PART I.

THE GEOLOGY OF BERMUDA.

BY

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THE GEOLOGY OF BERMUDA.

HISTORY AND LITERATURE OF THE SUBJECT.

The Geology of Bermuda has already been the subject of more or less elaborate discussion by several authors. An important memoir by Lieut. (now Maj. Gen.) Richard I. Nelson, R. E., is contained in the Transactions of the Geological Society of London, Second Series, Vol. V., Part first, pp. 103–123. This paper is based on observations made in the years 1827–1833, while the author was stationed on the islands. The excavations made in the construction of the fortifications under his charge afforded him admirable opportunities for the study of the structure of the rocks, and his work gives evidence of thorough and conscientious investigation. Though written before the genius of Darwin and Dana had given the world the true interpretation of coral reefs and islands, and therefore failing to trace aright the history of the events recorded in the Bermudian limestones, this paper is invaluable to subsequent investigators as a store-house of facts. J. Matthew Jones, F. L. S., who has resided a number of years in Bermuda and paid much attention to its natural history, has given us important geological notices in his Naturalist in Bermuda,* and Visitor's Guide,† and various papers in the Proceedings and Transactions of the Nova Scotia Institute of Natural Science, and in Nature. In 1873 Bermuda was visited by the Challenger expedition, and important observations were made on the geology, as well as other branches of the natural history, of the islands. Some important points, notably the origin of the "red earth," were first explained by the naturalists of the Challenger. Bermuda forms the subject of an interesting chapter in Sir Wyville Thomson's work.‡ Brief references to Bermudian geology are contained in the classical works

* The Naturalist in Bermuda; a Sketch of the Geology, Zoology, and Botany of that remarkable group of islands; together with Meteorological Observations. By John Matthew Jones. With a map and illustrations. London, 1859.

† The Visitor's Guide to Bermuda. With a sketch of its Natural History. By J. Matthew Jones. London.

‡ The Atlantic. A preliminary account of the general results of the Exploring Voyage of H. M. S. Challenger, during the year 1873 and the early part of the year 1876. By Sir C. Wyville Thomson. New York, 1878. Vol. I., Chapter IV.

of Darwin* and Dana;† but their treatment of the subject is less satisfactory than it would have been if these masters of the theory of coral formations had had the opportunity of visiting the islands. My own observations were made during a sojourn of a few weeks in the winter of 1876–'77. It is a pleasure to me in this connection to acknowledge my obligations to Prof. G. Brown Goode, of the Smithsonian Institution, J. Matthew Jones, F. L. S., Maj. Gen. Sir J. H. Lefroy, Governor of Bermuda at the time of my visit, Mr. James Carruthers, of Her Majesty's Dock-yard, and Mr. C. M. Allen, United States Consul, for calling my attention to interesting and instructive localities; and especially to Prof. James D. Dana for most important suggestions in regard to the problems presented by the islands, communicated in a conversation just before my visit.

PHYSICAL GEOGRAPHY OF BERMUDA.

The reefs and islands comprised under the name of Bermuda are nearly included between the parallels of 32° 10′ and 32° 20′ N., and between the meridians of 64° 40′ and 65° W. from Greenwich. The line of the outer reef incloses an approximately elliptical area, whose major and minor axes are respectively about twenty-five and about twelve miles in length. The major axis trends about N. 50° E. Only a very small part of the elliptical area thus described is dry land. The dry land is almost confined to the south-easterly side of the ellipse, forming a narrow and broken strip about fifteen miles in length, and nowhere more than three miles in width. The areas of the principal islands are as follows:

	Acres.
The Main Island	9,725
St. George's Island	706
Somerset Island	702
David's Island	527
Ireland Island	133

The whole area of dry land in the archipelago is estimated at 12,378 acres.‡

About three quarters of the whole area of dry land is included in the Main Island, or Bermuda proper. The line of the Main Island is con-

* The Structure and Distribution of Coral Reefs. By Charles Darwin. Second edition. London, 1874. Appendix, pp. 264, 265.

† Corals and Coral Islands. By James D. Dana. New York, 1879. pp. 218–221, 361, 370, 391, 393–395.

‡ The Bermuda Pocket Almanack. Bermuda, 1877. pp. 60, 61.

tinued north-eastward by St. George's and David's Islands. The south-western extremity of the Main Island bends around towards the north, and the curve is thence continued northward and north-eastward by the islands Somerset and Ireland. The hook-like south-west extremity of the Main Island, with its continuation in Somerset and Ireland Islands, incloses a lagoon called Great Sound. Two other lagoons are included within the chain of islands on the southeast side of the ellipse: namely, Harrington Sound, inclosed entirely by the Main Island, and communicating by a passage not exceeding 50 feet in width with the great elliptical lagoon inclosed by the outer reef; and Castle Harbor, inclosed by the eastern end of the Main Island, St. George's, David's, and several smaller islands. The central part of the Main Island is occupied by a peat-bog. The surface of this part of the island is elevated but little above the sea-level; and the peat, as I am informed by General Lefroy, extends to a depth of 40 or 50 feet below the sea-level—a depth about equal to that of the great lagoon inclosed by the outer reef. This bog appears to mark the situation of a small lagoon now entirely filled up.

The surface of the land is considerably diversified, though nowhere attaining any great elevation. The highest hills are only about 250 feet above the level of the sea.

In consequence of the small extent of the land both horizontally and vertically, and the extreme porosity of the rock of which it is composed, there are no springs, streams, or lakes of fresh water in the islands. The rain that falls, where it is not collected in artificial tanks, soaks down into the porous rock until it mingles near the level of the sea with the salt water with which the lower parts of the rock are saturated. The water in the ponds and marshes, which occupy considerable areas in the less elevated parts of the islands, is always brackish. The inhabitants depend for their supply of water chiefly on the collection of rain in tanks. These tanks are connected not only with the roofs of the houses, but with areas on the hillsides scraped smooth for that purpose.

The chain of islands is bordered on the south-east by a fringing reef, distant perhaps a quarter of a mile on the average from the shore. On the north side of the ellipse the line of the reef is nearly continuous; but the only dry land is the little islet, or group of islets, the largest of which, called North Rock, is about 8 feet in diameter and about 14 feet in height.

Along the course of the reef are numerous rings of calcareous rock, a few feet or yards in diameter, rising to a level of about 2 feet above low-tide level. The crest of these circular ridges is formed in large part of the calcareous tubes of tubicolous worms. They are appropriately called by Nelson "serpuline reefs."* The elevation of these serpuline reefs above low-tide level is due to the fact that these worms, unlike the coral-forming anthozoa and hydrozoa, can survive an exposure for some hours out of water. There are circular ridges of coral reef similar to these serpuline reefs, except that they are less elevated, their upward growth being limited by the inability of the coral animals to survive an exposure above the water. These circular reefs are called, commonly, "boilers." The form of both varieties of these "boilers" illustrates well Chamisso's theory of atolls—a theory which, though inadequate for the explanation of atolls in general, recognized a principle which has played an important part in the history of coral formations.†

The depth of water in the elliptical lagoon inclosed by the outer reef is generally 6 or 8 fathoms, though there are many patches of reef scattered through the lagoon. Outside of the reef the water deepens gradually for a mile or more, the average depth at the distance of a mile being only about 12 fathoms. A little further from the shore a more abrupt descent commences, the depth at a distance of 10 miles in every direction except the south-west being from 1,500 to 2,250 fathoms. "Twenty miles to the southwest-by-west from the Bermudas there are two submerged banks, 20 to 47 fathoms under water, showing that the Bermudas are not completely alone, and demonstrating that they cover a summit in a range of heights."‡ The Challenger expedition obtained a sounding of 2,950 fathoms about 300 miles further on in the same direction, indicating apparently that the range is not of great extent in that direction.§

IS BERMUDA AN ATOLL?

The general form of the Bermuda Archipelago, as represented on a map, is strikingly suggestive of the belief that it is a compound atoll, similar to Mahlos Mahdoo and some other atolls of the Maldiva Archipelago. The great depth of water within a few miles of the islands, and the exclusively calcareous character of the rocks of which the islands are composed, tend to confirm this impression. Dana‖ and Thomson¶ regard Bermuda as truly an atoll. Darwin apparently

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* *Op. cit.*, pp. 105, 116.

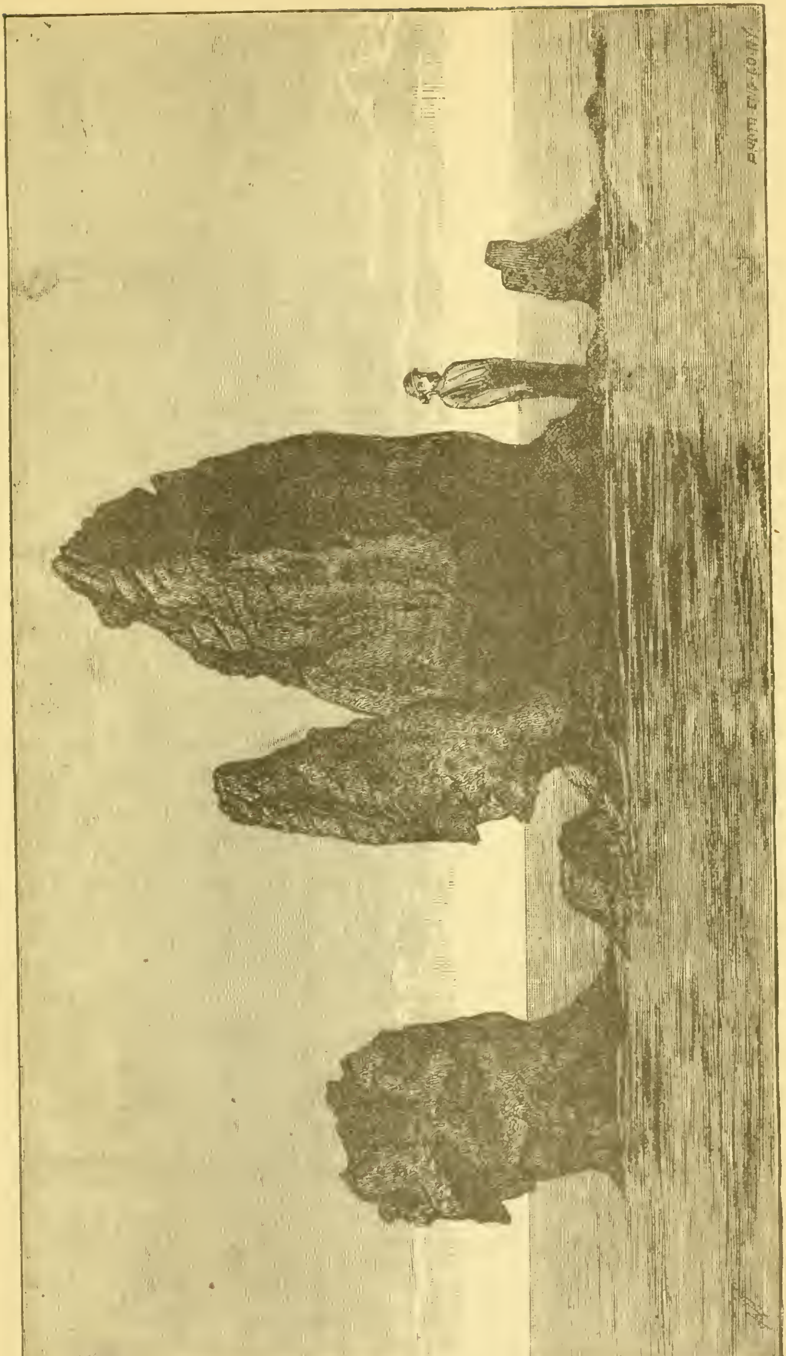
† Darwin, Coral Reefs, pp. 78, 118.

‡ Dana, Corals and Coral Islands, p. 370.

§ Thomson, *op. cit.*, Vol. I., p. 286.

‖ Corals and Coral Islands, p. 218.

¶ *Op. cit.*, Vol. I., p. 280.



North Rock, Bermuda.—(From a photograph by J. R. Heyl, of Hamilton, Bermuda.)

inclines to the belief that it is not an atoll, and calls attention to the following points in which Bermuda differs from atolls in general: "First, in the margin of the reef not forming a flat, solid surface, which is laid bare at low water; secondly, in the water gradually shoaling for nearly a mile and a half in width round the entire reef; and, thirdly, in the size, height, and extraordinary form of the islands, which present little resemblance to the long, narrow, simple islets, seldom exceeding half a mile in breadth, which surmount the annular reefs of almost all the atolls in the Indian and Pacific Oceans."* These differences are certainly of great importance; yet I believe that they are all capable of explanation on the theory that Bermuda is an atoll. I believe we may recognize the causes of these peculiarities in the peculiar history of the islands. Bermuda has a special interest in view of its position. It is perhaps the only atoll in the Atlantic Ocean, the atoll character of the Bahamas being at least doubtful.† Bermuda is also remarkable as being more remote from the equator than any other coral formation, the growth of corals there being rendered possible by the influence of the Gulf Stream.

THE CORAL LIMESTONE AND ITS VARIETIES.

As already stated, the only rock found *in situ* in Bermuda, if we except the peat or muck of the bogs, and the "red earth," which will be specially treated of hereafter, is limestone. The rock varies, however, exceedingly in texture. The extremes are an unconsolidated, calcareous sand, a subcrystalline rock of almost flinty compactness, and a coarsely crystalline stalagmite. The hard, compact rock is locally called "base rock," and the name is employed in that sense by Nelson;‡ but it does not uniformly underlie the softer rocks, nor is there any evidence that it is older than they.

Dana distinguishes in coral reefs and islands three kinds of rock in respect of the mode of formation: viz., reef-rock, beach sand-rock, and drift sand-rock.§ The reef-rock is that which constitutes the reefs proper. It is formed by the accumulation of the more or less finely comminuted material of the corals, shells, and other skeletons of marine animals, on the grounds where the corals are growing. It can therefore never be formed at an elevation much above low-tide. The beach sand-rock is formed by the action of the waves sweeping up against the

* Coral Reefs, p. 264.

† Darwin, Coral Reefs, pp. 256–259; Dana, Corals and Coral Islands, pp. 213–218.

‡ *Op. cit.*, p. 109.

§ Corals and Coral Islands, Ch. II.

shore the calcareous sands resulting from the disintegration of shells and corals, precisely as in other places the waves sweep up the silicious sands of an ordinary beach. The beach sand-rock is therefore formed chiefly between the levels of low and high tide, though the action of storms may cause it to extend somewhat above the ordinary high-tide level. The drift sand-rock is formed by the action of winds seizing the dry sand at the upper margin of the beach and transporting it further inland and to greater elevations. The drift sand-rock may therefore be formed at any level, from that of high-tide upward. The cement which converts all these fragmental deposits into solid rock is formed by the solution of the calcareous particles themselves.

A most important step in the investigation of the history of a coral island is the recognition of the respective distribution of these three kinds of rock. The discrimination of the true reef-rock from the sand-rocks is not usually a difficult task. The reef-rock, whether fossiliferous or not, is usually readily distinguishable by the impalpable compactness of parts of the mass, resulting from the consolidation of the finely triturated coral mud; while the sand-rocks, even when appearing quite compact, will almost invariably reveal on closer examination their arenaceous texture.

The discrimination of the two kinds of sand-rock from each other is much more difficult. Indeed, no absolute criteria exist for the discrimination of beach-rock and drift-rock, though serviceable indications may be obtained from the texture, lamination, and fossil contents of the rocks. The beach-rock is, on the average, of coarser grain than the drift-rock, as the wind sweeps along chiefly the finer sands; but some specimens of the drift-rock are coarser than some specimens of the beach-rock. The beach-rock is, on the average, more perfectly consolidated than the drift-rock, but in this character also both rocks vary widely. Drift-rock, when submerged by a subsidence subsequent to its deposition, may come to assume the degree of consolidation usually observed in beach-rock. On the south shore of the Main Island, near Spanish Rock, I observed strata perfectly continuous dipping towards the water, exceedingly hard at the margin of the water, but becoming considerably softer as they were traced upward and landward. Mr. Ebenezer Bell, who some years ago had charge of some works in progress on Boaz Island, informed me that he found that rock so soft as to crumble in one's fingers became quite hard on immersion for a week or a fortnight in sea-water. Some of the hardest rock which I observed in

Bermuda was shown by other characters to be unmistakably drift-rock A more reliable distinction is found in the lamination, the beach-rock showing a gentle and tolerably uniform dip towards the water, while the drift-rock shows the high and extremely irregular dips which are characteristic of wind-blown sands. But not every section exhibits characters sufficiently marked to settle the nature of the rock, since the beach-structure admits of a considerable degree of irregularity in dip, while wind-blown sands in a long ridge or dune may have for long distances a gentle and nearly uniform dip. The indication furnished by the fossil contents of the rocks is important. The beach-rock is often richly fossiliferous, containing shells and pieces of coral of considerable size. The drift-rock can, of course, ordinarily contain no relics of marine animals except fragments so small as to be blown by the wind. A high wind can, however, sweep along pieces of shell and coral larger and heavier than one would at first suppose. The flat, thin valves of lamellibranchs are more likely to occur in drift-rock than shells of gasteropods. In the recent sand-drifts at Tucker's Town I collected a number of organic relics, thinking they might afford some indication as to the limit of size of marine fossils likely to occur in the drift-rock. Among them were a fragment of the shell of Spondylus weighing 1.8 grammes; a valve of Chama, incrusted with tubes of Serpula, weighing 2.7 grammes; and a fragment of the coral Mycedium, having a length of 45 millimeters and a breadth of 30 millimeters, and weighing 8.3 grammes. Of most frequent occurrence in the drift-rock of Bermuda is the large and heavy shell of Livona pica. This seems at first sight utterly paradoxical, as the shell is altogether too large to be moved by the wind. The true explanation is undoubtedly that given by Nelson, who states that he has on more than one occasion seen soldier-crabs running about in these shells.* While the presence of marine fossils in a sand-rock is an indication that it is a beach-rock, the drift-rock is quite apt to contain the shells of land snails. The presence of snail-shells cannot, however, be regarded as a sure proof of drift-rock, since they might easily be washed down by rains from a bank or bluff above the beach, and imbedded in the beach sands.

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. Near Elbow Bay and at Tucker's Town, sand-hills are now in process of formation. At the

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* *Op. cit.*, p. 112.

former locality the advancing dune has nearly buried two small houses, and is encroaching upon cultivated grounds. Nelson* gives us an account of the beginning of this invasion, and Thomson† describes the present condition of the dune. At these localities there is an opportunity to study the mode of formation of the two kinds of rock, and to observe the perfect continuity of the two formations. As the wind catches the sand on the upper and drier part of the beach, and moves it landward, the beach merges above, with no perceptible line of demarkation, into the base of the sand-hills. But though, in the nature of the case, there can be no absolute distinction between beach-rock and drift-rock, it is practicable, by noting all the indications of texture, lamination, and fossil contents, to decide in most cases with confidence whether the rock exposed in a particular section is beach-rock or drift-rock.

There is no reef-rock in Bermuda *in situ* above the water-level. Nelson speaks of blocks of coral reef imbedded in the rock on the south shore of the Main Island.‡ I observed detached blocks of reef-rock on the shore at Stock's Point, but none *in situ*. In the statement, "Toward the shores the solid reef-rock outcrops,"§ Dana is apparently misled, in a way very natural for one who has not visited the locality, by a statement of Nelson. The rock described in Dana's quotation from Nelson as "very hard, fine-grained or compact limestone, in which scarcely a vestige of organic structure is to be seen,"‖ shows on careful examination an arenaceous texture, though consolidated by percolating waters to a sub-stalagmitic condition, exhibits traces of irregular lamination, and contains fossil shells of land snails. It is unquestionably an extremely hard drift-rock, such as is found at several localities and at various altitudes.

Beach-rock occurs at various localities along the shore of the islands. Thomson's statement that the Bermuda limestone is entirely an "Æolian formation"¶ is certainly inaccurate. I have never observed the beach-rock in the interior, nor at an altitude of more than about 15 feet above the water-level. To the category of beach-rock may undoubtedly be referred the fossiliferous stratum described by Nelson** as appearing in the chain of islands stretching across the mouth of Crow-lane or Hamilton Harbor. This stratum reaches an elevation of about 6 feet above the water, and its nearly horizontal lamination con-

* *Op. cit.*, pp. 109, 110. † *Op. cit.*, Vol. I., pp. 289–291.

‡ *Op. cit.*, p. 111. § Dana, Corals and Coral Islands, p. 220.

‖ Nelson, *op. cit.*, p. 106. ¶ *Op. cit.*, Vol. I., p. 287. ** *Op. cit.*, p. 111.

trasts strongly with the high dips observable in the drift-rock on the Main Island in the vicinity of Hamilton. Near the south end of Ireland Island I observed a stratum of almost perfectly unconsolidated sand abounding in shells. In the lower layers of this sand the shells are of marine species. In the uppermost layer the shells are those of land snails. The stratum is overlain by ordinary drift-rock. The layers containing marine shells attain an elevation of about 15 feet above the water. In spite of the lack of consolidation of this stratum, I can hardly doubt that its lower layers are truly a beach formation, and that the transition from marine to terrestrial fossils marks an epoch of elevation. A conglomerate evidently of beach origin appears at Stock's Point, the part which remains *in situ* on the north shore of the Point reaching an elevation of about 12 feet; though Mr. J. T. Bartram, an enthusiastic self-taught naturalist residing near the spot, assured me that, in a part of the bluff which has been removed in quarrying, the conglomerate attained a considerably greater altitude. Unquestionable beach-rock appears on the north shore of St. George's near Fort Catherine. The rock is at that locality richly fossiliferous. But the most instructive localities of the beach-rock which I have observed are along the south shore of the Main Island. At various points along that shore the beach-rock, more or less fossiliferous, with its characteristic gentle dip seaward, forms a gently sloping platform, at the back of which rises a low cliff of drift-rock with steep landward dips. The most thoroughly satisfactory locality which I observed for the exhibition of the relations of the two rocks is near Devonshire Bay. There the beach-rock, which forms (as in other localities along the south shore) a platform gently sloping seaward, is in places fine-grained and very hard, in other places fossiliferous with shells and pieces of coral of considerable size. It is surmounted by the usual low cliff of drift-rock with high landward dips. Overlying the hard beach-rock of the shore platform, and underlying the drift-rock of the cliff, is a stratum of unconsolidated sand, resembling that observed at Ireland Island, containing marine shells in its lower layers and land shells in its uppermost layer. This stratum of sand is mentioned by Nelson,* though he seems to have misapprehended the character and relations of the fossiliferous beach-rock which underlies the sand stratum. The sand stratum is not recognizable at some of the localities on the south shore where the phenomena are in other respects as above described.

* *Op. cit.*, p. 107.

All the rock in the interior of the islands, and all the rock which is much elevated above the water level, is drift-rock. Indeed, substantially the whole mass of the rock visible in the islands is drift-rock. Probably along the greater part of the shore drift-rock comes down to the water's edge, no other rock being visible. I was not able to examine the whole of the coast, but I am confident that drift-rock comes down to the water's edge along the north shore of the Main Island from Spanish Point to the Flats and beyond, along a part at least of the north shore of St. George's, around a considerable part, if not the whole, of the circuit of Harrington Sound and Castle Harbor, around the head of Hamilton Harbor, and in many places even along the south shore of the Main Island—the region of the coast in which the beach-rock is best exhibited. North Rock, at least in its upper part, is formed of drift-rock, as is shown by the high dip of its lamination.* This character of the rock is well shown in the beautiful photograph taken by Mr. J. R. Heyl, of Hamilton. The drift-rock is usually very soft, so that it is quarried out for building purposes by means of a peculiar long-handled chisel, in large blocks, which are readily sawn into pieces of such size and shape as may be wanted. Most of the houses in Bermuda are built of this exceedingly friable stone. Even the roofs are covered with the same material sawn into thin slabs. This stone, covered with a coat of whitewash, is sufficiently durable for ordinary buildings in the Bermudian climate. Exposed to the frosts of a New England winter, it would of course crumble very rapidly. Although the drift-rock is generally quite soft and friable, it is sometimes very firmly consolidated and of a subcrystalline texture. This hard rock is quarried like any ancient limestone or marble, and has been used in the construction of the fortifications and other government works. The quarries at Paynter's Vale and on Ireland Island are in such a hard drift-rock. The quarry of the Royal Engineers, near Elbow Bay, appears to be in beach-rock. It would be a curious question, what are the precise conditions which have determined the varying action of the rains on these accumulations of coral sand. While in some localities the sands have been merely washed away and dissolved, in others the grains have been, by the action of the same rains, cemented firmly together, until the rock has assumed a sub-stalagmitic texture, as at Paynter's Vale.

The usual softness of this drift-rock has made it a matter of small labor and expense to secure easy grades on most of the roads in the

* Thomson, *op. cit.*, Vol. I., p. 296.

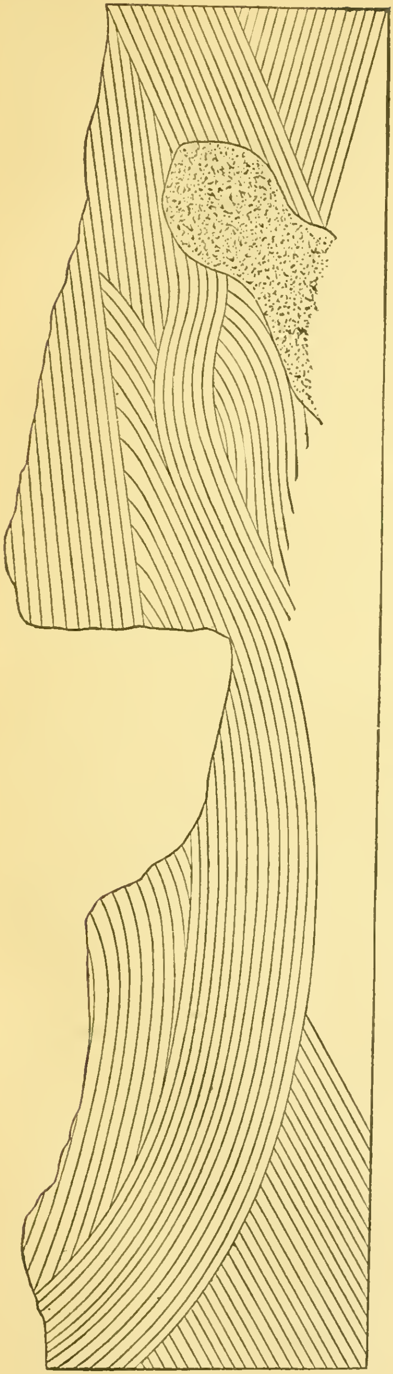


FIG. 1. Section near TRINITY CHURCH, Hamilton, Bermuda.

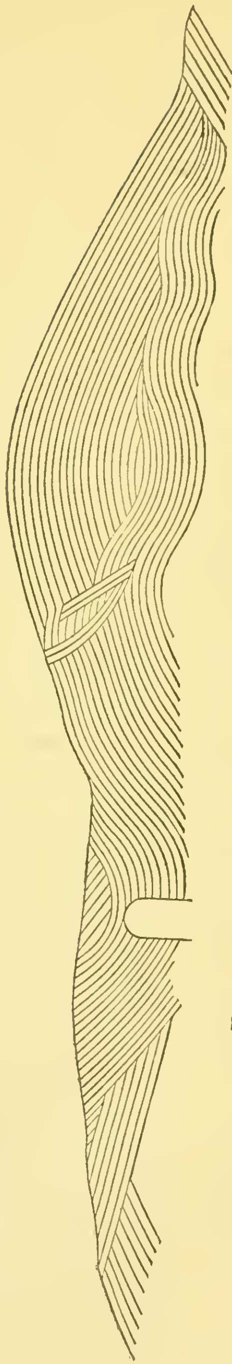


FIG. 2. Section near GOVERNMENT HOUSE, Mount Langton, Bermuda.

islands, by making quite deep cuts wherever they are required. These cuttings are of great interest to the geologist, from the beautiful illustrations which they afford of that extreme irregularity of lamination which is characteristic of wind-drifts. Not only the country roads, but also the streets of the towns abound in these beautiful and instructive sections. Fine exhibitions of this same structure are to be seen in the natural sections afforded by the cliffs and pinnacles of the shore. The characteristic structure of the drift-rock is shown in plates III and IV.

The height of these accumulations of wind-blown sands is certainly remarkable. The highest hills on the islands attain an altitude of about 250 feet; and, since no rock of marine formation has been observed at an elevation of more than about 15 feet, it is evident that nearly the whole elevation of these hills must be due to the accumulated sand-drifts. Sand-drifts, however, of such extraordinary altitudes, though exceptional, are by no means unparalleled. Prof. W. C. Kerr, State Geologist of North Carolina, informs me that sand-hills more than 100 feet in height occur along the coast of that State. Dunes of even greater altitude than those in Bermuda occur on the coast of Gascony and near Cape Verd.*

In one respect, it seems to me, calcareous sands are better adapted than silicious ones for the formation of hills of great height: viz., the comparative solubility of the material, producing a more rapid consolidation by the cementing of the grains. At times when the direction of the wind is unfavorable to the increase of a sand-hill, in a region of variable winds, the tendency will be to reduce the height by removal of the sands from the summit. If the sand has already become partly consolidated, the loss from this cause will be much lessened.

MOVEMENTS OF ELEVATION AND SUBSIDENCE.

The facts which have been already detailed in regard to the distribution of the various kinds of rock, and other facts which will presently be referred to, afford clear evidence as to changes of level which the islands have undergone. The occurrence of beach-rock above the water-level, as noticed at several localities, is of course unquestionable proof of elevation. Proofs of subsidence are equally clear. The relation of the beach-rock and drift-rock at Devonshire Bay and various other localities along the south shore is evidence of subsidence. The cliff of drift-rock which in these localities rises immediately back of the narrow platform

* The Ocean, Atmosphere, and Life. By Élisée Reclus. New York, 1873. p. 195.

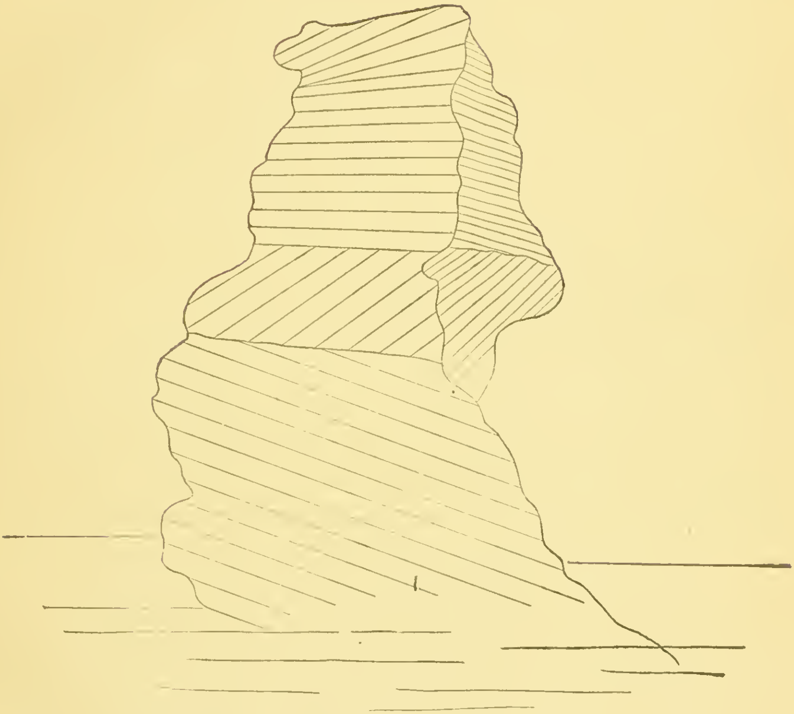
of beach-rock, is shown by its steep landward dip to be the landward side of a dune, whose seaward slope has been removed by erosion. The dip of the laminæ of sand on the seaward face of a dune is, of course, seaward. If we conceive the seaward face of the dune to be restored, it would certainly in some localities extend beyond the narrow shore platform into the area now covered by the sea. It is evident, then, that the drift-rock of these cliffs on the south shore was formed at a time when the islands stood at a higher level than at present. It is easy to see the reason why the exposures of beach-rock should be much more frequent and extensive on the south shore than on the north, in the fact of the vastly greater erosive action of the sea on the south shore. The south shore receives the full dash of the waves of the Atlantic, while the north shore is acted upon only by the lighter waves raised in the great lagoon between the shore and the north reef. Another proof of subsidence is seen in the occurrence of caves with floors of stalagmite below the water level, and with stalactites whose tips are immersed in the sea-water.* About the year 1870 "submarine blastings were carried on at the entrance of Hamilton Harbor, and at a depth of over 6 fathoms a cavern was broken into which contained stalactites and red earth."† In the excavations made somewhat later for the lodgment of the immense floating dock at the Dockyard on Ireland Island, 46 feet below the water-level was found a stratum of "red earth," 2 feet in thickness, containing remains of cedar trees. This stratum was underlain by a stratum, 4 feet thick, of hard calcareous sand-rock, containing land snails. J. Matthew Jones has called attention to the fact that an elevation equal to the subsidence indicated by the phenomena observed in the excavations at the Dockyard would lay bare the whole elliptical area inclosed by the outer reef.‡

The series of movements required to account for the main features of Bermudian geology seems to be the following: 1. A subsidence, in which the original nucleus of the islands 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

* An elegant description of one of these beautiful caverns may be found in Thomson, *op. cit.*, Vol. I., pp. 304, 305.

† Jones, Recent Observations in the Bermudas: in Nature, Vol. VI., p. 262.

‡ Recent Observations in the Bermudas.



Rock pinnacle near the shore of IRELAND ISLAND, Bermuda.

the soft drift-rock around the shores suffered extensive marine erosion, and the shore platform and cliffs already described were formed.

On this hypothesis, the peculiarities of Bermuda mentioned by Darwin as rendering its atoll character at least doubtful,* admit of ready explanation. The absence of the usual horizontal reef-platform, and the gradual shoaling of the water for a mile or more around the islands, may be accounted for by the supposition that the last subsidence was too rapid and too recent to allow the growth of the reef into its usual and typical form.† The original atoll character has, indeed, been greatly modified by the subsequent changes; and the gradually sloping bottom for some distance from the shore presents, instead of the typical horizontal reef-platform, a plane of marine denudation formed by the rapid erosion of the soft calcareous sand-rock during the progressive subsidence. Dana has shown that a subsidence too rapid for the growth of the reef to keep pace with it may lead to the formation of narrow fringing reefs, producing thus an effect which may counterfeit the effects of elevation.‡ Darwin is inclined to regard the fringing reefs on the south shore of Bermuda as evidence of recent elevation;§ but I believe all the facts taken together are far more satisfactorily explained on the hypothesis that the latest movement has been one of subsidence. The extraordinary size and elevation of Bermuda, as compared with other atolls, is accounted for by the vast accumulation of drift-sand during a period of elevation. Darwin, indeed, admits that the probable Æolian formation of most of the Bermudian rock renders the unusual height of the islands immaterial as an objection to their atoll character.||

The difference in the amount of dry land between the northern and southern sides of the ellipse is doubtless due, as suggested by Dana,¶ in part to the prevailing southerly winds, the windward side of the atoll being the more favorable both for the growth of the reef proper and for the accumulation of beach and drift sand-rock; and partly to differencies in the configuration of the lands around which the reefs were formed.

It is a profound and comprehensive suggestion of Professor Dana

* Coral Reefs, p. 264.

† For estimates illustrative of the extreme slowness of the growth of coral reefs, see Dana, Corals and Coral Islands, pp. 249–254.

‡ Notes on the new edition of Mr. Darwin's work on the Structure and Distribution of Coral Reefs: in Nature, Vol. X., pp. 408, 409.

§ Coral Reefs, p. 265.

|| Coral Reefs, p. 265.

¶ Corals and Coral Islands, p. 221.

that the great oceanic subsidence recorded by the coral islands of tropical seas was the counterpart of the great elevation of the continental lands in the Glacial Period.* It is not improbably a legitimate following out of this suggestion to recognize, in the three great movements which are indicated for at least a part of the North Atlantic basin by the geological phenomena of Bermuda, the counterparts of the three great movements of the North American continent which have characterized in American geology the epochs of the Quaternary Age. The great subsidence in which the Bermudian atoll was formed, would then be recognized as correlative with the Glacial elevation of the continent. The epoch of elevation in which the Bermudian lagoon was converted into dry land, would correspond with the Champlain subsidence of the continent. And the final subsidence, of which Bermudian geology affords evidence so manifold, would correspond with the re-elevation of the continent which marked the transition to the Terrace or Recent Epoch.

While we may reasonably conclude that Bermuda, in common doubtless with an area of the North Atlantic of very considerable extent, has undergone these comprehensive movements, it would be strange if there had not occurred at least locally minor oscillations. Such oscillations may possibly be indicated by the stones reported by Nelson as occurring in the layers of "red earth" in Ireland Island.† His statement, however, is somewhat indefinite. At one locality on the south shore, a short distance west of Tucker's Town, I observed a hard layer of rock containing marine shells immediately overlying a soft layer containing land shells. The clearest evidence, however, of repeated oscillations of level is afforded by a remarkable locality on the north shore of Stock's Point. The rock which has been quarried there, and which now appears in the base of the bluff, is a very hard rock of subcrystalline texture and of ferruginous color. It shows vestiges of irregular lamination, and contains fossil Helices and no marine fossils. It is undoubtedly a drift-rock, like that at Paynter's Vale. The upper surface of this rock is exceedingly irregular, giving evidence of much subaerial erosion preceding the deposition of the overlying strata. It is overlain by a remarkable conglomerate, evidently a beach-rock, containing fragments of the underlying hardened drift-rock, peculiar ferruginous nodules, compact lumps of "red earth," and pretty large marine

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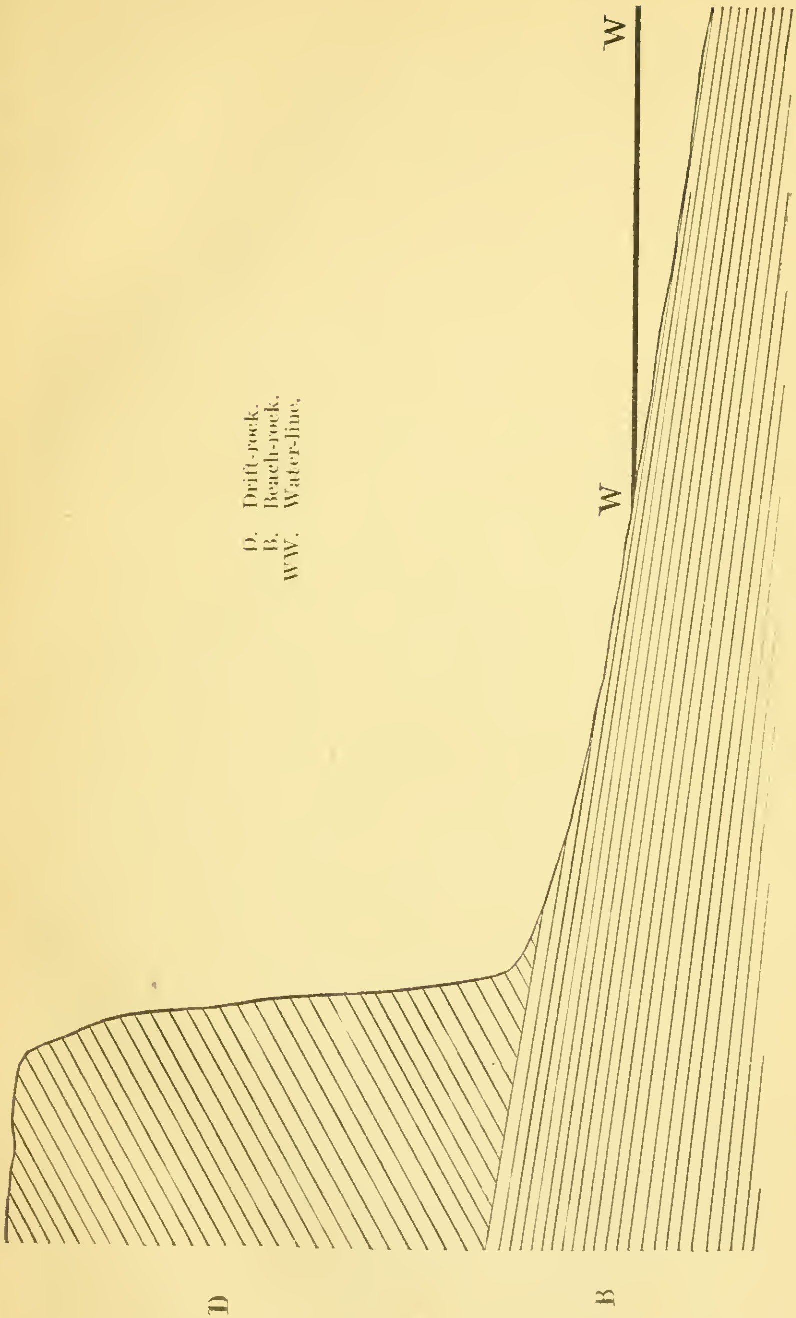
* Corals and Coral Islands, pp. 366–372.

† *Op. cit.*, p. 118.



Section illustrating relation of beach-rock and drift-rock.

shells. The upper surface of this conglomerate, unlike its lower surface, is quite regular—the usual plane of marine deposition. This conglomerate is overlain in places by a stratum of sand, like that observed at Devonshire Bay, containing shells of land snails in its uppermost layers. Above this sand, where the sand is present, in other places resting immediately upon the conglomerate, is the ordinary drift-rock.

HAS BERMUDA SUBSIDED WITHIN HISTORIC TIMES?

Assuming that the last movement of subsidence has occurred in times geologically very recent, the question arises whether that subsidence has occurred within historic times. The affirmative of this question is held by General Lefroy in his interesting and valuable work on the early history of Bermuda.* Mr. J. Matthew Jones coincides with this view.† This opinion is supported chiefly by three passages from early writers, which I propose to examine in chronological order.

The earliest is from Gonzalo Ferdinando de Oviedo, who visited the islands about the year 1515.‡ It reads as follows: "In the yeere 1515, when I came first to enforme your maiestie of the state of things in India, and was the yeere following in Flanders, in the time of your most fortunate successe in these your kingdoms of Arragon and Castile, whereas at that voyage I sayled above the Iland Bermuda, otherwise called Garza, being the furthest of all the Ilands that are found at this day in the world, and arriuing there at the depth of eight yards of water, and distant from the Land as farre as the shot of a piece of Ordinance, I determined to send some of the ship to Land, as well to make search of such things as were there, as also to leave in the Iland certaine Hogs for increase. But the time not seruing my purpose by reason of contrarie winde, I could bring my ship no neerer the Iland,

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*Memorials of the Discovery and Early Settlement of the Bermudas or Somers Islands, 1515–1685. By Major-General J. H. Lefroy. 2 vols., London, 1877, '79.

†Recent Observations in the Bermudas.

‡The extract is quoted by General Lefroy (*op. cit.*, vol. I., pp. 2, 3) from an early English version contained in a work entitled as follows: "The history of Trauayle in the West and East Indies and other countreys lying eyther way towards the fruitfull and riche Moluccaes, as Moscouia, Persia, Arabia, Syria, Ægypte, Ethiopia, Guinea, China in Cathayo and Giapan. With a discourse of the North-West Passage. Gathered in parte and done into Englyshe by Richard Eden. London, 1577." The same version of Oviedo's narrative, under the title, "Extracts of Gonzalo Ferdinando de Oviedo his Summarie and Generall Historie of the Indies," appears in Purchas his Pilgrimes, Part 3, pp. 971–1000, London, 1625. The passage here cited may be found in Purchas, p. 989. The original Spanish of the same passage is quoted in Lefroy, *op. cit.*, Vol. I., p. 677.

being twelue leagues in length, and sixe in breadth, and about thirtie in circuit, lying in the three and thirtieth degree of the North side. While I remayned here, I saw a strife and combat betweene these flying-fishes, and the fishes named giltheads, and the fowles called sea mewes, and cormorants, which surely seemed unto one a thing of as great pleasure and solace as could be deuised."

On this passage, General Lefroy comments as follows:* "The terms of this narrative imply a stay of some slight duration, which is to be inferred also from the approximation with which the dimensions of the group are fixed; and it is very unlikely that none of the party landed. * * * It is probable that the purpose he was prevented from fulfilling was that of landing hogs, not that of communicating with the shore." It seems to me, on the contrary, a more likely inference from the language of Oviedo, that he was altogether prevented from landing. It would not require a sojourn on land to witness a fight between flying-fishes and cormorants—the only incident which he refers to in connection with his visit to the islands. Certainly every circumstance indicates that Oviedo's estimate of the size of the archipelago must be taken as merely a rough guess, and no inference can be drawn from the slight excess of that estimate over the present actual dimensions.

The chief evidence relied upon by General Lefroy to support the belief of a subsidence within historic times is the testimony of Henry May, an English sailor in a French vessel, who was shipwrecked on the islands in December, 1593, and remained there until April, 1594.† The statements in May's narrative bearing upon the subject in question are as follows: "We made account at the first that we were cast away hard by the shore, being hie cliffs, but we found ourselues seuen leagues off, but with our boat and a raft, which we had made and towed at our boats sterne, we were saued some 26 of us. * * * We rowed all the day until an hour or two before night yer we could come on land, towing the raft with the boat. * * * This island is diuided all into broken islands; and the greatest part I was upon, which might be some four or five miles long, and two miles and a halfe ouer, being all woods, as cedar and other timber, but cedar is the chiefest."

General Lefroy adds to this narrative the following comments: ‡ "There

* *Op. cit.*, Vol. I., p. 3.

† Hakluyt's Collection of the early Voyages, Travels, and Discoveries, of the English Nation. New edition, with additions. 5 vols. London, 1809–'12. Vol. IV., pp. 55, 56. May's narrative is quoted in Lefroy, *op. cit.*, Vol. I., pp. 7–9.

‡ *Op. cit.*, pp. 9, 10.

is nothing more remarkable in this narrative than the statement that they made account at the first that they were cast away hard by the shore, being high cliffs, whereas they found themselves seven leagues off. It is a positive proof that the north-west reefs, only a few points of which are now above water at the lowest spring tide, were then some feet above it. The expression high cliffs must be interpreted by the circumstance of seamen in a small boat approaching a dangerous shore, with a heavy swell on, rendering it dangerous and difficult to land. But if they were only 10 feet high, the amount of subsidence in less than three centuries, shown by their present submergence, is a most significant geological fact; and Henry May has rendered an invaluable service by mentioning the circumstance. The map in Purchas, published 1625, confirms it. It shows three distinct islets, that have now disappeared, along the line of the northern reefs. The North Rock of Bermuda, 14 feet high, and some smaller rocks near it, are all that remain to attest the accuracy of these early descriptions." The statements of May appear to me rather to warrant exactly the contrary inference. If the northern reef formed then a line of cliff nearly or quite continuous, I am unable to understand how he could have supposed himself hard by the shore when really several leagues from it. But, on the supposition that the vessel struck near some islet or group of islets like North Rock, the account becomes perfectly intelligible. The rocky islet could easily have been mistaken in the storm for a line of cliff, and the mistake would speedily become obvious on starting to row to the supposed shore. The 7 leagues of distance is, of course, the exaggerated estimate of men who were rowing a heavy-laden boat, with a raft in tow, on a stormy sea. That there may have been several islets scattered along the line of the north reef, which have now succumbed to the action of the waves, is on all accounts exceedingly probable. May's statement that the island is divided into broken islands, and his estimate of the dimensions of the island on which he found himself, and which he supposed to be the principal one of the group, though the description is not sufficiently definite to afford any very reliable conclusions, certainly favor the belief that the land was then not appreciably higher than at present. An elevation which would convert the north reef into a continuous line of cliff, would very seriously modify the broken character of the southern side of the atoll, connecting most of the islets by continuous dry land.

The last notice supposed to indicate a subsidence within historic times is from John Smith's History of Virginia.* In an enumeration of the birds found in Bermuda occurs the expression: "Very many crows, which since this plantation are killed, the rest fled or seldom seen, except in the most uninhabited places, from whence they are observed to take their flight about sunset, directing their course towards the north-west, which makes many conjecture there are some more islands not far off that way." † The statement is too indefinite to justify any very positive conclusions. If we accept it as indicating the existence of some dry land in the position of the north reef, it may perhaps be sufficiently accounted for by the supposition already suggested: namely, that there may have been a number of small islets which have since been degraded to the water-level by the erosion of the waves. Certainly the statement does not justify a belief in the recent subsidence of the islands, in opposition to the evidence now to be presented.

The earliest descriptions of Bermuda which are sufficiently accurate and detailed to admit of intelligent comparison with the present condition of the islands, date from the time of the shipwreck of Sir Thomas Gates and Sir George Somers in 1609. The following extracts from these descriptions will show that at that time the size and form of the islands and the depth of water within the reef were essentially the same as at present. The statement of the depth of the water seems to me perfectly conclusive against the theory of any considerable subsidence within the last three centuries.

The first of these extracts is from the narrative of William Strachy.‡ "The Bermudas bee broken Ilands, fiue hundred of them in manner of an Archipelagus (at least if you may call them all Ilands that lie, how little soeuer into the sea, and by themselues) of small compasse, some larger yet then other, as time and the Sea hath wonne from them, and eaten his passage through, and all now lying in the figure of a Croissant, within the circuit of sixe or seuen leagues at the most, albeit at first it is said of them that they were thirteene or fourteene leagues; and more in longitude as I have heard. For no greater distance is it

* The General History of Virginia, New England, and the Summer Isles. By Capt. John Smith. London, 1624. The work is reprinted in A General Collection of Voyages and Travels in all parts of the World. By John Pinkerton. London, 1808–'14. Vol. XIII., pp. 1–253.

† Pinkerton, *op. cit.*, Vol. XIII., p. 173.

‡ A true repertory of the Wracke, and redemption of Sir Thomas Gates Knight; upon, and from the Ilands of the Bermudas: * * * written by William Strachy, Esquire. The narrative is contained in Purchas, Part 4, pp. 1734–'58. Copious extracts are given in Lefroy, *op. cit.*, Vol. I., pp. 22–54.

from the Northwest point to Gates his Bay, as by this Map your Ladyship may see, in which Sir George Summers, who coasted in his boat about them all, tooke great care to expresse the same exactly and full, and made his draught perfect for all good occasions, and the benefit of such, who either in distresse might be brought upon them, or make saile this way. It should seeme by the testimony of Gonzalus Ferdinandus Oviedus, in his Booke intituled, The Summary or Abridgement of his generall History of the West Indies, written to the Emperor Charles the Fift, that they haue been indeed of greater compasse (and I easily beleeue it) than they are now, who thus saith [here follows the extract from Oviedo, as above given, except that, by a mistake of copyist or printer, the breadth of the group is given as sixteen leagues, instead of six]. True it is, the maine Iland, or greatest of them now, may be some sixteene miles in length East North-East, and West South-West the longest part of it, standing in thirtie two degrees and twentie minutes, in which is a great Bay on the North side, in the North-west end, and many broken Ilands in that Sound or Bay, and a little round Iland at the South-west end."*

The second extract is from the narrative of another member of the expedition.† "This Iland, I meane the maine Iland, with all the broken Ilands adiacent, are made in the forme of a halfe Moone, but a little more rounder, and divided into many broken Ilands, and there are many good harbors in it, but we could find but one especiall place to goe in, or rather to goe out from it, which was not altogether free from some Danger, there there is three Fathoms water at the entrance thereof, but within, six, seauen, or eight Fathoms at the least, where you may safely lie Land-locked, from the daunger of all Winds and Weathers, and moore to the trees."‡

To me these descriptions appear to justify a very positive conclusion that there has been no considerable subsidence since 1609; and, of course, all geological probabilities are against so rapid a subsidence as

* Purchas, *op. cit.*, Part 4, p. 1738.

† A discovery of the Barmudas, otherwise called the Ile of Divels, by Sir Thomas Gates, Sir George Sommers, and Captayne Newport, with Diuers others. Sil. Jourdan. A reprint of this narrative bears the title: A plaine Description of the Barmudas, now called Sommer Ilands. With the manner of their Discouerie Anno 1609, by the shipwrack and admirable deliuerance of Sir Thomas Gates, and Sir George Sommers. London, 1613. Hakluyt, *op. cit.*, Vol. V., pp. 551–8. Tracts and other papers relating principally to the Origin, Settlement, and Progress of the Colonies in North America. Collected by Peter Force. Vol. III., No. 3. Lefroy, *op. cit.*, Vol. I., pp. 14–21.

‡ Hakluyt, *op. cit.*, Vol. V., p. 557. Force, *op. cit.*, Vol. III., No. 3, pp. 13, 14.

would be required to convert the north side of the atoll from a high cliff to a sunken reef in the interval between May's shipwreck in 1593 and Somers' in 1609, or to diminish considerably the area of the archipelago in the century succeeding Oviedo's voyage in 1515. A conclusion so improbable is certainly not to be adopted on evidence so indefinite or ambiguous as has been gathered from the narratives of Oviedo and May. The belief that the level of the islands in the time of John Smith was higher than at present is utterly out of the question. The opinion advocated in this paper finds additional confirmation in the Map by Richard Norwood, in 1663.* That map is an accurate delineation of the islands in their present condition, and renders it certain that within the last two hundred years no considerable subsidence has taken place.

EROSION.

One of the most interesting incidental subjects of study for a geologist in Bermuda is the immense erosion which has taken place. The softness of most of the drift-rock, and the solubility of calcium carbonate in rain-water, combine to produce an exceedingly rapid erosion, even though the powerful agency of frost is wanting. Many of the most picturesque features of Bermudian scenery are due to this erosion. The shore cliffs in many localities are carved into the most picturesque pinnacles, in whose endless variety of form the eye may find perpetual delight. Another result of erosion is the formation of innumerable caves, ranging in size from exquisite miniature grottoes to extensive caverns. One of these beautiful miniature caves I observed at Paynter's Vale. It had been laid open by the removal of the stone in quarrying. Its horizontal diameter was about 5 feet, its height in the middle about 2 feet. Pygmy stalagmites rose from the floor, and pygmy stalactites depended from the roof. In the peripheral parts of the little cavern the stalactites and stalagmites united in many cases to form little columns. Many of the larger caves are of exceeding beauty; but it is unnecessary to give any detailed description of them, as the phenomena are of course those which occur in all limestone caverns. A curious feature which the traveler meets here and there in Bermuda is a deep hollow with walls nearly vertical, or in places even overhanging. One may be walking over a nearly level plain, and suddenly find himself on the edge of a precipice looking down into a

* The curious history of Norwood's Map is given in Lefroy, *op. cit.*, Vol. I., preface. A copy of the map itself faces p. 645 of Vol. II.

Rocks on the south shore of Bermuda.

deep and wide gulf. These hollows are simply caves whose roofs have been eroded by the mechanical and chemical action of water, until, too weak to support themselves, they have caved in. On the walls of these unroofed caves beautiful stalactites may be seen half enveloped with velvety mosses and feathery ferns—a strangely beautiful combination of the adornments of the underworld with those of the world of daylight. In other cases the process of erosion has continued still further, so that the sides of the cave, as well as the roof, have been entirely removed, and nothing is left to mark the site of the former cave but a floor of crystalline stalagmite. Near Walsingham on the Main Island, and near Mullet Bay on St. Georges, I observed considerable areas where the coarsely crystalline calcite forming the surface rock is unquestionably a stalagmite floor—the only memorial of a former cave.

THE "RED EARTH."

The so-called "red earth" bears striking testimony to the amount of erosion which the islands have undergone. The usual superficial soil of the islands is a clayey earth, sometimes of a deep brick-red color, sometimes showing various shades intermediate between this deep red and the white or cream-color of the underlying rock. The material is occasionally somewhat firmly consolidated, but usually quite soft and earthy. It varies much in depth, forming deep pockets in some places, while in other places the white rocks are bare. It often occurs in cracks and cavities in the rocks. Where any considerable thickness of the drift-rock is exposed in a section, as at the extensive quarries on Ireland Island, one or more layers of the same "red earth" may generally be observed extending nearly horizontally at intervals through the rock. Various unsatisfactory explanations of the origin and nature of this "red earth" have been given. Jones formerly believed it to be "composed of decayed vegetable matter";* and this is indeed the common opinion of the inhabitants of Bermuda. Nelson conjectured that it was largely derived from the excrements of bats and birds.† The true explanation of its origin is undoubtedly that given by Thomson, as follows: "The coral-sand, like the mass of skeletons of surface animals accumulated at the bottom of the ocean, does not consist of carbonate of lime alone. It contains about 1 per cent. of other inorganic

* On the Geological Features of the Bermudas: in Proceedings and Transactions of the Nova Scotian Institute of Natural Science, Vol. I., Part IV., Art. II., 1867, p. 21.

† Dana, Corals and Coral Islands, p. 391. The citation is from a paper on the Bahamas, in Quarterly Journal of the Geological Society of London, 1853.

substances, chiefly peroxide of iron and alumina, silica, and some earthy phosphates. Now these substances are to a very small degree soluble in water charged with carbonic acid; consequently, after the gradual removal of the lime, a certain sediment, a certain ash, as it were, is left behind. One per cent. seems a very small proportion, but we must remember that it represents one ton in every hundred tons of material removed by the action of water and of the atmosphere; and the evidences of denudation on a large scale are everywhere so marked, that, even were some portion of this 1 per cent. residue further altered and washed away, enough might still be left to account fully for the whole of the red earth."* Assuming the "red earth" to be the insoluble residue left by the solution of the major part of the calcium carbonate of the coral rocks, it should be observed that its materials doubtless have the same twofold origin which has been recognized in the case of the somewhat analogous red clays of the deeper parts of the ocean bottom.† They are doubtless in part derived from the minute quantity of non-calcareous mineral matter existing in the corals, shells, and other calcareous skeletons of marine animals and plants; in part from the decomposition of volcanic minerals, which are continually being transported in various ways to all oceanic islands. Analyses of samples of the "red earth" are quoted by Thomson‡ from a "Report from Professor Abel, F. R. S., to H. E. General Lefroy, C. B., F. R. S., on the Character and Composition of Samples of Soil from Bermudas."

PHENOMENA RESULTING FROM UNEQUAL HARDENING OF THE LIMESTONE.

A number of interesting phenomena result from the unequal hardening of the sand-rock where vegetable stems or roots or other accidents have determined the location of channels for the percolating waters. On the weathered surface of cliffs and banks of the drift-rock may often be observed hard bodies somewhat projecting, consisting of a more firmly consolidated sand-rock, having the form of slender cylinders irregularly branching, the main trunks being generally nearly vertical. These stems may generally be seen to be tubular, and in the slender cavity may generally be found more or less of woody fiber. These bodies have much the form and aspect of the "branched bodies" observed by Darwin at King George's Sound on the south-west coast of Australia, and at the Cape of

* Thomson, *op. cit.*, Vol. I., pp. 294, 295.

† Thomson, *op. cit.*, Vol. I., pp. 215–218; Vol. II., pp. 255, 256.

‡ *Op. cit.*, Vol. I., pp. 325, 326.

Good Hope*, though differing from them in some respects, particularly in the very general presence of woody fiber in the center. Darwin states that the "branched bodies" at King George's Sound have "the central parts filled either with friable calcareous matter, or with a substalagmitic variety; this central part is also frequently penetrated by linear crevices, sometimes, though rarely, containing a trace of woody matter." In the similar bodies found at the Cape of Good Hope, he says, the "centers are often filled with black carbonaceous matter." Darwin's theory of the origin of these bodies is that they were "formed by fine calcareous matter being washed into the casts or cavities left by the decay of branches and roots of thickets buried under drifted sand."† The more distinctly tubular character of the Bermudian specimens, and the very common presence of a core of woody matter, seem to point to a slightly different mode of formation; and I believe the true explanation of the origin of the Bermudian "branched bodies" is that given by Jones. He believes that they have been formed by percolating waters, which would naturally follow in their descent the channels formed by underground stems and roots, cementing the grains of sand into tubes of harder rock inclosing the stems and roots.‡ Both theories assume the burial of the vegetation beneath drifted sand. But, while Darwin considers the bodies in question as casts formed after the decomposition of the stems and roots, Jones considers them as having been formed by the cementing of the sand around stems and roots as yet undecomposed. Closely analogous to these "branched bodies" is the sort of stalagmitic net-work formed in some localities around the roots and stems of smaller plants.

Essentially analogous, also, are probably the so-called "palmetto stumps." These have been described by Nelson,§ Jones,‖ and Thomson.¶ They appear generally as shallow, cup-shaped or saucer-shaped cavities, a few inches in diameter, the rim somewhat elevated above the general surface of the ground, the bottom evenly rounded and pitted with small depressions. The surface of these cups is quite hard; and the rock

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* Geological Observations on the Volcanic Islands and parts of South America visited during the Voyage of H. M. S. Beagle. Second edition. London, 1876. pp. 161–165. Journal of Researches into the Natural History and Geology of the Countries visited during the Voyage of H. M. S. Beagle round the World. New edition. New York, 1875. p. 450.

† Geological Observations, p. 163.

‡ Geological Features of the Bermudas, p. 24.

§ *Op. cit.*, pp. 115, 116.

‖ Geological Features of the Bermudas, p. 21.

¶ *Op. cit.*, Vol. I., pp. 306–311.

beneath for some inches in depth, though less hard than the superficial crust, is more firmly consolidated than the surrounding rock. The objects accordingly appear, when the surrounding rock is removed by weathering or otherwise, as irregular cylinders. It has often been crudely supposed that these cylinders are petrifactions or casts of the trunks of the palmetto; but this is certainly erroneous. I believe, however, that this error is but a misconception of the truth. The base of the palmetto stem is convex, with numerous small roots radiating from its surface. Its form is the counterpart of the shallow cup, pitted with little depressions, which is the characteristic feature of the bodies in question. The true explanation of the formation of these bodies appears to be simply this: the rain-water trickles down around the convex base of the palmetto stem, and thence follows the little radiating roots. As in the other cases already discussed, the course of the waters is marked by a more perfect cementing of the grains of calcareous sand, giving the rock in those parts a sub-stalagmitic character. When the tree finally dies, and drops out of its socket, there is left a saucer-shaped cavity, lined by a sub-stalagmitic crust, and an irregular cylinder of somewhat hardened rock beneath it. Sir Wyville Thomson combats the idea of the organic origin of these bodies, and calls attention to the frequent irregularity of their form. He tells us that a perfect series of gradations may be traced from the regular circular form ("the most characteristic, and probably by far the most common")* to forms so irregular that their organic origin is entirely out of the question. Now in maintaining that the common and typical sort of these bodies are produced by the rain-waters following the course determined for them by the stem of the palmetto, I by no means deny that by accidents of a totally different sort special channels for the percolating waters may be determined, and "calcareous concretions" produced of all sorts of irregular forms. Moreover, it would be the most natural thing in the world that some of the concretions whose form is determined by other conditions should considerably resemble some of the least regular and perfect of those formed in the way I have explained. Admitting that all the "concretions," regular and irregular, are the result of the unequal hardening of the stone by the cementing action of water, the regular saucer-shaped cavities already described are so frequent and so characteristic that it is worth while to inquire what is the special condition which has hardened the rock in precisely that form. That ques-

* Thomson, *op. cit.*, Vol. I., p. 308.

tion, I believe, is satisfactorily answered in the explanation I have given. Sir Wyville Thomson's explanation I transcribe entire, lest I should do injustice in criticizing a passage which I do not quite understand. "In the caves in the limestone, owing to a thread of water having found its way in a particular direction through the porous stone of the roof, a drop falls age after age on one spot on the cave-floor accurately directed by the stalactite which it is all the time creating. The water contains a certain proportion of carbonate of lime, which is deposited as stalagmite as the water evaporates, and thus a ring-like crust is produced at a little distance from the spot where the drop falls. When a ring is once formed, it limits the spread of the drop, and determines the position of the wall bounding the little pool made by the drop. The floor of the cave gradually rises by the accumulation of sand and travertine, and with it rise the walls and floor of the cup by the deposit of successive layers of stalagmite; and the stalagmite produced by the drop percolating into the limestone of the floor hardens it still further, but in this peculiar symmetrical way."* On this explanation I will only remark that stalagmites deeply and broadly concave on the top, and cave-floors rising by accumulation of sand and travertine (the material having the structure of drift sand-rock) so as to keep nearly on a level with the growing bosses of stalagmite, are phenomena never observed, to my knowledge, in Bermuda or elsewhere.

NON-CALCAREOUS ROCKS AND MINERALS.

While the only indigenous rocks in Bermuda are the various varieties of limestone, the "red earth," and the peat or muck of the bogs, grains and nodules of various minerals, mostly volcanic in origin, occur mingled with the coral sands, and blocks of various rocks are liable to be occasionally brought in the roots of drifted trees. These accidental arrivals are common to all oceanic islands.

John Murray, F. R. S. E., in a letter to General Sir J. H. Lefroy (a copy of which has been furnished me by the kindness of J. Matthew Jones, F. L. S.), names the following minerals as occurring in samples of Bermuda sands examined by himself: menaccanite, magnetite, augite, olivine, hornblende, sanidin and other feldspars, mica, and perhaps quartz. Mr. Murray notes the fact that the "red earth," on treatment with acids, leaves a residue much resembling the "titaniferous sands" found at various localities along the shore. He suggests that the volcanic minerals of the "titaniferous sands" may have been in

* *Op. cit.*, Vol. I., pp. 308, 309.

great measure washed out by rains from the "red earth." The following interesting passage is quoted from the letter above mentioned: "I think it most probable that in the far past there would be a great quantity of this sand on the shores of the then Bermuda. This, however, as the island sank, and the coral grew, would become less and less in proportion to the coral sand. Some of it would, one may be sure, always be carried up by the wind along with the coral sand, and these grains would accumulate in the 'red earth,' which one must regard as the residue after the removal of the calcareous matter. In this way, much of this volcanic sand may have belonged to the original Bermuda. Much of it, I cannot but think, has been carried to the island by pumice stone. Volcanic and other dust carried by the winds will doubtless have contributed to the mineral particles we now find in the rock of Bermuda." The considerable abundance of menaccanite, magnetite, augite, olivine, and other volcanic minerals in the sands at various localities may be due to the fact that the material has been repeatedly worked over—now blown up in sand-dunes, now washed down to the shores by the rains. Thus the comparatively insoluble grains would be concentrated and reconcentrated by the removal of the more soluble calcium carbonate. Whether these volcanic grains are in part indigenous, as Mr. Murray supposes, or have all been transported to the island in the form of pumice or otherwise, we might reasonably expect that they would now occur here and there in considerable abundance as the result of this process of concentration.

Nelson reports the occurrence of "small pieces of oxide of iron, of very questionable origin; menaccanite, found near the ferry between St. George's Island and Bermuda or Main Island; arragonite; and a minute quantity of manganese in the red earth." * Among the nodules of oxide of iron I have recognized both hematite and limonite. J. Matthew Jones has noticed the occasional occurrence of pieces of trap, doubtless brought among the roots of drifted trees.† George W. Hawes, Ph. D., late of the United States National Museum, has noticed the occurrence of pebbles of a variety of kinds of rocks. In a letter to me, a few weeks before his death, he wrote concerning them as follows: "One is a beautiful augite porphyry with large crystals finely formed of augite, and most of them are eruptive rocks; but I have two that are plainly silicious, apparently metamorphic rocks. I have found two quartz (flint) pebbles, small in size, and one I took out of the inside of a sponge."

* *Op. cit.*, p. 105. † Geological Features of the Bermudas, p. 22.

FOSSILS.

Fossils of recognizable character are found chiefly in the comparatively scanty deposits of beach-rock. The drift-rock, however, contains in abundance shells of several species of land snails, the most common being *Zonites bermudensis* and the perhaps specifically distinct variety *nelsonii*, *Helix microdonta*, and *Helix circumfirmata*. Among these it is noteworthy that *Zonites bermudensis* var. *nelsonii* no longer exists in a living state. The other three forms are still abundant residents of the islands. Shells of *Livona pica* are also abundant in the drift-rock, having doubtless been carried up from the water by "soldier" or hermit crabs. I have also observed bones of birds and fragments of the shells of crabs. The remains of marine shells and corals in the drift-rock are usually so finely comminuted as to be unrecognizable.

The beach-rock in several localities contains marine shells in great abundance and variety. Nelson appears to be not far out of the way in the statement that "almost every shell now known in the surrounding sea may be found in the rock."* I made no endeavor to make a complete collection of the fossils of the beach-rock. I append, however, a list of the shells which have been recognized among the specimens of rock which I collected to illustrate the geology of the islands. The list may be of some interest as indicating in general the most common species of fossils:

Mytilus exustus, Linn.,
Pectunculus ———,
Barbatia domingensis, Lam.,
Lucina pennsylvanica, Linn.,
Chama macerophylla, Chem.,
Chama lingua-felis, Reeve,
Bulla media, Linn.,
Fissurella barbadensis, Gmel.,
Fissurella graeca, Lam.,
Livona pica, Linn.,
Nerita peloronta, Linn.,
Truncatella ———,
Vermetus lumbricalis, Linn.,
Tectarius muricatus, Linn.,
Cerithium versicolor, C. B. Ad.,
Cyphoma gibbosa, Linn.,

* *Op. cit.*, p. 114.

Cypraea ———,
Trivia rotunda, Kien.,
Columbella mercatoria, Linn.,
Columbella cribraria, Lam.,
Olivella oryza, Lam.,
Nasa candei, d'Orb., var. *antillarum*.

For the preparation of the above list I am indebted to Henry L. Osborn, A. B., formerly assistant in Natural History in Wesleyan University. Besides the shells of mollusks, those of Balanus also occur. Fragments of coral admitting of specific identification appear to be rare, the fragile skeletons of the coral animals having generally been pretty thoroughly comminuted.