf of Mexico as free from coral reefs.

Along the Yucatan coast to the south of Cape Catoche, Mugerres Harbor (Hydrographic Charts Nos. 402, 1379) is formed by the extension northward of the two fringing reefs which run along the east and west face of the island and pass into the shifting ledges forming the Blancas Lagoon. Corals are reported upon Arrowsmith Bank in twelve fathoms.

Cozumel (Hydrographic Charts Nos. 402, 1380) is flat, not more

<sup>1</sup> Proc. Phil. Acad. Nat. Sci., 1890, p. 303.

than forty to fifty feet in height. It is sandy, with rocky ledges separating the beaches. It is separated from the mainland by deep straits. From the northern end of the island a sand bank extends eleven miles. The west side has deep water close to the shore.

Espiritu Santo and Ascension Bays (Hydrographic Charts Nos. 402, 1380, Admiralty Chart No. 1795) are both protected by narrow reefs extending across the mouth of the harbors. These reefs rise from a depth of from four to six fathoms.

### The Reefs and Banks of British Honduras.

The extensive barrier reef running along the edge of the Honduras Bank reaches from Ambergris Cay to the southern part of the Gulf of Honduras, and forms a broad stretch of reef building patches separated from the coast by a wide channel parallel with it and carrying from ten to twenty fathoms. It resembles, on a much smaller scale, the great Australian barrier reef. The Honduras Reef rises in from six to seven fathoms, and the depth gradually increases as we go westward towards the deeper parts of the channel which form the inland sea separated from the Caribbean by the wide barrier reef composed of numerous detached patches and cays. The reef varies in width from one or one and a half miles at the southern end to sixteen and even twenty miles in the latitude of Gladden Spit, where the channel is divided by an irregular area of banks, cays, and patches of coral heads, with many narrow but deep veins of water between them. These banks are often awash, or rise from six to seven fathoms, and carry from one and a half to three fathoms. One of the channels leading across the bank, the English Cay Channel, carries more than twenty fathoms. The principal passages through the reef carry from four to six fathoms, and rapidly open into the deeper water leading to the main inside channel. Chetumal Bay and the adjoining territory to the north and east seem to indicate the manner in which the cays and barrier reef of Honduras have been formed. The outer sea face, as well as the inner eastern line of the bay, is edged by a reef. If a general subsidence or erosion of the Honduras coast is going on, that part of it must soon be changed into a bank like the banks flanking the present coast, or into something similar to the barrier reef near Point Gladden, the small banks and cays indicating the position of the former low ranges of hills and valleys such as we find on the lowlands to the east of Chetumal Bay. Subsidence or erosion, or both, have formed the outline of the bank; coral reefs have edged it, but there is nothing



to prove that they have formed the land intervening between the existing lines of reefs. The bank limited by the 100 fathom line off British Honduras is narrow compared to the wide bank off the Mosquito coast, the width of which at its northern extremity seems to a certain extent to influence the growth of coral reefs and patches, for they are by no means so flourishing as upon the narrow bank off the Honduras coast.

In addition to the barrier reef off British Honduras there are a number of outlying banks which from their description resemble the smaller of the Bahama Banks. They are the Chinchorro Bank, the Turneffe Islands, and Lighthouse and Glover Reefs, which in a certain degree resemble irregular atolls. They all lie within the 500 fathom line. The greater part of Chinchorro Bank (Hydrographic Charts Nos. 394, 1072, Admiralty Chart No. 1796) is bounded by a reef. There are several openings into the interior which are navigable for small fishing vessels. Lighthouse Reef (Hydrographic Charts Nos. 394, 1120) is bounded by an edging reef; the north end forms a half-moon curve about four miles in diameter; the east side of the reef is steep to. The Turneffe Islands (Hydrographic Charts Nos. 394, 399, 1120) are an extensive cluster of mangrove islands on a bank of coral and sand thirty miles long and from four to nine wide. The cays are all skirted, at a short distance from both the east and west sides, by a barrier reef with an inside channel having over two fathoms. Glover Reef (Hydrographic Charts Nos. 394, 1120), with the exception of a small part of the east side, is fringed by a barrier reef.

### The Mosquito Bank.

Upon the Mosquito Bank (Hydrographic Charts Nos. 394, 945), as upon the Yucatan and Honduras Banks, there are patches and reefs rising upon the surface, not entirely covering it, but scattered, as we find the Arcas, Triangles, Madagascar, Alacran, and other small reefs. They are more numerous upon the Honduras Bank, and get the full benefit of the prevailing winds, and of the sweep of the currents against their sides and over their surface.

There are a great number of irregular patches of coral reefs from Monkey Point north of the Bluefield Lagoon (Hydrographic Charts Nos. 391, 1292, Admiralty Chart No. 1504), within four or five miles from the coast. From Pearl Cay Lagoon to Man-of-War Cay there are a number of small irregularly shaped banks rising from a depth of eight to ten fathoms, the largest of which are the reef patches of the Pearl



Cays and of Tyra Bank. The distance of these reefs from the shore varies from one to fifteen miles.

The small banks from which the Pearl Cays (Hydrographic Chart No. 392, Admiralty Chart No. 1503) rise, which themselves rise from the Mosquito Bank at depths varying from eight to twelve fathoms, are fringed and covered by irregularly shaped reef patches, generally placed on the eastern and northern sides of the banks adjoining the cays or connecting them. Long Reef Bank has a continuous reef on its eastern edge rising from a depth of three to four fathoms.

Great Corn Island (Hydrographic Chart No. 392, Admiralty Chart No. 1476), twenty-nine miles east of the Bluefield River, rises to a height of three hundred and seventy feet. It is probably of volcanic origin. The northern and northeastern shores of the island are protected by an elliptical coral reef forming a great curve at a distance of about a mile from the shore, with numerous heads and patches between the outer reef and the shore. Off the island the bank has a depth of from thirteen to twenty fathoms, the reef rising from a depth of four to six fathoms. Off Little Corn Island there is a similar reef, about a quarter to half a mile from the shore, with two to three fathoms upon it, which skirts the eastern and northern face of the island. Great Corn and Little Corn Islands are seventeen or eighteen miles from the 100 fathom line, the bank sloping seaward very gradually from twenty or thirty fathoms.

Upon the eastern half of the Mosquito Bank, between the Corn Islands and the cluster of reefs and banks to the south of Edinburgh Reef, there are a few isolated patches of coral in from six to ten fathoms. The Mosquito Shoals and the Morrison Cay Bank are the centre of an extensive area of rocky heads and of coral patches south of Edinburgh Channel. Both banks are skirted by an irregular undulating line of reefs. Edinburgh Reef is crescent-shaped, convex to the east, rising from thirteen fathoms, with fourteen fathoms to the westward of the reef (Hydrographic Chart No. 945). North of Edinburgh Reef there is also a cluster of small isolated coral patches and banks, of which the most prominent are the Main Cape Bank, the Half-Moon Reef and Cays, and the Alargate Bank.

The Mosquito Bank extends as a narrow belt varying from four to forty miles along the north shore of Honduras from Patook Point to the Gulf of Honduras. That part of the bank is free of shoals, with the exception of a few patches to the east of Cape Honduras. On the outer edge of the bank, to the eastward of Truxillo, twenty miles from the coast, is Utilla Island. Utilla with the cays and islets at its western end may be con-

sidered as the remnant of the former extension of the north coast of Honduras: it is remarkably clear of coral patches. With the exception of a narrow ridge rising to a height of two hundred and ninety feet at the eastward, the greater part of the island is low and swampy. To the northeast of Utilla are the islands of Roatan and Bonacca, both within the 500 fathom line. Bonacca (Hydrographic Chart No. 396, Admiralty Chart No. 1718) reaches to a height of over twelve hundred feet: it rises from the 5 fathom line upon the eastern end of an elongated bank formed by the 100 fathom line. It is surrounded by clusters of coral bars and cays, which are most abundant on the southeast face of the island. Roatan (Hydrographic Chart No. 394) has an average height of three to five hundred feet: its highest point is nearly eight hundred feet. Its northern shore and that of the eastern islets are all skirted by coral reefs, which sweep round the eastern face of the Roatan Bank and extend in irregular stretches along the southeast coast, where the shore is steep to and the reef disappears, the 100 fathom line running close to the western spit of the island.

The northern part of the Mosquito Bank (the 100 fathom line), which extends nearly one hundred and forty miles to the east of Cape Gracias a Dios, is remarkably free from coral patches and banks. North of Half-Moon Reef there are only insignificant clusters of coral reefs and bars, forming the Caxones and Vivorilla Cays, to the eastward of which there are a small reef and some insignificant cays designated as the Gorda Bank.

The submarine scenery of some parts of the West Indies must be most striking. We have first the long line of steep eastern slopes of the Bahamas, with the valleys separating them, which rise abruptly from a great submarine plain, extending far to the eastward and constituting the floor of the ocean, from a depth of twenty-five hundred fathoms. This plain extends all the way from the Little Bahama Bank to Navidad, a distance of over seven hundred miles. Then follows the long, unbroken submarine slope extending off Porto Rico to the eastward of the Anegada Channel for a distance of over four hundred miles, with the remarkable sink of more than forty-five hundred fathoms in depth north of Porto Rico, one of the greatest depths as yet discovered in any ocean. Then the valley, over twelve thousand feet deep, which extends south of the smaller eastern Bahama banks, gradually lessening in depth toward the Old Bahama Channel and flanked on the southern face by the mountains of San Domingo. And finally, perhaps the most striking topographic feature of the West Indian area, the deep valley skirting the southern shore of

Cuba and extending eastward as far as Misteriosa Bank and into the Gulf of Honduras. This valley reaches to Swan Island ; it is flanked on the south by the gentler slope of the eastern end of Jamaica, and the steeper lines of the western end of that island ; on the northern edge rise the high mountains of the southern coast of Cuba, some of the peaks of which attain a height of over eight thousand feet. This range is continued to the westward of Cape Cruz, and its summits are the Caymans and the shoals of Misteriosa Bank. This valley is known as Bartlett's Deep : it is in many places more than three thousand fathoms in depth. The folds, islands, and banks which give the hydrography of the northern, western, and eastern boundaries of the Caribbean so varied an appearance are in striking contrast to the great sea-sunken plains which form the basin of the Caribbean and of the Gulf of Mexico.

The steep slopes off the southern coast of Cuba due to the elevation of that part of the island, as well as the slopes off the northern and south-western shores of San Domingo, are fully as steep as any of the sea faces of the Bahama banks. If in the one case, where the coral limestones are of limited extent, we find no difficulty in interpreting the origin of this slope, we should not in the other, where the reef limestones merely form a capping to submarine folds which owe their origin to the same causes, attempt to explain its existence in any other manner.

## THE BOTTOM AND ROCKS ON THE BAHAMA BANKS.

### The Bottom.

The nature of the bottom<sup>1</sup> on the banks varies greatly according to the locality. In proximity to the shores of the islands, where the sea is constantly wearing away and disintegrating the æolian rocks, the bottom consists of æolian sand, varying in size according to the character of the adjacent rocks from coarse composite grains to the finest, almost impalpable powder. As we pass into deeper water,<sup>2</sup> away from the influences

<sup>1</sup> Judging from the specimens of the bottom brought up in the dredge, the action of the sea has still considerable force at a depth of nearly fifteen fathoms.

<sup>2</sup> By an unfortunate oversight, the coral ooze which extends only a comparatively short distance from the 100 fathom line along the line of the Florida Reefs and of the coast of Cuba is marked on the colored map of bottoms of the "Three Cruises of the Blake" (Fig. 191) as extending all the way across the Straits of Florida. The central part of the channel of the Gulf Stream should be colored to indicate the extension of the modified Pteropod and Globigerina ooze which covers so great a part of

of the shore sand kept in more or less constant motion, the grains of æolian sand become mixed with fragments of corallines, or of Invertebrates which have lived upon its surface, and where corallines occur in great abundance the flat fragments of their stems often constitute the greater mass of the bottom samples. In the vicinity of coral heads the bottom is composed of æolian sand of different degrees of coarseness, more or less mixed with comminuted fragments of Gorgonians, of Millepores, and of other corals. On such parts of the banks there also occur a very considerable number of Orbitolites and other Foraminifera. Of course, in the proximity of the edging reefs and along their faces fragments of corals, of corallines, of Nullipores, of algæ, and of Invertebrates are an important component of the bottom, the pieces of coral and of corallines often constituting by far the greater mass of the sand.

The beaches are, according to their locality, composed either of very fine coral sand, or of coarser coral sand mixed with corallines and æolian sand, or of large pieces of corals and of other Invertebrates which become cemented together to form a breccia or a conglomerate, so that we may have bottoms composed of particles varying from an impalpable powder to coarse fragments, the components of which can readily be recognized. When a considerable amount of vegetable matter has become mixed with the æolian or coralline sand, the bottom becomes more or less sticky and marl-like, and assumes a grayish color. This is the character of a great part of the bottom on the interior of the Little Bahama Bank; while on the eastern shank of the Great Bahama Bank, and on the smaller banks extending to the eastward of it, the bottom varies greatly according to the local conditions; on the western shank of the Great Bahama Bank a large area off the west coast of Andros is covered with the "white marl" already described.

The principal coralline algæ are species of *Penicillus*, *Acetabularia*, *Halimeda*, and *Udotea*, fragments of which can readily be recognized as components of the bottom specimens wherever they grow in numbers. The decaying of other algæ which compose the flora of the bottom merely adds more or less vegetable matter to its calcareous components; the most abundant of these algæ are species of *Thalassia*, of *Padina*, Cau-

the Gulf of Mexico and the Caribbean Sea, and which also extends over the bottom of the wider passages between the Bahamas. The so called coral ooze is in reality a calcareous mud formed of decomposed corals and corallines, consisting sometimes of very fine particles, which often accumulate along the shore line in sheltered localities, or are carried to considerable distance when held in suspension in the water along the line of currents.

lerpa, Laurencia, Blodgettia, Liguria, and Sargassum. Professor Farlow, who examined the algæ collected, notes as an interesting acquisition from the Bahamas specimens of Caulerpa Webbiana, thus far known only from the Canaries.

Dr. T. W. Richards was kind enough to have some analyses made of bottom specimens selected with regard to their locality on the banks: one specimen off the west shore of Eleuthera from two fathoms of water to represent the bottom on the interior edge of the bank; one on the middle of Salt Cay Bank, half-way between Elbow Cay and Anguila from three fathoms, and one from Exuma Harbor in two fathoms, to represent the bottom on the outer weather edge of the bank; one specimen from Bemini, in two fathoms of water, to represent the bottom on the lee side; and a sample of the white marl off Billy Island, in one and a half fathoms.

The analyses, made by Mr. Donald Churchill, show a variation of the percentage of CaO between 52.38 and 53.43, with the exception of the sample from the west coast of Eleuthera, in which the percentage is only 45.94. This bottom specimen was composed in great part of fragments of Orbitolites, with comparatively little æolian sand, while the other samples varied from the impalpable powder of which the white marl is composed to finer and coarser æolian sand, and to a bottom consisting of fragments of broken shells of Nullipores, corallines, Millepores, corals, Gorgonians, and coarse æolian sand.

The percentage of CaO (average of two analyses) in the specimens of bottom from off the west side of Eleuthera, in two fathoms, is 45.95; from the outer edge of the bank, Exuma Harbor, in two fathoms, 53.38; from the western edge of the bank, North Bemini, in two fathoms, 52.46; half-way across Salt Cay Bank, in three fathoms, 52.39.

A qualitative examination of the white marl showed a very large quantity of  $\text{CaCO}_3$ , a little magnesian oxide, a little ferric oxide, and a very little silica and organic matter. Five grams of the powdered  $\text{CaCO}_3$  bottom lost  $7 \pm$  milligrams upon being washed with 200 c.c. of water. Five grams of the same were digested with 250 c.c. of sea water (from the Bahamas) for a week. Upon washing upon a Gooch crucible with  $200 \pm$  c.c. of water, the  $\text{CaCO}_3$  was found to have lost  $3 \pm$  milligrams. The carbonate was tested qualitatively for sulphuric acid, which was found in small quantities. A saturated solution of gypsum in water at  $20^\circ$  contains about one gram of CaO per litre. Nearly four times as much dissolves in a saturated salt solution. Dr. Richards hopes to make some additional experimental trials with reference to the solubility of gypsum in sea water.



The amount of CaO in sea water from the Bahamas appears to be quite constant, as far as shown by the analyses kindly made for me by Dr. Richards. Water taken from the Tongue of the Ocean, No. 1, or from the central part of the Great Bahama Bank half-way between Green Cay and Exuma Sound, No. 2, or close to Exuma Sound on the eastern edge of the bank from the west side of Flamingo Cay, No. 3, or near the western edge of the bank south of New Providence, No. 4, showed only slight variations in the composition of the sea water. The mean of two measurements of 1,000 c.c. of sea water at 4° were as follows: No. 1 contained 0.585 gram CaO; No. 2, 0.585 gram; No. 3, 0.580 gram; No. 4, 0.588 gram.

The percentage of carbonate of lime present in the bottoms surrounding coral reefs depends in part upon the presence of magnesia or upon the admixture of decomposed vegetable or animal matter, and in part upon the amount of moisture. In districts where the coral reefs occur on shores consisting of stratified or volcanic rocks, the coral sand is also more or less mixed with particles derived from the rocks composing the basement or abutments of the reefs. In volcanic regions the limestones are often greatly modified, either by heat or by their mixture with volcanic ash. The same action was also effective in modifying the reef limestones of the dolomitic region of Tyrol. We also find in volcanic regions a proportionally larger percentage of magnesia.

A number of specimens of coral, of coral rock, and of coral beach sand, from different localities, have been kindly analyzed for me by Prof. F. W. Clark. The greatest variations in the percentage of carbonate of lime are found in the specimens from the volcanic region of the Sandwich Islands, and in the deposits of Sombbrero (West Indies). The coralline bottoms and coral sands from the Sandwich Islands also contained a larger percentage of MgO than any similar bottoms from the Florida Reefs or Bahama Banks. The elevated limestones of Cuba from the Yunque are not dolomitic, and show no trace of magnesia. In the coral sand mixed with volcanic ash the amount of magnesia in one case rose to over eleven per cent.

	CaO	CO <sub>2</sub>	MgO	Moisture.
Piece of <i>Siderastrea</i>	55.16	43.74	0.20	0.54
Very coarse sand, coral fragments, Tortugas	51.52	41.58	2.08	3.18
Finer sand, " " "	52.24	41.46	1.53	3.27
Tortugas, fairly coarse sand	51.24	41.07	2.09	3.57
" finer sand	51.95	41.53	1.44	3.07
Key West, very fine beach coral sand	49.38	40.39	1.93	5.12
Loggerhead Key (stratified shore coral rock)	53.54	43.71	0.78	0.81



		CaO	CO <sub>2</sub>	MgO	Moisture
Salt Key Bank, oolite		53.54	43.87	0.71	1.13
Sombrero deposits	(P <sub>2</sub> O <sub>5</sub> 39.12)	51.15	3.47	trace	7.55
Coralline Bottom, Tortugas		46.45	43.40	5.15	2.73
Senote limestone near Merida		54.87	43.89	0.64	0.11
Diamond Head, Sandwich Islands, coral rock		44.82	40.81	5.32	1.86
Kohuku Bluff, " " " "		51.09	43.64 <sup>1</sup>	2.50	0.79"
Kohuku Beach, " " sand		49.34	44.33	4.60	0.40
Honolulu Reef, coral rock		46.52	40.59	2.45	2.75
Prison Knob, Honolulu (elevated coral)		52.67	42.81	0.42	1.24
Waiauea (hard ringing limestone)		50.69	43.96	2.98	0.46
Modern chalk, Oahu					
(SiO <sub>2</sub> 33.25, Al <sub>2</sub> O <sub>3</sub> 19.13, Fe <sub>2</sub> O <sub>3</sub> 10.71)	}	11.37	11.09	—	9.84
Lava soil bedded with coral near Pearl River					
(SiO <sub>2</sub> 46.22, Al <sub>2</sub> O <sub>3</sub> 19.16, Fe <sub>2</sub> O <sub>3</sub> 12.94)	}	1.72	0.00	2.24	16.84
Same from Diamond Head					
(SiO <sub>2</sub> 32.83, Al <sub>2</sub> O <sub>3</sub> 12.12, Fe <sub>2</sub> O <sub>3</sub> 11.52)	}	12.20	11.41	11.70	5.30

### The Rocks of the Bahamas.

The characteristics of the æolian rocks of the Bahamas have been noted in the description of the different islands of the group. They vary from a fine-grained compact oolite to a coarse-grained rock composed either of rounded or of small angular fragments, according to the condition of the fragments of the sand from which the æolian hills were composed. These rocks vary according to the conditions to which they have been subjected, and which often greatly alter their aspect. They become more or less hardened or covered with a hard ringing crust when exposed to the action of the sea or of the rains, or to the decomposing effects of the acids generated by the decomposition of vegetable matter. Sufficient time has not elapsed since my return from the Bahamas and Bermudas to report more in detail regarding the composition of the rocks and bottoms of these regions. But I hope to return to this subject, and present the results of the examination of the rocks now making by Professor Wolff.

### SOME RECENT VIEWS ON THE THEORY OF THE FORMATION OF CORAL REEFS.

It may not be out of place to pass rapidly in review some of the points relating to the theory of the formation of coral reefs which have been brought forward in the discussion of the subject in the new issue of Dar-

<sup>1</sup> Trace of organic matter.

win's Coral Reefs, edited by Professor Bonney ;<sup>1</sup> in the interesting review by Dana of the whole subject in the *American Journal of Science* (1885, Vol. XXX. pp. 89, 169) and in the new edition of Dana's *Corals and Coral Islands* (New York, 1890), with the Appendix on the Sandwich Islands ;<sup>2</sup> and in the essay by Dr. Langenbeck<sup>3</sup> on the Theories of the Origin of Coral Islands and Coral Reefs.

In this chapter I shall bring together and discuss only such questions as have naturally been suggested by my explorations of the Bahamas, the Florida Reefs, the Cuban elevated reefs, and the reefs of the Windward Islands. Minor points will be found referred to in other places of this report, and in the articles of the Duke of Argyll and of Professor Huxley, as well as in the more recent communications in "*Nature*" and elsewhere by Murray, J. C. and G. C. Ross, Irvine, Harrison and Browne, Bourne, Guppy, Hickson, Captain Wharton, Studer, Ortmann, Dall, Balfour, H. O. Forbes, Supan, Perrier, Heilprin, Captain Moore, Sluiter, Walther, Lendenfeld, Kent,<sup>4</sup> and many others, as well as the Presidential Addresses of Sir Archibald Geikie and of Professor James Geikie at Edinburgh in 1883 and 1892.

While it is undoubtedly true, as Professor Bonney states, that many of Darwin's critics may have perused his book with overmuch haste, yet he must admit that when explorers examined the coral reefs of districts which apparently had nothing in common with coral reefs formed in areas of subsidence, it was most natural that they should seek some other

<sup>1</sup> *The Structure and Distribution of Coral Reefs*, by Charles Darwin. Third Edition. With an Appendix by Prof. T. G. Bonney. London, 1889.

<sup>2</sup> See also A. Agassiz, *Bull. Mus. Comp. Zool.*, Vol. XVII. No. 3, p. 121, 1889, "*The Coral Reefs of the Hawaiian Islands.*"

<sup>3</sup> *Die Theorien über die Entstehung der Koralleninseln und Korallenriffe und ihre Bedeutung für Geophysische Fragen.* Von Dr. R. Langenbeck. Leipzig, 1890.

<sup>4</sup> Kent, in his *Monograph of the Great Barrier Reef of Australia*, has added comparatively little to our knowledge of the theory of its formation. "He looks for the conditions of subsidence which have made the formation of the Great Barrier Reef possible in the former undoubted connection of Australia with Tasmania and New Guinea; and if that is not satisfactory, he is quite ready to call upon a still greater subsidence of the Australian continent as shown by its presumed connection with New Zealand. If, as is probable, and as Mr. Kent suggests, the Great Barrier Reef existed as a narrow fringing reef in the late Tertiary, there has elapsed more than ample time also for its transformation into the Great Barrier Reef of to-day from other causes than those called upon by him. The Great Barrier Reef has entirely obliterated the Australian coast shelf itself, and it may have found upon that all the conditions of depth for the vigorous growth, both vertically and laterally, of the original insignificant fringing reef of the northeastern coast of Australia." — *Nation*, No. 1463, July, 1893.

explanation of their formation than that suggested by Darwin, and thus call upon factors which he had relegated to a subordinate value. The want of unanimity among the opponents of the Darwinian theory of the formation of coral reefs has, it seems to me, nothing to do with the question whether Darwin is right or not. It merely shows that there are many points of difference which are more or less apparent in the various districts examined by recent writers on coral reefs, and that perhaps the problem of their formation is not quite so simple as the upholders of the subsidence theory would have us believe.

The disadvantages of a discussion of the theory of the formation of coral reefs by one who has not faced the problem in the field are apparent in the essay of Dr. R. Langenbeck. It undoubtedly is a most useful summary, and, while the writer has endeavored to retain an impartial attitude, his views naturally do not carry much weight, based as they are only upon cartographic knowledge, and consisting in great part of special pleading in favor of the theory of subsidence. His essay does not seem to me to have the importance assigned to it by Huxley in his discussion of the article on "A Conspiracy of Silence,"<sup>1</sup> by the Duke of Argyll. This and similar essays can give us only interesting speculations, of little value except when tested by observations.

Dr. Langenbeck has been unfortunate in the exposition which he gives of the Florida and West India reefs. His description of the reefs of Cuba and of the Bahamas differs greatly from that given by the writers from whom he has taken his data. But he is the first writer on the theory of reefs who, while of the opinion that the theory of Darwin is the only one which can explain the formation of atolls in the extensive tracts of the Pacific where atolls are so numerous, yet acknowledges that there are extensive districts in which the formation of reefs has not been influenced by subsidence. This was the principal point at issue between the earlier opponents of the theory of subsidence. Subsequent investigations in the Pacific and elsewhere have shown most clearly that the reef

<sup>1</sup> I am unable to understand the statement of Professor Heilprin (The Bermudas, p. 21) regarding the authority of "A Conspiracy of Silence." It is most extraordinary if, as is stated by Heilprin, the "younger school of geologists" have pinned their faith to the statements of its author and have chosen for their leader one who has never made any original observations on the subject of coral reefs. The great majority of recent observers of coral reefs have stated that the generally accepted theory of their formation was not applicable to the particular district they examined. Each has endeavored to give an explanation of the facts, and they have not "pinned their faith to any standard bearer," or to any theory, or to any leader, or to any creed.

problem is a complicated one, and that we have not heard the last word on the subject. As far as the formation of many of the Pacific atolls is concerned, either they have been formed by subsidence, and owe their origin to causes different from those which in the West Indian and other districts have formed atolls upon comparatively shallow bases, or they have been formed by the same causes to which the latter owe their shape independently of subsidence, or we may further assume that atolls can be formed in regions of subsidence independently of the subsidence, as well as in regions where no subsidence has been observed.

Darwin, and after him Langenbeck, as well as other writers on the West Indian coral reefs, speak of the "extensive banks of sediment which have been heaped up along the whole north coast of Cuba by sea currents." I find it difficult to account for the origin of such a belief. That a great part of the food supply of the animals living upon the banks has been brought to them by sea currents is self-evident, but the mass of sediment so conveyed is insignificant as compared with the accretions to the banks due to the accumulation and cementing of the carcasses of the Invertebrates living upon them. There is, it is true, a long stretch of sand reefs and islands all the way north from Key Biscayne to beyond Cape Hatteras, but these have nothing in common with the limestone barriers forming the basement of the Florida, Cuban, and other West Indian (Mexican and Caribbean) coral reefs.

I am surprised that Professors Dana and Bonney should both speak so strongly against the statement of Murray, that there are known numerous submarine elevations, mountains rising from the general level of the ocean bed, which may serve as the foundation of a coral reef. Surely, we know as yet too little of the hydrography of the Pacific to sweep away the statement with the suggestion "that such a thing may occasionally occur."

Professor Dana, who has made such a thorough examination of the Feejee Islands, considers the conditions of the coral reefs of the islands of the group as admirably illustrating Darwin's theory of the formation of barrier reefs and of atolls. In spite of the general aspect of a sunken continent made by the Feejee Archipelago, it is no proof that the reefs owe their present condition to subsidence. It seems to me that the illustrations he brings up merely emphasize the great diversity of substructure of banks and islets and of large islands in the Feejee Islands upon which fringing, barrier reefs or atolls might be found; just as in the Windward Islands and the Virgin Island Bank we find all possible conditions of elevation, from islets at the sea level, or sunken banks,

to islands with peaks of over four thousand feet, at the base of and around which barrier and fringing reefs may be formed, or crescent and horseshoe-shaped reefs might grow.

The somewhat insignificant coral reefs of the Eastern Pacific, as far as known, occur upon volcanic islands. Those of the Sandwich Islands and the unimportant coral patches of the Galapagos grow upon a basement of volcanic origin, while the only atoll of the Eastern Pacific — Clipperton Rock, off the Mexican coast — holds to its trachytic nucleus much the same relation which some of the reefs of the Caribbean hold to the volcanic peak they surround.<sup>1</sup>

<sup>1</sup> The absence of extensive coral reefs off the west coast of Tropical America is probably due to several causes, the most important of which as regards the mainland is the large amount of mud brought down the shore mountain slopes during the rainy season. Similar conditions exist along the shores of the Galapagos, where corals are formed merely in patches, as along the coast of the mainland, in addition to whatever influences detrimental to their growth may be due to volcanic action. (See Dana, *Corals and Coral Islands*; Pourtales, *Am. Journ. Sci.*, 1875, Vol. X. p. 282; and A. Agassiz, *Bull. Mus. Comp. Zool.*, Vol. XXIII. No. 1, 1892.)

It is interesting to add here some notes relating to Clipperton Rock, which prove the existence of an atoll on the borders of the Panamic region, seven hundred miles southwest of Acapulco. I am indebted to Professor George Davidson of the U. S. Coast Survey for a sketch of Clipperton Island by Carl C. Jensen, made in 1893, as well as for a specimen of the rocky nucleus. The latter was examined by Professor J. Eliot Wolff, who reports it to be "a volcanic rock with typical trachytic structure, of the same general class as the rock from the hospital quarry at Panama."

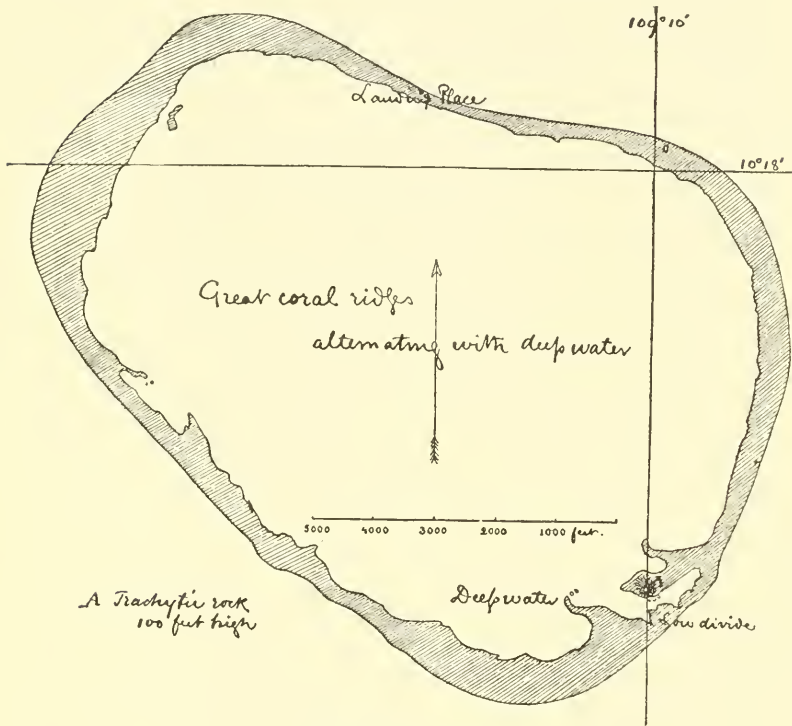
The description drawn up from the notes and chart he kindly sent me agrees in the main with the one given by Lieutenant Griswold, and published by W. H. Pease in the *Proceedings of the California Academy of Natural Sciences* (1865, p. 199).

Clipperton Rock was seen from the northeast by Sir Edward Belcher in 1839, and described by him as a coral lagoon island with two entrances, both on the weather side. It was, according to W. H. Pease, visited in 1861 by Lieutenant Griswold, who landed upon the island, and says in his *Journal*: "It is girdled by a broad barrier of coral about fifteen feet above the level of the ocean. There is no entrance to the lagoon. The water inside is fresh and potable; it is slightly brackish. . . . The rock is a ragged pile of volcanic formation, on the south end of the island. . . . The highest pinnacle of the rock is about 120 feet, and it covers about two acres. It stands on the edge of the lagoon, or rather within it. . . . The lagoon is a quiet fresh-water pond about two miles long and one broad, with a long spit of mud running out into the middle of it, but elsewhere of a light green color which seemed to indicate a considerable depth. [Light green does not in coral districts indicate a considerable depth; on the contrary, it may indicate a depth of six to seven fathoms at most. — A. Agassiz.] The shores are abrupt. . . . I did not find the least sign of vegetable life upon the island."

Mr. Jensen says there are no trees on the island. It is surrounded by a reef of coral over which the sea continually breaks. Outside of this unbroken reef the bottom deepens rapidly, and vessels must anchor in not less than fifty fathoms of



In the West Indies, beginning with the Bermudas, is the mass upon which the so called atoll has been formed, — an island rising out of a



CLIPPERTON ISLAND.

water. Best boat landing on the north side of the island. On the chart "Deep water" is marked in the atoll to the westward of the trachytic rock near the southern face of the island. "Great coral ridges alternating with deep water" is the legend of the central part of the lagoon. A few insignificant islets are mapped in the lagoon near its northwest face. The atoll is pear shaped, its axis running southeast to northwest; its greatest breadth is over one and a half miles, and its length more than two.

On Mr. Jensen's chart the island is represented as a narrow ring of coral rock surrounding the lagoon. This dry belt is nowhere more than seven hundred feet wide, except to the southwest of the trachytic rock, where there is a short spit extending into the lagoon, the point of which is perhaps fifteen hundred feet from the outer edge of the island. At several points the coral rock belt is not more than two hundred feet wide, and along the greater part of the southwest coast it varies between four and five hundred feet in width. A similar narrow stretch of perhaps three quarters of a mile extends along the north side. This connects the two broader shore tracts of the eastern and northwestern parts of the island.



depth of two thousand fathoms. Has that atoll been formed by its subsidence? If so, we should have a great oceanic depression in the vicinity of the Bermudas. We know nothing of the hydrography which does not indicate that the mass underlying the coral reefs rises abruptly from the ocean floor; as to what height it originally rose, we have no data.

Examine next the submarine range of the Windward Islands, with its varied depths, of which the islands beginning at the Grenadines and ending with Saba are the exposed summits. Note the gradual widening of the bank as we go north, and finally reach its widest part, upon which are situated islands of recent limestone which have risen from a comparatively shallow bank, while farther south the recent limestones are limited to the Basse Terre of Guadeloupe, or to the fringing reefs of Martinique, St. Vincent, Dominica, and the Grenadines.

Isolated from the other islands in the line of the submerged chain, we have Sombrero, a recent limestone island, while Bird Island and the Barbados are the summits of two isolated banks, both of different heights. Surely, we have in that submarine chain a sufficient variety in the depths of the bank to account for the irregular position of the limestone deposits now going on, and a sufficient number of points which have reached by elevation the depth necessary and favorable for the growth of coral reefs. Some of the localities have been elevated above that level, as Barbuda, Antigua, Anguilla, Barbados, and Basse Terre, while at other points — as Martinique, St. Vincent, and the Grenadines — the fringing and barrier reefs are still in full activity.

The Saba Bank, the bank upon which have risen Antigua and Barbuda, and the bank within which are found Anguilla and St. Bartholomew, are extensive shoals compared with the dry land of the island. Upon the Mosquito Bank also numerous coral reefs are found, rising from varying depths, similar to those of the Yucatan Bank.

Between the Mosquito Bank and Jamaica are a number of banks within the 100 fathom line, some of which, like those surrounding St. Andrews or Old Providence and the Morant Cays, have come to the surface; while others again, like the Serrana, Rosalind, Serranilla, and Pedro Banks, have not reached a depth at which corals can begin to grow, or have sunk below it. This gives in such a limited district as the Caribbean Sea proper a sufficient number of instances of submarine banks reaching all possible levels, some of which are in localities where corals have developed to form fringing or barrier reefs, others where the corals are reduced to irregular patches, and others where, the conditions for their growth not being favorable, the banks are

free from corals, their surface being more or less disturbed by the action of the trades, thus choking off the growth of any delicate marine forms. This leaves out of notice the great number of banks of the Bahamas, that of the west side of Florida, of the banks extending from Cape Sable to the Tortugas, of the banks to the south of Cienfuegos, extending from the Isle of Pines to Cape Cruz, and, finally, the bank to the eastward of Porto Rico upon which rise the Virgin Islands. Corals flourish upon all these banks; they form fringing and barrier reefs, and in a few instances atolls, such as Alacran, the Hogsty Reef, and the atolls of the Mosquito Bank, which I have not, however, examined myself. We cannot assume that corals are only to grow where the base has reached the proper depth during a period of subsidence, while they are denied that privilege where the right depth has been reached in a period of elevation.

There is no greater distance between the elevated reef of the south shore of Cuba and the fringing reef of parts of San Domingo and Jamaica than there is between those of the north shore of Cuba and the barrier reef of the Florida Keys. The time at which the reefs of different areas in the West Indies were elevated need not necessarily have been synchronous, nor should we expect this in a district where volcanic agencies have been at work on so great a scale. This would go far to account for the great diversity of coral reefs we meet with in the West Indian district within comparatively short distances.

In fact, what I have seen so far in my explorations of the coral reefs of the West Indies would show that wherever coral reefs occur, and of whatever shape, they form only a comparatively thin growth upon the underlying base, and are not of great thickness. In Florida they rest upon the limestones which form the basis of the great peninsula. On the Yucatan Bank they are underlain by a marine limestone. In Cuba they abut upon the Tertiary limestones of its shores. Along Honduras, the Mosquito Coast, and the north shore of South America, they grow upon extensive banks or shoals, parts of the shore plateau of the adjoining continent, where they find the proper depth.

Similarly, along the shores of the Greater Antilles they are found rising from depths suitable to their growth upon the shore plateaus, as well as upon the peaks and summits of submarine ranges which either come to the surface or approach it. Round the Windward Islands they thrive upon the banks which surround them. But in neither case have they played any important part in the building up of the banks or of the shore plateaus upon which they occur. Upon the Bahamas

and Bermudas the corals now growing form a thin veneer upon the æolian rock ledges, the remnants of the vanishing land formed from a coral reef which must have flourished at the beginning of the present epoch.

But Dana himself has even more distinctly and emphatically than any other writer stated the objections to the general application of the theory of subsidence for the formation of barrier reefs. In "Corals and Coral Islands," he says (p. 347): "The amount of subsidence determines in some cases the distance of barrier reefs from shore; but it by no means accounts for the difference in their extent in different parts of a single group of islands. Indeed, if this cause be considered alone, every grade of extent, from no subsidence to the largest amount, might in many instances be proved as having occurred on a single island. Of far greater importance, as has appeared, is the volcanic character of the land." The remainder of the paragraph quoted above, describing the relations of volcanoes and of zoöphytes as the land-making agents of the Pacific, seems hardly consistent with the subsidence theory.

Many of the observations made on elevated coral reefs do not distinguish between the elevation of a thin mantle on a slope to a certain height, and the thickness of the reef itself. Furthermore, in such a difficult problem only the observations of trained observers can be of value. Many of the data, and even many of those quoted by Dana, are the records of merely casual observations of individuals with little or no experience in this field.

The island of Lafu, one of the Loyalty group, the geology of which has been described by the Rev. W. B. Clarke,<sup>1</sup> is one of the few elevated coral islands of which we may feel certain that the highest points, two hundred and fifty feet above the sea, are covered by an elevated coral reef, the elevation being connected in that case, not with volcanic action, but with the elevation of the adjoining island of New Caledonia. Subsequent investigations of the Loyalty group by Balansa<sup>2</sup> and Chambeyron have shown that other islands of the group are covered by elevated coral reefs. Ouvéa attains a height of a little over fifty feet, with an interior lagoon; and while Lafu shows three terraces, the neighboring island of Mari has five distinct terraces, attaining a height of one hundred meters, with a nucleus of trachyte.

From the interesting accounts given by Captain Chambeyron, in his "Note relative à la Nouvelle Calédonie,"<sup>3</sup> we can see how much remains

<sup>1</sup> Proc. Geol. Soc. London, 1846, p. 61.

<sup>2</sup> Bull. de la Soc. de Géog., Vol. V. p. 521, 1873.

<sup>3</sup> Ibid., Vol. IX. p. 566, 1875.

to be learned regarding the barrier and fringing reefs and the great lagoon of New Caledonia. We need additional information regarding the thickness of coral reefs to complete the evidence of their great thickness as due to subsidence. The thickness of such elevated reefs as may without question be considered true coral reefs is not as great as it has been supposed by various observers (see Dana, p. 274). The more recent examinations of the thickness of the elevated coral reefs in the Solomon Islands by Guppy, in the Barbados by Harrison and Jukes-Browne, in Cuba by R. T. Hill<sup>1</sup> and myself, all tend to prove that elevated coral reefs nowhere have attained a thickness of more than two hundred to two hundred and fifty feet. This shows that a thickness of two thousand feet observed in Cuba by Professor O. W. Crosby, of twelve hundred feet near Matanzas reported by myself, and of two thousand feet of the white limestones of Jamaica, are not the thickness of coral reef builders, but of marine limestones of very different character; and that the true reef-building corals have merely built a sheet of moderate thickness upon these older limestones, which have been mistaken for limestones built up by reef-building corals. The reefs of the weather side of the island of Oahu form quite a thin sheet overlying the volcanic rocks.

Similar conclusions have been reached by the recent examinations of dolomitic limestones, which are of great thickness (over two thousand feet), and were until recently unhesitatingly considered as coral reef limestones. They have now been shown by Miss Ogilvie and by Rothpletz to be marine limestones, while the true coral reef builders formed deposits of very moderate thickness, a coral growth, as it were, not thicker than one hundred and fifty feet. It is very evident that, in the examination of the coral deposits of former geological periods, great care must be taken to distinguish between coral growths forming a comparatively thin veneer and marine limestones of great thickness in which corals are occasionally found.

The discussion of Langenbeck on the coral reefs of former geological periods is subject to revision after a re-examination of the localities, in accordance with the recent explorations of the dolomite region, and of our more accurate knowledge of the distribution and thickness of the West Indian reefs. The fossil reefs of the Jura were among the earliest known. Attention was first called to them by Thurman (1859) and Gressly (1860), but they have not been examined recently with reference to the points now in dispute regarding the formation of coral reefs.<sup>2</sup>

<sup>1</sup> Amer. Journ. of Science, September, 1894.

<sup>2</sup> See Zschokke, F. Die Korallenriffe im Schweizerischen Jura. Aarau, 1890.

In no case has Thurman or Gressly observed ancient coral reefs of very great thickness (one hundred meters) at all to be compared with the thickness claimed for modern reefs by Darwin and Dana (two thousand feet).

The evidence brought forward from the existence of recent limestone beds of great thickness in Java and in the Philippines and other localities, to which reference has been made as proof of the great thickness of coral reefs, must be taken as subject to modification. One of the most interesting of the fossil coral reefs is the atoll of Benguet, in the island of Luzon, mentioned by Drasche.<sup>1</sup> It has walls of five to six hundred feet above the valley, which itself is about four thousand feet above the sea level. The surface of the limestone is filled with red earth, often several feet in thickness. The limestones, unlike coral reefs, are distinctly stratified. The corals and other fossils belong to genera which still occur in the Indian Ocean of to-day, so that the limestones of the atoll of Benguet and of Northern Luzon belong to the most recent formations of the island, and from their description differ greatly from the coral reef limestones of to-day.

Richthofen's<sup>2</sup> theory that the Schlern Dolomite was a coral reef was adopted in the main by Mojsisovics,<sup>3</sup> and their views, although opposed by Gümbel,<sup>4</sup> have received general recognition until comparatively recently. Miss M. M. Ogilvie, in the *Geological Magazine* for January and February, 1894, perhaps first called attention to the peculiar occurrence of the so called coral reefs in the Dolomites.

In the interesting account of coral in the Dolomites of South Tyrol by Miss Ogilvie an entirely new view is taken of the reef-like appearance assumed by the dolomitic massifs, which she traces to the movement of the rocks in Tertiary times, and to the variation in the character of contemporaneous Triassic deposits, her conclusions being that, "as far as positive evidence goes, the coral rocks of South Tyrol in the Wengen and Cassian period are not the majestic massifs of Dolomite, but much less obtrusive lenticular masses of limestone," the "Cipit limestones."<sup>5</sup> Miss Ogilvie has shown in the diagrams I.-IV., on Plate II., (a) that coralline "Cipit limestone" and coral Dolomite form com-

<sup>1</sup> Drasche, R. von. *Fragmente zu einer Geologie der Insel Luzon*. Wien, 1878.

<sup>2</sup> Geognost. Beschreib. der Umgegend von Predazzo in Süd-Tirol. 1860.

<sup>3</sup> Die Dolomit Riffe v. Süd-Tirol u. Venetien. 1879.

<sup>4</sup> Sitzb. d. Akad. d. Wiss. München. 1873.

<sup>5</sup> See Plate II., February number of the *Geological Magazine* for 1894, and the figure on page 53 of the same number.



paratively small thicknesses of interbedded rock, and not the main body of the mountain masses ; (b) that corals began to grow in Wengen time on a submarine volcanic ridge on the northern edge of a great area of subsidence, and travelled northward and inward in Cassian time ; (c) that extensive banks of coral were found in scattered localities during the Raibl period of shallower water and Dolomite deposit. And the final paragraph of the paper contains the following statement : " My special survey in a part of the district seems to me to justify, without doubt, the position of those authorities who have contended that the immense thicknesses of ' Schlern Dolomite ' rock were an ordinary marine deposit, and not ' coral reefs.' "

In the descriptions of the Dolomitic region by Richthofen and by Mojsisovics, " the thick dolomitic massifs of Schlern Sella," etc., were regarded as dolomitic reefs, though they have originated as marine deposits, and not coral reefs. " The Wengen and Cassian coral reefs of Gröden, Ennenberg, and Upper Fassa have remained, with but rare exceptions, limestone. The actual thickness attained by the individual lenticular coral reefs or the coral banks is in no case very great, seldom more than one hundred and fifty feet, and usually much less."

Finally, Rothpletz,<sup>1</sup> after a thorough examination of the field, comes to the following conclusion : —

" Wir können also die zu Beginn dieses Capitels aufgeworfene Frage, ob der Schlerndolomit eine Korallenriffbildung sei, jetzt mit einem entschiedenen Nein beantworten, so bald man die Frage in dieser Allgemeinheit noch stellen will. Die bisher besprochenen reinen Kalk- und Dolomitmassen der oberen Trias sind allerdings vorwiegend organogenen Ursprungs und verdanken ihre Massigkeit dem Wachstum von Thieren und Pflanzen in wenig tiefen oder sogar seichten Meerestheilen. Aber Korallen haben dabei durchaus keine besonders hervorragende Rolle gespielt, wenn schon sie stellenweise wahre Rasen bildeten und wohl auch zu kleinen echten Riffbildungen geführt haben mögen. An den meisten Orten hingegen treten sie anderen Thieren und den Pflanzen gegenüber so sehr in den Hintergrund, dass wir sie nur als einen untergeordneten Bestandtheil der Fauna bezeichnen können. Viel bedeutsamer werden sie statt dessen mancherorts in den Cassianer und Raibler Schichten. Es ist bezeichnend genug, dass der Schlerndolomit des Schlermes selbst nur sehr wenige Spuren von Korallen aufweist, während die wenig mächtigen Dolomitplatten der Raibler Schichten auf dem Schlernplateau, also unmittelbar im Hängenden des letzteren, geradezu

<sup>1</sup> Ein Geologischer Querschnitt durch die Ost-Alpen, p. 67. Stuttgart, 1894.

aus Korallen zusammengesetzt sind, so dass sie als wahre Korallenrasen bezeichnet werden müssen. Die Dolomitisierung des Gesteines hat dieselben keineswegs verwischt und unkenntlich gemacht. Wir können aber auch da nicht von eigentlichen Riffen, sondern nur von Rasen sprechen, den ihre Höhenentwicklung ist nur eine sehr geringe. . . .

“Soll nun aber für den Schlerndolomit wenigstens der Name ‘Riff’ beibehalten worden, wofür neuerdings auch Suess<sup>1</sup> sich ausgesprochen hat? . . . Das wird von der Definition abhängen, die man dem Worte geben will. Versteht man darunter steil und hoch vom Meeresboden aufragende Massen, etwa wie die Koralleninseln des Stillen Oceans, dann passt der Name für die Ost Alpen ganz und gar nicht. Begreift man darunter aber auch die submarinen, organogenen Plateaus des Golfes von Mexico und die Dacia-Bank der Tiefsee, dann liesse sich der Name ‘Dolomitriff,’ wohl auch fernerhin auf die Alpen anwenden, doch musste vorher eine entschiedene Umprägung dieses Gliedes unseres Wortschatzes vorgenommen werden.”

I do not mean in any way to deny the possibility of the formation of marine limestones by subsidence. But I must also call attention again to their formation at great depths by accretion, and to the fact that true coral reef builders have as yet been shown positively to attain only a moderate thickness.

The difference in the steepness of the slope of the Florida Charts off the Florida Reef and that of the steep submarine slope of the Eastern Bahamas off the edging reef, I believe, can be explained on the supposition that the Eastern Bahamas are a series of more or less disconnected summits, with slopes no steeper than those of the volcanic Windward Islands to the south of them. In the one case, the Florida reef is the belt edging a gentle slope in depths of from four to fifteen or sixteen fathoms. In the other, the edging reef of the Bahamas is a similar belt limited to the same depths on the brink of a steep slope. The structure of the coral reef and its bathymetrical range are in neither case affected by the nature of the underlying rocks, or by the angle of their slopes beyond the bathymetrical range of the corals.

Professor Dana himself, when speaking of the limited thickness of the elevated coral reefs of the Solomon Islands described by Dr. Guppy, says (Corals and Coral Reefs, p. 291): “Such observations have great interest, but they only prove that in coral reef seas corals will grow over any basis of rock that may offer when the water is right in depth and other

<sup>1</sup> Antlitz der Erde, Bd. II. p. 331, 1888.

circumstances favor. . . . They are not evidence against the subsidence theory, but simply local examples under the general principle just stated." It seems to me that in the first part of the passage quoted Professor Dana grants the principal factors which have been advanced in opposition to the universal application of the Darwinian theory of coral reefs. The objections to it from this and that quarter have little by little circumscribed the area within which it is applicable. It is not applicable to the West Indian and Caribbean Sea reefs. It does not hold true for the Bahamas or Bermudas any more than for Cuba or Florida. It does not hold for the Sandwich Islands or the Galapagos. It has not been accepted by Semper, by Rein, by Murray, by Bourne, by Guppy, nor by others who have in recent years examined many of the localities which are considered by Dana and Darwin as typical of the subsidence theory.

Perhaps one of the best sections of coral reef rock and limestone is that given by Julien,<sup>1</sup> as far back as 1867, in his description of the geology of Sombrero, W. I. The beds examined by him vary in thickness between thirty-three and sixty-six feet. From his description of the key as an atoll, I imagine it must resemble either Hogsty Reef or some of the smaller pseudo-atoll banks of the Bahamas, only it has been elevated about forty feet. Some of the beds are separated by a thin layer of limestone differing from the preceding.

The formation of hills of nearly four hundred feet in height, in a district showing a probable subsidence of at least two hundred and fifty or three hundred feet, shows very plainly how a limestone bed of that thickness may have been formed from a coral reef flourishing at the time when the beach which bordered the æolian islands was at least two hundred feet higher than the present beaches on the Bahamas. It is not probable that during the period of subsidence the reef kept up its growth with sufficient vigor to add to the material which helped to build the æolian hills now disappearing before the action of the sea. On the contrary, we can only imagine such high æolian hills as those of the Bahamas to have been formed in a period of rest, during which the great beach of the then existing reef constantly supplied fresh material to be changed by the surf and the winds into sand for the heaping up of sand dunes. They could not be formed in a district of subsidence unless the subsidence was slower than the rate of growth of the corals, which is not the case in the Bahamas, as the reefs of to-day, even when they come to the sur-

<sup>1</sup> On the Geology of the Key of Sombrero, W. I., by Alexis A. Julien, *Ann. Lyc. of Nat. Hist. of New York*, Vol. VIII. p. 251.

face, are not the sources from which the material for the great dunes of the Bahama Islands is derived.

How far formations similar to those of the Bahamas occur in districts where there are coral limestones of considerable thickness, and where their original structure can no longer be detected, is an open question. There are groups of islands in the coral reef districts of the Pacific which from their resemblance to the Bahamas it is interesting to compare with them. I refer specially to the Maldives, to the Louisiade Archipelago, and to the Keeling Islands. The explanation which Darwin gives of the disseverment of the larger Maldivé atolls, that the smaller ones have been formed during subsidence by a process of which traces can be detected in the northern part of the group, does not seem natural. The sunken coral reefs of which we have surveys show no such method of formation, while, on the contrary, banks of which the depth is somewhat varied, forming more or less irregular knobs or folds, could give a suitable substructure for the growth of irregularly shaped atollons such as constitute the Maldivé Archipelago and the Mallos Mahdoo atolls. We may compare with these atolls the circular reefs of the Mosquito and Yucatan Banks, which have formed wherever the conditions of depth and currents and configuration of the bottom have been favorable, in the midst of other irregularly shaped patches of corals, many of which are of considerable extent. The similarity of the eastern and western ranges of land of the Great Bahama Bank to the distribution of the atollons on the opposite sides of the Maldivé atoll group has been suggested by Professor Dana; but while this is marked, the structure of the islands in one case and of the atolls in the other is, as I have shown for the Bahamas, very different. The similarity of the Bahamas to the Louisiade Archipelago suggested by Dana does not seem to me so well established. In the latter we have high islands of older rocks, and upon the edge of the plateau surrounding them barrier reefs have developed; while in the former we have a fringe of islands of æolian origin edged by a barrier reef.

In the account which Dana gives of the breaking up of the Maldivé group into an archipelago of atolls, and of the Louisiade Archipelago, there is nothing clearer than that subsidence has taken place so as to bury all the high land of the archipelago, but the connection between the subsidence and the growth of the atolls and barrier reefs of these archipelagos is not so apparent. That there are submerged banks, such as the Great Chagos Bank, the Macclesfield and the Tizard Banks described by Captains Wharton and Aldrich, seems to me to show the impossibility of the synchronism of the rate of subsidence of a district

with the rate of growth of its coral reefs. Off the west and northwest coasts of Australia, to the north of Houtman's Abrolhos there are extensive coral reefs surrounding adjoining islands and skirting the shores of the Australian continent. From their appearance on the Hydrographic Charts they bear a certain resemblance to the reefs of Yucatan, Honduras, and the Mosquito Coast, extending as they do out on the comparatively shallow continental platform of that part of Australia.

One cannot fail to be struck with the general resemblance of the Keeling atoll described by Darwin, and of which a chart is given by Guppy in his article on the Cocos-Keeling Islands in the *Scottish Geographical Magazine* for June, 1889, to some of the smaller of the Bahama Banks. The filling up of the interior lagoon from the sand driven in through the narrow and shallow passages between the islands edging the bank, and perhaps also from the disintegration of the islands themselves, will in time produce, as suggested by Guppy, a bank, the interior of which will be entirely choked by sand, while corals will continue to thrive in the northern part of the lagoon in numerous patches, much as they do in the Bahamas, where their growth is not affected by the movement of the bottom, or by the sand held in suspension during heavy weather.

The sunken banks of the Bahamas, the Navidad, Silver, and Mouchoir Banks, remind us of the Great Chagos Bank, although there is no evidence to show that these banks owe their peculiar shape to the growth of corals due to subsidence, but merely that by subsidence what was once a flourishing coral reef edging a marine bank is now by subsidence left at a depth at which corals can no longer thrive, while they still flourish and grow on the edges and interior floors where the subsidence has not been great enough to sink that part of the bank to as great a depth, or in other localities where little or no subsidence has taken place.

The Bahamas can hardly be said to have lagoons in the sense in which we understand an atoll lagoon. With the exception of the lagoon of Hogsty Reef, the lagoons of the Bahamas are either huge sinks or sloping faces extending from the inner side of islands on the edge of the banks towards their open side, or they are small salt sinks like the lakes of New Providence, the lagoon of Watling, and the many salt ponds existing on Long Island, on Inagua, on Grand Turk Island, and others.

On the Great Bahama Bank the only sinks which are enclosed by higher banks are the extensive depression between New Providence and Eleuthera, with a greatest depth of six fathoms near Eleuthera, and the two to the west of the line of cays between Highborn Cay and Harvey Cay, with a maximum depth of four and a quarter fathoms. On the



Little Bahama Bank are two depressions, one to the north of Little Abaco, the other to the south, with a maximum depth of three and three quarters fathoms. These sinks are depressions in the general topography of the banks, and have no definite relation to the islands and to their edging reefs. The slopes to the west of Cat Island and of the open banks, such as the Crooked Island, the Caicos, and Turk's Island Banks, are very gradual until they reach the edging coral reef in from four to six fathoms, whence the pitch is more rapid and quite sudden from the 20 fathom line to the 100 fathom line. There is nothing on the Bahamas which exactly corresponds to the sounds of the Bermudas, such as Harrington Sound, Castle Harbor, and the Great Sound, the land which once may have fringed the greater sinks on the Bahamas having disappeared by erosion, only flats of a more moderate depth indicating its former existence.

As is well known, a depth of fifty to sixty fathoms has been assigned to some of the lagoons in the Maldives, of twenty-five fathoms at Keeling Island by Darwin, and of twenty fathoms at Matilda atoll. In the composite atolls, like those of the Mahlos Mahdoo atoll, and other of the Maldives, the depth in the smaller atollons is stated by Darwin to be not more than five to seven fathoms, while the depth of the greater lagoon — of the bank itself — is sometimes as much as two hundred and fifty to three hundred feet. May this not be due to causes similar to those which in the Bermudas have formed the sounds, attaining a depth of nearly sixteen fathoms, and in the Bahamas have formed deep channels between adjacent but more distant banks and islands? Are the atollons perhaps, only on a larger scale, such formations as the Serpulæ reefs occurring off the south shore of the Bermudas,<sup>1</sup> which are purely mechanical structures, and in the formation of which the Serpulæ or corals in the case of the Maldives and Mahlos Mahdoo atoll have had but a limited share?

The islands and islets of the two archipelagos named may be only the summits of a bank of very irregular outline, upon which corals have established themselves. Subsidence has taken place there to a very considerable extent, as stated by Darwin, but the position of the corals and the shape and distribution of the reefs have only been affected in a limited manner by it and are not due to it any more than in such localities as the Bermudas and the Bahamas. The depth between Horsburgh atoll and the southern end of the Mahlos Mahdoo atoll (over two hundred fathoms) is no more surprising than the great depth of the channel be-

<sup>1</sup> A. Agassiz, *Am. Journ. of Science*, June, 1894.

tween the *Miraporvos* Bank and Crooked Island Bank, or in the passage between the outlying banks to the south of the Bermudas.

Granting that the deep channels have been formed by subsidence, it does not follow that the present distribution and existence of the corals on the summits of the banks is due to the same cause.

In fact, we may apply, only inverting the argument, the reasoning of Professor Dana against a theory of elevation as explaining the origin of barriers and atolls : "Coral reefs may, like sea beaches, be made at different heights on the slopes of rising land ; but this is not the result of elevation, which is implied ; for barrier reefs and atolls are the objects whose origin is to be accounted for." Substitute subsidence for rising land, and remembering that reef corals will not grow at a greater depth than twenty fathoms, we eliminate subsidence as a factor, unless we are prepared to accept and imagine a synchronism between the growth of corals and subsidence in a great number of the districts in which they flourish, — of which we have no proof.



# INDEX.

THE following references to the Charts of the U. S. Hydrographic Office (H. C. No. . . .) and to those of the Hydrographical Office of the Admiralty (A. C. No. . . .), give the numbers of the charts relating to the Bahamas, to Cuba, to the Gulf of Mexico, to the West Indies, and to the Caribbean, which have been consulted during the preparation of this Report on the Cruise of the Steam Yacht "Wild Duck." In the Introduction, see page 15, reference has been made to the general charts covering the region explored by the "Wild Duck" published by the British Admiralty and the U. S. Hydrographic Bureau, as well as by the U. S. Coast and Geodetic Survey. These charts are included in this Index, and the localities referred to them of which there are no separate charts.

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## EXPLANATION OF THE PLATES.

## PLATE I.

Chart of the Bahamas, prepared by the Hydrographic Bureau, Commander C. D. Sigsbee, U. S. N., Hydrographer.

## PLATE II.

- Fig. 1. Hogsty Reef, from a sketch sent by Captain W. J. Wharton, R. N., Hydrographer to the Admiralty. A few soundings made by the "Wild Duck" have been added outside the 100 fathom line.
- Fig. 2. Longitudinal section across Hogsty Reef, from the 120 fathom point on the east to the 140 fathom line on the west.
- Fig. 3. Transverse section from the 120 fathom line on the north to the 206 fathom point on the south.
- Fig. 4. The same as Figure 2, on a larger scale, to show the slope of the lagoon from the eastern ledge to the main entrance of the lagoon.
- Fig. 5. Section across the lagoon near the eastern ledge.
- Fig. 6. Section across the lagoon to the west of South Cay somewhat to the east of the entrance.
- Fig. 7. Section across the lagoon at its widest part, near the middle.

## PLATE III.

Charts of the vicinity of three prominent Blue Holes, from sketches kindly sent by Captain Wharton, R. N., Hydrographer to the Admiralty.

- Fig. 1. Thirty-eight and seventeen fathom holes. These holes are south of the eastern extremity of Thunder Channel, Tongue of the Ocean.
- Fig. 2. Thirteen fathom hole.
- Fig. 3. Twenty-four fathom hole.

The holes in Figures 2 and 3 are immediately north of Blue Hole Point.

## PLATE IV.

- Fig. 1. Section across the Straits of Florida, from Jupiter Inlet to Memory Rock, across the Little Bahama Bank to off Pensacola Cay.
- Fig. 2. Section from Hillsboro Inlet across the Straits of Florida and the Northwest Providence Channel, to Mores Island and across the bank to off Great Abaco.

- Fig. 3. Section from Fowey Rocks, across the Straits of Florida to Gun Cay, the Great Bahama Bank, the Northeast Providence Channel, to Royal Island and off Eleuthera.
- Fig. 4. Section from Orange Cay across the Great Bahama Bank to Andros Island, the Tongue of the Ocean, Nassau, to off Eleuthera.
- Fig. 5. Section across Salt Cay Bank, the Santaren Channel, the Hurricane Flats to Andros, the Tongue of the Ocean to Green Cay, to Harvey Cay across Exuma Sound to off Cat Island.
- Fig. 6. Section across Salt Cay Bank, the Santaren Channel, the Hurricane Flats, the Tongue of the Ocean to Great Exuma, Exuma Sound, Conception Island, and off Watling's Island.
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- Fig. 1. Section from Buenavista Bay (Cuba) across the Old Bahama Channel.
- Fig. 2. Section from the Coast of Cuba across Romano and Paredon Cays and the Old Bahama Channel to Guinehos Cays.
- Fig. 3. Section from the Coast of Cuba across Romano Cay and the Old Bahama Channel to a point somewhat west of Lobos Cay.
- Fig. 4. Section from the Coast of Cuba to Romano Cay across the Old Bahama Channel to Diamond Point.
- Fig. 5. Section from the Coast of Cuba to Cay Sabinal across the Old Bahama Channel to Blue Hole Point.
- Fig. 6. Section from Pan de Sama to off Cay San Domingo and to Ragged Island.
- Fig. 7. From Point Azules (Cape Maysi) to Inagua.
- Fig. 8. From Cape Isabella (Haiti) to Turk's Islands.
- Fig. 9. From Cape Cabron (Haiti) to Navidad Bank.
- Fig. 10. From Castle Island (Acklin Island) to Hogsty Reef to Inagua.
- Fig. 11. From Cay Verde to South Cay (Mira por vos Bank) to Castle Island (Crooked Island Bank).
- Fig. 12. From Cay Verde (Long Island) to Bird Rock (Crooked Island Bank).
- Fig. 13. From Cay Sal Bank across the Nicholas Channel to Bahia de Cadiz (Cuba).
- Fig. 14. Section from Coffin's Patches across the Straits of Florida to Elbow Cay (Cay Sal Bank).
- Fig. 15. Section across Cay Sal Bank from Elbow Cay to Anguila.
- Fig. 16. Section across the Straits of Florida from Key West (Sand Key) to Havana.

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- Fig. 2. Section off the southeast spit of Fortune Island (Crooked Island Bank) to 300 fathoms.
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- Fig. 4. Section off No Name Cay to 500 fathoms (south of Green Turtle Cay, Little Bahama Bank).
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## PLATE VIII.

Contour Chart of the Caribbean Sea, prepared by the Hydrographic Bureau in 1885, Commander J. R. Bartlett, U. S. N., Hydrographer for the "Three Cruises of the Blake."

## PLATE IX.

The Smaller Banks from Navidad to Watling Island, to illustrate the transition from such islands as Great Inagua, Watling Island, Rum Cay, Mariguana to Crooked Island and Caicos Banks, to such banks as Turk's Islands and Mira por vos Banks, and finally to the three easternmost sunken Banks of Mouchoir, Silver, and Navidad. From Hydrographic Chart No. 946, Admiralty Chart No. 393.

- Fig. 1. Crooked Island Bank.  
 Fig. 2. Caicos Bank.  
 Fig. 3. Great and Little Inagua Islands.  
 Fig. 4. Mariguana Island.  
 Fig. 5. Turk's Islands Bank.  
 Fig. 6. The northern part of the same bank, to show the mass of heads left to the south of Grand Turk Island by the disintegration of the former Grand Turk land. Reduced from Hydrographic Chart No. 1000.  
 Fig. 7. Mouchoir Bank.  
 Fig. 8. Silver Bank.  
 Fig. 9. Mira por vos Bank.  
 Fig. 10. Navidad Bank.  
 Fig. 11. Conception Island and Rum Cay.  
 Fig. 12. Watling Island.

## PLATE X.

From Hydrographic Charts Nos. 26<sup>b</sup>, 26<sup>c</sup>, 944, and 946.

- Fig. 1. Little Bahama Bank. See Admiralty Chart No. 399, for a larger scale.  
 Fig. 2. The northern extremity of the eastern part of Great Bahama Bank, including New Providence to Eleuthera, and the Middle Ground to the southeast of New Providence.

- Fig. 3. A part of the same Bank from New Providence as far as the Douglas Channel, on a larger scale than Fig. 2.
- Fig. 4. The west face of Crooked Island Bank, from the southern spit of Fortune Island to Bird Rock, showing the disintegration of the lowlands of the banks, and the formation of lagoons and the line of soundings taken by the "Wild Duck" to 300 fathoms. Reduced from Admiralty Chart No. 393.
- Fig. 5. The southwestern edge of Exuma Sound, showing the formation of the outer chains of cays from Great Exuma Island on the narrow shore plateau bounded by the 100 fathom line, and the disintegration of the inner face of Great and Little Exuma Islands to form the low cays, flats, shallows, and sand bores on the adjoining parts of the bank. The dotted line indicates the line of soundings taken by the "Wild Duck" to 266 fathoms. Reduced from Hydrographic Chart No. 26°.
- Fig. 6. The southern extremity of Long Island, showing the transition of the western face of the central part of the island into the bank flats, and the breaking up of the west face of the southern promontory of Long Island by the Salina Flats. Reduced from Hydrographic Chart No. 26°.

## PLATE XI.

- Fig. 1. The Cays and Bores to the eastward of Exuma Island. Soundings in feet. Hydrographic Chart No. 340.
- Fig. 2. Clarence Harbor and the adjoining Cays and Bores. Soundings in feet. Hydrographic Chart No. 2093.
- Fig. 3. The northeastern extremity of Andros with the Joulter Cays and Bores. Soundings in fathoms. Hydrographic Chart No. 1496.
- Fig. 4. Washerwoman's Cut Channel (south of Andros), leading from the Tongue of the Ocean to Hurricane Hole. Soundings in fathoms. Hydrographic Chart No. 2077.
- Fig. 5. The Ragged Islands Cays on the southeastern extremity of the Great Bahama Bank. Soundings in feet. Hydrographic Charts Nos. 341, 1399.
- Fig. 6. Russell and Royal Islands, on the northeastern extremity of the Great Bahama Bank. Soundings in fathoms. Hydrographic Chart No. 2098.
- Fig. 7. Green Turtle Cay, with the adjoining cays on the eastern face of Little Bahama Bank. Soundings in feet. Hydrographic Chart No. 398.

## PLATE XII.

- Fig. 1. The Channels between the Sand Bores leading from the southern extremity of the Tongue of the Ocean on to the Bank. Hydrographic Chart No. 2009.
- Fig. 2. The Beminis, Gun Cay, and the adjoining flats to the eastward. Hydrographic Chart No. 1496.
- Fig. 3. The three Bights dividing the Island of Andros to the south of Wide Opening. Hydrographic Chart No. 1496.
- Fig. 4. Great Stirrup Cay and the Sand Bores to the west of Great Harbor, on the northeastern point of the western shank of Great Bahama Bank. Hydrographic Chart No. 1432.

The soundings in Figures 1-3 are in fathoms, those of Figure 4 in feet.



## PLATE XIII.

- Fig. 1. North Shore of Cuba from Port Padre to Cay Guajaba, showing the harbors of Nuevitas to Padre, and the mode of separation of the shore cays from the main island.
- Fig. 2. The Cays of the North Shore of Cuba, from Cay Guajaba to Cay Coco.
- Fig. 3. The Cays of the North Shore of Cuba from Buenavista Bay to Lanzasillo Cay, and the Boca de Cañete.
- Fig. 4. The Western Cays of the North Shore of Cuba, from Boca de Cañete, Sagua la Grande to Cardenas Bay.
- Fig. 5. The Cays of the Western Extremity of Cuba and the Colorado Reefs, from Inez de Soto Cay as far as Cape San Antonio. All figures from Hydrographic Chart No. 947.

## PLATE XIV.

- Fig. 1. The Cays of the Coast off Sagua la Grande.
- Fig. 2. Cay Confitas, one of the outer cays on the edge of the plateau of the north shore of Cuba. Admiralty Chart No. 2384.
- Fig. 3. The Harbor of Baracoa, one of the most easterly indentations of the north shore of Cuba. Admiralty Chart No. 435.
- Fig. 4. Alfred Sound, the reef harbor at the northwestern extremity of Great Inagua. Admiralty Chart No. 2022.
- Fig. 5. Port Guantanamo, a flask-shaped harbor on the south shore of Cuba between Cape Maysi and Cape Cruz. Hydrographic Chart No. 377<sup>b</sup>.
- Fig. 6. Port Banes, one of the flask-shaped harbors of the north shore of Cuba, Admiralty Chart No. 426.
- Fig. 7. Port Padre, a characteristic flask-shaped harbor of the north shore of Cuba, showing the separation of a part of the shore land by the narrow passage connecting Padre and Malagueta forming a cay still closely joined to the main island. Admiralty Chart No. 419.

## PLATE XV.

Æolian Rocks at the foot of the Queen's Staircase, Nassau.

## PLATE XVI.

Distant View of Nassau across the Grantstown Plain

## PLATE XVII.

Eroded Mangrove Flat off a beach on the south side of New Providence.

## PLATE XVIII.

North Shore of New Providence near the Tea House, Nassau.

## PLATE XIX.

Inland Vegetation. Pine Barren with Palmettos near Lake Cunningham, New Providence.

## PLATE XX.

Vegetation along the North Shore Road, New Providence, near Nassau.

## PLATE XXI.

Green Turtle Cay, with the adjoining Cays to the northward, Little Bahama Bank.

## PLATE XXII.

Beach on Green Cay, east side of the Tongue of the Ocean.

## PLATE XXIII.

Great Lagoon, Watling Island.

## PLATE XXIV.

Part of North Shore of Great Isaac. On the northwest corner of the west shank of the Great Bahama Bank.

## PLATE XXV.

General View of a part of the South Shore of Great Isaac.

## PLATE XXVI.

A Nearer View of a part of the South Shore of Great Isaac. Æolian rocks greatly honeycombed.

## PLATE XXVII.

A Stretch of the Western Coast of Eleuthera, between the Glass Window and Governor's Harbor.

## PLATE XXVIII.

A Part of the West Side of Eleuthera, immediately south of the Glass Window.

## PLATE XXIX.

The Cliffs of Eastern Face of the same part of Eleuthera, looking north towards Harbor Island, from a point south of the Glass Window.

## PLATE XXX.

Honeycombed Æolian Rocks on the West Face of Eleuthera near the Glass Window.

## PLATE XXXI.

Elbow Cay, the Double Headed Shot Cays, and Salt Cay Bank.

## PLATE XXXII.

Booby Island on the eastern edge of Douglas Channel, Great Bahama Bank.

## PLATE XXXIII.

Morgan's Bluff, near the northern extremity of the eastern face of Andros Island.

## PLATE XXXIV.

Stretch along the western shore of Cat Island.

## PLATE XXXV.

Flamingo Cay, on the eastern edge of the southeastern part of the Great Bahama Bank.

## PLATE XXXVI.

The Cays of Conch Cut, on the western side of Exuma Sound, Great Bahama Bank.

## PLATE XXXVII.

A Part of the Western Shore of Crooked Island north of the French Wells (Crooked Island Bank).

## PLATE XXXVIII.

A part of the West Shore of Fortune Island, south of the settlement (Crooked Island Bank).

## PLATE XXXIX.

Memory Rock, on the west side of the Little Bahama Bank.

## PLATE XL.

Great Abaco Light and the Hole in the Wall, southern extremity of the Little Bahama Bank.

## PLATE XLI.

The "Yunque," west of Baracoa, Cuba, seen from the harbor.

## PLATE XLII.

Yumuri Cañon, entrance to the Yumuri Valley, seen from the east shore of the harbor of Matanzas.

## PLATE XLIII.

A part of the Yumuri Valley.

## PLATE XLIV.

Elevated Reef (First Terrace) running along the north shore of Cuba between Matanzas and Havana, near the Canasi River. Cliffs composed of older limestones.

## PLATE XLV.

Entrance to Havana Harbor. Soboruco Reef in foreground.

## PLATE XLVI.

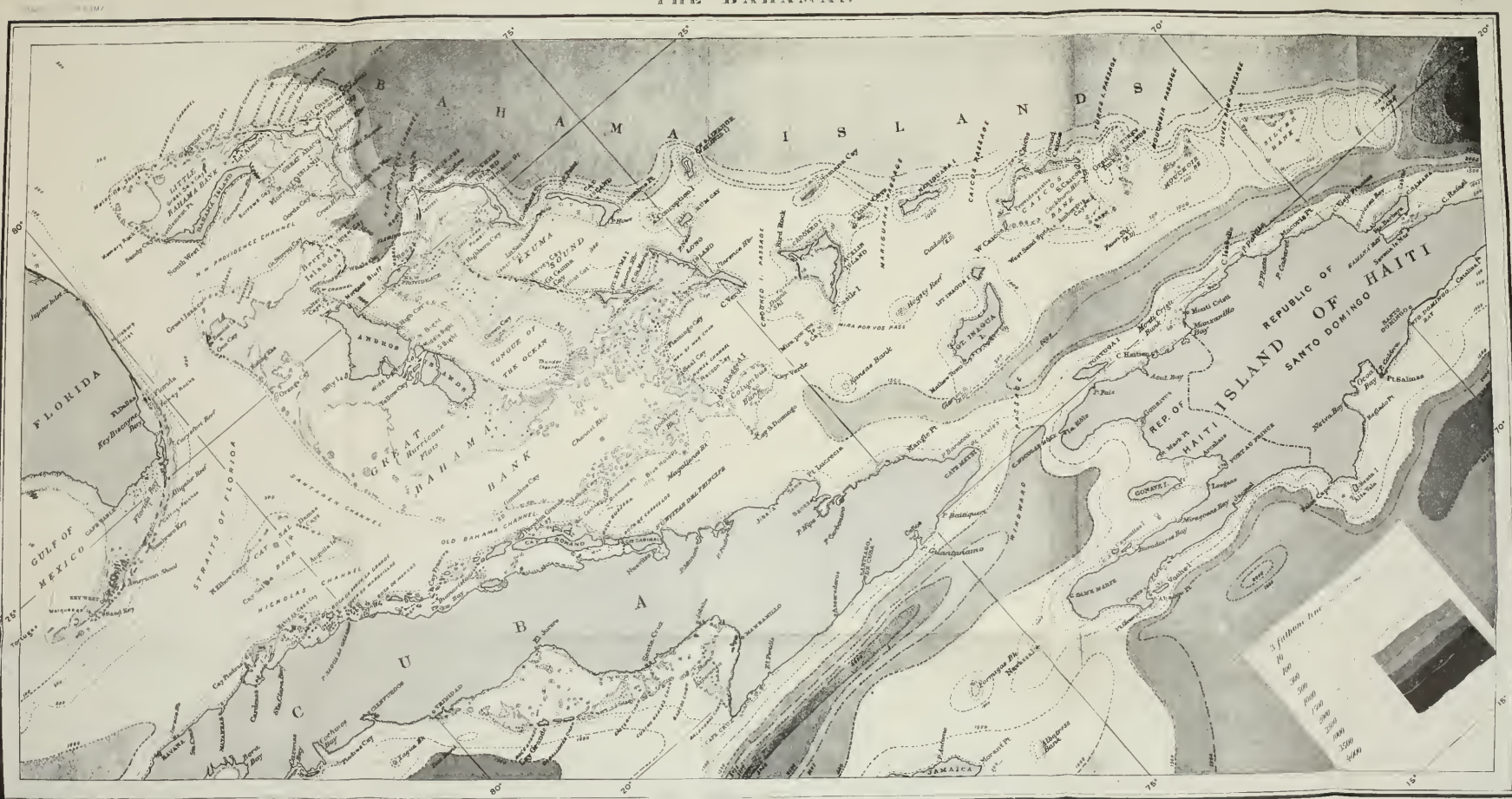
Patch of Soboruco near Morro Castle, Havana.

## PLATE XLVII.

Morro Castle, entrance of Santiago de Cuba. Patch of Soboruco at right-hand corner.

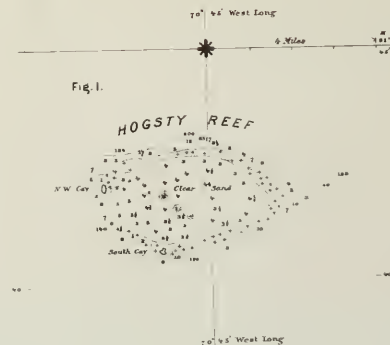
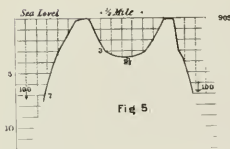
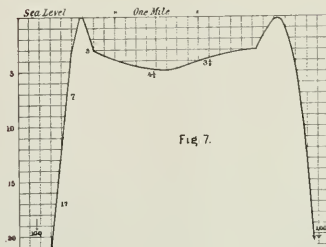
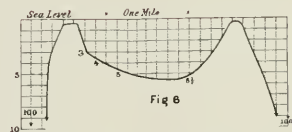
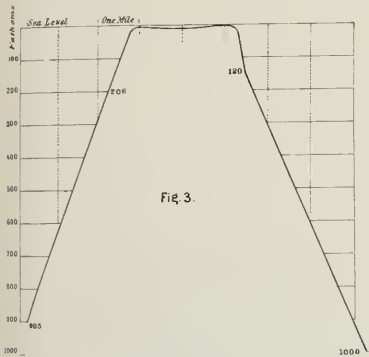
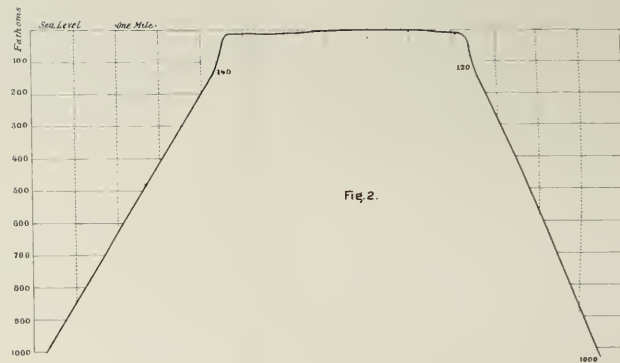
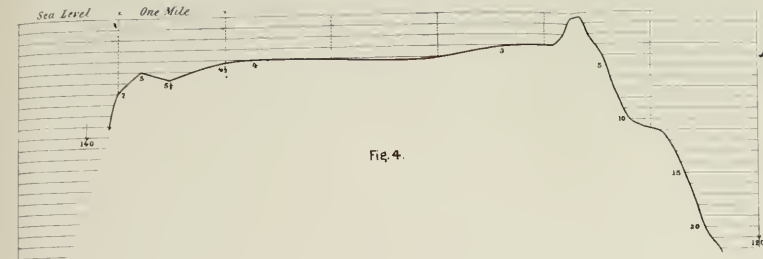


# THE BAHAMAS









Depths in fathoms

B. Mason, J. L. Boston.



2

A detailed map of a rectangular field with dimensions 76°30' by 29'. The map shows a grid of points with numerical values and labels. A central point is labeled 'Blue 13' and 'Hole'. A star symbol is in the top left, and a cross symbol is in the bottom right. The map is oriented with North at the top.

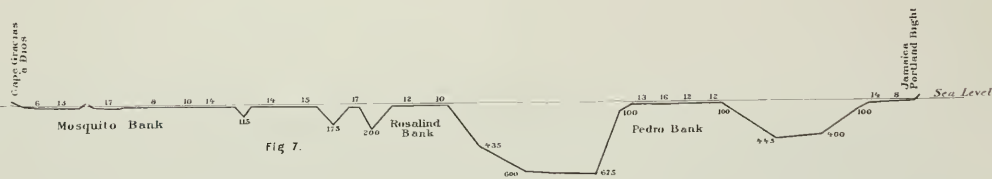
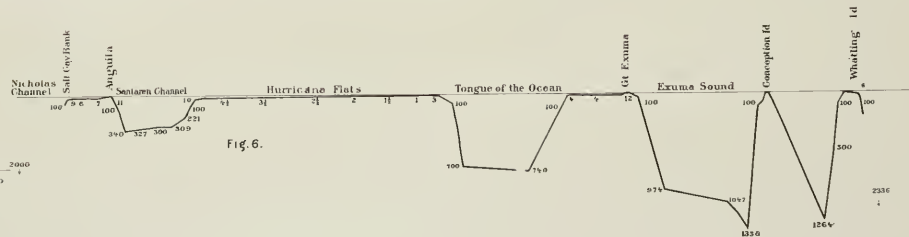
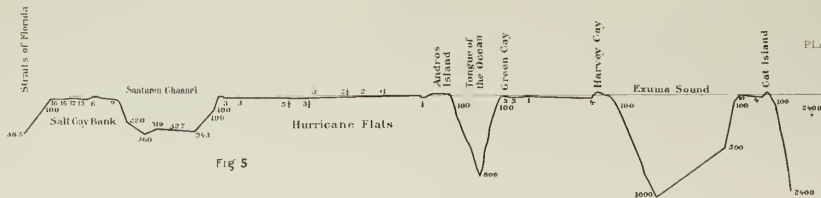
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2	6				6			5 1/2
3	6	Blue 13	5 1/2	4	Hole	6		6
4	6		5 1/2	4	5	d. wd		6
5	6		6		5 1/2			6
6	6 1/2		6		5 1/2		5 1/2	5 1/2
7					5 1/2		5 1/2	5 1/2
8					5 1/2	4		5 1/2

25

A detailed map of the 'Hole' area, showing a rectangular plot with dimensions 30' by 28'. The map includes a central star-shaped feature labeled 'Hole' and various numbered points (1-6) and measurements (5 1/2, 5 3/4, 6). The map is oriented with North at the top. The plot is bounded by a dashed line, and the area outside is labeled 'N. 22' 15' W.' and '30' West Long.'

*Soundings in Fathoms.*

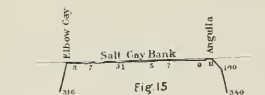
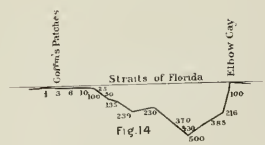
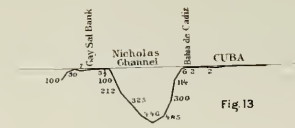
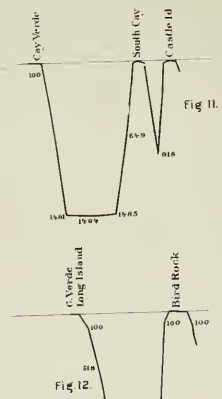
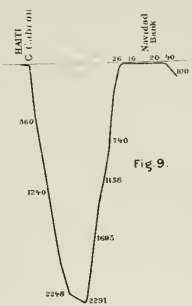
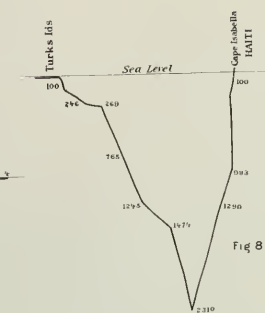
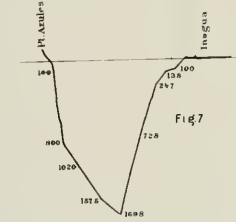
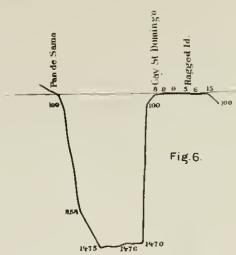
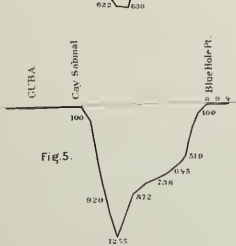
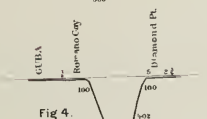
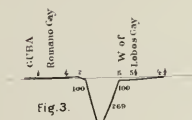
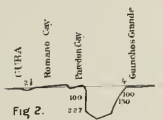
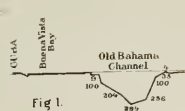




Horizontal Scale, 1.25' 60 nautical miles  
Vertical Scale, 1"=1000 fathoms  
Depths in fathoms.

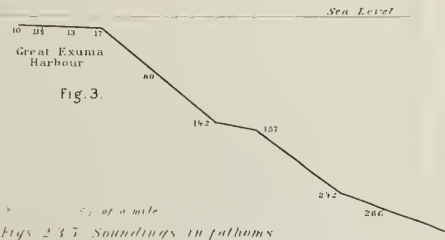
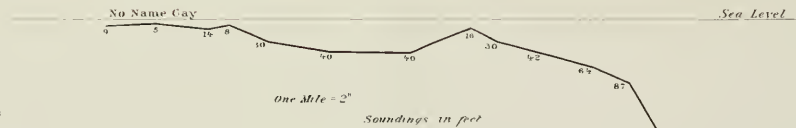
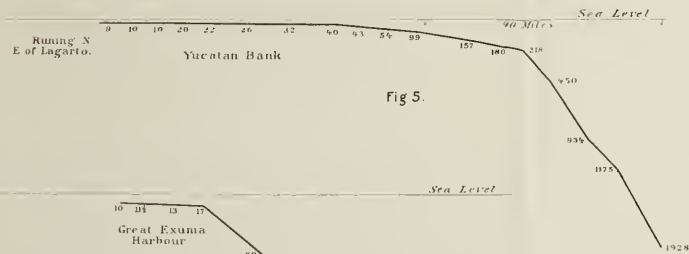
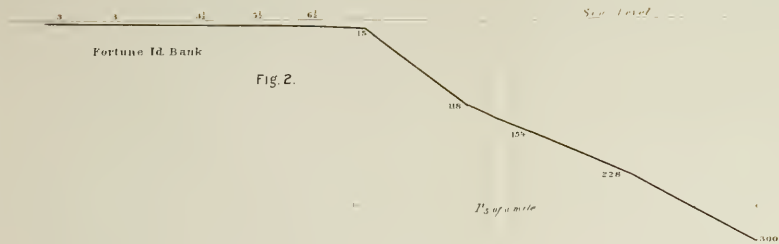






Horizontal Scale, 1.25" = 60 nautical miles  
Vertical Scale, 1" = 1000 fathoms  
Depths in fathoms

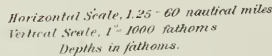




Figs. 2 & 3. Soundings in fathoms

Horizontal Scale, 1.25' = 60 nautical miles  
Vertical Scale, 1" = 1000 fathoms  
Depths in fathoms.









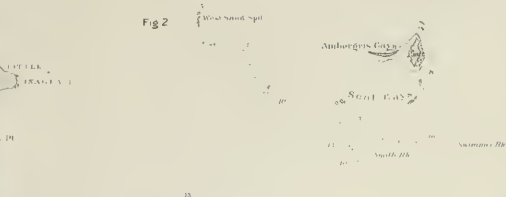
CONTOUR MAP  
OF THE  
CARIBBEAN SEA

1885

*Prepared from data furnished by the  
U.S. Hydrographic Office,  
based on the deep-sea soundings of the  
U.S.C.S. Str. Blake and the U.S.F. Str. Albatross.*







DEPTH IN FATHOMS  
 3 fathoms  
 5 " "  
 10 " "  
 100 " "







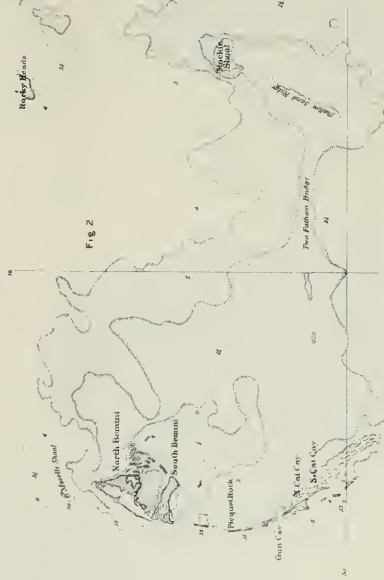
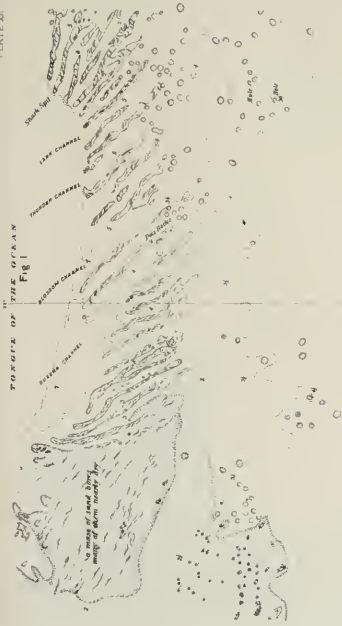






## TONGUE OF THE OCEAN

Fig. 1













SAGUA LA GRANDE



Fig. 2



Fig. 3



Fig. 4



10

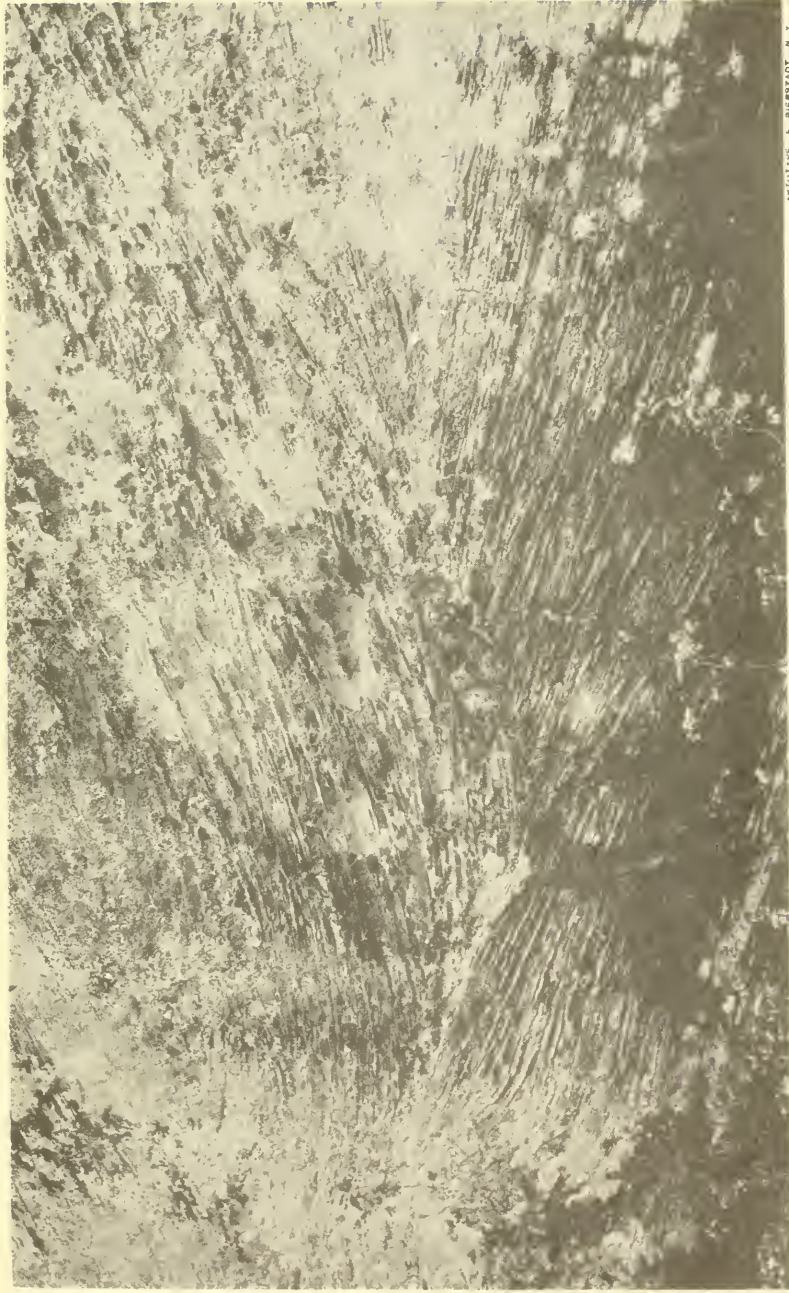


Fig. 6



Fig. 7

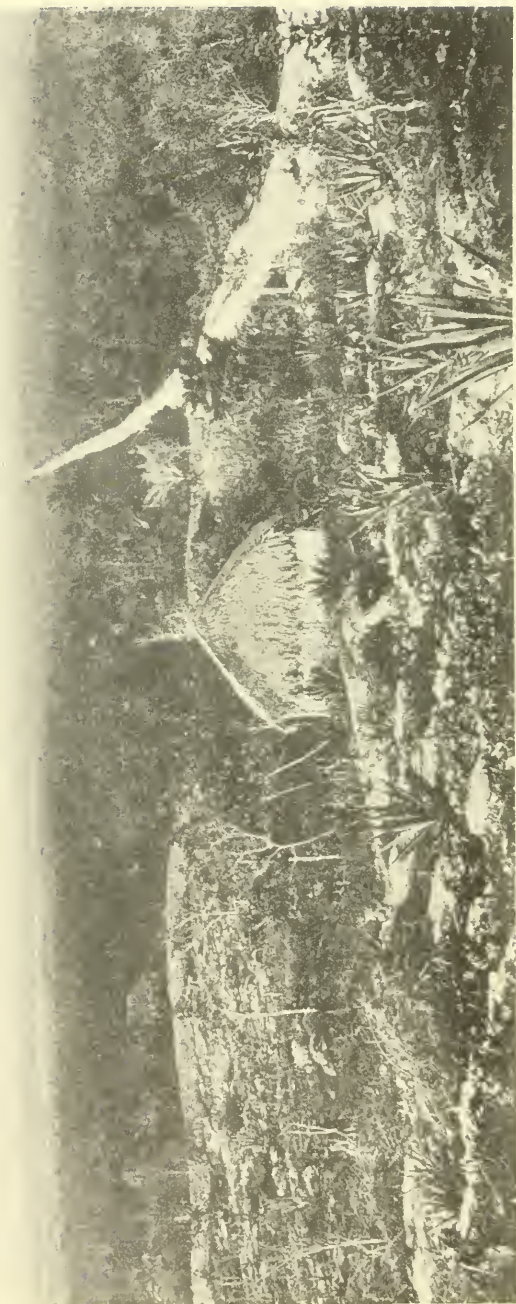




ANTIQUE, E. BIERSTADT, N. Y.

ÆOLIAN ROCKS, NASSAU.





ARTIST TYPE E. BIRNSTADT, N. Y.



AMTOLIVE & BIERSTADT, N. Y.



AGASSIZ. P. BOSTON. N.





NEGATIVE E. REICHSBACH, N. Y.

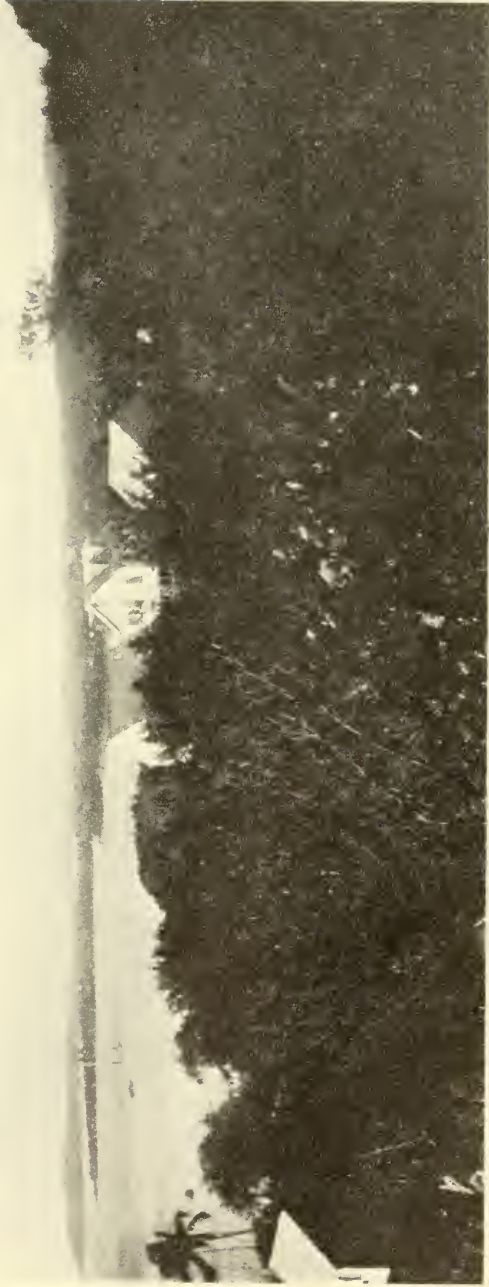
INLAND VEGETATION, NEW PROVIDENCE.

Agassiz "Bahamas."



ARTIST: E. BERTAD, N. Y.

SHORE VEGETATION, NEW PROVIDENCE.



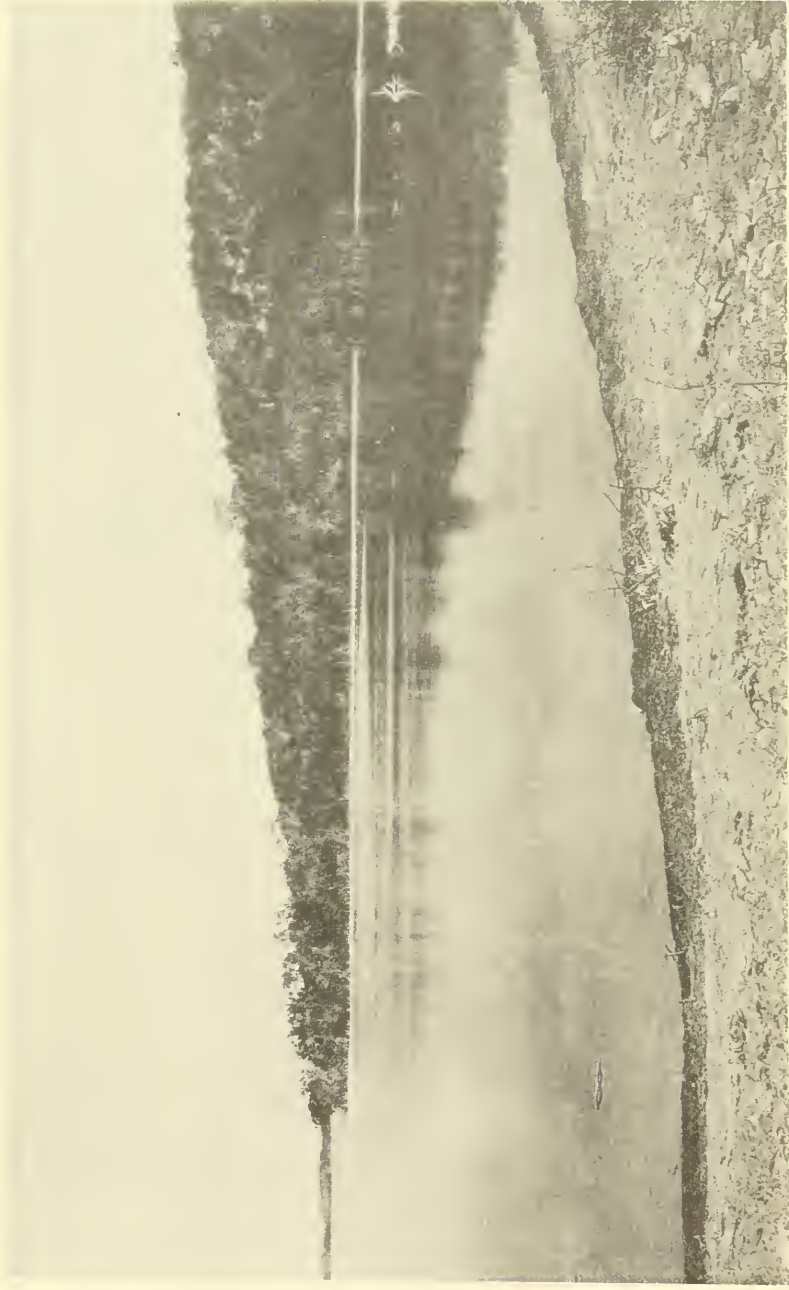
ANTHONY & BLENKARD, N. Y.



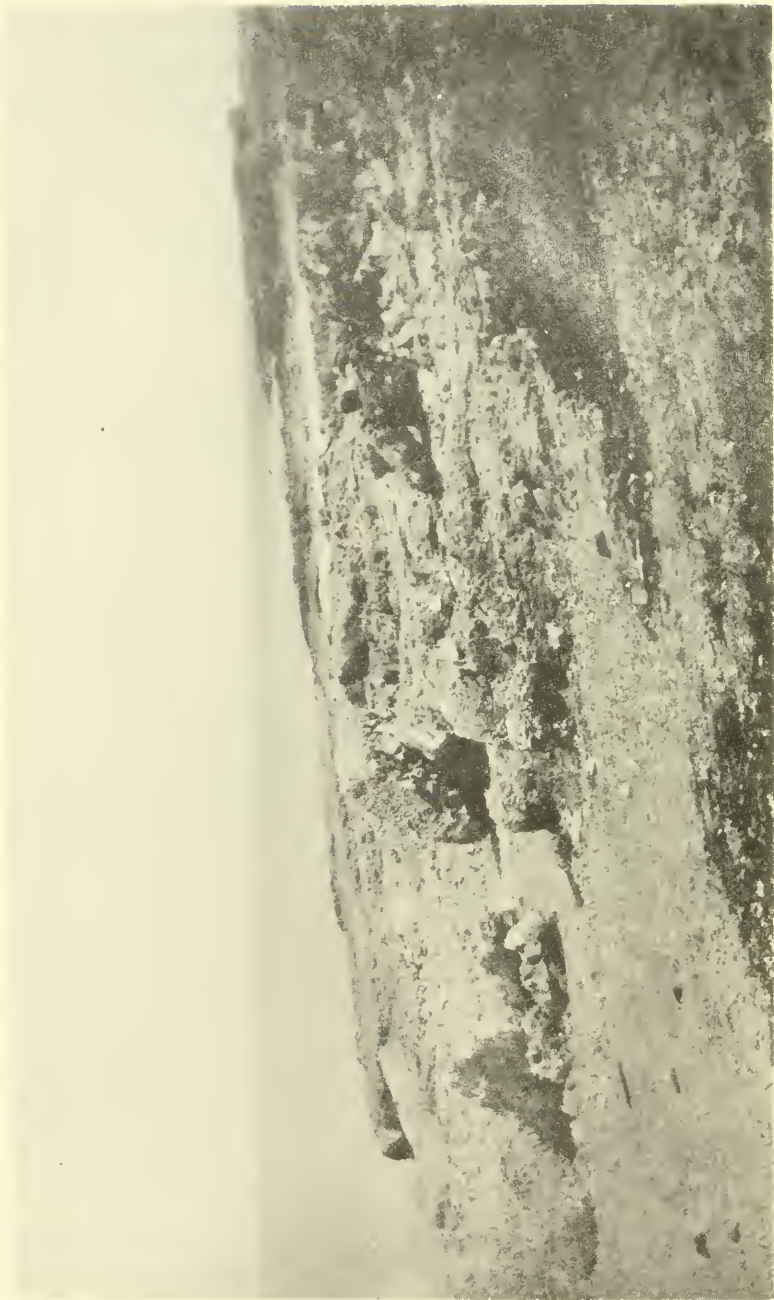


ANTHONY, E. BENTLEY, N. Y.

BEACH ON GREEN CAY.



ARTIST: F. BIERSTADT, N. Y.



NORTH SHORE OF GREAT ISAAC

ANTIQUE, L. HILSTADT, N. Y.

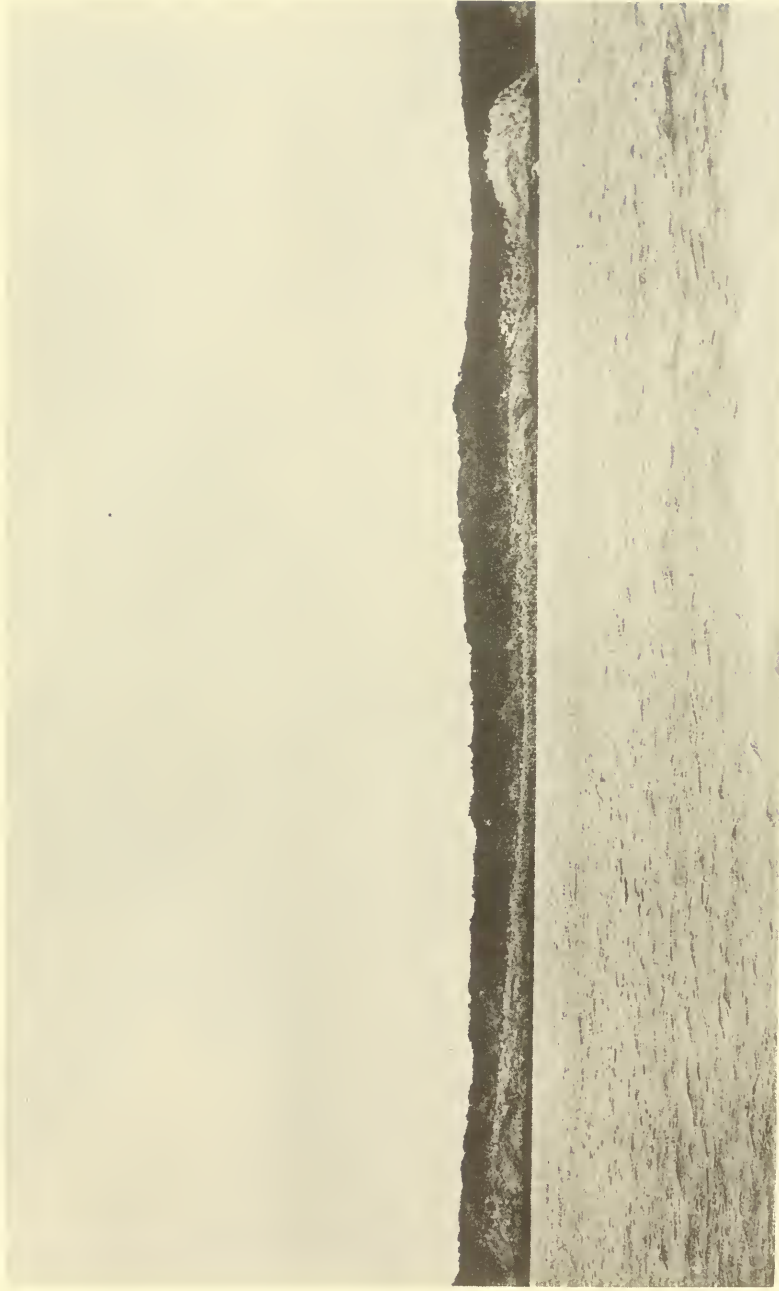




ARTISTE, F. BUCHSTADT, N.Y.



SOUTH SHORE OF GREAT ISAAC



441017P. F. BERNHARDT N. Y.



—RIOTYPE, L. BIERSTADT, N. Y.





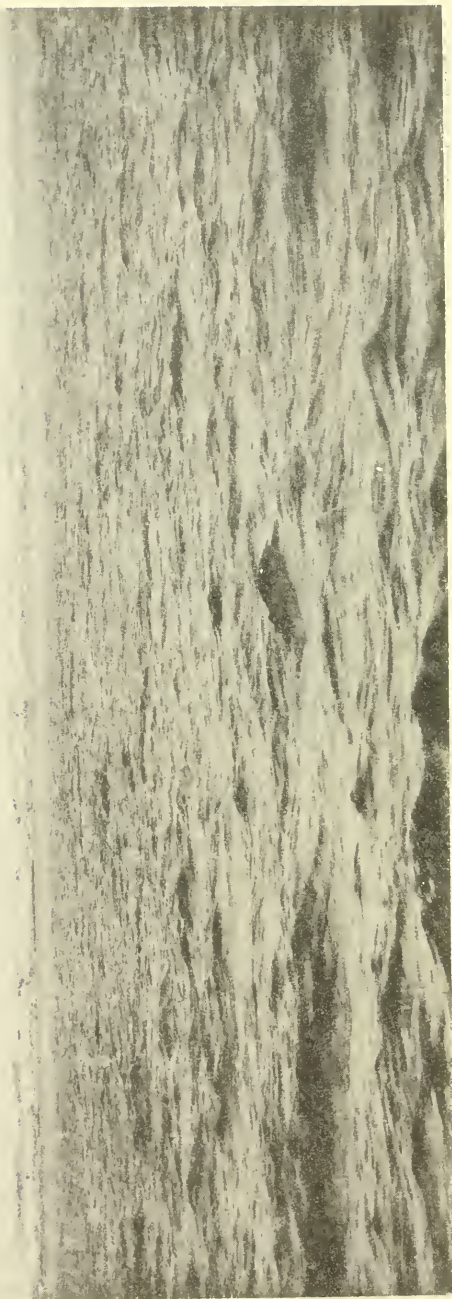


ARTOTYPE, E. BIERSTADT, N. Y.





ELBOW CAYS.





MORGAN'S BLUFF, ANDROS.



ARTOTYPE, E. BIENSTADT, N. Y.



ANTIQUE. J. BERNARD. N. Y.



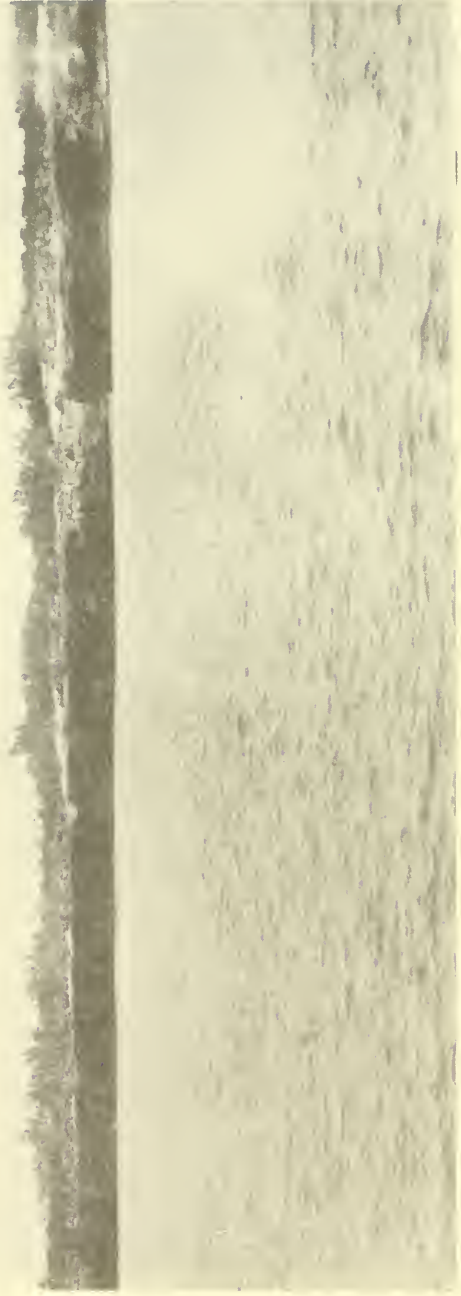




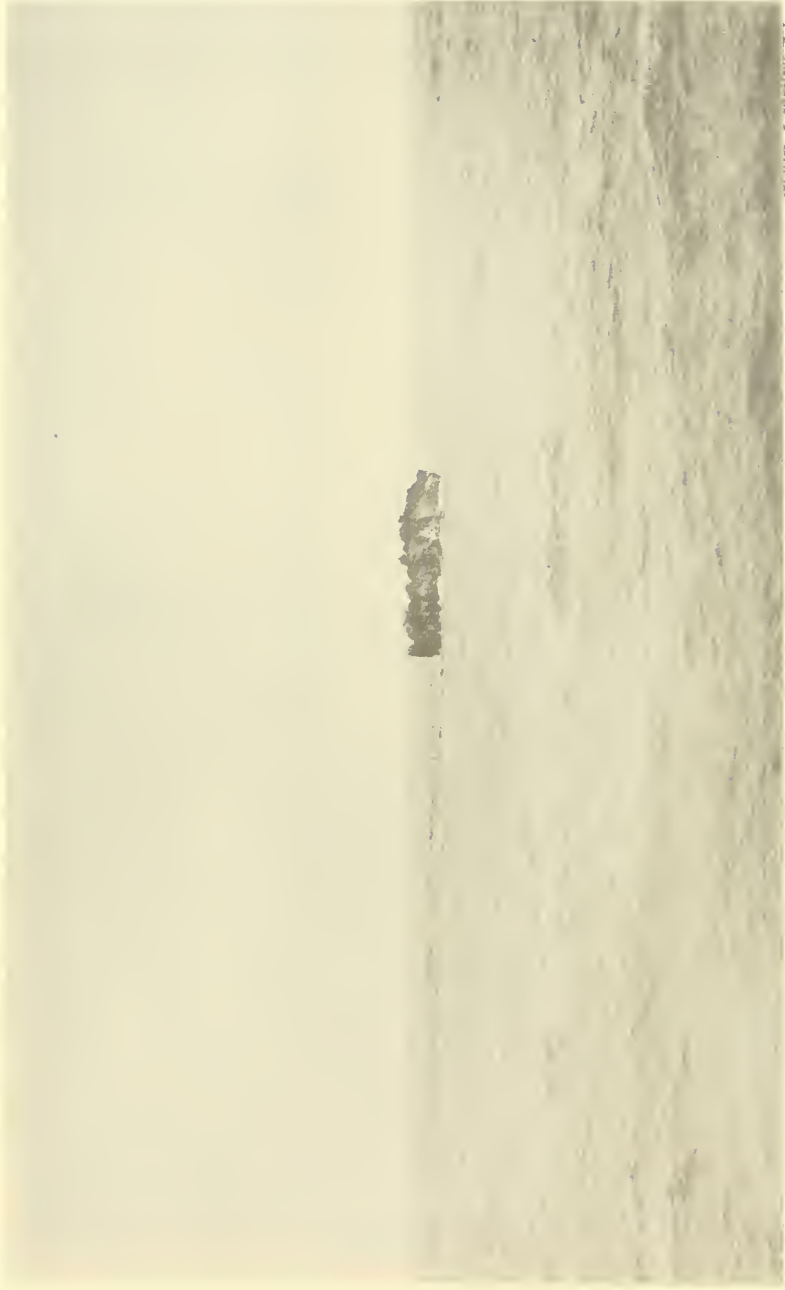


ARTIST: P. H. B. STADT. N. 5

WEST SHORE. CROOKED ISLAND.



ARTOTYPE, E. BIERSTADT, N. Y.



MEMORY ROCK.



GREAT ABACO LIGHT.



AGASSIZ'S BAHAMAS.



ARTOTYPE. E. BIENSTADT. N. Y.

YUMURI CAÑON.



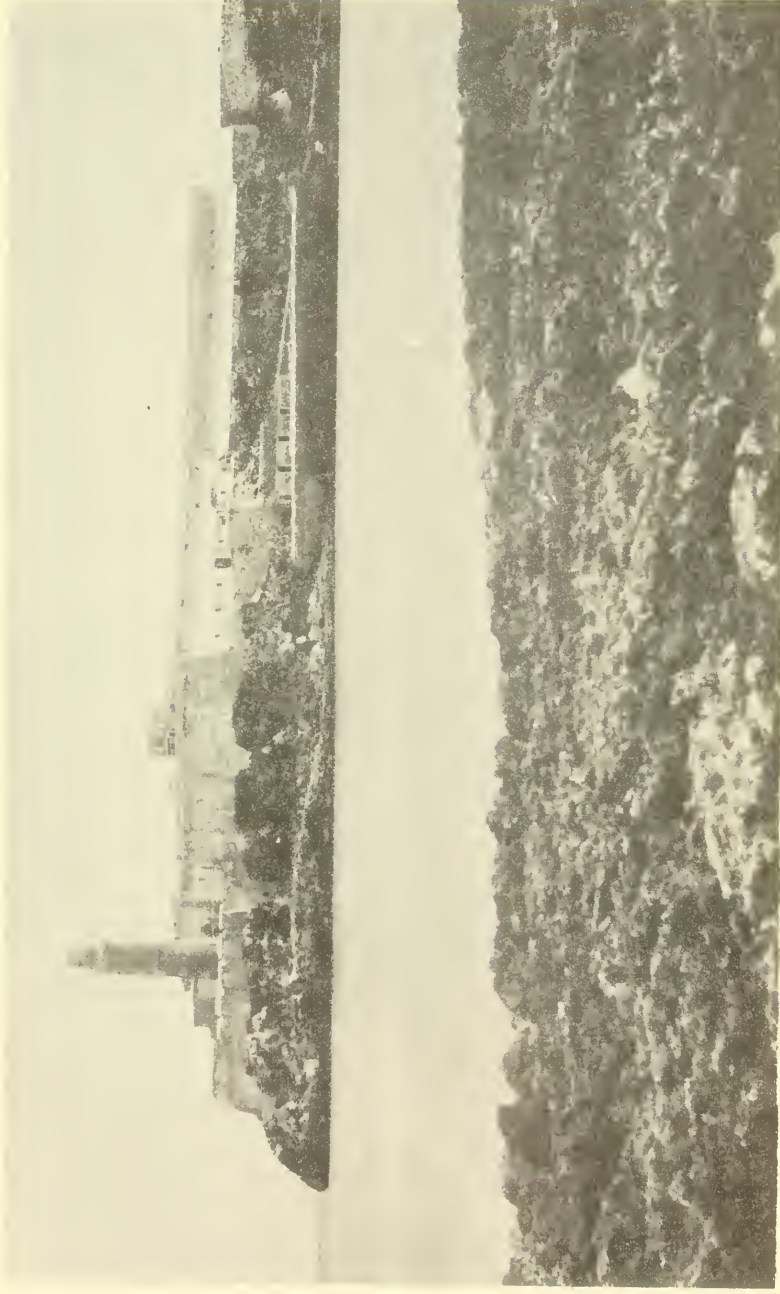


ARTOTYPE, E. BIERSTADT, N. Y.



ARTIST: J. BIERSTADT N. Y.

ELEVATED REEF, NORTH SHORE OF CUBA



ENTRANCE TO HAVANA HARBOR.



PATCH OF SOBORUCO, MORRO CASTLE, HAVANA





ANTOTYPE, E. SIENSTADT, N. Y.

MORRO. ENTRANCE TO SANTIAGO DE CUBA.





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AT HARVARD COLLEGE.  
VOL. XXVI. No. 2.

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A VISIT TO THE BERMUDAS IN MARCH, 1894.

BY ALEXANDER AGASSIZ.

WITH THIRTY PLATES.

CAMBRIDGE, MASS., U. S. A. :  
PRINTED FOR THE MUSEUM.

APRIL, 1895.



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No. 2. — *A Visit to the Bermudas in March, 1894.* By  
ALEXANDER AGASSIZ.

GENERAL DESCRIPTION.

BEFORE completing my article on the Bahamas I was anxious to visit the Bermudas. During my visit I chartered a sea-going tug, and was thus able in a comparatively short time to cover every interesting spot on the shores of the islands and on the inner and outer ledge flats. During the spring of 1894 I spent about a month in their examination,<sup>1</sup> and find that the story of their present condition is practically that of the Bahamas, with the exception that at the Bermudas we have an epitome as it were of the physical changes undergone by the Bahamas. One cannot fail to be struck with the insignificance of the corals as compared with those of Florida, of the Bahamas, and of the Windward Islands. It is true that on the ledge patches inside of the so called "ledge flats" the Gorgonians and Millepores are very flourishing, but the development of the true reef builders, of the massive corals, is insignificant; while the absence of Madreporas is remarkable, and changes the whole aspect of the coral growth.

I shall have little to add to the description of the Bermudas as given by Nelson, Rein, Thomson, Rice, and Heilprin, but I am inclined to take a different view of the part which the corals now growing there have played in the formation of the reef ledge flats. The corals have not added any material part to the reefs; they form only a thin veneer over the disintegrated ledges of æolian rock which constitute the so called reef off the south shore of Bermuda and the ledge flats of the reef ring near the outer edge of the Bermuda Bank. Æolian rock ledges underlie the coral growth not only on the patches off the south shore and on the ledge flats of the outer reef, but they also underlie the so called patches and heads forming the flats which extend on both sides of the main channel and divide the lagoons or interior waters of the bank into irreg-

<sup>1</sup> Notes from the Bermudas. By Alexander Agassiz. From a letter to Professor James D. Dana, dated Bermuda, March 12, 1894. American Journal of Science, 3d ser., Vol. XLVII No. 282, June, 1894.

ular sounds, like Murray Anchorage. The passage of the shore æolian rock ledges into the coral patches can easily be traced, off both the north and the south shores, as will be seen later on.

I have to thank his Excellency, the Governor of the Bermudas, General Lyon, for permission to make soundings and dredgings among these islands with the view of studying the coral formation. To the Hon. Archibald Alison, Colonial Secretary, I am indebted for assistance in many ways during my visit to the Bermudas, especially in obtaining information from the government officers, and for a fine specimen of floating pumice stranded upon the south shore; and to Captain Carr, R. N., in charge of the Bermuda dockyard, for information regarding Ireland Island and the flats. I have to thank General Russell Hastings and the American Consul, the Hon. Marshall Hanger, for their interest in my explorations, and to Mr. John C. Watlington I am indebted for statistics regarding the temperature of the sea water at different seasons of the year.

The slope of the mountain of which the Bermudas are the summit varies considerably, judging from the three sections given on Plate II. The slope off North Rock (Plate II. Fig. 3) is steeper than the slope off Castle Harbor (Plate II. Fig. 4). Off North Rock the distance from the 100 fathom line to a depth of nearly 1,400 fathoms is about six miles, while off Castle Harbor the 100 fathom line is nearly eight miles from a depth of less than 1,250 fathoms. Off the Argus Bank the 100 fathom line is about ten miles from a 1,370 fathom sounding (Plate II. Figs. 1, 2). These sections show the slope of the island to be steeper off the north face than on the south side of the island.

On the southwest face off Long Bar 1,250 fathoms is found at a distance of five miles from the 100 fathom line, and the 1,000 fathom line is only two miles from the 100 fathom line. Northeast from the East Ledge Flats 1,260 fathoms is found at a distance of five and a half miles from the 100 fathom line. South-southeast from the Southwest Breaker 960 fathoms is found two and a half miles from the 100 fathom line.

The distance of the 100 fathom line from the sea edge of the ledge flats varies but little, though it is true that off the south shore it is nearer as a whole, and it comes to within one mile and a quarter of the shore off Castle Harbor, and on the north side it is as much as three and a half miles from the North Ledge Flats, and east off Mills Breaker it is nearly five miles (Plate I.).

The Bermudas (Plate I.) form a hook-shaped line of islands, the main island running northeast from Gibbs Hill to Castle Harbor, which is



bounded on the north by a chain of islands of which St. David is the most prominent, and on the east by a chain of smaller islands, the continuation of the spit east of Tuckerstown, which is the easternmost point of the main island. Outside of Castle Harbor on the north extends a chain of islands which bound St. George Harbor, the largest of which is St. George Island. Endless islets and rocks flank the south shore from Tuckerstown to Church Bay, where the main island makes a sweep to the southwest as far as Wreck Hill. It is separated by a narrow channel from Somerset Island, to the northward.

From Somerset Narrows a chain of small islands extends to the north-east, on the last of which is built the dockyard. The north shore of the main island is flanked by numerous islands, which form Hamilton Harbor, Port Royal Bay, Great Sound, and the connecting waters to the westward of Spanish Point (Plate III.). At the eastern end of the main island a narrow channel opens into Little or Harrington Sound, which covers the greater part of that end of the island. The position of the former Bermudian land is indicated by isolated rocks, like North Rock (Plate VIII.), the Pilchard Dicks, the Southwest Breaker, the South Reef, the Mills and Northeast Breakers, and others rising above the general level of the broad belt of ledge flats which completely surround the summit of the Bermuda mountain. These flats leave only here and there a narrow passage into the interior sounds, bounded by the many belts of flats crossing the inner waters. The principal passages are the Narrows, or Ship Channel, Hog Fish Cut, Chub Cut, North Rock, and Mills Breaker channels, in addition to a few insignificant boat passages. The Narrows is really the only channel navigable for heavy draught vessels.

The Lagoon, lying to the northward and northwestward of the islands, is bounded by the curve of the outer ledge flats. They are submerged at low water, except at a few points such as the North Rock, Mills Breaker, Southwest Breaker, and others marked on the chart (Plate I.). The depth of the Lagoon is in general from seven to nine fathoms, though a few of the deeper points are twelve or thirteen fathoms. Between the outer ledge flats and the islands are found the many secondary flats, called Elies Flat, Cowground Flat, Brackish Pond Flats, Green Flats, Bailey Bay Flats, Three Hill Shoals, and the like, which consist of endless patches of Millepores and Gorgonians, reaching many of them to within a few inches of the surface. The Gorgonians and Algæ which cover the patches have grown upon the remnants of ledges of the proto-Bermudian land that attest to its former existence

at so many points, not only of the outer reef ledges, but on the flats intervening between them and the Lagoon (Plate XVIII.). Between these patches separated by deep water, and plainly seen by its discoloration, it is comparatively easy to find one's way when the water on the banks is not rendered milky by winds stirring up the bottom.

Lagoons similar to those between the reef and the islands are Great Sound, Port Royal Bay, Hamilton Harbor, Harrington or Little Sound, St. George Harbor, and Castle Harbor. These sounds, as the inner lagoons are called, differ from similar sinks in the outer lagoon by being bounded in part or wholly by land, while the sounds in the outer lagoon are more or less indistinctly limited by flats formed of "coral head" patches (Plate I.).

Harrington Sound is connected with the outer lagoon by a narrow channel, the Flats Inlet; it is, in fact, in the condition of many of the smaller bays on the south shore, where the sea has only comparatively lately encroached upon the interior sinks. I refer to such bays as Sinky, Hungry (Plate XV.), Devon, and the like. In the case of Little Sound, the opening at Flats Inlet broke through the ridge separating the outer lagoon from an extensive sink, the smaller elevations of which have entirely disappeared, with the exception of a few islands and shoal patches. Castle Harbor and St. George Harbor were probably similar sinks, the outlines of which are still indicated by the line of islands protecting in part the southern face of Castle Harbor, while the outline of the narrow sink forming St. George Harbor is shown by the islands which separate it from the Narrows, and by St. David and Long Bird Islands, which are the remnants of the ridge dividing St. George from Castle Harbor. But both these ridges are now broken through, so that Castle Harbor connects with St. George Harbor and on the north with the lagoon forming Murray Anchorage.

The æolian hills extending eastward from the northern entrance to St. George Harbor are most characteristic, and the saddles separating them are of varied elevations, and show how readily the sea could, after a very limited subsidence, find its way into sounds like Castle and St. George Harbors at a time when they probably appeared much like the nearly closed Harrington Sound (Plate V.).

As Professor Heilprin has stated, it is merely a question of time when Harrington Sound will be more of an open bay than of a land-locked lagoon, presenting in time the appearance of Castle Harbor, and finally perhaps that of Great Sound.

An examination of the chart (Plate I.) reveals faintly the position of

similar lagoons, the limiting land of which has been entirely washed away. Such are the three small lagoons situated in the flats to the south of East Ledge and to the west of Mills Breaker, showing channels leading into them from the bank similar to the Narrows which lead from the edge of the bank to the lagoon forming Murray Anchorage. A number of such open lagoons facing south are found extending into the inner edge of the reef flat, to the eastward and westward, directly south of North Rock, as far west as the Eastern Blue Cut. On the outer face of the reef south of Western Blue Cut, at the Chub Cut, the Chub Heads, and between High Point and the Chaddock Bar, a number of such open lagoons can be traced. Long Bar is a flat ledge which once may have formed the barrier of a narrow lagoon open at its two extremities.

The so called reef off the south shore I look upon as a series of ledges, the remnants of the cliffs of the shore when it formerly extended to the present position (Plates XXI., XXIII.) of the reef. One cannot fail to read the mode of formation of this reef on seeing the work of destruction which has been and is still going on all along that coast (Plate XIX.). The shore of the island is gradually being eaten away at all the low points leading either into sinks like those of Sinky or of Hungry Bay, or into more elongated sinks like those which will be formed when the ponds lying close to the shore to the westward of Tuckerstown are invaded by the sea (Plate XIV.). The next process is the formation of a line of islands, such as still protect Castle Harbor and St. George Harbor on their sea face (Plate XXI.), or, as is well seen at Sinky Bay, where the line of rocks to the north and south of the opening is still connected with the shore line by a beach or neck, but which will soon disappear and change that bay and the one to the north of it into an extension of Whale Bay. On the sea face of that part of the coast extends a long line of isolated rocks, islets, rocky patches, and sunken ledges, which plainly tell of their former connection in a continuous ridge. Parts of these ledges are worn to the water's edge, forming flat ledges or mushroom-shaped rocks overgrown with *Algæ* and *Serpulæ*, and likewise the *Serpulæ* atolls (Plates XXIV.-XXVI.) and boilers of the shore line, similar to those which form the outer reef, and are separated by a belt of water varying from one and a half to four fathoms close to the lee side of the reef. At some points of the shore it is difficult to separate the line of the outer reef, and of its ledges extending towards the shore, from the ledges which form the *'Serpulæ* reefs of the shore line itself (Plate XXVI.).

The amount of material which is kept in constant movement by the action of the sea within the outer line of ledges is very great, and is constantly increased by the additional material derived from the breaking up of the outer ledges by seas of unusual violence. The outer as well as the inner ledges become disconnected; passages between them are opened with four fathoms of water, or even more. The outer slope of the ledges is greater than the inner slope, the depth of water increasing in some places rapidly from the ledges which are awash at low water to six or seven fathoms, or even up to twelve off Castle Harbor. From that depth, judging from the soundings on the hydrographic charts, the slope is quite gradual, twelve fathoms usually being found at a distance of nearly a mile from the outer ledges; off the outer side of the western reefs the slope is somewhat steeper, and off the north-eastern face of the reefs from the Western Blue Cut to North Rock the slope is slightly flatter.

Two small disconnected banks exist to the southwest of the Bermudas with a least depth, the one of twenty-one, the other of twenty-four fathoms (Plate II.). A depth of over 1,900 fathoms has been sounded between the main Bank and the Challenger Bank, while one of 580 fathoms has been obtained in the channel between it and the Argus Bank. The bottom in these is stated to be coral sand, and these banks may, like the Bermuda Bank itself, be the summits of volcanic peaks which have risen from a greatest depth of more than 2,000 fathoms at a distance of about nine miles from the 100 fathom line.

The Bermudas present quite a different physiognomy from that of the Bahamas. The hills are more diversified in shape, many of them quite conical, surrounding lowlands or sinks of considerable extent and of great variety of shape. Along the northern shore of St. George Island, except towards the east end, the hills are undermined as they reach the water line, forming low cliffs in marked contrast to those of the south shore, or on the waters of Harrington Sound and St. George Harbor and the northern coast of Castle Harbor, where in certain places the water has undermined the cliffs, and from them have dropped off huge masses leaving vertical sides of considerable height, from fifty to seventy feet. On the north shore only a few short stretches of the coast are occupied by sand beaches. Shelly Beach is the only one of considerable length. On the south shore we find sand dunes and many long stretches of broad sand beaches (Plate XI.) which supply the material for the dunes that are still in some places forcing their way inland over the ancient dunes, as at Tuckerstown, Elbow Beach (Plate XII.), and Whale Beach.

Professor Heilprin is of the opinion that perhaps the natural arches at Tuckerstown were formed at a time when the relations of land and water were different from what they are now ; though it is difficult to ascertain precisely what his views are. Here, as at the Bahamas, many sinks occur in which, owing to the porosity of the rock, but little water can remain ; if the sinks are at some height above the sea level, this undoubtedly permeates the interior of the island, and whenever the sinks reach below the level of the sea they are filled with brackish water. There is very little difference in the appearance of the rocks composing the islands. We have by no means the variety in the appearance of the æolian rocks met with in different islands of the Bahamas.

Solution has undoubtedly played some part in producing many of the fantastic spires of æolian rocks one meets in the Bahamas and Bermudas. The undermining of the shore cliffs, the mushroom shape of many of the isolated rocks and shore ledges, both above and below low-water mark, is in part due to the solvent action of sea water. This is especially well seen in the Bahamas on every island or islet at many of the channels leading from the sea face on to the bank.<sup>1</sup> On the Bermudas this is perhaps best seen in the formation of the pinnacles in the comparatively quiet waters of Mullet Bay and of Castle Harbor, and in the undermining of all the shore cliffs and the cavernous and honey-combed condition of the older ledge patches between the islands and the reef flats and those of the ledge flats themselves. Close to the Causeway at the northwest part of Castle Harbor there is quite a patch of low pinnacles from two to two and a half feet in height, which seem to show an active solvent action by the sea.

But the solvent action of the salt water cannot be compared in efficiency with the destructive mechanical action of the sea ; the latter has to a great extent been arrested by the covering coat of Gorgonians, Millepores, Algæ, and Corallines, as well as of the more massive corals found thriving upon the heads, patches, ledges, and ledge flats of the inner and outer waters of the Bermudas. But these heads, ledges, etc. do not, as has been stated by former observers, owe their existence and their gradual increase to the corals, as they consist of æolian rock with only a protecting veneer of corals over their surface, constituting a coral growth, and not a coral reef.

In the region of the Everglades of Florida,<sup>2</sup> the process of solution of

<sup>1</sup> See A. Agassiz, *The Bahamas*, Bull. Mus. Comp. Zool., Vol. XXVI. No. 1, 1894, p. 49.

<sup>2</sup> *The Topography of Florida*, by N. S. Shaler, Bull. Mus. Comp. Zool., Vol. XVI.



the limestone rocks has been an important factor in shaping the general plane of the region. No one can find their way any distance into the Everglades without being struck with the deeply corroded and honey-combed aspect of the rocks, and the numerous sink-holes, due to the effect of the rain water saturated with acids derived from the decaying vegetable matter.

Heilprin has well shown that the lagoons and sounds of the Bermudas are not kept open through solution, and do not owe their origin or increase to that cause.<sup>1</sup> But I think he has underestimated the effect of solution on the cliffs and ledges where exposed to the action of the sea. The solution effected by the percolation of fresh water is clearly seen in the sinks,<sup>2</sup> pot-holes, and caverns opening out on all the cliff exposures and in many of the cuts in the honeycombed surfaces of the æolian rocks wherever laid bare. There is hardly a vertical wall or cut for a road which does not show some trace of the solvent action of water percolating through the æolian beds and covering patches of the edges of the strata with a stalagmitic coating, so as to obliterate their dividing lines or form small stalactites from bed to bed.

A comparison of the base of the sea faces of the cliff ledges with the sides of the mushroom-shaped rocks below low-water mark will clearly indicate the different kind of work accomplished by solution by sea water acting upon the more or less submerged vertical faces, and that exhibited by the action of fresh water some yards above the high-water mark. The effect of the solvent action of the sea water is readily traced above the high-water mark as far as the waves or spray can reach, and the encroachment of the sea water upon the area partly honeycombed by fresh water is most instructive (Plates XXVIII, XXX.). Above high-water mark the area exposed to this action is very considerable, and by the solvent effects of sea water upon the limestone area exposed be-

No. 7, 1890, p. 145. See also Murray and Irvine on Coral Reefs and other Carbonate of Lime Formations in Modern Seas, *Proc. R. Geog. Soc. Edinb.*, 1889-90, Vol. XVII. p. 79.

<sup>1</sup> Bermudas, p. 44.

<sup>2</sup> Professor Dolley accounts for the formation of banana holes by the action of decaying vegetation collected in the holes, kept moist by the action of rains undergoing fermentative changes by the product of which the soft calcareous rock is dissolved and leaches away. This process undoubtedly acts as suggested by Professor Dolley, but only to a limited extent, as the most active honeycombing takes place on the surface of barren islands, where the vegetation has long ago disappeared, but where the surface is exposed to the combined action of rain and of salt water spray, as at Glass Window, Great Isaac, and other places in the Bahamas. See A. Agassiz, *Bull. Mus. Comp. Zoöl.*, Vol. XXVI. No. 1, 1894, pp. 30, 60.



tween high and low water mark a very considerable amount of lime must be removed, probably as much as the sea water will hold in a saturated solution. Additional lime may also be taken in solution, while innumerable minute particles are held in suspension during rough weather. At the time of our visit, the wind having blown for two days quite persistently from the northwest, the whole bank was fairly milky white in a belt extending from five hundred to seven hundred feet from the north shore. The isolated patches on the edges of the greater ledge flats were also indicated by the white waters surrounding them, while the deeper parts of the outer sounds were indistinctly indicated by a more bluish tint of the water.

The so called patches and reefs appear like diminutive vertical cliffs, or parts of cliffs, which once were broken off from the larger shore line cliffs then existing. Of course their faces and surface have been to a certain extent modified by the growth of corals upon them, but that only to a very limited degree. The coral patches are built up over a substratum of æolian rocks.

The islands as seen from the north present in general the features of the æolian hills of the Bahamas, although they have a more varied outline (Plate IV.). There are more conical hills, and there are not as many of the distinctive lines of ranges of æolian hills trending in one direction. Many of the islands in Hamilton Harbor are quite bare, their surface indurated by the action of rain and more or less honeycombed, as is the case in the majority of the Bahamas. The absence of vegetation is also marked over a great part of the western extremity of Spanish Point. There is a very fine æolian cliff on the bay at the foot of Admiralty House (Plate XVI.).

On the north shore the trees and shrubs of the main island do not run close to the water's edge. From the somewhat scantier groves of juniper crowning the summits of the successive æolian hills run broad grassy undulating slopes, terminating in the comparatively low vertical cliffs which characterize the north shore of the principal island. All the way from Spanish Point to Harrington Sound there is an unbroken line of these low vertical cliffs (Plate XXVIII.), with the exception of a few insignificant sandy beaches breaking in occasionally, the only prominent exception being Shelly Beach. The islands of St. George and St. David are comparatively bare (Plate V.), and the general aspect of the country at the eastern extremity of Bermuda reminds one of the aspect of the long lines of barren islands so common in the Bahamas. On the southern and western slopes of St. David junipers grow more abun-

dantly, and the narrow band separating Castle Harbor from Harrington Sound is comparatively well wooded (Plate VI.). Though there has been over that district a greater denudation, judging from the general appearance of the outcrops of isolated patches of weathered æolian rocks, which form here and there low vertical cliffs.

The hills to the eastward of the flats extending on the north shore to St. George Island and the islands protecting the entrance of the harbor are comparatively bare of vegetation. The few stunted cedars and other bushes growing on the north side of that part of the Bermudas are mainly limited to the southern slopes. In fact, all the eastern part of the Bermudas, including the territory around Harrington Sound, shows far more than the central part of the principal island the effect of denudation which has taken place both there and in the western district of the group. The æolian rocks crop out in all directions, greatly weathered, and are near the surface changed to hard ringed limestone.

Toward the summits of the hills and in the saddles passing into the interior of the main island the cedars are more abundant, and in the lower and better watered valleys palmettos grow in small groves, forming the same contrast with the Bermuda cedars which they do in similar localities with the pines in the Bahamas. In all directions the wild verbena is to be found, either as the only growth in the more barren districts, or encroaching to a great extent on the open spaces of the wooded parts of the islands. In the valleys and lowlands of the islands, the soil is sometimes of considerable thickness. This is especially the case in the series of longitudinal sinks parallel with the south shore, which extend from Hungry Bay through the greater part of Devon.

At the western as at the eastern extremity of the islands we find a similar diminution in the vegetation. The southwest end of Somerset Island is bare, and the surface greatly worn. On the rest of the island there are fewer junipers than on the main island, and they are smaller and more scattered, as they are on the east end of the main island all the way from Wreck Point to High Point.

The difference in the aspect of the Bermudas and Bahamas is perhaps due to the prevalence of the trade winds in the latter, where they have had the tendency to build sand dunes bearing in one direction, their sea slope being abrupt, while the bank slope is more gentle, thus forming long lines of dunes lapping and running in one direction. This leaves long, narrow valleys between the ranges of dunes, and, as is well seen at Nassau and Andros, produces a greater monotony in the outlines of the islands as compared with the varied landscape of Bermuda. These valleys

often become sinks (Plate XIV.) or elongated pools, and when broken into by the sea soon leave a line of cays parallel to the main shore. The winds are more variable at Bermuda, the islands being several degrees north of the limits of the trades, while the Bahamas are on their northern edge.

The general aspect of the Bermuda vegetation is characterized by the presence of the Bermuda juniper, which has assumed in these islands the prominence which the pine has taken on the Little Bahama Bank, on Andros, and on New Providence. Comparatively few of the plants so characteristic of the shores of the most barren of the Bahamas are met with near the shore line.

The Algæ and Corallines which I collected at the Bermudas were kindly examined for me by Professor Farlow. Off the sand beaches of the south shore on the bottom of the interior sounds the calcareous Algæ consisted mainly of species of *Penicillus*, of *Bostricha*, of *Udotea*, and of *Halimeda*, identical with West Indian types. On the rims of the serpuline atolls (Plates XXIV.-XXVI.) were collected species of *Turbinaria*, *Galaxaura*, *Blodgettia*, *Dasyclades*, *Codium*, *Laurencia*, *Dyctyota*, *Enchenna*, *Sargassum*, *Zonaria*, *Caulerpa*, and *Janca*, all of which also occur on the outer ledge of flats and inner patches.

Professor Moseley collected a number of marine plants at the Bermudas which have been described in the *Journal of the Linnean Society*, and his collections of the flowering plants formed the basis of the extended Report on the Botany of the Bermudas by Hemsley,<sup>1</sup> where a full account of the earlier sketches of the flora of these islands will be found. Professor Charles S. Dolley has also given an account of the Botany of the Bahamas.<sup>2</sup>

The principal accounts we have of the geology of the Bermudas are those of Captain Nelson.<sup>3</sup> The geology in Jones's "Naturalist in the Bermudas" (1859) is taken mainly from Nelson's Report. Rein gave a most interesting sketch of the geology of the islands in the *Bericht. ü. d. Senckenbergische Naturf. Gesellschaft* for 1870, page 140; he was followed by Sir Wyville Thomson,<sup>4</sup> who spent a short time in the Bermudas, and next in order came the visits of Rice,<sup>5</sup> of Fewkes,<sup>6</sup> and of Heilprin.<sup>7</sup> Darwin is of the opinion that the Bermudas "have a close general re-

<sup>1</sup> Voyage of H. M. S. "Challenger," Botany, Part I., W. H. Hemsley, 1884.

<sup>2</sup> Proc. Phila. Acad. Nat. Sciences, 1889, p. 130.

<sup>3</sup> Trans. Geol. Soc. of London, V. 103, 1837.

<sup>4</sup> The Atlantic, I. 289, 1877.

<sup>6</sup> Proc. Bost. Soc. Nat. Hist., 1888.

<sup>5</sup> Bull. U. S. Nat. Museum, No. 25, 1884.

<sup>7</sup> The Bermuda Islands, 1889.

semblance to an atoll," although they differ from one in several respects which he enumerates. Dana and Sir Wyville Thomson regard the Bermudas as part of an atoll. Thomson thought the islands were formed "by the raising of the weather edge of the reef above the level of the sea."<sup>1</sup> Professor Rice also considered it an atoll, but he was careful to distinguish between the present outlines and those which belonged to the original atoll.

Professor Rice suggests the following heads as his explanation of the geological history of the Bermudas:—

"1. A subsidence in which the original nucleus of the island disappeared beneath the sea, the characteristic atoll form was produced, and the now elevated beach rock was deposited.

"2. An elevation in which the great lagoon and the various minor lagoons were converted into dry land, and the vast accumulations of wind-blown sand were formed which now constitute the most striking peculiarity of the islands.

"3. A subsidence in which the soft drift rock around the shores suffered extensive marine erosion and the shore platform and cliffs already described were formed."

As regards 1. This is the natural explanation which would be given by the Darwinian theory of the formation of coral reefs to account both for the disappearance of the original nucleus and for the formation of an atoll. To those who do not accept the theory the disappearance of the nucleus is of course explained by subsidence also, but by the subsidence which followed the formation of the dunes from an extensive ring-shaped coral sand beach of which the material was derived from a reef growing upon the upper plateau of the Bermudian mountain, from a depth of less than twenty fathoms.

2. Whenever the accumulations from the reef were sufficient to build up a beach reaching the surface, all the conditions necessary for the formation of sand dunes existed, and we need not call upon either a subsidence or an elevation to account for the existing condition of the Bermudas.

3. The subsidence which I imagine to have taken place after the building of the dunes from the broad beach surrounding the original nucleus—now sunk or disintegrated—is, it seems to me, quite sufficient to explain the existing condition of the dunes and cliffs of the Bermudas, if the interpretation I have given of the base rock is the correct one.

<sup>1</sup> The Atlantic, I. 302.

I shall have occasion to refer to the views of Heilprin in the course of the following pages. Regarding the statement he makes on the nature of the Dolomitic reefs of the Tyrol, I would refer the reader to my Report on the Bahamas, page 179, where I have given an abstract of the views of the latest researches on the nature of the dolomitic reefs, views which are diametrically opposed to those advocated by him.

Heilprin says: "If it ever existed (the atoll condition), it has been completely masked by overgrowth; . . . the facts, such as they are, show with sufficient clearness that the present islands and reefs have little or nothing in common, beyond occupying position, with a pre-existent ring."<sup>1</sup> Yet it is on observations gathered in a district thus characterized by him that Heilprin bases his assent to the Darwinian theory of coral reefs, and he dissents from those who hold opposite views with a vehemence which might be excused in one having an extended acquaintance with coral reefs.

### ÆOLIAN HILLS AND DUNES.

Captain Nelson was the first to call attention to the æolian character of the rocks of the Bahamas and Bermudas. This character *sauté aux yeux* in every direction. In the Bahamas the vertical cliffs of the weather side of the islands show this to perfection, and here and there a quarry or a cut leaves no doubt that the substructure as well as the superstructure of the island is all of the same character. On the Bermudas one comes upon quarries of all sizes at all points, close to the sea level or near the highest summits, and at all possible intermediate elevations. The rock everywhere presents the same structure. There are also endless rock cuts for the passage of roads (Plate IX.), giving excellent exposures of the æolian strata twisted and turned in every possible irregular manner according to the direction of the then prevailing winds, or we may come across a patch exposed in a cliff or in a deep cut where the strata run parallel for quite a distance. As in the Bahamas, the surface of these æolian rocks has become indurated by the percolation of fresh water through its mass, and has formed here and there the thin ringed coating so common all over those islands, where the surface is not so well protected by vegetation as it is in the Bermudas. Throughout the islands we come upon evidence of the extensive denudation and erosion which have affected the æolian rocks of the islands and

<sup>1</sup> Bermuda Islands, p. 40.

worn them into the varied forms they have assumed, either along the more exposed shores or in the sheltered bays and inlets and sounds. Some of the æolian pinnacles off Castle Harbor have assumed the most fantastic shapes, due to the combined action of the weather and of the solvent and wearing action of the sea and rain.

Sir Wyville Thomson<sup>1</sup> has also given an excellent account of the general characteristics of the æolian formation. Heilprin has called attention to the comparatively insignificant part which corals play in the supply of the material which has gone to form the æolian hills of the Bermudas, and which, as in the Bahamas, is made up of many other organisms. Among them Nullipores, Corallines, broken shells, and Millepores take a most important place. In some localities, where the æolian rocks have not become well indurated, it is not infrequent to have secondary dunes formed from the sand derived from the breaking down of one of the softer cliffs, the dunes covering to a certain extent the older æolian hills, much as the æolian sand of the south coast climbs over the faces of the older hills.

The fine coral sand, which is so often spoken of as washed up on the shores by the sea,<sup>2</sup> is not, strictly speaking, coral sand, but is primarily composed of fine sand derived from decomposed æolian rock. This material is derived from the disintegration of the shore cliff ledges, and from that pounded off by the sea from the outer reef ledges, together with the broken shells of the mollusks living upon the flats and the small amount of material supplied by the breaking up of the massive corals and Gorgonians forming the coral growth upon the ledges, the ledges themselves consisting of æolian rock covered by Algae, Corallines, Serpulæ, and Millepores. On the south shore this fine sand is blown far inland, forming dunes which cover extensive tracts;<sup>3</sup> at Middleton Bay beach they run up over the surfaces of the older solidified dunes, and reach to a height of over one hundred feet from high-water mark, encroaching upon the vegetation near the lee summit of the saddle through which they are blown. A row of small dunes has formed on the edge of the beach south of Whale Bay; a larger dune has also been piled up inland within the line of the beach dunes, extending over an older but smaller solidified dune (æolian hill); just as the beach sands at Elbow Beach (Plates XI., XII.) have run to a height of more than one hundred feet, although here the sand dunes do not extend as far inland.

<sup>1</sup> Voyage of H. M. S. "Challenger," The Atlantic, I. 310.

<sup>2</sup> Ibid., I. 307.

<sup>3</sup> See the excellent accounts of the dunes by Thomson, Ibid., 312.



It is probable that the other non-calcareous rocks and minerals which have occasionally been found may have been brought here by floating trunks and roots of trees, as is the case in many of the oceanic islands. We should, however, not forget the possibility of their being the fragments of the volcanic summit around which the proto-Bermudian reef was first formed, a summit which has completely disappeared, either owing to subsidence or to disintegration, or to both combined. There exists in the collection in the Government Building a piece of fine-grained æolian rock of a reddish tint from the north shore near Warwick Road, in which is embedded an angular fragment of basalt, or some eruptive rock.

For a coral island the elevation of the Bermudas is very considerable. The highest points are Sears Hill, 260 feet, Gibbs Hill, 240 feet, and Prospect Hill, 222 feet; a number of points reach an elevation of nearly 150 feet. On the Bahamas, with the exception of the highest points of Cat Island, which are said to reach 400 feet, the greater number of the æolian hills do not rise to more than from 60 to 100 feet, very many of the islands attaining a height of not more than from 20 to 40 feet, and only a few summits reaching over 200 feet. But it should be remembered that the heights named are not due to the elevation of coral reef rock, but to the height attained by the æolian hills which constitute the dry land of the two groups.

The Bermudas and Bahamas<sup>1</sup> offer an example of the thickness that a recent limestone deposit may attain during a period of rest. Assuming for the Bermudas a probable subsidence of 70 feet and a greatest elevation of 260 feet, we get an æolian coral limestone of 330 feet in thickness, the material of which has all come from a reef which itself was probably not thicker than 120 feet, or a total thickness of 450 feet. When we remember how readily these coral limestones are changed into hard ringing rocks, we introduce a new element into the discussion of the mode of formation of huge masses of limestone, especially in the region of the trade winds.

The beach rock and the so called base rock which have been observed at the Bermudas belong, I believe, to two different types. The former, the beach rock, consisting of coral or other sand, is deposited in strata dipping to the sea at a slight inclination, and is characteristic of all coral reef districts where sand is accumulated along a shelving line of coast. This frequently becomes hardened and changed to a ringing limestone, and is composed usually of rather coarse particles, but not

<sup>1</sup> A. Agassiz, Bull. Mus. Comp. Zool., Vol. XXVI. No. 1, p. 183.

necessarily so. The base rock, considered by some of the writers on the Bermudas to underlie the æolian hills, I look upon as the modified part of the lower portion of the æolian strata changed into a hard ringing limestone in which all traces of stratification have often disappeared (Plates XVI.-XVIII.).

Heilprin argues that the beach rock has been elevated and is still found at an elevation of 12 to 16 feet; that it "antedates the last subsidence, . . . is at least as ancient as the lagoons and sounds, and probably much more ancient. Indeed, there is nothing that could lead one to suppose that it is not the original rock which was formed when the island first came to the surface. Although now exposed on the sea border, it is really an interior rock, as is proved by the broad band of land which must have been removed from the seaward side of the existing cliffs."<sup>1</sup> But this neither indicates elevation, nor that it is an original beach rock, since at the western extremity of the Bermudas, at Ireland Island, it is underlaid by true æolian beds fifty feet below low-water mark. It does not seem to me that beach rock is found at any greater elevation than that at which it could have been thrown up (and subsequently cemented) during a hurricane or violent gale.

The shore platform of which Professor Rice speaks appears to consist only of modified æolian strata, changed into hard ringing rock by the action of the sea, and of a shore platform eroded to ledges, as he himself describes them. He well says, when speaking of the relation between drift and beach rock on the south shore, "If we conceive the seaward face of the dune to be restored, it would certainly in some localities extend beyond the narrow shore platform into the area now covered by the sea."

Can we not find a simpler explanation of the formation of the Bermudas than the one suggested by Rice? Instead of a subsidence during which the nucleus disappears, followed by an elevation during which the æolian hills were formed, and then by a subsidence during which the present soft drift rock was eroded, as is suggested by Rice, we need only a single subsidence to explain all the phenomena, if, as I have suggested, base rock is only modified æolian rock, and beach rock has been forming continuously, and the æolian hills were formed at the time when the atoll was one gigantic annular beach constantly receiving fresh material from the outlying reef. This primordial reef has disappeared, and its remnants exist perhaps at depths of from twenty fathoms or more near the edge of the bank.

<sup>1</sup> Bermudas, p. 43.

Darwin's suggestion that the fringing reef on the south side of the Bermudas is evidence of recent elevation, does not, in view of the fact that the reef is made up of æolian ledges, need any discussion. Nor is the reason given by Dana regarding the cause of the great difference in the amount of dry land on the north and south side of the atoll a satisfactory one, if the ledges are æolian ledges, which were the first to disappear after subsidence began. I am inclined to look upon the present state of things as due to the former existence of lower æolian hills on the northern edge of the islands;<sup>1</sup> but his views would apply for proto-Bermudian times.

My observations lead me to look upon the beach rock of the Bermudas as consisting mainly of the larger and heavier æolian materials, which either have not been carried so far or blown to so great a height as the lighter æolian sand. The effect of the intermittent submersion of the æolian rocks exposed at low-water mark seems to be to cement the particles on the exposed lines of the knife-edged strata by a process very similar to that going on in all the deep road cuts on the islands. By it all traces of stratification are gradually lost, and an upper crust running over the exposed surface is formed irrespective of the æolian layers. Thus a belt of comparatively hard rock is formed, covered with a crust ringing to the hammer, which at first sight appears to be unconformable with the æolian strata. A closer examination invariably reveals at no great distance traces of the continuation of the æolian stratification, which continue plainly visible to high-water mark, to points below it, and at intermediate heights. Where the sea breaks violently against a vertical cliff, this cementing effect, accompanied by the disappearance of the evidence of stratification, can be traced in some cases well above high-water mark, where it gradually passes into the region honeycombed and pitted by the action of the rains. Such parts of the rocks cannot be distinguished from the base rock, and they have all its characteristics except that the cementation is not quite so complete (Plates XV.-XVII. and XXVIII.).

Here and there along the beaches beach rock is forming, as in some parts of Great Turtle Bay, of the shore south of Whale Bay, in Whale Bay itself, and between short projecting headlands where the *débris* from the outer and inner ledges accumulates in greater quantity. This beach

<sup>1</sup> It seems somewhat hazardous to attempt, as Rice has done, to correlate the movements of elevation and subsidence of what probably is a volcanic cone — of which he has, as he thinks, found evidence — with those of the American continent. (Bull. Nat. Mus., No. 25, p. 18.)

rock is generally readily recognized as such. It is formed in fairly thick layers, from two to six inches, and always dips toward the sea at a very moderate angle, and has nothing in common with the æolian strata against which it abuts. Parts of it may be ground up again by a storm should the calm between heavy surfs not continue sufficiently long for it thoroughly to consolidate.

All along the south shore one can find patches of beach rock dipping, as observed by Professor Rice, to the sea at a slight angle,— the modern beach rock of to-day, formed from the remodelling of the material thrown up from the outer ledges. This beach rock is formed similarly to that of the Florida Reef, where it plays so important a part in its economy, while at the Bermudas it is of comparative insignificance. It is often difficult to separate the beach rock from the base rock, but if, as I believe, what is called "base rock" is only modified æolian rock, the latter has not the importance attributed to it by Professors Rice and Heilprin. On White Cliff Bay there are some æolian cliffs dipping at a sharp angle into the sea, showing remarkably well the transformation of the thin æolian layers into massive compact beds of base rock, in which the dip of the strata can scarcely be detected, obliterated as it has been by the cementing and solvent action of the sea water acting upon them.

At Hungry Bay, Middleton Bay, and many points on the south shore, and on the north shore at Ireland Island, and on the north shore of St. George, there are numerous localities where it is possible to observe the transition of the inclined or horizontal æolian strata above high-water mark to the solid ringing limestone characteristic of the "base rock." On the shore of Godet Deep to the west of Heron Bay, at the foot of Gibbs Hill, the "base rock," can be seen passing gradually from the æolian beds into the solidified ringing limestone characteristic of the intratidal limits. The action of the sea cements the strata together, so that all trace of their æolian structure is lost. In many cases, however, we can trace the continuation of the æolian stratification indistinctly, so that I am inclined to consider what is termed "base rock" as due merely to such cementing action of the sea; the more so, as similar phenomena are clearly observable all along the Cuban coast on the shore edge of the elevated reefs between low and high water mark, where there is no question of an underlying base rock.

Professors Rice and Heilprin both speak of the "base rock" as distinguishing the old beach formation, and as indicating the position of the former sea border. It seems to me that this basal rock is æolian rock which has become excessively indurated by the action of the sea

water upon the lower part of the æolian strata, and from being friable and crumbling, as they are above the reach of the sea, have been changed into a solid compact limestone, which rings under the hammer and can be chipped off in sharp-edged flakes. This is similar to the hard ringing beach rock now forming, and does not, it seems to me, indicate the position of the former sea border. Almost anywhere on the south shore one finds the base of æolian cliffs consisting of strata dipping inward, changed as high up as the sea can reach, into this hard compact ringing limestone. A similar "base rock" fringes all the Bahama Islands; inland at Nassau, as at the Bermudas, a few steps from the shore inside of the "base rock," the æolian structure is clearly defined in quarries and wells extending below the water line, but the sea, acting merely by percolation, has not changed their thin edges and cemented them as it has on the sea face of the shores where the strata are fully exposed to the action of the sea, and are in addition exposed for a longer or shorter time to the atmosphere during low-water periods or during the intervals between consecutive breakers.

Rice says of the locally called base rock, "that it does not uniformly underlie the softer rocks, nor is there any evidence that it is older than they."<sup>1</sup> A part of the confusion between base and beach rock seems to me to have arisen from considering the ledges of æolian rock as reef rock, and from the fact that there are a few localities on the south shore where beach rock is actually forming from æolian rock sand, derived from ledges in deeper water, mixed with broken shells and fragments of corals and Millepores, all of which particles are cemented by the deposition of lime held in solution in the water percolating through its masses.

Rice further says, "That there can be no absolute distinction between beach rock and drift rock will be manifest from the consideration that the two formations are in their origin strictly continuous." Yes, but their origin is not the same; the beach rock of to-day is formed in great part of the æolian rock of former days. I would go one step further in believing that the base rock is by no means usually beach rock, but that beach rock is a very local phenomenon, and is younger than the æolian rock, and belongs to the present epoch, and has been forming at different levels, as it is forming to-day in favorable localities, from the time the islands began to subside, as well as before that time. I am at a loss to know what Rice and Nelson can mean by reef rock, unless it be the thin crust of coral growth upon the ledges. I am inclined to adopt

<sup>1</sup> Bull. Nat. Mus., No. 25, p. 9.

Thomson's view,<sup>1</sup> that the Bermuda limestone is entirely æolian, and that the base rock does not underlie the softer æolian rock,<sup>2</sup> but to modify it by the above statement regarding the formation of base rock and of beach rock as now forming mainly from the remodelling of older material.

Rice accepts the Agers Island strata as beach rock, as well as the stratum at the south end of Ireland, a statement from which I must most emphatically differ. These beds contain marine shells in æolian strata. The base rock of the islands of Hamilton Harbor appears, as far as I have observed it, to be due to the induration of the lower strata of the æolian rock exposed to the action of the sea. There are but few islands in Hamilton Harbor of which the æolian strata do not dip at a considerable angle towards the low-water mark line into the sea. It is true that in some cases there are also æolian rock strata parallel with the sea, everywhere lying nearly, if not quite, horizontal, but these strata present the character of æolian rocks modified by the action of the sea.

On Grace Island, Hawkins Island, and off the Quarantine in Hamilton Harbor, we traced most distinctly, at low-water mark, æolian strata dipping at a high angle into the sea, and yet at many points they have passed into what is called base rock by the complete obliteration of the knife-edged strata from the abrading, the cementing, and the solvent action of the sea. The third island south of the Quarantine, Post Island, and Darrel Island all present the same phenomena of modification of the æolian rock into base rock. In the interior of a cavern leading into Quarantine Island we could trace the dip of the æolian rocks into the sea, and the same was the case at Hanson's Island. On the southwest side of Post Island the fine æolian lamination could still readily be detected below high-water mark through the "base rock" coating.

Nowhere in the Bermudas have I found corals above high-water mark or higher, the presence of which could not be accounted for by the action of high winds or waves during hurricanes, and surely the presence of caves above high-water mark is not in a limestone district an indication of elevation. If the explanation I have given of the formation of base rock is correct, its existence at a height of a few feet above high-water mark is not a proof of elevation.

<sup>1</sup> Thomson, *Atlantic*, I. 307.

<sup>2</sup> There was no "base rock" found while cutting through the æolian strata during the excavation of the Ireland Island Dry Dock.



## FOSSILS.

On a small island to the south of Agers Island I found quite a number of species of marine shells identical with those now living embedded in nearly horizontal æolian strata a few feet above high-water mark. Also a bank of *Chama* evidently thrown up or blown up during a hurricane, much as we find *Strombus* on some parts of the Bahamas thrown up in great banks high above high-water mark. That marine shells should thus be thrown up or blown up to such considerable heights in what may, in proto-Bermudian time, have been a protected sound, as well as is Hamilton Harbor, is not extraordinary. We need only recall the great violence of the hurricanes which sweep past and over the Bermudas, during which vessels have dragged their anchors in the sheltered inner harbor of Hamilton, where the wind and sea have a comparatively limited range.

Below that, but in æolian strata, these fossils extend to low-water mark, apparently embedded in the "base rock." These lower strata have at first sight all the appearance of beach rock; they consist mainly of particles larger than æolian sand, which probably have not been blown a great distance upward from their base. But these strata, consisting of larger brecciated fragments, have, like other æolian beds, been changed into the hard ringed limestone so characteristic of nearly all the exposures below high-water mark.

During the very low tides which prevailed for the last days of my visit at the Bermudas, I was able to trace the existence of æolian beds underlying the fossiliferous beds with the base rock lying between them. The fossils are embedded in æolian rock, and in certain spaces, which have become cemented so as to destroy the laminations, they appear to be embedded in the base rock. The existence of these fossiliferous beds above high-water mark in the islands of Hamilton Harbor has led Rice to assume a period of slight elevation as having occurred in the Bermudas, and further to maintain that much of the interior of the islands is underlain by beach rock, a statement with which Professor Heilprin agrees in the main. The size of the material and the broken shells thrown up at Shelly Beach, show how high up material similar to it may, even under ordinary circumstances, have been thrown up and become embodied into æolian beds without its being any indication of a period of elevation.

The fossiliferous strata of St. George Island,<sup>1</sup> mentioned by Professor Rice, seem to me to belong to the same category of rocks which crop out in Hamilton Harbor. They are æolian rocks containing many species of *Lucina*, *Chama*, and the like; and as all the marine shells near Agers Island must have found their way into these æolian strata under the action of the winds or the sea, the parts of the strata below high-water mark have here also been partly changed into the hard ringed limestone of the base rock. Professor Heilprin also found marine shells in æolian rocks.<sup>2</sup> In a hill to the eastward of Stone Hill I have found a few recent land shells in very friable æolian rock.

An interesting collection of rocks and sub-fossils from the æolian rock quarries and other localities is preserved in the Government Building. It contains among other specimens a small collection of casts of *Tellinas* and *Lucinas* obtained from a submarine cut in Tomlin's Narrows, sixteen feet below low-water mark. This would indicate the existence of a bay or sound, as in our day, at the time when the level of the sea was higher, before the land had by subsidence obtained its present level, and it is no indication of elevation any more than the presence of the living shells of to-day as fossils would indicate such a change. It also contains the shell of a tropic bird egg found in æolian rock quarries in the Middle Road in Devonshire, the bones of a snipe? obtained from æolian rock near St. George, and marine shells from a bed twenty feet above the sea and one hundred feet away from it, occurring in æolian rock on the main road from the north side of Gibbs Lighthouse Hill. There is also in the Government collection a large *Turbo*, which was found in a cutting in æolian rock at the east end of Hamilton; this *Turbo* is said to be extinct, but is found sub-fossil in the highest æolian hills.

<sup>1</sup> I would consider the peculiar conglomerate of Stocks Point as only the higher limit of a local beach rock, which may have been thrown up in a locality specially exposed to gales or hurricanes, and limited in extent. It contains fragments of the underlying drift rock, and resting upon it, as Rice observes, is the ordinary drift rock. But on both sides of the beach rock we find æolian drift rock reaching to the sea, which would indicate either a fault or that the conglomerate was older than the æolian hills of the Bermudas, neither of which suppositions is in accordance with other facts observed in the vicinity.

<sup>2</sup> "At several points, more particularly along the north shore, I found marine shells (*Lucina*, *Tellina*, etc.) embedded in unquestionable drift rock, and indeed it could hardly have been expected that such association should not occur. . . . The same is also true in a measure of the occurrence of land snails. . . . One of the commonest shells of the lower drift rock is the large *Turbo* (*Lirona*) *pica*, a shell which appears to be very abundant about the coast." Heilprin, Bermudas, p. 35.

## THE SOUNDS AND LAGOONS.

Plates II., IV., VI., VII., XIV., and XXVII.

The sounds are sinks and depressions filled with sea water, as was first suggested by Rein, and none of them are secondary atolls. They owe their origin either to the breaking through of low saddles dividing sinks from outer lagoons, or to subsidence, allowing the water of adjacent lagoons or the sea to flow in over separating ridges, or to both these causes.

Professor Heilprin gives an excellent description of the rapid waste which the islands are undergoing, and of the formation of the sounds, on pages 36 and 37 of his *Bermudas*.

The improbability of the sinking of the roofs of large cavernous areas to form the sounds, as has been suggested by Rein<sup>1</sup> and Fewkes,<sup>2</sup> does not militate against local disruptions on a limited scale, of which, as Heilprin states, there is abundant evidence.<sup>3</sup>

The lagoons of the south shore between Tuckerstown and Newton Bay are brackish pools separated by low hills from the sea (Plate XIV.). In many places it would require comparatively slight inroads of the sea, or but little subsidence, to change them into diminutive harbors or sounds, similar, but of course on a smaller scale, to Castle Harbor or Harrington Sound. The shore platforms of Harrington Sound and Castle Harbor are similar to the ledges which extend off the cliffs from the outer shores of the islands (Plates VI., XXVII.).

Harrington Sound seems to have been formed in exactly the same way as the smaller harbor indentations of the coast. Its shores present all the phenomena of disruption by waves exhibited by the outer shores, although in a less degree. The action of the sea is of course much less powerful, yet is sufficient to have undercut the cliffs, and in some places, as on the north shore of the sound, they are fully as high as many of the more striking cliffs formed on the sea faces outside by the splitting off of large slices of the æolian hills.

We find in Harrington Sound islands, islets, and many honeycombed ledges (Plate XXVII.), pinnacles, and mushroom-shaped rocks, due to

<sup>1</sup> Rein, *Bericht.*, 1870.

<sup>2</sup> Fewkes, *J. W., Proc. Bost. Soc. Nat. Hist.*, 1887, p. 518.

<sup>3</sup> *Bermudas*, p. 45.

erosion or to the solvent action of the sea, differing in no way from those made along the north and south shores of the islands. Along its shores there are numerous ledges running out from or parallel with them, extending between the small rocky promontories, which if cut off would form a series of patches close to shore similar to those which extend from the north shore inside of the banks towards the outer ledge flats and upon them. Gorgonians, corals, and other growths, have settled upon the ledges since the time when they and the saddles have sunk or have been eroded to their present level, giving the sea access into the interior of the various sounds so characteristic of the Bermudas. This is admirably shown by the cutting of the sea into St. George Harbor, so as to give access to it both from the outer and inner waters of the bank. These passages are narrow, so that corals do not get a sufficient supply of fresh water, and hence are far less common than on the shelves of Castle Harbor, which is freely connected with the sea on its southern exposure. In Harrington Sound the connection with the lagoon is still less open, a narrow cut on the north being the only opening through which the inner waters of the bank gain admission to it. Castle Harbor in the same way is connected freely with the sea on the south, and but slightly with the inner waters of the bank, through the same opening which connects them with St. George Harbor.

A narrow cut separates Somerset Island, which forms the western boundary of Great Sound, from the main island. This sweeps round to the eastward and forms the southern flank of Port Royal Bay, which is separated from Great Sound by the line of islands extending outward from Tucker to Darrel Island (Plate II.).

The depth of water in the sounds is very considerable, not only in the sounds themselves, but also in the inner waters of the reef, which have been called lagoons, but are hardly such in the sense in which that term is understood. It would greatly conduce to accuracy to call the inner basins of deep water—surrounded on one side by the outer ledges of the reef, and on the other either by the connecting patches of ledges or by the islands in part—sounds also, for such they undoubtedly are, and were sounds similar to those now existing and known as Great Sound, Port Royal Bay, Hamilton Bay, St. George Harbor, Castle Harbor, and Harrington Sound.

In Great Sound we find from ten to eleven fathoms. In Harrington Sound as much as twelve fathoms is found in several spots. In the outer sounds we do not as a general rule find so great depths. What we may call the Brackish Pond and Bailey Flats Sound has a general depth of

only from five to six fathoms. The great sound known as Murray Anchorage, to the northeast of Bailey Bay Flats, is somewhat deeper, and varies from seven to nine fathoms. To the north and northwest of Murray Anchorage the water is still deeper, varying from seven to ten fathoms, with a deeper bight to the northeast of Three Hill Shoals, where the depth is twelve fathoms close to a spur of the East Ledge Flats. These depths all run close to the five fathom line, which may be called the inner edge of the outer flats or ledges extending from East Ledge to the Ledge Flats north of Blue Cut. On these the depths vary from one and a half to four fathoms, with occasional deep holes, with a white sandy bottom, or islets separated from the edges of the Ledge Flats or inlets running in from the sounds, and patches surrounded by from seven to ten fathoms. To the westward of Three Hill Shoal the clear bottom averages from seven to eight fathoms. In the sound between Brackish Pond Flats and Elies Flats the depth varies from six to ten fathoms, with occasionally a five fathom sounding between the numerous isolated patches of ledges inside of the five fathom line. The extensive sound to the west of Wreck Hill, extending to the Western Ledge Flats and southwest of Elies Flats, varies from seven to eleven fathoms (Plate II.).

In St. George Harbor the bottom is hard in five fathoms. The dredge brought up many specimens of *Toxopneustes* and *Echinometra*. We found only a few patches of Gorgonians and of massive corals in the harbor itself, while in Castle Harbor, which has a freer communication with the sea, the patches of corals on the ledges are quite numerous, having much the same characteristics as those of the Ledge Flats.

In Harrington Sound the growth of Gorgonians and massive corals is also less prominent than in Castle Harbor, and the development of Gorgonians, Algae, corals, and corallines in these sounds, as well as in the sounds at the western end of the islands (Hamilton Harbor, Port Royal Bay, and Great Sound), seems clearly to indicate that as fast as they became connected with the outer sounds and in proportion to the accessibility of the sea, corals have gradually found their way into these sounds, and have also developed in proportion to it, being less abundant in sounds indifferently connected with the open sea. All the conditions of the coral growth indicate a comparatively recent inroad of the sea, first into Castle Harbor, next into St. George Harbor, and finally into Harrington Sound. The corals have found their way into the sounds much as the corals forming the venter of the outer reefs have found

their way from the West Indies in the track of the Gulf Stream, or perhaps have been derived from the corals forming the proto-Bermudian reefs, which in their turn were introduced from the West Indies through the same agency.

It seems probable that the cedars dredged up in the excavations for the channel in St. George Harbor were floated into the basin from the adjoining hillsides; but in the case of the red earth coming from the excavation in Ireland Island, the site of the present dockyard was probably a banana hole, which during the subsidence sank to its present level, say fifty feet or so below low-water mark.

The conditions of growth of the corals in the sounds of the Bermudas do not seem to me to have any bearing on the growth of corals in the lagoon of an atoll. The lagoon of an atoll swept by the currents, with its rim pounded upon by the surf, and the Bermudian Sound, with its comparatively quiet expanse of water formed under such different conditions, do not seem to have many features in common.

There are near Harrington Sound, between it and Castle Harbor, three small sounds in the process of formation, which present all the characteristics of the larger sounds, only on a most diminutive scale in proportion to the range of the sea they enclose. The two most interesting are one to the east of Harrington House, and one called Webb's Pond, on the road to St. George, after passing the Flats. The latter is an irregularly pear-shaped, miniature sound, about 200 by 180 feet, and perhaps 200 feet from the north shore. At its southern extremity there are low crumbling cliffs. The depth is said to be fourteen feet. Both of them are merely sinks close to the sea, but only connected with it under ground, and perhaps filled by percolation of the sea through the æolian rock. The tide rises and falls in both.

Spittle Pond, on the south shore, is a brackish sink surrounded by grassy shores, which barely reaches high water-mark. Between Tuckers-town and Newton Bay there are also a couple of brackish ponds, the shores of which are protected by mangroves.

While the sounds undoubtedly indicate subsidence, they are not lagoons surrounded by corals, such as we find in atolls, and should not be compared to them. They are sinks or low tracts, which have become connected with the outer waters into which corals have found their way. Such sinks we find ready to be changed to sounds or pseudo lagoons at many points of the Bermudas; as, for instance, along the South Shore road from about Walker Bay nearly to Hungry Bay, there are a series of low valleys about at the sea level, and separated from the sea by a ridge



of low æolian hills. A further slight subsidence would change them into shallow harbors by the rushing in of the water over the lowest of the dividing saddles. A similar low tract extends to the south of Government House between it and Hamilton, with an outlet into Boss Bay.

### DISTRIBUTION OF THE CORALS.

The Bermudas are the most northerly limit<sup>1</sup> where reef-building corals are known to occur, unless we can call coral districts areas where *Astrangia*, *Primnoa*, and other northern types, like *Caryophyllia* and *Lophohelia*, are to be found.

The absence of Madrepores, to which Thomson called attention, is very striking. There are thus wanting the very elements to supply the bulk of the material broken off and thrown up by the sea to accumulate as beaches or islets.

It is interesting to note that the littoral marine fauna of the Bermudas is the same as the shallow water fauna of the West Indies, and that its existence here is one of the finest examples of the effects of great oceanic currents in shaping the geographical distribution of animals the embryos of which are pelagic a sufficient length of time to be transported to this their northern limit from the Bahamas and other parts of the West Indies. During my stay at the Bermudas, every day when the wind blew from the southwest or west the common West Indian *Physalia* appeared in great numbers.

Besides marine animals, floating masses of wood coming from the West Indies are frequently stranded on the shores of the Bermudas, these sometimes carrying fragments of rocks. A large ellipsoidal mass of floating pumice, measuring eleven inches in length, was picked up off the south shore by the Hon. Archibald Alison. A similar float, thrown up on the south shore, is preserved in the Museum of the Government Building. This piece is filled with red earth.

<sup>1</sup> The minimum temperature of the surface of the sea occurs in January and February, when it varies between 59° and 63°. In March it varies from 62° to 66°. In April its maximum has already risen to 71°; in May the maximum is 76°, minimum 70°; in July the minimum is 79°, maximum 82½°; in August the maximum is 85°, minimum 82½°; in September the maximum is 83°, and the minimum 75°. The temperature then falls rapidly from 69° and 74° in October, down to 61° and 65° in December. The minima are remarkably low temperatures for a coral reef district. The above data were kindly furnished me by Mr. John C. Watlington, of Hamilton.

Wallace lays great stress upon the pumice thrown up from the sea as being a possible explanation of the source of red earth. Although I examined the beaches of the south shore many times, I never succeeded in finding a single piece of pumice. Red earth is abundant, both at the Bahamas and Bermudas, in localities to which drift pumice could not have access.

I was greatly struck with the apparent want of adaptation to their surroundings of the coloring of many of the Bermudian marine invertebrates. The dark violet *Diadema* and *Echinometra* are very common on the faces of the steep rocky patches, as well as in the sandy hollows of the surface of the bank. In the one case they are part of the brilliant patchwork forming the coloring of the reef surface; in the other, they stand out most prominently against the whitish *Nullipores*. *Diadema* in Florida, as well as in the Bahamas, is often found in colonies entirely filling the bottom of some sandy depression in the midst of a white field of surrounding coralline bottom, the patches of brilliantly colored corals and *Gorgonians* themselves standing out as a whole in striking contrast to the whitish bands of coralline or *æolian* sand separating them.

Professor Heilprin has greatly added to our knowledge of the fauna of the islands,<sup>1</sup> which was previously mainly derived from the sketch of their Natural History by Jones,<sup>2</sup> and has also given a list of the species of corals belonging to the islands.<sup>3</sup>

The low tides prevailing during the last days of my stay at the Bermudas enabled me to note the luxuriant growth of *Millepores* and *Gorgonians* on the surface of the many patches which were nearly awash during these days. The flats extending to the north of Ireland Island, and the flats to the southeast of the North Rock Ledge, were specially noteworthy for their abundant coral growths.

On passing through Mangrove Bay to reach Hogfish Cut from Great Sound, we dredged *Oculinæ* from the deepest part of the bay; the bottom in four fathoms is very fine sticky silt, almost marl. Corals in Hamilton Harbor, Great Sound, and Port Royal Bay are limited to a very scattered growth along the shores of the islands of these sounds below low-water mark. In the deeper parts of the sounds *Oculinæ* grow to considerable size. *Zoanthidæ* are abundant on the higher knolls of the outer reef, and also on the serpentine atoll-like structures. *Porites* is quite common on the outer reef. This is in marked contrast to the

<sup>1</sup> Bermudas, p. 97.

<sup>3</sup> Bermudas, p. 98.

<sup>2</sup> The Naturalist in the Bermudas.

abode of *Porites* in Florida, where it is usually most abundant on flats more or less sheltered.

The corals at the Bermudas as well as at the Bahamas do not generally reach the surface. They form a more or less connected belt of coral growth in from five to six fathoms on the inner edge of the flats to the outer limits, the beginning of the broken ground, the corals extending to eight or ten fathoms on the southern sea faces of the flats.

## LEDGE FLATS AND PATCHES.

Plates II., XV., and XVII. to XXVI.

The ledge flats, patches, or coral heads, are names given to different parts of the reef, which has universally been considered to owe its existence to the growth of corals, and much of the confusion existing regarding the structure of both the Bahamas and Bermudas is due to the fact that corals have been assigned a part in the building up of these islands which they have never performed.

The flats consist, not of coral heads, though they are often so called both here and at the Bahamas, but of ledges of æolian rock rising from a depth of five to six fathoms or more (Plate XVIII.). These ledges, with their nearly vertical sides and their slopes deeply honeycombed, drop rather abruptly into the coralline bank bottom, which forms more or less extensive irregularly shaped patches separating the ledges. The surface and sides of the ledges are veneered by corals,<sup>1</sup> Gorgonians, and Millepores; the sharper edges of the ledges are covered by incrusting masses of Millepores, and calcareous and other Algæ grow in great profusion between the corals and Gorgonians. The Millepores, Gorgonians, Nullipores, and calcareous and other Algæ, are by far the most abundant growth on the inner patches. On these we find only comparatively few of the larger *Mæandrinæ* and *Astreas*. The massive corals increase greatly in number as we approach the outer edge of the reef, and the finest and most numerous specimens appear to grow on the outer sea face in from five to seven fathoms of water. Beyond that, or even at lesser depths, in five to six fathoms, the broken ground begins. This consists mainly, as far as I could ascertain from the observations of others and gather from my own notes and dredgings, of Gorgonians,

<sup>1</sup> Thomson thinks that the patches have been built up by the corals. Atlantic, I. 304.

masses of Algæ and of coralline Algæ, and Nullipores, with comparatively few massive corals. As far as I am aware, this broken ground does not extend on the northern sea face of the ledges as far out as off the southern ledges, where the fishermen report its existence to a depth of from sixteen to seventeen fathoms.

The ledge patches rise in steps from the coralline bottom depths, much as they fall in successive ledges off the shore cliffs. As we approach the bank edge of the flats, the ledges become smaller, the depth of water increases, and the sand spaces between the patches increase, often forming long tongues extending into the main body of the ledges of the flats. Many of the ledges near the edge come quite close to the surface, and a great number are awash at low water, although the depth of water between them is greater than at the point we might call the crest of the ledges. The nearer we come to the breakers, the greater becomes the wear of the sea slopes of the ledges, so that in many places their slope is quite abrupt, from two or three to five fathoms, and a somewhat gentler slope extends from that point seaward to form the broken ground.

The high æolian cliffs of the south shore probably extended to the outlying reef, which is itself only a series of ledges running parallel to the coast, the crests of which are bare at low water. On these and the inner irregular flat ledges which dot the bottom over greater or smaller areas between the outer ledges and the shore grow corals and Gorgonians, — a comparatively thin veneer, which supplies, when dead or beaten off by the surf, a part of the material which goes to form the sandy beaches of the south shore, — though by far the greater mass of the material is derived from the disintegration of the ledges themselves. So that the submarine remnants of the ancient æolian hills supply the material which to-day creeps over their faces and finds its way inland, much as they in their own time must have crept over the lowland existing within the limits of the proto-Bermudian coral reef.

From the observations I have thus far made, it seems to me as if the corals now growing at the Bermudas had, as at the Bahamas, played a very unimportant part in building up the mass of the reefs. It is true that some of the flats are largely formed of coralline coral and æolian sand, derived in part from the coral patches which line their faces. But as yet no islands or islets have been formed by their disintegration, showing that the coral growth is not rapid; and although in some of the patches along the inner edges of the flats and on some of the connecting patches the corals have attained sufficient

thickness to conceal the original ledges, and perhaps in many cases to build them up from a couple of fathoms or so to within the limits of low-water mark. Their growth can in no way be compared to the massive coral reef structures we find in the West Indies and Florida.

Off the north, as well as off the south shore, the patches nearest the land are merely ledges consisting of larger or smaller pieces which have become separated from the shore cliffs by the action of the sea, or else they are more extensive patches marking the position of small islands, islets, or rocks which were once more or less closely connected with the main island, and which now run as ledges parallel to the shore line. These ledges, if close to the shore, are barely covered by Algæ and a few barnacles, or *Mytilus*, or isolated corals, or such animals and plants as we find on the immediate shore line. Farther from the shore they become overgrown with a greater profusion of Algæ and Nullipores. As we proceed from the north shore to the ship channel, we gradually come upon ledges on which are found corals and Gorgonians, Algæ and Nullipores occurring as on the ledge flats, but in less profusion. It is on the outer ledge flats, which have probably been under water longest, that we find the most abundant growth of corals. While I do not deny that some of the ledges have been increased in height, and slightly in width, by the corals covering them, yet the corals have played but an insignificant part in building up the ledges themselves. The ledge flats are the remnants of the proto-Bermudian æolian land worn down by the action of the sea to a certain level, and upon these æolian ledges forming the underlying foundation of all the patches, the coral reefs — viz. corals, Corallines, Gorgonians, and Algæ — have grown, but only as a comparatively thin veneer upon the pre-existing æolian ledges.

The surface of many of the ledges outside of Hungry Bay on the south shore, exposed at low water, is covered with coral growth, especially the ledges on the inner face of the outer patches of the south shore reef. The ledges exposed at extreme low water are irregularly shaped, rising from two to four fathoms of water; they are greatly undercut and abraded, and show signs of the solvent action of the sea. The vertical and sloping faces of the ledges near shore are covered and protected from wear by a thick growth of Algæ and Corallines, similar to the growth which protects the upper face of the ledges. But on the upper surface there is in addition an abundant growth of *Serpula*. Between the outer ledges and the shore, more or less protected by the isolated outer patches extending to the reef, a sort of lagoon is formed. In this lagoon are found numerous ledges; then, closer to the shore, overgrown

with Algæ, Corallines, and Serpulæ, there is deeper water, with corals and Gorgonians. Many of the ledges within the lagoon consist of the miniature serpuline atolls and reefs described in another section of this Report.

On the inside of the outer serpuline reef ledge, corals and Gorgonians flourish, according to the depth and the position of the ledges intervening between the outer reef and the shore. Off Sinky Bay the bottom outside of the outer reef ledges is hard. Off Castle Harbor, as far as the channel leading into St. George Harbor (Plate XXI.), we can readily trace the gradual formation of islands and islets originally constituting the continuous barrier to a sound formed by the breaking through of the lower saddles of the ridges dividing it from the sea. The outer row of these islets and islands differs from the inner one in having comparatively wide ledges, projecting round the base of a central pinnacle more or less undercut. As the central pinnacles are cut away, they leave only a narrow ridge on the broad platform, the ridge itself also disappears, and on the outer line of ledges have grown Algæ, Serpulæ, and other organisms, which prevent in some cases the further wearing away of the whole ledge, protecting its most exposed parts. The sea breaking upon the upper surface of the ledge soon forms the more or less regular serpuline atolls and "boilers" of the south shore which will be described later on. They are found on all the breakers on the outer side of the reef ledge flats, like Mills Breaker, the North Rock, and others; serpuline reefs extend off the headland on the west of Church Bay. The Southwest Breaker is the westernmost of the line of serpuline reefs skirting the south shores. It has three "boilers" on it, a long one and two smaller ones, with a small serpuline atoll to the southwest of the main ledge.

There are on the eastern part of Castle Harbor itself a number of ledges coming to within a foot or two of the low-water mark. They are covered with corals and Gorgonians, Algæ and Corallines. The Gorgonians are not very flourishing, but the Nullipores and Algæ grow in abundance between the massive corals. The patches are separated by a fine sandy bottom. On the outside of Castle Harbor there are many coral patches, boilers, and ledges extending outward of the outer ledge, to a depth of from seven to eight fathoms, with an occasional ledge rising from ten fathoms (Plate XXI.). But, as a rule, outside of the outer reef ledges we come upon the "broken ground."

The line of reefs to the south of the island extends unbroken from St. David Head to off High Point. The ledges are all æolian shore cliffs which have become separated from the island by the action of the sea, then beaten away, abraded and eaten into by the surf, and, accord-



ing to their position, the depths in which they are found have been transformed into the peculiar agglomeration of reefs and ledges off the south shore. . They form an incipient ledge flat, as it were, of which the outer line is still very prominent, and which the outer breakers have not as yet undermined and eaten away, so as to leave, as they do round the ledge flats, only a few isolated rocks cropping to the surface. Some of these ledges are a hundred and fifty feet in length, and even more, with a breadth exposed at low water varying from two or three feet to thirty or forty feet ; others are only small pinnacles a few feet in diameter. All, however, present nearly vertical faces, and rise abruptly from two and a half to four fathoms. They are all more or less undercut, eaten away, of irregular mushroom shape, and the breaking up and disintegration of the exposed pinnacles after they have been so undermined as to break from their base supply a large amount of the material thrown up on the beaches.

A section along the slope of the sea beach of the south side of the island shows first a shore line of flats, ledges, and pinnacles, then a second or a third row of mushroom-shaped undercut rocks, some reaching to above low-water mark, others barely awash, or a few feet below. A few of the ledges may still be surmounted by æolian rock pinnacles, while the submerged surface of other flats is either protected by Algæ, Corallines, or Serpulæ, and according to their depth they are changing or have been changed into serpuline reefs. A few of the ledges in deeper water inside of the outer line of ledges are covered with corals and Gorgonians. The outer row of ledges forming the reef do not differ from the rows of rocky ledges inside of the reefs, or from those close to the shore. There are on the outer lines, however, no ledges surmounted by pinnacles, most of them having been changed into boilers, or into long ledges with winding or S-shaped vertical walls, the surface of which is protected by Algæ, Serpulæ, and other growths. Outside of the outer row of ledges we come upon the broken ground bottom, which consists of flat ledges extending from five to fifteen or more fathoms. Upon these in the shallower parts flourish the massive corals and Gorgonians, while over the deeper parts extend mainly the Gorgonians and Algæ, as well as Corallines. Such broken ground bottom occurs off Chaddock Bar, off Long and Little Bar, off the Chub Heads, and all the way from the Southwest Breaker outside of the south shore reef to off Castle Harbor and off St. David Head. Similar broken ground occurs wherever on the Admiralty Chart it is marked *r*, — off the Mills Breaker Channel, outside of the North Rock Channel, the Eastern and Western

Blue Cuts, and Chub Cut, as well as between Long Bar and the West End Ledge Flats. There are outside of the reefs many areas of rocky bottom, marked *r* on the chart, the remnants probably of extensive æolian ledges.

Nowhere do we find more fantastic shapes in the pinnacles remaining on some of the ledges than those which are seen to the south of Nonesuch Island, and extend to the eastward toward St. David Head. The islands pass into pinnacles, into ledges, and finally into boilers, in regular succession, and in proportion to the exposed condition of their position. Similarly eroded pinnacles are also seen on a smaller scale, but of fully as fantastic shapes, in St. George Harbor, in Mullet Bay, and on the south side of the causeway on the western side of Castle Harbor.

The patches outside of the reef off the south shore can be clearly seen extending a short distance to sea, separated by irregular white patches of sand. The inner ledges, forming the patches between the outer reef and the shore, are most capriciously distributed. Outside of the reef off the south shore the corals do not seem to thrive, and the broken ground is comparatively barren, though we find an occasional patch where Gorgonians, Algæ, and massive corals are more abundant. The coral growth is more that of the broken ground than of the reef flat ledges or of the connecting patches.

Heilprin has noted the great importance which the Millepores take in the composition of the bank sand bottom. On the south shore, where Serpulæ are so abundant, the fragments of their pinkish shining tubes can readily be distinguished in the coarser fragments of the sand thrown up on the many beaches along the shore. While in the Bahamas I was struck by the importance of the Millepores in the economy of the reefs. They seem to be far more abundant there than upon the Florida reefs, where the Madrepores take an extraordinary development, while they are absent in the Bermudas.

The south reef extends at a distance from the coast of about one thousand to fifteen hundred feet throughout its length from the entrance to St. George Harbor to the eastern side of Hogfish Cut. It has nothing to do with a barrier reef as such. It is a barrier ledge of æolian rocks derived from the old shore line, and not a barrier reef formed by corals, as Heilprin would lead us to suppose. The description which he gives of the work of destruction going on upon the barrier reef which skirts the southern coast is somewhat unfortunate, as the material of which he speaks as "blocks of coral and

of coralline . . . detached and broken," is derived from the rehandling of the ledges of æolian rock of the former sea-shore. The corals now growing play an infinitesimal part in the forming of the sand dunes which "stand on the eminences which to-day are the Bermudas." His description would apply to the original reefs from which the Bermudian hills were formed, but is scarcely applicable to the work doing in our day.

Heilprin, after quoting Dana's description of the reef of an atoll, finds it largely applicable to the condition of the Bermudas, an opinion to which exception must be taken. From what has been said it will be seen that the Bermudian coral reefs have little if anything in common with the coral reefs of an atoll. Certainly no more erroneous statement could be made than that "the more seemingly favored patches are the creations of the surf themselves." The Bermudian reef corals are, like the Bahama reefs, submerged, rarely come to the surface, and have not supplied any considerable part of the material which has gone to build up an extent of land either in the Bahamas or the Bermudas. In the Bahamas the corals flourish most profusely in depths of from five to twelve fathoms; at the Bermudas six to seven is their limit, and those on the sea face of the ledges do not seem any more abundant than those on the edges of the flats. I was not able in the several sections I made across the sea faces of the southern reef to find the unbounded profusion of coral growth which Heilprin observed. In fact no one has better shown than he that the coral reefs which now encircle the Bermudas have had no share whatever in their formation, and I fail to see how the fact that subsidence has given to these islands their outline of to-day has any bearing upon the theory of the formation of coral atolls by subsidence. Any land surface exposed to the action of the inroads of the sea owing to its subsidence would have been eroded to some extent according to the nature of the rocks composing it. The subsequent formation of a thin veneer of coral reefs upon its sunken ledges would not have any bearing on the theory of the formation of thick masses of limestone by subsidence. It may be interesting, in this connection, to refer to Heilprin's statements "that the present form of the Bermuda Islands bears no relation to the ring of an atoll," and that "the existence of an atoll is not demonstrable."<sup>1</sup>

I fully concur in what he says regarding the subsidence which followed the elevation of the islands to their greatest height. Heilprin was impressed by the absence of loose boulders of rock (coral?).

<sup>1</sup> Bermudas, p. 46.

This is natural, for we find on the ledges of the Bermudas mainly æolian rock masses readily crumbling to pieces, a thin coral belt, and but little solid material to be shaped into boulders by the sea, and similar to that of reefs studded with massive corals and Madreporæ, which are usually crowded with boring Annelids, Sponges, and Mollusks, and which thrive in such localities, but find nothing to feed upon in the æolian rocks forming the base of the ledges of the Bermudas, or in the æolian sand flats, the bottom of which is constantly kept in movement. One finds only occasionally on the beaches of the south shore very limited deposits of flattened pebbles composed of corals, fragments of æolian ledges, and shells of *Nassa*.

We can readily follow off the north shore of St. George the transition of the æolian shore ledges into mushroom ledges, or other patches gradually becoming coated with coral growths as they come nearer the main channel into deeper water towards Murray Anchorage. We find here also a few serpuline atolls and fragments of vertical walls protected by *Algæ* or other growths. *Sargassum*, *Algæ*, and *Corallines* are especially abundant on the inside ledges.

The ledges I have examined immediately north of the main channel, the southernmost patches of the connecting ledges, all present a very similar structure. They are deeply eroded on the sides and surface. Sometimes one side drops nearly vertically from a depth of two to three feet at low water to six or seven fathoms. The top is more or less flat, resembling the ledges near shore, and differing from them only in being covered by a thick growth of *Algæ* and *Corallines*, which protects their sharp edges and ridges from the effects of the sea. The other faces are more or less sloping, dropping in steps much as the shore cliffs do, and they are more or less undermined and honeycombed. One can sometimes trace what may perhaps have been the low-water shelf of the ledge before the subsidance had reached its present height, when it was a part of the old shore line cliff, or one of the outlying rocks or islets.

On the Devil's Flats there are large patches which have in some cases been covered with bank sand, leaving the æolian rocks exposed only on the outer edges, where they are covered with the usual coral growth. In Port Royal Bay, in Great Sound, and in Hamilton Harbor there are many rocky patches rising above the sandy bottom on which *Ocninae* are growing. Along the north shore the rocks are generally thoroughly honeycombed immediately above high-water mark; between that and low-water mark they show signs of abrasion and of the solvent action of the sea. The low shore cliffs usually extend from low-water mark outwards

in shelves of very varying width, terminating either abruptly, or passing into deeper water, either by one or more steps, or by a gradual slope. The shelf immediately above low-water mark is usually protected against abrasion by species of Algæ, or small barnacles, or patches of *Serpulæ* or *Mytilus*, or a thin coating of Nullipores, while below or at low-water mark *Sargassum* and coralline Algæ begin to grow.

It is easy to trace out on the chart the former connection of the flats with the present land surfaces in all directions. The evidence obtained from an examination of a number of ledge patches between the north shore and the south side of the main ship channel is most conclusive that all these patches are only æolian ledges, parts of the cliffs which once were connected with that shore and have become separated from it by causes similar to those now acting upon its cliffs. Upon these ledges have gradually grown Algæ, Corallines, a few *Porites*, *Gorgonians*, and *Millepores*. When the patches are close to the shore Algæ predominate.

The shore cliffs extending into the sea usually have vertical or steep faces, and one can readily follow their indented and honeycombed outlines to a depth of three to four fathoms or more, where the base of the cliff passes abruptly into the coarse bank bottom. An examination of the patches to the north of the main ship channel shows ledges with the same structural features, except that their surface is more thickly coated with corals, Corallines, and Algæ, as well as *Millepores*; we find also a few indistinct serpuline atolls on these patches, but their number cannot be compared with those of the south shore. Many of the ledges are only protected by small barnacles and Algæ. Off Bailey's Beach there is a row of isolated cliffs and ledges forming an outer barrier to the bay, the remnants of the hills which once separated what now forms Bailey's Bay from the sea. The interior patches of ledges are more isolated; they stand out vertically, or nearly so, in from five to six fathoms of water, while those in deeper water nearer the outer belt of ledges may be more or less choked and covered up by the masses of coralline and æolian sand constantly accumulating and forming there.

Some of the ledges which are not too far removed from the shore line, like those off Bailey's Beach or some parts of the north shore off Spanish Point, are most instructive as showing ledges which still are capped by æolian pinnacles, of which the æolian stratification is most distinct. In the submerged base of these pinnacles the stratification has completely disappeared, and between high and low water mark the æolian rock has been changed into a hard compact ringed limestone, more or less worn and honeycombed by the solvent, as well as the



mechanical, action of the sea. This irregular honeycombed and cavernous surface extends to the base of the ledge, where it passes into the coarse bank bottom. The base of the ledge may spread somewhat, or it may have been greatly denuded above low-water mark, so as to form a wide base for the æolian pinnacle surmounting it. The interesting feature, however, is to trace the gradual increase of coral and Gorgonian as well as Nullipore and Coralline growth upon these ledges below low-water mark, as we examine them both in deeper water and at a greater distance from the shore. So that when we reach a certain distance from shore where ledges surmounted by æolian pinnacles are rare, and where we find only ledges reaching up to low-water mark, we soon pass into the coral patches, where the coral growth has become so vigorous that it appears at first glance to have been itself the builder of the patches, having so completely buried under its coating the æolian ledge which constitutes its foundation. Unless one has traced the gradual development of these coral patches from æolian ledges through all their transitions, such an interpretation would be most natural.

The rocks and ledges off Craw Point out to the ship channel, and the rocks and ledges off the north end of Shelly Beach (the Stags), leading to the outer patches as far as the south side of the main ship channel, all tell the same story. We have everywhere the gradual change of an æolian cliff which has become detached from the shore passing into a ledge, and, according to the distance from the shore and depth of water becoming a ledge coated with Millepores, Algæ, Corallines, and coral growth, known as "coral heads." The more massive corals and forests of Gorgonians thrive better on the patches near the flats, or on the ledge flats themselves. There is a fine lot of patches to the westward of Mangrove Bay; they are æolian ledges close to Ireland Island, which gradually pass into coral and Gorgonian patches as one goes to the westward.

To the west of Mangrove as well as to the west of Daniel Island the patches are in comparatively shallow water, and are surrounded by great stretches of sand, the ledges being more widely separated and cropping out in greater number close to the outer edges of the sand flats. Gorgonians and Millepores flourish mainly on the inner flats, while corals grow, but not in abundance, on the outer ledges. These sand flats with pretty steep slopes seem to be due to the disintegration of great numbers of ledges which must have yielded more readily than ledges elsewhere on the bank to the destructive agency of the sea. An examination of the ledges of the great sound bounded by the Daniel



Island Flat shows them to be similar to those of corresponding position which we examined off the north and south shores of the main island, and there is nothing to show that they, any more than the ledges just mentioned, owe any considerable part of their increase to coral growth. We found here many patches of limited extent, with nearly vertical or steep faces, greatly honeycombed, and worn and covered with Algæ, Corallines, and coral growth, some of them rising from seven fathoms up to near low-water mark.

The corals on the ledges of Brackish Pond Flats increase in profusion on the patches as they increase in distance from the main channel. But the appearance of the animal and vegetable growth on the ledge is practically the same on all the ledges of the Bermudas; it is a question of quantity mainly. The greatest profusion of corals and Gorgonians, as far as I have observed them, has been found on the ledges of the flats of the northern, northwestern, and northeastern parts of the banks. The ledges and patches to the west of Ireland and Somerset Islands are connected with the patches to the westward, and form a continuous line of flats as far as the Western Reef Flats. They constitute a series of proto-Bermudian cliff ledges which have been worn away from the shore cliffs, or from the edges of former lagoons and sounds, and have been overgrown by a thin veneer of corals, Millepores, and Gorgonians.

The west shore of Somerset has been greatly encroached upon by the sea; its northern extremity has been divided into a number of islands terminating with Ireland Island and the islets flanking it. One of its extensions forms the western line of rocks and islets of Mangrove Bay. It was formerly connected with the spit running from High Point to Wreck Hill, but the sea has eaten its way through, and the islets running north from Wreck Hill are the western barrier of Wreck Bay. All along the shores numerous mushroom-shaped rocks are seen, either isolated or still connected by a basal ledge, especially in the ledge running south of Daniel Island. From Wreck Hill Bay to Ireland Island innumerable ledge patches are found, with from two to six fathoms between them. These patches extend in a wide flat to the westward, forming what is known as Elies Flat until they join the western ledge flats to the eastward of Chub Cut, where there is a narrow and somewhat intricate channel with four to five fathoms of water leading from the inner waters to the outer bank. This channel separates the Western Ledge Flats and the flats to the eastward of the Blue Cuts. The bottom of the channel is covered with massive corals, Gorgonians, and Algæ. An examination of patches which reach out from the shore, and have been

disconnected from it but comparatively recently, gives us the key to the formation of coral heads and of the ledge flats. Many of these patches are not as yet covered with coral growths of any kind, and their origin can still be plainly traced. From these we pass to more distant patches, in somewhat deeper water, on which Millepores, Gorgonians, Algæ, and corallines have begun to obtain a foothold, but of which the ledge structure is still apparent. Some of the ledges and patches on the north side of Spanish Point show<sup>a</sup> admirably the passage from the æolian rock cliffs, which have fallen into the sea covered only with a thin coating of Algæ, to ledges with a more abundant growth of Corallines and Algæ, and finally to patches with corals and Gorgonians at a greater distance from the shore.

The mouth of Wreck Bay is protected by a number of islands running across the opening of the harbor, the remnants of the land which once connected Somerset Island with the main island. The rocks and islets to the westward of Mangrove Bay are the continuation to the south of a series of ledges which connected it once with Ireland Island. Traces of the proto-Bermudian land are found in the many patches of ledges to the westward of Ireland Island which extend towards Green Flat and thence to the west of Mangrove Bay, reaching out to Cow Ground Flat. The patches between Wreck Bay and Daniel Island reach out to Elies Flat and connect with the Chub Cut Flat. They are the northern boundary of an extensive sound bounded on the south and west by the flats reaching to the westward of Hogfish Cut, and sweeping northerly east of the Chub Heads to join the Western Ledge Flats. Similarly, south of Chub Cut, Elies Flat is the sunken boundary of a smaller sound bounded on the north by the western extension of the Cow Ground Flat.

On the western ledges we find large patches of sand intervening between the ledges on which corals grow; sometimes these sand patches form long sand bars with coral-bearing ledges only on the windward edges, the lower ledges having been triturated into sand which is more or less shifting according to the direction of the wind.

The formation of the sand flats from the disintegration of the æolian rock ledges shows how little material the corals have supplied to form the flats; they often come up close to low-water mark, and yet no coral sand islets have been formed anywhere on the ledge flats, either near the outer reefs or on the interior flats. These sand patches gradually pass into the ledges forming the outer flats, where the coral growth is most abundant and gradually diminishes on the sloping ledges of the sea face to a depth probably of twelve fathoms. The finest corals and Gorgonians

appear to have their limit at a much less depth, in from five to seven fathoms. Beyond this depth the broken ground sets in, which the fishermen state that they can trace to seventeen or even twenty fathoms.

The ledges on the sides of the causeway connecting St. George with the hills to the east of Harrington Sound, together with the flats which connect them, indicate the former existence of a chain of hills which have been disintegrated. These flats form the platform of the east and north sides of Castle Harbor, and they give us an explanation of the sand flats to the westward of Ireland Island. The causeway flats are literally packed with coralline Algæ.

To the northwest of Western Blue Cut there is a stretch of coral covered ledges, which, like the ledges to the north and east of a line running west of Ireland Island, are somewhat isolated, and have remained disconnected from other ledge flats. They have not, like the Devil's Flat, and those to the westward and southwestward of them, been pounded and ground up to form coarse sand ledge flats with steep slopes, from the surface of which scattered æolian ledges barely project high enough to allow a scanty growth of Millepores and Gorgonians.

On the inner side of the reef massive corals do not as a rule seem to exist beyond four to six fathoms, the point at which the great expanses of coralline bottom begin, and which extend nearly unbroken to the greatest depths of the inner waters on the banks.

The greatest width of the belt in which corals grow from the inner edge of these flats or patches to the outer six or seven fathom limit is about three miles at the eastern extremity. This is nearly the width of the land and water belt included between the island of St. George and the entrance to Castle Harbor. The belt between Ireland Island and Gibbs Hill is however considerably wider than any of the ledge flats. At the western end it is not more than a mile, the ring of ledge flats being widest west of Mills Breakers, and diminishing towards North Rock. The ledge flats are much narrower along the whole western and southwestern face of the Bermudas. The gradual shelving slope of the ledges which have been abraded on the sea face of the flats is well seen between the entrance to Hogfish Cut and the Western Blue Cuts. The Little Bar and Chaddock Bar form two wide spits with a gradual slope from two to seven fathoms, covered by Gorgonians, Corals, Millepores, and Algæ. Long Bar is a similar ledge, separated however from the Western Ledge Flats by a channel of from six to seven fathoms, the bottom of which is covered with corals and the attendant Algæ and Sargassum. These bars are full of just such ledges as have been described, only they have

been the first to feel the effect of the inroads of the sea upon the proto-Bermudian land, and have been abraded to a greater depth. We find on their slopes as much as four to eight fathoms as a general depth; the channels between the ledges are in most cases overgrown with coral and Algæ. Outside of the six or seven fathoms at which they still flourish, Gorgonians and Algæ extend on the broken ground down to a depth of seventeen to twenty fathoms, with here and there an irregular sandy patch between the ledges. In the channels between Long Bar and Little Bar and the Ledge Flats, which have a general depth of six to eight fathoms, corals and Gorgonians grow in patches which are separated by coarse bank sand. The same slope similarly overgrown extends to the Chub Cut, and from the Western Blue Cut it becomes narrower towards the Southern Ledge Flats.

On crossing the Ledge Flats opposite the southern end of Long Bar, one meets the same ledges, but more worn and covered by a larger number of massive corals and Gorgonians. In the channel between the Southwest Ledge Flats and Long Bar, which is itself made up of patches similar to those of the outer edge of the Southwest Ledge Flats, the heads and patches do not come so near the surface, they form patches of massive corals, Gorgonians, and Corallines, or Algæ separated by areas of clear, coarse bank sand bottom. Such is the character of the outer rim of the reef, wherever we examined it, to the westward of Hogfish Cut, beyond Chaddock Bar, outside of Chub Cut, to the west of the Blue Cuts, outside of North Rock Flats, and to the south of Mills Breaker and off the outer reef of the south shore. The ledge patches and coral heads increase rapidly in height and number as we approach the outer edge of the flats and Gorgonians, Corallines, and massive corals become more abundant also in the spaces between the patches. The bulk of the corals and Gorgonians do not seem to grow beyond ten to twelve fathoms: beyond that depth Gorgonians, Algæ, and Corallines preponderate, and cover the bottom.

Off High Point extend the Bream and Kitchen Flat Ledges. They are like all the other ledges of æolian rock, with more or less vertical honeycombed sides. On Chaddock Ledge there is a depth of two to five fathoms. It is, like Long and Little Bars, made up of ledges in somewhat deeper water. It is continuous with the flat ledges to the west of Hog Fish Cut, and not separated from them by a channel. On Chaddock Bar there is a fine growth of Gorgonians, of Corals, of Corallines, and of Algæ, which stop in from six to seven fathoms, where we pass into the broken ground described above. The bottom of the channel of Hogfish

Cut in eight fathoms, as it passés out on to the bank becomes hard, and is covered with *Thalassia*.

On the inner edge of the reef to the north of Three Hill Shoal, starting from Mills Breaker Passage, we could observe in the close network of ledge patches no differences between them and those of other localities. The massive corals are perhaps finer and more numerous than elsewhere on the reefs. The *Mæandrinæ* and *Astræans* are more abundant, as well as the *Gorgonians*, *Algæ*, and *Corallines*. The submerged faces of the reef ledges, as examined through the water glass, show no difference from those of similar ledges, such as we see rising from six to seven fathoms of water to a depth of two or three fathoms at low water, on which corals, *Gorgonians*, *Algæ*, and *Corallines* have not as yet obtained a foothold. In the deeper parts of the interior sounds, in from ten or more fathoms (sixteen at the outside), the bottom sand is much coarser than we find it in the shallower patches somewhat protected by the reef ledges, or in the reef bights in which patches of sand run in a considerable distance between the ledges. The reef ledges close to the edge, with nearly vertical or very steep sides, in from ten to eleven fathoms, are often separated by deep passages covered with sand, though occasional patches of *Gorgonians* and *Algæ* or *Corallines* grow over this bottom, and form connecting bottom strips between the ledges. A considerable amount of dead material accumulates at the foot of the reef patches and ledge flats, and, according to its position, is being slowly ground into the characteristic bank sand bottom composed of fragments of *Millepores*, *Corallines*, *Algæ*, *Gorgonians*, and *Nullipores*.

The "breakers" known as special rocks on the outer edge of the reef flats, such as Southwest Breaker, the Mills Breaker, North and Northeast Breakers, and many others, of which the North Rock is the most prominent, are the remnants of islands and islets or of ranges of æolian hills which once rose upon the outer reef flats, and surrounded the now sunken sounds, the lagoons and waters of the inner part of the Bermudas to the northward of the islands. They have by most observers been considered as owing their origin entirely to the growth of the corals we find thriving upon the surface of the ledges which compose these patches.

There are also three or four breakers bare at low water between the North Rock and the Pilchard Dicks. The Southwest Breaker is the westernmost of a series of ledges parallel to the south shore extending to the eastward as far as the entrance to St. George Harbor, the æolian character of which can readily be observed. The inner ledges extending



from the south shore reef towards the main island are the remnants of the platforms of rocks once rising above high-water mark, or forming perhaps small islands, rocks, and islets across the bays of the proto-Bermudian land. We find to-day such islands and rocks separating Castle Harbor from the sea, those across the mouth of St. George, or islands belonging to an outer line of ledges which may be entirely disconnected from land promontories, or form, as they do across Whale Bay, Sinky Bay, and parts of other bays, an outer barrier protecting the south shore somewhat from the beating of the surf till they have crumbled and in turn been reduced to ledges bare only at low-water mark. The true character of many of the ledges forming the flats or the connecting patches is hidden by the coral growth. But both on the north and on the south shore we can follow the passage of the æolian rock ledges as they recede from the shore, from nearly bare ledges still connected with the shore cliffs to the coral patches. The ledge at Briggs Flat is mainly covered with Gorgonians and Millepores. We find there but few heads of massive corals; they are small *Mæandrinæ*s and *Astræans*, together with an abundant growth of *Sargassum*, *Algæ*, and *Sponges*. The *Sponges* are more abundant on the connecting ledges, if I may so call the patches extending from the north side of the main channel towards the flats, than they are upon the outer ledge flats.

As far as we can judge from such an examination as can be made in crossing the reef flats from the inner waters to the open sea, in the sections across the reef at Hogfish Cut, across the Western Ledge Flats at Little Bar and opposite the west end of Long Bar off the Chub Heads, across Chub Cut, across the Blue Cuts, across at the Northwestern Ledge Flats, across at the North Rock, Northeast Flats, Mills Breaker Passage, and the main channel, all the "coral heads" or patches seem to be growing on the tops of pinnacles of æolian rocks, or of flat ledges, or of mushroom-shaped tables, or of large irregularly shaped ledges rising sometimes gradually in irregular shelving strata, or in nearly perpendicular steps, from six or seven fathoms of water to near the surface.

Passing through Chub Cut to the outside of the reef, we find in four to five fathoms large *Mæandrinæ*s, *Astræans*, and fine *Gorgonians*, together with the usual accompaniment of *Millepores*, *Sargassum*, *Corallines*, and other *Algæ*. As we pass into deeper water the massive corals become smaller; in seven fathoms they are quite small and not numerous, and the whole bottom becomes thickly covered with *Gorgonians*, *Corallines*, and *Sargassum*.

An examination of the charts of the Bermudas will show many places



outside of the reef to a depth of twenty fathoms which are marked rocky (*r*). These spots are most probably the outcrops of æolian ledges of the proto-Bermudian hill lands projecting slightly above the sandy bank bottom and forming a part of the broken ground. Beyond that depth (twenty fathoms) the lead brings up what is called coral bottom, made up in great part of æolian sand and of fragments of Corallines, Algæ, and the like. There are also patches of this rocky bottom inside of the reef ledges, as for instance close to the Western Blue Cut, where all the hauls of the dredge only brought up small quantities of the bank sand bottom.

The bottom over the Bermuda Bank is quite uniform in character. The greater part of it is covered with æolian sand of different degrees of coarseness, and more or less mixed with fragments of coralline Algæ and of Millepores or Gorgonians.

In other localities the surface of the old æolian rocky ledges is exposed, and is comparatively bare of æolian sand, as in some of the sounds, and the bottom may be called rocky. On this *Oculinæ* grow in profusion in the deeper waters of the sounds, or the more massive corals where the sea has free access to the sounds.

To the westward of Wreck Hill there is a small extent of bottom in seven fathoms of water covered with very fine mud, much like the white marl off Andros. A similar patch of marl occurs to the eastward of Ireland Island.

## THE SERPULINE REEFS.

### Plates XXI. to XXVI.

The serpuline reefs described by previous observers are perhaps the most interesting structures of the Bermudas. They are most numerous off the south shore, constituting miniature atolls and barrier and fringing reefs apparently formed by the upward growth of *Serpulæ*. While *Serpulæ* undoubtedly cover a great part of the surface of the structures, yet Algæ, Corallines, barnacles, mussels, and other invertebrates, are found to be fully as abundant as the *Serpulæ*, which in many cases play only a secondary part in the organic covering. In fact, it would be as correct in some localities to call them Algæ or Coralline atolls. Neither the *Serpulæ* nor the Algæ, nor any other organisms, have to any considerable extent built up the vertical walls of the different kinds of diminutive reefs so characteristic of the south shore. The

Serpulæ, Algæ, Corallines, and other growths have only protected the surface of the mushroom-shaped æolian rock ledges which form these structures from the action of the breakers. They have not built up the raised rims of the atolls, or the crescent-shaped or the horseshoe-shaped reefs, or the vertical walls forming the irregular convolutions and curves of the broader ledges.

Before my visit to the Bermudas I accepted the explanation given by older writers of the mode of formation of the atolls, as due to the accelerated growth of Serpulæ on their outer rim. I was therefore greatly surprised, on hammering at some of these structures, to find that the vertical walls were not built up, as is generally believed, of serpuline limestone, but were composed of æolian rock, and to discover that in many cases the elevated rim was protected by the hard ringing crust so characteristic of limestones exposed to the action of the sea, and further to find that the coating of Serpulæ, of Algæ, of Corallines, and of Nullipores was quite superficial.

Some of the serpuline atolls are circular and quite regular in outline, others crescent-shaped, while others are apparently formed by the accretence of two or three atolls. Some of the circular atolls are symmetrical, with a central depression, at the bottom of which more or less sand has gathered. The rim of these atolls may project from a few inches to one and a half feet, or even more, from the nearly vertical base; its surface is completely covered by a thick growth of different species of Algæ, Zoanthidæ, Corallines, and Serpulæ. The rim varies greatly in width; in some cases it is not more than eight to ten inches, in others from one to five feet, and in some cases there is only a small circular pot-hole or a very circumscribed area left bare of growth in the centre. The rim is often greatly developed on the weather side, forming a crescent, tapering gradually to a thin wall on the opposite side. The crescent is often open for a great part of the circumference, the weak wall of rock forming its lee edge having been carried away by the breakers.

On the outer reef the ledges which are awash are similarly constructed. It is true there are few of the regular atoll shape, by far the greater number being long ledges of compound atolls made up of diminutive crescent-shaped reefs. Upon these ledges low vertical walls have been cut out varying from six to eighteen inches in height, following all sorts of curves, rising like a succession of S-shaped loops of circular or crescent shape, or re-entering curves, running in all possible ways, and which at first sight would appear to be all due to the growth of vegetable and animal life which covers the top and sides of the walls.

The Algæ, Serpulæ, Corallines, Mytilus, and the whole growth which goes to form the serpuline atolls, form but a thin coating upon the ledges of æolian material upon which they happen to have grown. Underlying this animal and vegetable coating we find the æolian rock, which on some parts of the ledge may still be protected by the hard ringed crust so characteristic of Bermudian and Bahamian limestone. The inner parts of the pool or atoll within the raised walls is composed of softer material, or of material which has not been protected by animal and vegetable growth from the destructive agency of the sea. The serpuline atolls are æolian rock ledges which once were a part of the south shore cliffs at the time when the shore line was farther to the southward and had not yet begun to yield to the inroads of the sea.

The protecting growth of the atoll has little to do with the formation of the wall forming the rim of the atoll; in some cases it has undoubtedly grown up perhaps twelve to eighteen inches above the wall itself, but the deep lagoons and steep vertical walls of the serpuline atolls so characteristic of the southern side of the islands have been formed, I believe, by the mechanical agency of the breakers. These diminutive atolls are large pot-holes excavated by the surf and sand, and the varied forms of circular or of crescent-shaped reefs, of barrier reefs, and all the possible modifications one finds on the south shore of the Bermudas, are primarily due to the mechanical action of the sea. All these structures, from a circular or elliptical atoll to a barrier or fringing reef, with all their possible modifications, are due to the action of the surf and the sea in wearing away the surface of the mushroom-shaped rock, which is either softer than the surrounding parts or is not protected by the covering coat of Algæ, Corallines, or Serpulæ.

One can off the south shore trace the whole process from the time when the large fragments of shore æolian rock fall by undermining into the sea, until they are changed by the action of the surf into mushroom-shaped ledges surmounted by pinnacles, and next into the stage when the pinnacle has in turn been undermined and dropped alongside of the ledge to become the holding ground of coral and other growths. The surface of the flat ledge which formed the base of the pinnacle is now freely acted upon by the breakers. According to the nature of the upper crust, and to the extent of protection given to it by the covering coat of animal and vegetable life, the sea acts upon it, and we have hollowed out diminutive circular atolls, crescent or horseshoe-shaped structures, as well as the curved, straight, or convoluted or looped vertical

walls of broader ledges which stand up from the bottom and seem to have been built up by the organisms covering the surface.

The serpuline atolls are of all shapes, depending primarily upon that of the slab from which they happen to be formed. We may imagine one of the shore slabs or ledges more or less overgrown with *Algæ* and *Serpulæ* exposed to the action of the incessant breakers of the south shore. The sea face of the ledge either slopes rapidly or is more or less vertical, sometimes undercut or worn to a mushroom-shaped table. According to the hardness of the protected edge of the ledge or of its surface, it becomes more or less broken through by incipient pot-holes, which expose the softer æolian rock to the action of the sea. With each tide the wearing action increases, until a circular pool is formed, in which sand is constantly triturating and grinding away the softer surfaces. Thus a miniature inner lagoon becomes excavated, not more than a few feet in depth, and surrounded by a more or less regular rim; the depth of some of the shallower lagoons varies from twelve to fifteen inches. On a ledge in which a pot-hole has been formed the sea thus washes at first into a shallow dish, or into a series of dishes which are soon run together, and thus a straight or curved or **S**-shaped vertical wall may be excavated on the edge of a ledge of æolian rock, the inside depth in one case being eight feet.

The serpuline atolls take their greatest development towards the western part of the south shore. Off Great Turtle Bay we find the same extraordinary development of the serpuline atolls and reefs which we traced farther to the eastward, off Hungry Bay and off Elbow Bay. There is hardly a sunken ledge on or along or off the south shore of which the surface is not protected in some way by *Algæ* and *Serpulæ*, and covered with structures which are directly the result of the action of the sea upon the friable æolian rock of which the ledges are composed. It is indeed a remarkable sight to see, as far as the eye can reach in either direction, this narrow belt of ledges which have been so strangely modified by the action of the sea and the protecting agency of the animal and vegetable growth upon its surface.

The presence on the south shore of so many striking circular atolls and horseshoe-shaped, crescent, or curved rings, or partial rings, and **S**-shaped walls, withdraws the attention from the far greater number of mushroom-shaped blocks and ledges which no longer reach the surface, owing to the wearing of the æolian rock of which they are composed. The atoll-shaped ledges have attracted more notice, not on account of their greater number, but mainly from the interest centring

in such structures. For alongside the atolls, either rising to the surface, or near to it, or always covered at low water, there are other ledges, of endless differing shapes, which do not attract the eye, but which play as important a part in the economy of the ledges off the south shore as the atoll-shaped structures themselves, and which give us the clue to their formation.

Everywhere on the shores of the Bermudas where active degradation of the coast is going on we meet with a number of ledges, or pinnacles, or islets, or mushroom-shaped rocks, which have been fashioned by the sea into a nearly circular or elliptical form. Sometimes a number of these isolated rocks may stand in a row above high-water mark, the stems almost eaten away from the ledge upon which they stand. When the top tumbles over, the support, or a part of it, may remain well above low-water mark. It is upon these ledges of all sizes, from a foot or so in diameter to long elliptical or irregularly shaped masses of fifty to seventy feet in length, or even more, that the sea begins to act, and to shape the serpuline atolls of the south coast, though they are not confined to it, as I shall show hereafter. Standing on some parts of Elbow Beach, one may follow the irregular mushroom-shaped rock ledges standing between high and low water mark to those at and beyond that point into deeper water. We may note the changes which gradually take place as the protective growth upon these irregular ledges, at first bare, transforms them into the atolls, or crescent-shaped or S-shaped structures forming the reef off the south shore. One can watch at low tide and see the breakers combing in over the rim of the little atoll scouring the lagoon, and the superfluous water flowing over its sides. The sea breaks over the edge, carries off such loose fragments as may have been started by the preceding rollers, and scours the inside with the sand it may have brought in, in addition to what it finds inside.

Some of the crescent-shaped serpuline reefs are formed on ledges bare at low water extending out from shore. They form low vertical walls of from twelve to twenty-four inches in height, running in a series of irregular curves, a kind of festoon as it were, protecting the inner lagoon or lagoons of all sizes and shapes which have been gouged out by the waves. It is not uncommon on the south shore to find fine sand deposited on the flat ledges near low-water mark, and kept in place by the growth of a thin sward of *Algæ*; this, together with the thin crust formed over its surface, hardens the mass, keeps it in place, and enables it to resist the moderate action of the breakers.

Going westward from Great Turtle Bay to Warwick Bay we find the



same condition of things, — an outer ledge of boilers together with irregular inner rows of ledges running close to the line of low-water mark, and gradually passing into the mushroom-shaped ledges which still form a part of the shore cliffs.

The district extending from Sinky Bay west and east is specially instructive, as showing the method of irruption of the sea through low shore cliffs to form small boat bays, and the gradual passage of these shore cliffs to lines of rocks and islets running parallel to the coast, and cutting out such bays as Whale Bay, Bailey Bay, Warwick Bay, Great Turtle Bay, etc. We may next follow the passage of these cliffs to submerged ledges, and their transformation into the boilers off the south shore and the outer line of boilers forming the so called reef off the south shore. The most striking of the serpuline reefs are the fringing and barrier reefs, and their outlying atolls, off one of the points at the east end of Whale Bay, together with the lines of atolls and variously shaped serpuline reefs extending to the eastward. Nowhere perhaps on the south shore do we see so clearly the transition of the isolated mushroom rock ledges surmounted by æolian pinnacles into the ledges which are to become serpuline reefs, as in the district between Great Turtle Bay and the bay at the foot of Gibbs Lighthouse.

From the descriptions given above of such a variety of reefs formed by the serpuline ledges, and of the action of the sea upon them, we may obtain on a small scale an illustration of the mechanical theory of the formation of some coral reefs. This may be specially applicable to the formation of compound atolls, as has already been suggested. We find off the south shore, in the same area and subject to identical conditions, patches which assume the shape of atolls of fringing or barrier reefs all within a stone's throw of one another. But in this case the structure of the foundation gives us the explanation of their formation, for the shape of these diminutive reefs is primarily determined by that of the ledge, and not by the growth of the *Serpulæ*. The different shapes of these diminutive reefs can be traced to the manner in which the sea has acted upon their æolian substructure. It may have only honeycombed the surface of a large cliff fragment, and left it as it fell, merely covering its diminutive spires and hollows with a thin layer of *Serpulæ*, *Mytilus*, *Alge*, and *Corallines*. It may have washed off from the shore cliffs slabs of æolian rock in such a manner that as they lie on the beach the strata are horizontal, and, the edges having become cemented by the action of the sea, the division lines become obliterated, and over their surface has grown an animal and vegetable covering. It is not



an uncommon thing to see on some of the beaches large slabs of base rock, upon the hard ringing surface of which grow Algæ; these collect particles of sand, and thus form a coating from a quarter to three quarters of an inch thick, upon which larger Algæ then flourish. In the intermediate spaces grow the *Serpulæ*, *Mytilus*, and *Corallines*, which soon conceal the surface of the ledge by their protecting coat. Should this slab alone or with adjoining slabs form an extensive ledge far enough out from the beach to be exposed to the action of the breakers, its nearly vertical sides would form a rampart over which the sea combs and pounds down over the edge of the slab, striking beyond the outer edge well toward its interior, according to the size of the breaker. If there exist at the points reached by the breakers any weak spot in the protecting crust, or any incipient fracture, or any difference in the hardness of the upper layer, the sea soon makes an inroad upon it. It grinds out the softer interior parts, which are carried off, and thus forms the beginning of a flat shallow saucer-shaped cup on the inner part of the ledge. The outer rim, on the contrary, protected either by a hard crust or by a growth of Algæ and of *Serpulæ*, remains intact, and gradually rises higher and higher, partly from the additional growth of the *Serpulæ* and other calcareous organisms, but mainly by the grinding away of the interior of the ledge to form a basin, which little by little becomes deeper. The organic growth on the outer rim is more vigorous than in the basin itself, either on its sides or on the bottom, where the sea breaks and is at work grinding away the protecting growth. The Algæ, *Serpulæ*, and other growths become less abundant in proportion to their distance from the outer weather rim, until, towards the centre of the atoll, the inner ring or cup or slope is covered with sand. We thus have diminutive atolls, barrier reefs, or crescent-shaped or horseshoe-shaped structures formed out of the æolian rocky ledges. Should the sea face of the slab be harder than the faces of the sides or of the leeward side, some of those strata are soon broken through, and gaps made in the rim, forming a crescent-shaped wall or arc with its greatest height seaward, the wall gradually falling to leeward to the level of the ledge, and the raised edge sloping towards the horns of the crescent on either side. The lee face of the crescent-shaped atoll is in such a case thoroughly scoured by the outward rush of the sea, which, carrying with it a certain quantity of the sand that fills the depression, runs off the lower lee side with considerable velocity. The depth of the atolls varies from a few inches to six feet or more. The lee faces of both horseshoe-shaped and crescent-shaped atolls are frequently so rapidly removed as to leave nothing but a vertical wall of from one to two feet on the weather face of the ledge.

The diminutive reefs formed off the south shore of Bermuda are of all possible shapes, — atolls with regular rims of the same width on all sides, atolls with the sea face rim wider than that to the leeward, and parts of rims of circular atolls of horseshoe or crescent shape, or only of parts of arcs of greater or less extent. We also find belts of small atolls on ledges of considerable width, and atolls of an elongate type; others are dumbbell-shaped, formed evidently by the breaking through of division walls of circular atolls. We also meet with chains of atolls, each one forming a link as it were, or irregular parallel chains, which, when the separating walls are broken through, give the elements for all the possible figures assumed by the ledges off the south shore. When such reefs are formed on the shore ledges, we have all the possible types of fringing and barrier reefs, or combinations of these, forming diminutive reefs with low vertical walls apparently most irregularly placed, often as if their existence in their varying shapes and positions could be due only to the upward growth of the *Serpulæ* and *Algæ*. But I believe that the vertical growth of *Serpulæ* and *Algæ* is not of itself sufficient to account for the existence of the vertical walls, and that they are due only in small part to the upward growth of organic material, and in a great measure to the action of the breakers upon the æolian rock ledges, probably in the manner I have just described.

The barrier reef off the small spits to the east of Whale Bay at the Targets may be described as a vertical wall surrounding three sides of a rectangle, the diagonal of which is somewhat over fifty feet; the sea face corners are well rounded and the side walls formed of short arcs. The distance from the shore edge of the ledge to the outer wall is about twenty-two feet. The greatest width of the rim is at the two outer angles, where it varies from five to six feet; the inside edge of the sides of the rim gradually passes into the shore ledge, being in a general way parallel to the trend of the sides of the barrier reef. The raised part of the rim varies from twelve to sixteen inches in height. The outer vertical wall has a height on the west of eight feet, and on the east of about six feet, the slope of the ledge being more or less concentric round the deepest part as a centre, and sloping sideways towards the shore edge. The outer rim at two points is gouged out into two smaller elongated pits. The rim is everywhere well protected by *Algæ*, *Corallines*, and *Serpulæ*, the *Algæ* growing on the more or less level platform of the rim, and on the outer and inner faces of the vertical walls of the barrier reef. The ledge is greatly undercut, and its outer faces present all the irregularities of wear by water so characteristic of

shore ledges. The inner slope is covered by a thin growth of Corallines and smaller Algæ, which do not seem to thrive as well as where they receive the direct force of the breakers. Close to the westward of this diminutive barrier reef are ledges which may be regarded as typical of the changes which have taken place in a bare æolian ledge just dropped from the shore cliffs until it becomes a typical boiler of the south shore. One of these is separated from the western edge of the barrier reef by not more than six feet, and has a depth of water of more than ten feet in the passage between them. To one side of this dumbbell-shaped atoll, which is nearly thirteen feet on its longest axis, is another atoll on a mushroom-shaped ledge seven feet in diameter, with a regular rim and a pot-hole of three feet in depth. This is separated from the adjoining mushroom-shaped ledge by a gap of four feet, with a greatest depth of ten feet, and eight feet on the shore edge; it is separated from the shore and a large ledge to the south by a deep passage of nine feet in width. The length of the larger ledge, irregularly shaped, is over forty feet, and its width varies from twenty to thirty-five feet. Its outline is formed by curved walls, the edges of irregularly shaped elongated or circular dumbbell-shaped pits gouged out from a broad platform of æolian rock. On the lee part of the ledge an irregular rectangular pot-hole has been formed, five feet in depth on one side and four on the other, sloping upward toward the broad outer rim. Comparatively slight variations would change the surface of the ledge into an atoll with a narrow rim following the outlines of the ledge; or it may become divided into two irregularly shaped pits by the coalescence of the few smaller pits now upon the platform, and a single curved wall, the remnant of the face of one of the circular pits, would form a division wall; or the sea may break through to a greater extent than it has done already and leave on this ledge only disconnected fragments of wall of varying shape, in which it would be difficult to recognize the walls once limiting circular or dumbbell-shaped pits. Outside of the larger ledge is a pear-shaped atoll with a broad sea face or rim sloping inward, and a circular pot-hole about three feet in depth, the rim of which is narrower to the leeward.

All these ledges are deeply undercut and abraded, and are mushroom-shaped; their faces are vertical or nearly so, and all show traces of the action of the sea upon the pillar forming the base. The ledges I have examined close to the shore, half-way to the reef, or on the outer line of ledges, all present modifications of the ledges described. Their ultimate shape depends upon many local factors, and they show but a small num-

ber of the possible intricate figures that are found on the æolian ledges off the south shore. The Algæ, Serpulæ, and other organic growths which thrive upon the edges of the ledges and spread down upon the vertical faces, still further protect the sides of the mushroom tables from being washed or eaten away by the forward and backward rush of the sea.

Off the same locality an elliptical atoll forty by thirty feet, standing in a depth of ten feet at low water, formed the spreading top of a mushroom-shaped ledge from the vertical sides of which all traces of the æolian character of the substructure had disappeared. Where not overgrown with Algæ and Corallines, it showed the peculiar gouging out and honey-combing character of all shore rocks, either when exposed at low water or where extending below it. The inner part of the weather rim was not quite parallel with the outer outline; it projected in the centre and was somewhat scalloped in outline, with a few small deep pits. The rim varied in width from five and a half feet on the weather side to one foot in its narrowest part on the leeward edge. I could not detect that the weather rim was perceptibly higher than the leeward rim, though this is not unfrequently the case.<sup>1</sup> The pot-hole was six feet in depth nearer the western edge, gradually decreasing in depth to three feet on the opposite side. A crescent-shaped lagoon eighteen feet in diameter, greatly undercut, especially on the weather side, as all these ledges are, had a rim five feet wide at its widest part, gradually tapering to four or five inches at the two extremities of the crescent. Both this and the elliptical atoll just described had a narrow shelving platform on the inside of the weather rim. The lee edge of this crescent-shaped atoll was worn away five feet lower than the weather rim. A circular atoll twenty-five feet in diameter was surrounded by an irregularly elliptical rim twice as wide on the weather as on the lee side, forming a scalloped pot-hole with a greatest depth of three feet. Along the

<sup>1</sup> Heilprin speaks of the Serpulæ as occurring "in dense bunches," and where the surf beats hardest "the Serpula growth was most largely developed, and to such an extent as to form a raised rim or barrier to the more protected inner side." But, as he himself says, (and I am not quite clear whether he attributes the formation of the atoll to the Serpulæ,) "the breaking in on all sides of the surf has created a number of more or less irregularly oval islets with depressed centres, or, more properly, with elevated borders." In the one case he says, "The depression is merely a negative one, being such by reason of a somewhat more rapid growth developed only from the water line, or within the surf," but he feels satisfied, however, that the two structures (these serpuline atolls and the coral atolls), while seemingly alike, have practically little or nothing in common.

south shore I observed a great number of ledges with nearly flat tops, from which the surmounting æolian pinnacles had been worn away; some of them were just awash at low-water mark, others reached half-tide mark, and a great number were sunken ledges. On these last, if forming the inner part of the outer line of ledges, are found Gorgonians and corals, giving them to a certain extent the appearance of a coral reef.

Off White Cliff Bay there is an excellent specimen of an irregular crescent-shaped barrier reef formed upon a ledge barely in contact with the beach at low water. The wall on the inside is formed of short irregular steps, and the inner area of the ledge is thickly overgrown with calcareous Algæ, more or less covered with æolian sand washed from the friable parts of the ledge.

The narrow pedestals which are the bases of some of the pinnacles of æolian rock are often the remains of extensive flat ledges on which the different organic growths characteristic of boilers have obtained a foothold. The parts of the tops and sides of these ledges which have not as yet been covered by such a growth, or only partially so, plainly show that they differ in no way except in size from the smaller mushroom-shaped æolian rock ledges, and are formed by the same agencies. The larger pinnacles of æolian rock like those still standing off Whale Bay will become, when they fall, large flat ledges upon which the sea when breaking digs out irregular pot-holes of all shapes and sizes. The remnant of the base of the pinnacle becomes, when worn away by the sea, either a shelf or a flat corrugated ledge, and the more or less vertical sides below low-water mark are worn away by the wash of the sea into mushroom-shaped ledges.

At the east end of Elbow Beach several patches of honeycombed shore rock ledges have been left stranded in the midst of the beach sand surrounding them. These ledges, if exposed to the action of the sea, would soon be worn flat, and according to the angle of their stratification would be dug out into atolls or other irregularly shaped structures protected by Algæ and Serpulae. The same serpuline growths and similar convoluted walls occur on the North Rock and the adjoining ledges on the north. Similar structures, forming more or less distinct reefs, also occur off the north shore and elsewhere on the edge of the reef flats, but they are not as numerous nor so well defined as a rule. They consist, however, always of the same mushroom-shaped ledges, sometimes still surmounted by their pinnacles of æolian rock, and of others abraded to the level of low-water mark, or even well below it. The shore ledges on the south coast are acted upon by short, sharp breakers, formed in from one



and a half to two fathoms of water, beating upon the ledges much as a small waterfall drops upon the rocks at its base. On the north shore the breakers and sea do not act with the same regularity as on the south shore. There, owing to the existence of an outer line of reefs, the conditions are more uniform than on the north shore, where the effect of the winds upon a comparatively broad stretch of sea are far more variable.

On the north shore the surface of the ledges between high and low water mark is protected mainly by a small species of barnacle, clusters of small *Mytilus* and incrusting *Nullipores*, and a few species of small *Algae*. At or below low-water mark *Sargassum* begins. *Serpulæ* are not as common as on the ledges off the south shore. On the north shore serpuline atolls are most numerous on the ledges off Spanish Point in an easterly direction for a distance of four or five miles.

The mode of formation of the peculiar and intricate windings of the vertical walls which crop up to the surface on the summits of the ledges, and which take on such complicated curves can readily be explained from the manner in which the ledges themselves yield to the action of the surf from the wash of the sea, and also from the angle at which the æolian strata lie when attacked by the waves.

The following diagrams will further explain the mode of formation of the various serpuline reef structures which have been described.

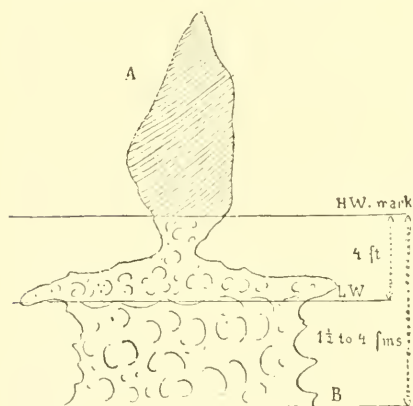


FIG. 1.

AB (Fig. 1) is a piece of shore cliff which has become isolated from the shore; the æolian lamination is clearly seen above high-water mark. Below high-water mark it is honeycombed and eaten away, leaving the æolian pinnacle supported only by a slender stem rising from an extensive base more or less covered with *Algae*, *Serpulæ*, and other growths. The surface of the ledge, as well as the base of the mass extending below

low-water mark, is more or less eaten away, and when the æolian pinnacle (A) has fallen off a mushroom-shaped mass is left, the upper surface of which may be above or below low-water mark. All trace of

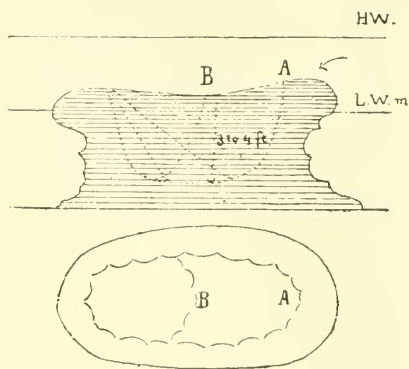


æolian stratification has been obliterated by the cementing and solvent action of the sea water. If the base, the mushroom-shaped ledge, is stratified horizontally (Fig. 2)

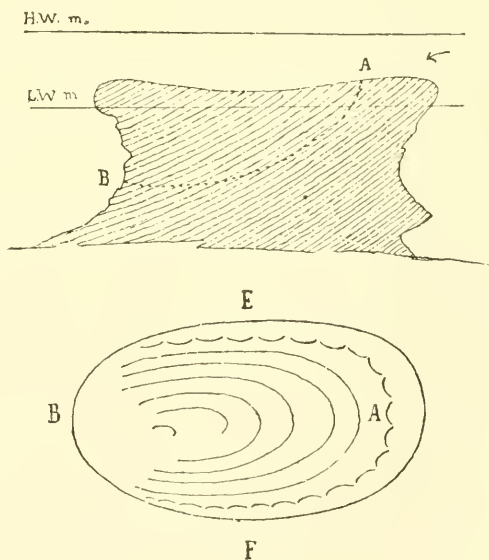
the result of the wash of the breakers upon any part of the top left unprotected will be to dig out circular or elliptical atolls (Fig. 3) like A or B. In one case, A, the atoll will have a rim of nearly the same width, while in the other case, B, if the softer parts of the top are on the lee side, the atoll will have a wider rim on the weather side from B to A, or a pot-hole may also be formed

between A and B. The pot-holes of these circular atolls are usually from three to four feet in depth. But in some cases I have measured them between five and six feet, and even more. In others they are only a few inches deep. I have not observed any growth of *Serpulæ* of greater thickness than from twelve to eighteen inches.

Should the æolian strata dip towards the lee side (Fig. 4) a horse-shoe-shaped atoll is formed, as indicated by the dotted line AB. The rim is widest at A, Fig. 5, gradually becoming narrower and lower towards the lee side as it nears B, the whole or the greater part of the



FIGS. 2, 3.



FIGS. 4, 5.

ledge having been carried away by the pounding of the surf, leaving

a high narrow wall with a deep opening at B between its extremities. Should the surf break through the sides at E or F, or both, we should have curved vertical walls left, apparently built up by *Serpulæ*, in reality walls of æolian rock which may be dug out as I have suggested, either in the case of Figure 2 or of Figure 4.

When the pinnacle finally drops off, it will in its turn be attacked by the sea, and go either to form a smooth ledge, to be covered with *Algæ* and *Serpulæ* according to the depth in which it lies, or may in its turn be attacked in a similar way to the ledge, and changed to an atoll or a crescent-shaped serpuline reef according to the dip of the strata. Before the breaking off of the pinnacle, *Algæ* and *Serpulæ* have already begun to grow upon the flat part of the ledge, and protect it to a great extent from the action of the sea. When the sea no longer washes round the pinnacle, but breaks on the ledge at low water, and finds a part which is not protected by *Algæ* or otherwise, it begins to erode it, the sand formed acting like a churn, and thus little by little forming a deep hole in the centre of the mushroom rock.

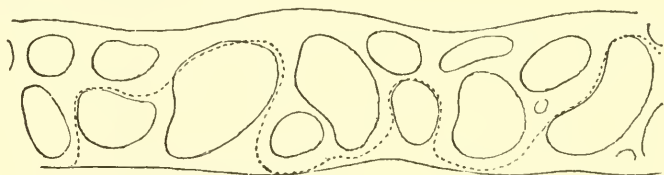


FIG. 6.

In the case of a long and wide ledge, there are formed upon it a number of secondary pits and atolls, or pot-holes, as indicated by the heavy lines of Figure 6. Let the walls of these break through and connect adjoining pot-holes and we obtain a vertical wall, of irregular outline, such as is indicated by the dotted line of the figure, which is a diagram of one of the ledges of the outer reef off the south shore. The wash of the sea may break through the continuous wall, leaving only disconnected parts standing, or we may have the outer walls on the edge of the ledge left, forming a long trough.

A flat ledge projecting from the base of a shore cliff, if eaten into in the same way by the surf (Fig. 7), may be worn into a circular reef with vertical walls, of which the top is protected by *Algæ* and *Corallines* or *Serpulæ*, with a pot-hole near its outer wall, in this case eight feet deep. We might call this a diminutive barrier reef. If the walls are parts of diminutive barrier reefs, the shore cliff behind them may disappear, and

thus leave a wall standing apparently isolated from the level of the ledge. It is not surprising that a cursory examination of these walls and atolls should have induced the earlier observers to attribute the growth to *Serpulæ*.

Rice accepts the theory that the serpuline reefs are due alone to the upward growth of *Serpulæ*. He has also observed the circular ridges of coral on the outer ledges (Millepores) similar to the serpuline reefs, except that they are less elevated, their upward growth being limited by the inability of the corals to survive an exposure above the water.

These circular reefs are either serpuline or edged by Millepores, and are called boilers; off the south shore they are generally serpuline, with only here and there a Millepore boiler on the inner patches. Along the east shore of Harrington Sound there are a number of such Mil-

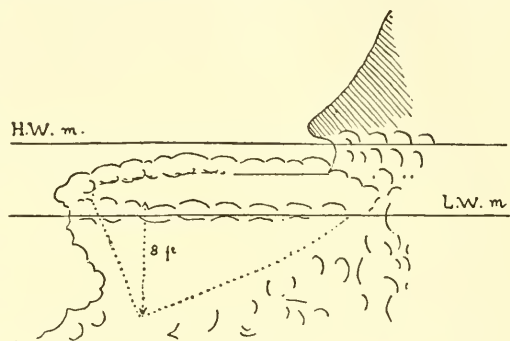


FIG. 7.

lepore atolls and barrier reefs which are merely rims of pot-holes protected by a growth of Millepores. A number of these Millepore reefs extend eastward on the northern side of the main channel off Spanish Point. Along the shores of Harrington Sound we meet occasionally one of the vertical walls or irregularly shaped pot-holes of a projecting ledge, the top of which is protected by a growth of Millepores, much as the *Serpulæ* and *Algæ* protect the walls of the pot-holes off the south shore. On many of the patches to the north of the main channel, in a line from Ireland Island to St. George, we find a similar growth of Millepores protecting the exposed ridges of æolian rocks. Thomson also considers the serpuline reefs as due to the agency of *Serpulæ*.

The existence of such a variety of reef forms under the same conditions naturally suggests whether the explanation by mechanical causes, such as finds here its application on a small scale for serpuline reefs, may not be a natural explanation also of the formation of the complicated systems of atolls of the Carolines, Marquesas, and Maldives, and whether small simple atolls like the typical ones of the Pacific, and many with complicated outlines, may not in many cases be due to the scouring ac-

tion of the sea working on a larger scale upon substructures easily yielding to its effects. When examining the Hogsty Atoll of the Bahamas I could not fail to be struck by the overpowering mechanical force incessantly at work. Huge breakers were constantly pouring an immense volume of water over the windward sea face of the atoll, filling its cup to overflowing, and it could find no outlet except over those parts of the sides which were lower than the windward face, or through which, near the lee ends, passages of considerable depth had been eroded, or, finally, through the still deeper channel between the lee extremities of the reefs forming the entrance to the atoll. That is, given a bank of suitable depth upon which corals can flourish, and upon a belt of a certain width, they will form a protective coating to the underlying rocks, just as the serpuline growths protect the rims of their diminutive atolls. Corals will naturally, from the centrifugal action of the sea, grow on the outer faces, and most abundantly in the direction in which they find least resistance in the way of detritus and other accumulations. The sea breaking over them will excavate a lagoon, and break through the sides or lee face to allow the water to flow out through the points of least resistance, and through the entrances to the lagoon. All these causes are important factors in any theory of coral reefs, and show the complexity of the problem, and the impossibility of framing a single hypothesis to explain the formation of coral reefs in all parts of the world.

Before seeing the serpuline atolls of the Bermudas it had occurred to me that the configuration of the Hogsty Reef and the formation of its atoll might be due to mechanical causes. We may imagine a bank of the proper depth, whether formed during subsidence or elevation is immaterial, on which corals begin to grow and form a barrier to the surf. The breaking of the surf over this living and protecting barrier digs out the least resisting portions of the surface of the bank, and the material thus dug out finds its way out on the opposite side. Little by little a lee channel is thus formed by the scouring of the mass of water poured over the reef into the incipient lagoon, and a lagoon may be formed on a large scale in the manner described for the formation of the serpuline lagoons of the Bermudas. We may imagine the Hogsty Reef at one time to have been a bank formed by a series of small, low æolian hills, which have been worn away and have disappeared from the same causes which acted on a larger scale at the Bahamas. The Hogsty Bank was thus brought by subsidence and erosion to its present level, or nearly so, after the growth of a barrier of reefs on the remnants of the æolian hill ledges, then began the action of the surf in eating away the central part

of the bank, scouring the lagoon to the depth and dimensions it has now attained. There is nothing to show that the depth of the lagoon of Hogsty Reef is due to subsidence, or that the rate of growth of the reef was synchronous with it, and thus formed the outer rim of the lagoon. On the contrary, judging by analogy and by the conditions existing in the Bahamas and Bermudas, we are led to infer that the lagoon of Hogsty has been formed by a mechanical process, that it is due to the action of the surf acting as an immense force pump driving the water over the weather face of the reef<sup>1</sup> out through the lee opening of the lagoon, or the openings of the sides of the ring, much as the diminutive serpuline atolls and crescent-shaped reefs or barrier reefs have been formed off the south shore of the Bermudas.

### POT-HOLES.

#### Plates XXIX., XXX.

Roots and stems, after being decomposed, may form branching cavities which if filled with stalagmitic matter would give rise to columnar structures. Such formations can be traced in the more recent dunes of the Bahamas and Bermudas, and of the Sandwich Islands. There is a type of pot-hole which imitates these structures<sup>2</sup> and has been confounded with the branched bodies, but which I do not believe to be organic structures at all.<sup>3</sup> They are the so called palmetto stumps, of which Rice has given an excellent description,<sup>4</sup> and which I imagine to be mechanical structures of a similar origin with the serpuline reefs (Plate XXX.).

To the north of the Devil's Hole, on the road skirting the east shore of Harrington Sound, we find a flat ledge of æolian rocks which is literally

<sup>1</sup> That water falling from a small height does thus excavate deep holes at the foot of falls is well known. Any country ditch dammed by a sluiceway will show this effect. It can be seen at the foot of every waterfall, and it occurs on the largest scale in the Mississippi, where the scour of the river below New Orleans has since the building of the jetties excavated a depth of between sixty and seventy feet in some cases,—a depth about the same as that of many lagoons of coral atolls.

<sup>2</sup> I cannot agree with Thomson (*Atlantic*, I. 330) in his explanation of the mode of formation of the pseudo palm stems, who considers them to have been formed on the bottom of caves by the dropping of stalagmite, and thus forming a single or double or dumbbell-shaped stem.

<sup>3</sup> Are not some of the tubes to which Professor Dolley ascribes a vegetable origin merely small pot-holes such as I have figured on Plate XXIX.?

<sup>4</sup> *Bulletin of the National Museum*, No. 25, p. 27.

riddled with pot-holes, many of which have become connected to form dumbbell-shaped cavities or other irregular forms (Plate XXIX.). They are in every respect similar to the serpuline atoll pot-holes off the south shore, but are much smaller, and become changed many of them into the so called palmetto bases.

An irregularly shaped pot-hole with a raised rim is one of the prominent features of one of the ledges on the north side of the causeway leading to St. George. In this case the greater hardness of the rim has formed the protective coat for the low vertical wall of the pot-hole (atoll). The transformation is readily followed in the pot-holes which are a little removed from the immediate action of the diminutive, but short and sharp, breakers of Harrington Sound. The inner cavity of the pot-holes becomes lined with a harder coating, being acted upon much as is the surface of the æolian rock. When the walls of adjacent pot-holes are eaten away or worn away by the action of the rains and of the sea, there may be formed an outer coating from the adjoining pot-hole, and thus an irregular cylinder will be left standing above the surrounding area. If the upper part of this is in turn disintegrated, we may have left a deep cup, or merely a ring of the base, or a side of the cylinder, or merely the harder inner coat of the bottom,—all of which stages resemble more or less the base of a palmetto (Plate XXX.). These pot-holes are often so close together (Plate XXIX.) that it is difficult to imagine a grove of palmettos the stems of which could be packed in the area occupied by the pot-holes. Captain Carr, R. N., called my attention to a locality on the east shore of Ireland Island where these pot-holes are numerous, and where one can trace all the transition stages just described from the pot-holes of the shore of Harrington Sound.

## NORTH ROCK.

### Plate VIII.

The North Rock is undoubtedly the most interesting monument left of the former extension of the Bermudian land. Owing to the difficulty of landing, it has not been visited frequently, but we were twice successful in landing at the North Rock Ledge.

Excellent descriptions of the North Rock pinnacles and ledges have been given by Rice,<sup>1</sup> and also by Heilprin in his volume on the Bermudas.

<sup>1</sup> Bulletin of the National Museum,



The flat ledge surrounding North Rock presents no features different from those of similar ledges off the south or north shore. Its surface rises here and there in low ridges, which are the remnants of the last pinnacles to be eroded; near the edges, and wherever the action of the breakers reaches, it has been dug into so as to form pools, pits, and pot-holes of various depths and shapes, and has been honeycombed in all directions, according to the quality and hardness of the rock and the extent of the protection afforded the rock surfaces by the growth of Algæ, Corallines, Serpulæ, and other organisms.

The North Rock Ledge is deeply undercut, and, like many of the larger islets off the main island, its sides are more or less vertical, or steep slopes deeply honeycombed and cavernous, and overgrown with Algæ, Corallines, Gorgonians, Millepores, and massive corals, much as any similar ledge or cliff or patch. The greater part of its upper surface is protected by the hard ringing æolian rock characteristic of the exposed intertidal spaces. The pinnacles which remain rising above the general level consist of æolian rock, and the lower base rock seemed to me to differ in no way from similar æolian rock as modified by the action of the sea in other localities. It is possible that the fossil *Cypræas* stated by Rein to have been found at the base of the pinnacles may be only such shells as have been collected from the serpuline rock in which they had become embedded. In some spots on the ledge it attains a thickness of from twelve to fifteen inches, and is full of boring Mollusks and of shells which have found a foothold in the cavities of the honeycombed rock. The serpuline rock itself often becomes quite hard, and might easily be mistaken for true hard ringing æolian rock, but is readily distinguished from it by the presence of the many sharp pinkish fragments of the tubes of Serpulæ.

The many Chamas and other Mollusks living on the edge of the North Rock Ledge at low-water mark would, if thrown up and embedded in æolian or serpuline rocks, present all the characters of the so called fossils found in the æolian rocks of the islands of Hamilton Harbor. At Agers Island and on the shores of the other islands of Hamilton Harbor we find at very low tides many specimens of *Chama* which would have to be carried but little way to become æolian fossils. Neither Heilprin nor myself found any fossils on North Rock. Heilprin considers the lower portion of the North Rock pinnacles to be unquestionably pits and pot-holes of the inner surface of the beach rock.

The outer edge of the northeastern part of the ledge is protected by Serpulæ, Algæ, and Corallines, forming low vertical walls as well as the

division walls of the irregular pot-holes of the ledge, and in places they overhang to a very considerable extent. The coating of Algæ and of Serpulæ on some of the walls of the interior pools is quite thin, as upon breaking off the edges we came upon the ringing æolian rock. On the northeast edge of the ledge a deeper pot-hole has formed a regular barrier reef, the edges of which are covered by Serpulæ, Algæ, and Corallines. On the interior of the ledge their growth is less vigorous. Outside of North Rock there are a few ledges, both to the southwest and to the northeast. Those towards the inner side of the reef are the outer reef patches, on which grow Millepores, Gorgonians, and the usual growth of corals, Algæ, and Corallines, which have completely hidden the nature of the ledges. The ledges which form the continuation of North Rock to the east and west, on the contrary, still plainly show that their structure in no way differs from that of the North Rock Ledge. Outside of North Rock "broken ground" extends to ten or twelve fathoms, but no patches of corals could be seen beyond five or six fathoms. We might call the outer ledges of the reef near North Rock a flat of coral heads and of Gorgonians. On the North Rock Ledge flat, Zoanthus, Millepores, Algæ, and Corallines are most flourishing.

Winding our way towards St. George Island from the North Rock, we picked our passage between the many mushroom-shaped ledges. Many of them came to the surface or nearly so, and on two of the ledge patches rather nearer the inner line of the ledge flats than to the North Rock I broke off a piece of hard ringing æolian rock in every respect similar to that of the North Rock Ledge flats.

We could not have a better example of the true nature of the reef ledge flats and patches than is exhibited by the North Rock Ledge and the adjoining patches. Those of the ledges nearest to the North Rock show the hard ringing æolian rock which marks the North Rock Ledge; some of the patches are separated from it by water five to ten fathoms deep.

We can easily imagine the whole of the ledge flats of the vicinity to have been made up of æolian rock ledges and pinnacles, very much like those off the north shore, on which corals, Gorgonians, and the like have little by little become attached, and have finally grown over not only the sides, but the upper surface after it became eaten away well below low-water mark.

There may have been on the northern reef flat ledges lower lines of hills than those now existing on the Bermudas, or low hills like those separating St. George and Castle Harbor, or along the west end of St. George Island and on the north side of Harrington Sound.

## PROTO-BERMUDA.

## Plate II.

Rein, Thomson, Rice, Fewkes, and Heilprin, all agree to the former greater extension of the Bermudian land, and Thomson,<sup>1</sup> speaking of the North Rock, and of Pulpit Rock off Ireland Island, says there can scarcely be any doubt that the dry land of Bermuda at one time occupied a space considerably larger than it does at present.

We may readily reconstruct the proto-Bermudian land from the existing charts (Plate II.). Beginning with the line and clusters of islands running from Ireland Island to St. David Head, these must in earlier times have been somewhat wider. The main island must have extended south beyond the line of the reef, and dry land must have completely barred the access of the sea to the sinks which on the east constituted Harrington Sound and Castle and St. George Harbors, St. George Island itself probably forming the western edge of the Ship Channel valley. On the west the main island reached to Hogfish Cut valley, and Somerset and Ireland Islands were probably connected with a range of æolian hills running from Chub Cut across Elies Flat. On the east, Ireland Island was connected with Spanish Point by a ridge which isolated Great Sound, Port Royal Bay, and Hamilton Harbor sinks from the outer lagoons, Great Sound and Hamilton Harbor both probably being disconnected sinks, and both isolated by low saddles from Great Sound sink. The ledge flats to the west of Hogfish Cut and to the north of Chaddock, Little, and Long Bars, which pass to the east of Chub Heads as far as Chub Cut, formed, in connection with the Elies Flat, hills of which the ledges are the remnants, the barrier separating a great sound larger than any now existing from the adjoining proto-Bermudian sounds. Of these we can trace four others of great size. One bounded on the southwest by the hills of Elies Flat, on the northwest by the hills of the ledge flat extending north from Chub Cut, on the north by the line of flats running east in the direction of Three Hill Shoals till they strike the eastern face of the sound formed by the Brackish Pond Flats, the eastern boundary reaching towards Spanish Point and separated from the shoals north of it by the Ship Channel valley. The second sound is enclosed by the Brackish Pond Flats on the west, by the Bailey Bay Flats on the north and east, and by the main island on the

<sup>1</sup> Thomson, *The Atlantic*, I. 318.

south. The third is the Murray Anchorage sound, limited on the west by the Bailey Bay Flats, on the north and east by the Three Hill Shoals and the flats west of Mills Breaker. The third sound opened by a narrow deep valley (the Ship Channel) towards the sea, and communicated by a wide passage with the fourth sound, bounded by the ledge flats of the northwestern part of the Bermudas, — flats which extend unbroken from the north of Western Blue Cut to the Eastern Ledge Flats, — and on the southern edge by the line of the Three Hill Shoals and by the western extension of the Bailey Bay Flats. This fourth sound is in reality a double sound, as the western part is separated from the eastern by a narrow line of æolian heads, indicating probably the position of a cross line of dunes connecting the Ledge Flats and Bailey Bay Flats. Its northern edge was deeply indented, as is indicated by the many tongues of deep water cutting into the width of the ledge flats (Plate II.). Two smaller and indistinctly connected sounds are similarly indicated to the west of East Ledge Flats and to the west of Mills Breaker. On the eastern ledge flats there are also a number of deep pockets, already referred to, as well as many deep bights running into the ledge flats, indicating the position of valleys running more or less at right angles to the trend of the ledge flats.

The Southwest Breaker and Chaddock, Little, and Long Bars are the base of lines of æolian hills, once running parallel with the edge of the western and southern Ledge Flats hills.

This proto-Bermudian land must have resembled the Bermudian landscape of to-day, and has been reduced to its present condition by the same causes which we see at work to-day on the islands of the group, and which have acted more vigorously either on the faces most exposed to the prevailing winds, or upon æolian hills of a lower altitude than those of the main island.<sup>1</sup> The proto-Bermudian sounds vary in depth from six to twelve or thirteen fathoms, the deepest being the sound to the north of Three Hill Shoal.

I also agree with Rice and Heilprin that the amount of subsidence must have been "sufficient to account for the depth of water which marks the lagoon and inner sounds," and that "before this subsidence took place probably the entire area now covered by the Bermudian

<sup>1</sup> "The prevalence of powerful winds on the south side would tend to elevate this side of the island, while the opposite side, not feeling this influence in any marked degree, would remain comparatively low and flat. In a period of subsidence the low side would naturally be the first to succumb to the waters, and would undergo submergence long before the elevated slopes. And this is precisely what appears to have taken place in the Bermudas." — Heilprin, *Bermudas*, p. 42.

archipelago, and much more, were dry land." But I do not think that "it was at this time, doubtless, that the great sand dunes were elevated." On the contrary, I do not imagine the dunes to have been elevated, but to have perhaps been blown to their greatest height in the manner suggested from a broad coral sand beach.

Heilprin adopts the suggestion thrown out by Rice, that these æolian accumulations could only have been formed at a time when large areas of reef, and not a simple atoll ring, were exposed above the water level,<sup>1</sup> while it is perfectly true, as Heilprin says, that all the sand formed at the present day is derived from the destruction of the existing land masses, and not as a product of the disintegration derived from the growing reef, — a statement which by the way hardly agrees with the graphic description of the destruction of the coral reef off the south shore given by him a page or two before.

It does not seem to me necessary that there should have existed very wide areas of coral reefs for the formation of the Bermudian æolian hills. A reef of a width of 1,200 to 1,800 feet, such as are known to exist, seems to me ample to supply the material necessary for the formation of the æolian hills, especially if, as may have been the case judging by the soundings off the reef, there also existed a comparatively wide shallow bank outside of it. Taking the subsidence of the Bermudas as twelve fathoms, this belt could have been a belt of twelve to twenty fathoms, a shallow bank, the wear and wash from which would alone supply a large part of the material needed for the formation of the Bermudian dunes, and carry the topography now prevailing pretty well over the whole of the bank inside the ten or twelve fathom line. In addition, we should of course also have the supply derived from the reef itself. The amount of material which can be supplied from a comparatively small reef and its adjacent bank I saw well illustrated at the Sandwich Islands. A number of dunes were constantly travelling inland from the beach at Spreckelsville, and had covered to a considerable elevation a great part of the isthmus connecting the two islands which constitute Mani. Very high dunes, from 120 to 180 feet, of nearly a mile in width, occur on the shores of the Baltic, the material of which is derived from a comparatively narrow beach range.

I fully agree with those who before me have examined the Bermudas, and who consider that subsidence has brought about the existing condition of the islands and sounds. But that is a very different thing from assigning to the corals now growing the formation of the islands owing to

<sup>1</sup> The Bermuda Islands, p. 46.



this subsidence. That the proto-Bermudian land was of elliptical shape, and owed its existence to the action of winds sweeping over an extensive coral beach, from which was gathered the material which now form the solidified æolian hills of the Bermudas, no one can question. But there is no evidence to show that the original annular coral reef was formed during subsidence. That reef has disappeared, and nothing is left of it except the remnants of the æolian ledges, extending to sixteen or seventeen fathoms outside of the reef ledge flats, ledges which owed their existence to the material derived from it, — the former æolian hills of the proto-Bermudian land. Remnants of such ledges and former æolian hills are the rocks forming the outer ledge flats, the breakers all along the south shore, the Mills Breaker, the North Rocks, the Chub Heads, the South-west Breaker, and others.

The evidence of the extent of the subsidence which has taken place at the Bermudas is very clear. It is based upon the depth of the sounds and of some parts of the lagoon, the existence of æolian rock at a depth of fifty feet below low-water mark, and the excavation of red earth from a depth of forty-eight feet below low-water mark on Ireland Island,<sup>1</sup> and at eighteen feet below low-water mark in the entrance to St. George Harbor. Numerous caves and caverns occur in the Bermudas, which have been fully described by previous writers. Many of them, although extending far below low-water mark, could only have been formed when the islands were at a greater elevation than at the present day. In the caves, as well as smaller ponds or embryo sounds close to the shores, the porosity of the æolian rock, as well as its cavernous and honeycombed structure, is indicated by their connection with the sea. The water rises and falls in the caverns with the tides, and the beat of the diminutive waves against the subterraneous shores of the caves closely follows that of the sea outside.

<sup>1</sup> Sir Wyville Thomson has given a section of the rocks exposed during the excavation for the basin of the dry dock at Ireland Island (Atlantic, I. 319.) Huge stalactites and stalactites covered with *Serpula* extending below low-water mark in some of the caverns clearly indicate the effects of the subsidence. Trunks of the Bermuda cedar have been found in the red earth at a depth of forty-eight feet in the excavation of the dry dock, and have also been dredged from the bottom of Hamilton Harbor in a depth of five fathoms. This is of no great value as evidence, since the stumps may have fallen in from the surrounding hillsides, have floated off, and become water-logged. According to General Lefroy, one of the great bogs of the main island extends to a depth of forty or fifty feet below the sea level, and indicates the depth to which one of the sinks of the proto-Bermudian land reached before the subsidence took place which resulted in the present configuration of the islands.



At the Bermudas we find nothing corresponding to the ocean holes of the Bahamas, unless it be that such cavernous sinks and indentations as occur all along the shores, and which can be detected on the edges of the reefs and ledges, or in the circular areas where the depth is sometimes greater by two to three fathoms than over the adjoining area, may correspond to ocean holes, but only on a smaller scale of depth.

Heilprin thinks "that the height of land in the archipelago was formed during a period of elevation." It seems to me more natural to suppose that the Bermudas were formed during a period of rest, when the level of the reef was stationary, and they were flanked by a broad sand beach with flats perhaps bare at low water. These would supply an abundant material for the formation of such dunes as we now find, and may imagine to have existed on the northern edge of the Bermudas and on the flats which determine the shape of the proto-Bermudian lagoons.

While I fully agree to the all-important part which subsidence has played in shaping the Bermudas as they now exist, I cannot trace any connection between these facts and the proposition that "the existence of an atoll in the present position of the Bermudas is not demonstrable." We certainly have a group of æolian hills formed from an annular ring of coral reefs which flourished when the land was at least seventy feet higher than at present. But the facts we observe on the islands to-day do not shed one ray of light on the question of the Darwinian theory of the formation of atolls. The position of the reef to which the Bermudas owe their origin can only be surmised, — and probably very correctly, — but we cannot state that it was formed during a period of subsidence, and have no data regarding this point. Subsidence has given to these islands their present configuration. But it is begging the question to state that the formation of the proto-Bermudian coral reef, about which Heilprin himself is careful to say we know nothing, if it does "not prove the correctness of the Darwinian theory of the formation of coral islands, measurably sustains it."<sup>1</sup>

We may also agree with him in the conclusion that the present form of the Bermuda Islands bears no relation to the ring of an atoll,<sup>2</sup> that

<sup>1</sup> "The question as to what form of coral structure the Bermudas actually are — what constitutes their fundament, and how they were built to their existing level — still remains unanswered, and possibly we may never be able to answer." — Bermudas, p. 47.

<sup>2</sup> Heilprin says: "In the case of the Bermuda Islands, which limit the field of my own investigations in this direction, I am confident that, whatever may have been the original construction of the region, the present lagoon features have been brought about through subsidence; and this conclusion was reached before me by

the existence of an atoll in the present position of the Bermudas is not demonstrable, and that the lagoons and sounds were formed, as Rice first showed, during a period of subsidence.<sup>1</sup> But granting all this, what is the connection of an island group which according to him has no relation to the ring of an atoll, of an island for which the existence of an atoll cannot be demonstrated, with the Darwinian theory of the formation of coral reefs? How can the conclusions arrived at by Heilprin be reconciled with the following statements made by him:—

“It will be seen that these results, so far as they go, are in absolute harmony with the views which Mr. Darwin entertained regarding the structure of these islands. They do not prove the correctness of the Darwinian hypothesis of the formation of coral islands, but they measurably sustain it; on the contrary, they are largely opposed to the requirements of the substitute theory which has been recently proposed. Elevation and subsidence are both shown to have marked the region in its development, and these conditions are more in consonance with the Darwinian hypothesis than with any other.”<sup>2</sup>

Investigators have been carried away by the simplicity of the theory of subsidence propounded by Darwin, and it is only of late years since a mass of observations have been made which could not be explained by the prevailing theory that we have at last realized how complicated the problem is. Heilprin, as well as others before him, has truly said, “We may not yet have fathomed the true method of the formation of coral islands.” But I must differ from him *in toto* when he says, “but such evidence as I was able to obtain at the Bermudas failed to convince me of the erroneousness of the time-honored theory of subsidence.”<sup>3</sup>

The exploration of the Bahamas and of the Bermudas has brought into prominence a condition of things relating to the formation of coral reefs, the bearing of which had not been realized before. It is perhaps one of the most significant examples of how little we as yet know of the history of the formation of the coral reefs.

Professor Rice, who seems to have been amply satisfied with the subsidence theory.” — Bermudas, p. 75.

<sup>1</sup> Heilprin has well stated the conditions of the disintegration of the land when he says: “The difficulty in the problem entirely disappears if we admit subsidence, and, as has already been seen, the positive evidences of subsidence are ample. On no other theory, it appears to me, can the waste of the cliffs on the south shore be explained. The direct evidences of subsidence, moreover, do not come from a single point in the archipelago; they are found from Ireland Island and Hamilton Sound, through the main island, to St. George.”

<sup>2</sup> Bermudas, p. 46.

<sup>3</sup> Bermudas, p. 21.