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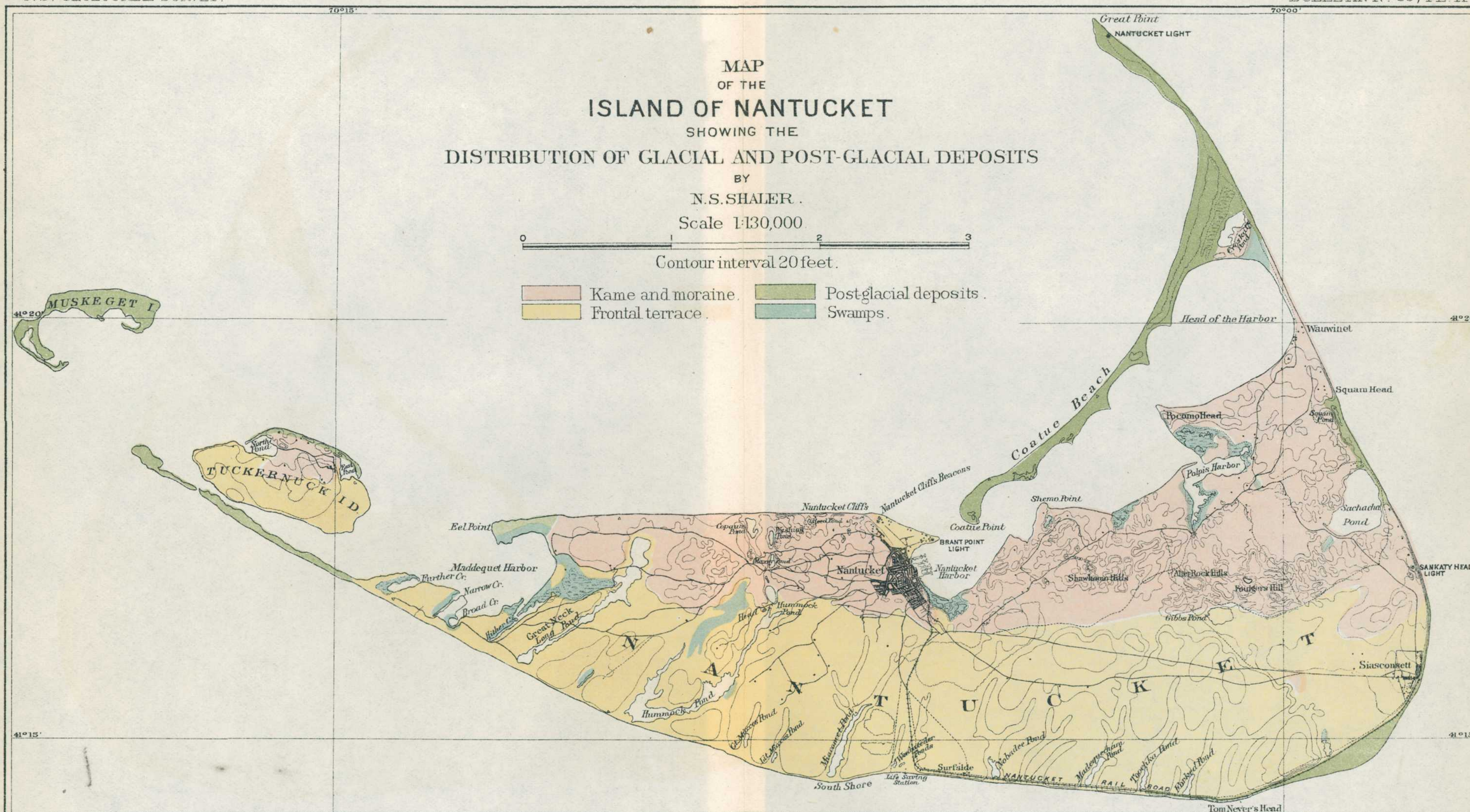

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

THE

GEOLOGY OF NANTUCKET

BY

NATHANIEL SOUTHGATE SHALER

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U. S. GEOLOGICAL SURVEY,
ATLANTIC COAST DIVISION,
Cambridge, Mass., April 26, 1888.

SIR: I have the honor to transmit herewith a report on the geology of the island of Nantucket. This report embodies a portion of the work which I have done in connection with the general study of the Atlantic coast line. Although part of a much more extended inquiry, it seems well to publish the results contained in this memoir in advance of my general report for the reason that the region constitutes a distinctly bounded field and also because the problems considered in this report have an important bearing on work which is in the hands of other divisions of the Survey.

Very respectfully, your obedient servant,

N. S. SHALER,
Geologist in charge.

HON. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

GEOLOGY OF THE ISLAND OF NANTUCKET.

BY NATHANIEL S. SHALER.

PREFATORY NOTE.

The island of Nantucket occupies a position which makes its structure of great interest to the geologist. It lies near the extreme southeastern point of a great salient of lands and shoals forming the southern front of New England. This district, unlike the main-land of New England, exposes none of the older rocks; it is composed of sands, gravels, and clays which were brought into their present position during or immediately before the last Glacial Period. It should be noted that the island of Nantucket is but a small fragment of a vast sheet of this glacially transported matter. The greater part of Plymouth County, Mass., the whole of Cape Cod, the larger portion of Martha's Vineyard, and the whole of Long Island, with all the many islands and islets at its eastern extremity, are the dissevered remains of a great shelf formed of the débris brought to its present position by the glacial ice and by the streams of water which flowed beneath it.

Owing to its extreme southeastern position the island of Nantucket affords evidence concerning the history of the ice sheet which can not be obtained at any other point on the coast: it has, therefore, seemed worthy of the detailed studies which will be presented in this report.

The general form and structure of the island will be first considered: after that the relations of the area to the other parts of the district will be set forth.

GENERAL FORM OF NANTUCKET.

As will be seen from the map that accompanies this report (Plate I), the form of the island of Nantucket is rudely crescentic; its shape may be compared to that of the implement known as a bill-hook. Its extreme length in an east and west line is about eleven miles. The westernmost mile of this length is formed by a sandspit which is constantly varying in its extension. At present this sandspit has only about one-third of the length indicated on the map, so that the permanent part of the island may be estimated at ten miles in length. The north and south width of the island does not at any point exceed seven miles, but the northern three miles of this width included in the spit of Great Head are made up of blown sands and detritus carried to its position by the currents of the sea; so that the part of the area which was formed during the glacial period does not exceed four miles in width. This measurement is also variable, for Great Head has lost 1,400 feet in length since 1784.[1]

The surface of the island, though varied, has a narrow range of height, the loftiest point being about ninety feet above the level of the sea. Through its central part there extends a series of low but extremely numerous and irregularly shaped hills of glacial drift. On the western part of the island this hill belt comes to the shore which forms a boundary of the island; on the eastern part the hills are cut transversely by the coast, forming the bluffs which face the sea from Siasconset to Squam Head. On the southern half of the island this line of low drift hills declines into a plain of sand, which extends with gentle slope from the base of the hills to the sea, terminating in a series of low bluffs rarely exceeding twenty feet in height.

The coast line of the island is cast in a set of very gentle curves united by lines of straight shore. On the southern and eastern faces the shores are either straight or very gently convex; on the northern coast the sea line exhibits no convex curves. This conforms to the general rule that long gravelly shores which face the open sea have, prevailingly, a straight or slightly convex form. (See Pl. IX.)

The details of the shore line of this island present many interesting features, most of which can be noted in connection with the geological structure of the island, but some of them may best be considered in this general sketch of its topography. The most remarkable of these topographic peculiarities is that which is commonly known as Coatue, including the harbor and the beach of that name, and the promontory of Great Head.

This remarkable district exhibits a number of very singular features. The most notable of these are Coatue Bay and the sand beach which separates it from the sound on the north. Coatue Bay has the most puzzling configuration of bottom and of shores of any inlet on the North American coast. The bottom is divided into two great basins and a third one of lesser extent. In these basins the sea-floor slopes gently from the shores to considerable depths, the two greater easternmost basins having about twenty feet of water at low tide, while the barrier between them has then only about three feet of water upon it.

The configuration of the shores is even more peculiar than that of the bottom. On the south the boundary of the bay is quite irregular, being decidedly more indented than the general outer face of the island, for the evident reason that it has been protected by Coatue Beach from the

[1] See Monomoy and its shoals, Henry Mitchell: Annual Reports of Harbor and Land Commissioner of Massachusetts, 1837 to 1842.

action of strong waves. On the north shore of Coatue Bay the low dune-covered Coatue peninsula has six small crescent-shaped bays, of which five are very distinct in their outlines and of about the same size. These bays are each a little less than a mile wide, and the base of their curves is about two hundred yards from the line which connects their promontories. From each promontory there extends for a distance of 200 yards or more out into the bay a sandspit which is not delineated on the general map, but which, if represented, would add much to the peculiarity of their aspect. They are diagrammatically indicated in the appended sketch (Fig. 1). The cause of these peculiar projections is not plain. They are possibly due in some way to the action of the tidal currents, which sweep up the bay with much speed and move the fine-grained sands with considerable ease. From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shore between these salients and accumulate the sand on the spits.

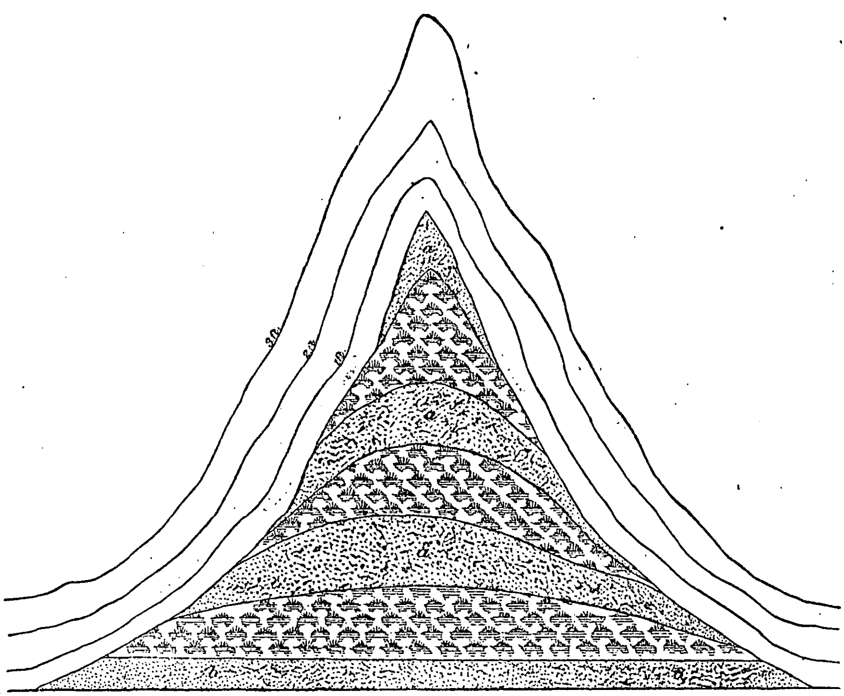


FIG. 1. Diagrammatic horizontal section of small spit on Coatue Beach.
a, a, a, successive beaches; *b, b,* promontory.

It is evident on inspection that the process which brought about the construction of these bays is still in operation. On each of the little headlands separating the basins there are traces of very recent, if not still active, building out of the point toward deeper water. On three of the points there are small salt-water ponds placed as indicated in the diagram. These pools are inclosed behind a low beach wall, formed during some great storm by the waves of the bay in which they lie. The lagoons are not clearly traceable on the other points, but they all have the general form and structure shown in the diagram.

Coatue Beach, on the southern boundary of which lie the above-described bays, is in itself a remarkable bit of shore topography. It clearly belongs to the class of barrier beaches such as are originated along coasts by the breaking of the waves in shallow water. It is evident that this beach has grown slowly and by successive and variable accretions; even in its narrow width we can trace a number of low walls which mark the line of the sea at various stages in the progress of its growth. The whole of these sands have been thrown up from the bottom of Nantucket Bay (Fig. 2). When we come to consider the successive changes of level of this island we shall find that this beach affords us evidence of some value as to the nature of these movements.

The long sand strip known as Great Head is the third element in this peculiar topography. This promontory is essentially like many others on the sandy shores of our coast. It will be observed that while the elevated and older portion of this spit trends in a northwest and southeast direction, the submerged and more recently formed portion, which is covered even at low water, has an axis nearly at right angles to this trend, and also that this under-sea part is much more irregular than the emerged portion. This sudden change in the direction of the spit may very properly lead us to the conclusion that there has been considerable change in the course of the currents which have swept these shores in recent time, a change dependent on the alteration in the shape of the lands, which has in turn affected the action of the sea. The structure and history of this point will be hereafter considered.

In connection with the shore line of Nantucket, we should notice the fresh-water system of the island. This is extremely peculiar. There is not a single well-defined stream on Nantucket. The only approach to brooks are a few obscure channels between ponds where the water has, except in times of flood, a feeble current. This absence of streams is due to the great porosity of the sand and gravel deposits. The fresh and brackish water ponds are quite numerous. They are divisible into two tolerably distinct classes, viz, the subcircular ponds, which are scattered irregularly through the sand-hills, and which range in size from a few score feet to a half a mile in diameter, and the elongate ponds, which lie in the long shallow troughs leading from the south slope of the range of sand-hills down to the Atlantic shore. With the single exception of Croskaty Pond, which lies on the northern part of the island, these elongated ponds are limited to the southern shore. With trifling exceptions, these elongated ponds have axes which trend in the direction of about N. 30° E. They are larger in the western than in the eastern half of the island. These singularities of position depend upon their relation to the remarkable shallow valleys in which they lie. As will be seen in the later portion of this paper, their peculiar form and arrangement have been given them by the conditions of the Glacial Period.

The reader should note the fact that, while the northern shore of Nantucket extending west from the harbor of that name to Matacut Harbor, presents a remarkably straight and unbroken face to the sea, the southern border of Coatue Bay or Sound is very deeply indented. The straight shore is the normal form of the coast line, where the materials exposed to erosion are of a very uniform nature, which is assaulted by waves of considerable power, such as break upon this coast in times of storm. The indented shore has the form which a coast composed of such materials assumes when it is not exposed to the action of strong current and powerful waves, as the inner shore of Coatue Bay must have been exposed before the present beach was constructed.

These considerations of the existing and more evident geographical features of Nantucket fairly present to us the problems of a geological nature which we shall have to consider in our study of the island. We shall first endeavor to determine the geological structure of the several parts of this area and the conditions under which the beds were accumulated; next we shall try to ascertain the changes which have taken place through the action of the waves and currents of the sea; and finally we shall consider the light which the structure of this island may throw on the geological history of the shore land, of which it forms a part.

FIG. 2. Diagrammatic section through Coatue Beach.

GENERAL GEOLOGICAL STRUCTURE.

The lowest deposit exposed on the island consists of a bed of clay, generally blue and compact, scantily intermingled with pebbles and sand, the whole forming a deposit which is probably to be classed as till or bowlder clay. The mass is apparently though obscurely stratified. Its pebbles are occasionally scratched. Throughout they have the angular or faceted character common to glacial pebbles. When considerable sections are exposed, as is the case at two or three points, the upper deposit for fifteen or twenty feet is seen to be altered to a yellowish or grayish color, while the mass below is of the characteristic blue color of such clays. In general aspect, as well as in details of structure, this mass is indistinguishable from the ordinary till of the mainland.

except that its pebbles are always of smaller size, rarely exceeding two or three inches in diameter, and that it is clayey and less compact than the similar deposits of more northern regions. At one point on the northern shore of the island, about a mile west of the harbor, the till passes upward into a fine-grained blue clay, this overlying deposit being at least ten feet in thickness; but generally the clay retains its admixture of pebbles to the upper surface. It is best seen at Squam Head (Fig. 3), on the north shore, near the pumping station of the water-works (Fig. 4), and in the village of Nantucket (Fig. 5).

FIG. 3. Generalized section of Squam Head.

The underlying till deposit does not rise above the level of the sea save in a small portion of the surface of the island. Along the larger part of the shore its upper surface is certainly below the level of the sea. The highest point at which it has been seen is in a clay pit worked for road material in the western part of the village of Nantucket. At

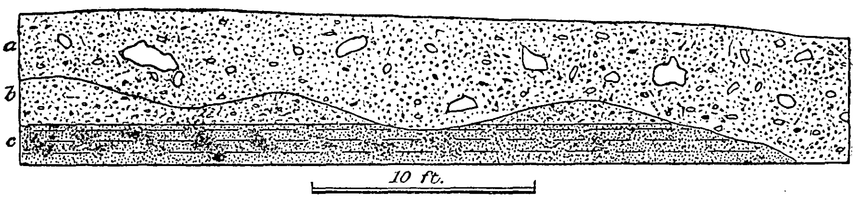


FIG. 4. Section at Weewocket.
a, till-like deposit; *b*, pebbly sand; *c*, blue clayey sand.

this point its upper surface is about thirty feet above the level of the sea. The next highest point where it has been observed is at Squam Head, on the eastern shore, where its surface is about twelve feet above the sea level. It is certain that at many other points in the central part of the island, as for instance in the promontory between the arms of Hum-

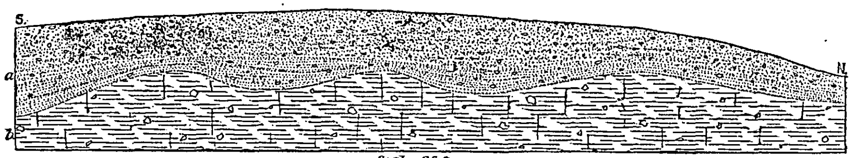
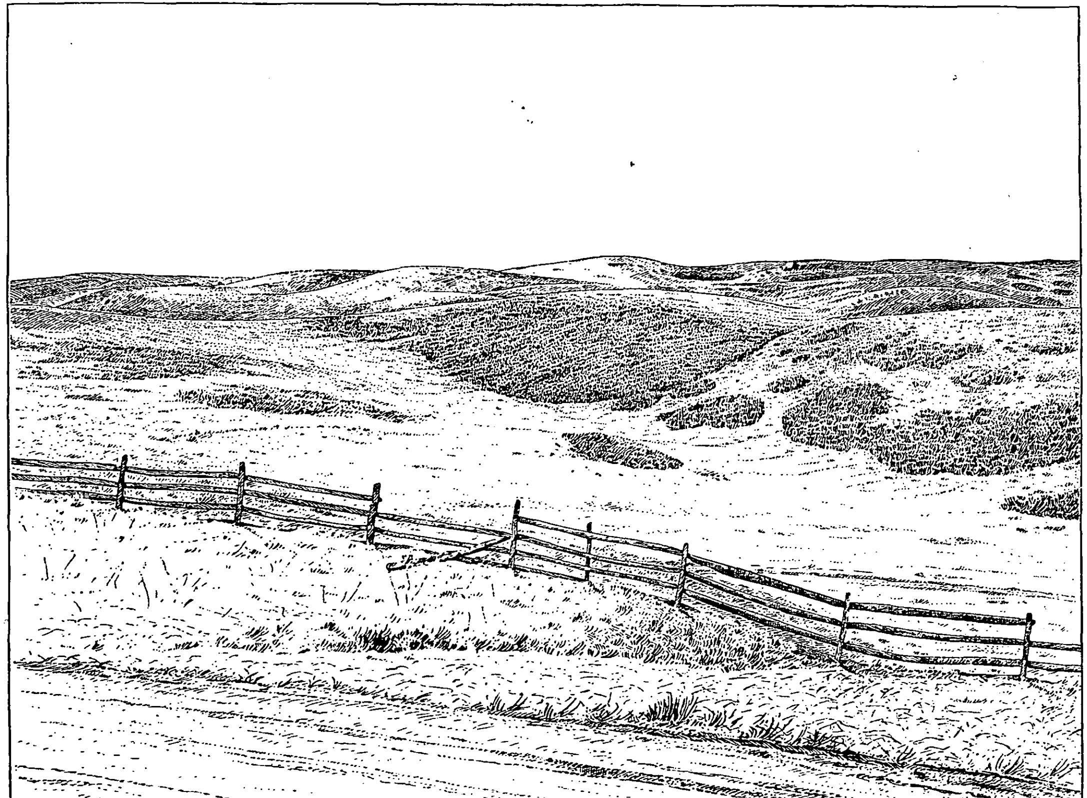


FIG. 5. Section on border of Lily Pond.
a, kame sands and gravels; *b*, bluish yellow till, very much jointed, with a few angular pebbles.

mock Pond, it attains equal elevation; but this interior surface is so masked by gravelly drift, that it is not possible to determine its position with accuracy.

The surface of this till appears to be cast into very broad and low arch-like elevations, with lesser hummocks upon them, the principal



ASPECT OF KAME MORAINE ON THE NORTHERN BORDER, NEAR SHEMO POINT.

axes of which extend in a north and south direction. At least three of these wide backed ridges project themselves above the level of the sea. One of these, perhaps the most extensive, rises from Coatue Bay, on the shore east of Pocomo Head, and underlies the lowlands about Polpis Harbor. It is traceable on both sides of that harbor, having at this point a width above the water line of about one mile. On the shores of Coatue Bay it does not at any point rise more than five or six feet above the water level. Half a mile south of Polpis Harbor the ridge may have an elevation of fifteen or twenty feet, and here it becomes completely masked by the gravel deposits. Its effect, here or elsewhere, is marked in the better quality of the soil, which shows itself in the gravelly beds as well as in the clay itself, for a certain amount of the underlying clay deposit has been mingled with the coarser detrital material, making the soil better suited for agriculture. It also affords several small springs where it intercepts the waters which sink through the gravel.

In the central part of the island there is another of these undulations of the till extending through the village of Nantucket (Fig. 5). The exposures of the clay on the north shore and in the western border of the village are upon the ridge. It may be a continuation of this ridge or it may be a separate undulation which appears in the low arched promontory between the two great branches of Hummock Pond. There is probably a similar arch of the till below the central part of the island of Tuckernuck. This was not actually seen, but has been inferred from the character of the soil on that island. There is probably yet another undulation which brings the till twenty or thirty feet above the level of the sea, at a point about a mile and a half west of Siasconset; here, too, the evidence is derived from the character of the soil and the nature of the bottoms in the low valleys, and is also indicated by the appearance of water in scanty springs. There are probably yet other points where the till rises above the sea level, but is hidden by the prevailing deep coating of the pebbly stratified drift. The diagrammatic section (Fig. 6) will give a general idea of

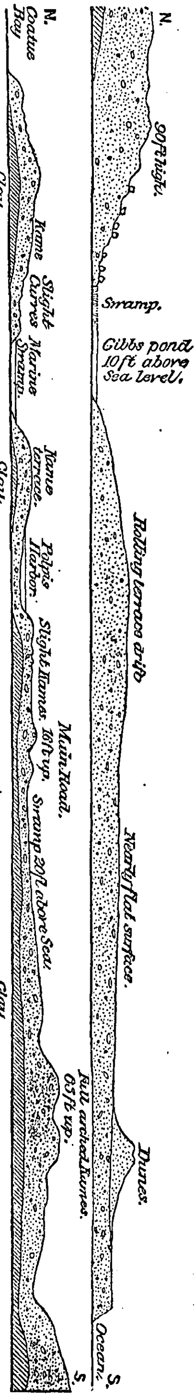


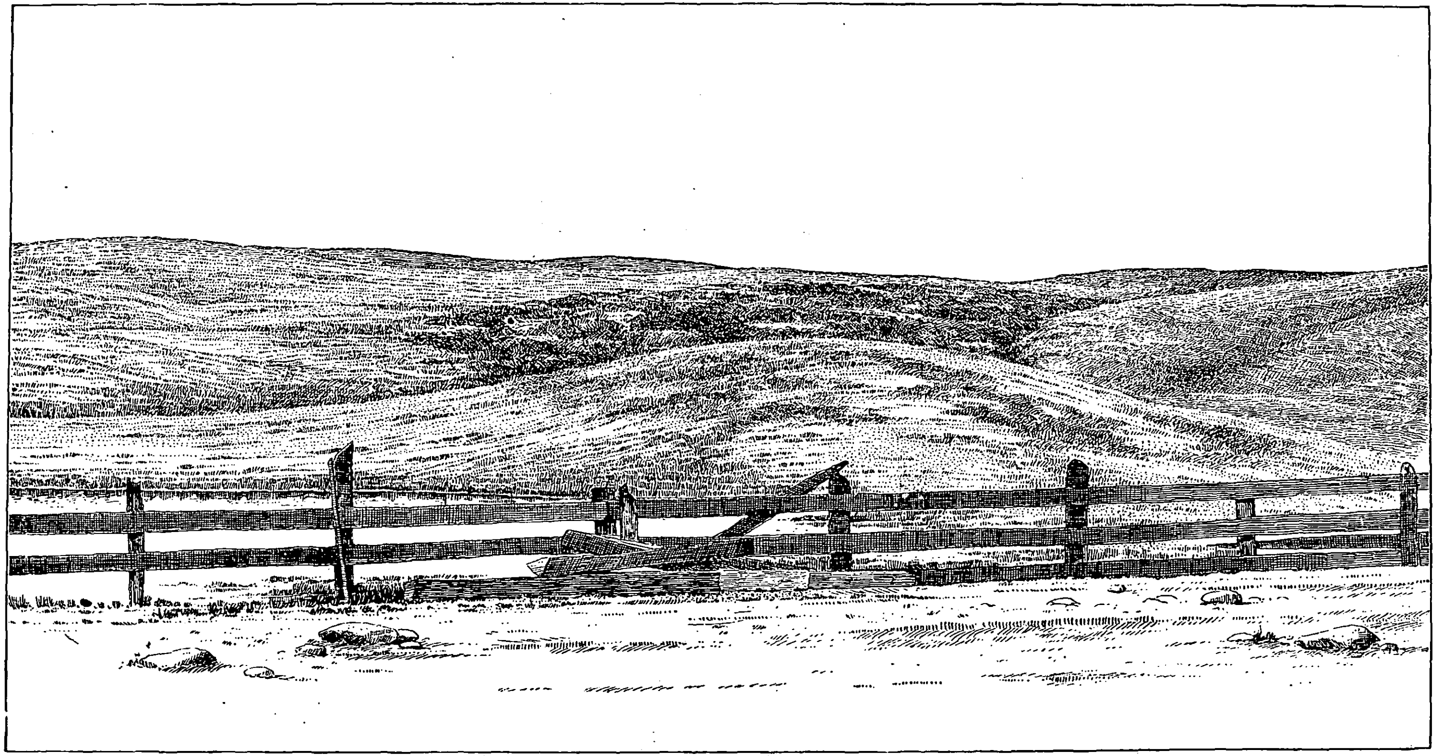
FIG. 6. Section from Coatue Bay to the ocean.

the relations of the underlying till to the sea level and to the overlying deposits of the stratified drift.

The undulating form of this underlying clay, the generally distinct boundary of its upper surface, the apparent elongation of the arches in the ridges in a north and south direction, all serve to indicate that the mass has been worn by the glacial ice since the time when it was deposited. This view is supported, as we shall hereafter see, by the character of the deposits overlying it.

Immediately above the undulating surface of the lower clay lies a mass of more or less stratified sand, which the student of glacial phenomena at once recognizes as, in part at least, belonging to that division of the drift known as kames and the terraces which commonly accompany them. The contour of the surface is of the most varied nature, and can not well be described to any one unfamiliar with this class of glacial accumulations. A tolerable idea of its extreme peculiarities may be gained from the appended diagram, which shows sections through certain parts of this surface. Most commonly it consists of a huddle of low hills never exceeding twenty feet in height, and with extremely irregular outlines. Generally they are more or less conical in figure, often elongated in an east or west direction to a length of from one to three thousand feet. Usually they are crowded together so that their bases are adjacent, but at some points they stand in an isolated position on the southern sand plain. Where they are the most crowded they have the steepest slope, which often rises to an angle of from 20° to 30° of declivity. Even where the belts are not elongated, they are often so arranged that their summits have an east and west alignment. Between the ridges there are often considerable trough-like valleys. In these valleys, which at many points appear to extend downward to or near the underlying till, there are occasional ponds or swamp grounds, which have evidently been sheets of water, but have been closed by the growth of peaty matter. Where they remain as pools, they are generally shallow, not exceeding twenty feet in depth and usually of circular outline. (See Pls. II, III, and IV.)

Where the hills are steepest they usually are very stony, large angular blocks being scattered over their surfaces. In such cases they clearly belong to the class of frontal moraines. Bowlders were once far more numerous than at present, for the reason that they have been extensively gathered during the last two centuries for masonry constructions, cellars, wharves, and retaining-walls. Some hundreds of thousands of these are now built into the edifices of the island. In many places the surface of the ground is dotted over with the pits from which the stones have been removed. The entire absence of other building stones on Nantucket, the scarcity of good brick clay, and the cost of fuel for burning bricks have made it necessary to resort to these erratics for building materials. The result is, that this district has been more thoroughly stripped of its bowlders than any other known to me.



KAME VALLEY, WITH DOME-SHAPED HILL, ON NORTH ROAD, NEAR SHEMO POINT, LOOKING SOUTH.

As before noticed, this belt of sand and gravel hills is limited to the central and northern portions of Nantucket; at no point does it attain the southern shore. The hills are relatively low on the north shore; they increase in height as we go southward toward the center of the island, and on the south they fall away suddenly into a slightly rolling sand plain, which gently descends to the Atlantic shore. Near the foot of the hills this plain is much more rolling than it becomes at a little distance to the south; at most points the section from north to south shows a somewhat gradual passage from the base of the hills to a tolerably level surface near the sea.

The distribution of the sand hills within the field they occupy is not entirely regular; there are certain broad spaces where they do not occur. One of these is occupied in part by Polpis Harbor, another of less size by Sachacha Pond. There are several others of less extent. These blank spaces are common in all moraines of this type. Here, as elsewhere, they often form considerable valleys with no outlet, the rain-water passing off through the interstices of the ground. They were probably formed by the irregular motion of the ice-front, which in its retreat abandoned considerable parts of the area with such suddenness that no morainal matter was deposited upon it. If I am right in my supposition that these kame moraines were deposited at a considerable depth beneath the sea, there is a possibility that these low spaces were formed by the separation of icebergs at the front of the glacier. Such a separation of large fields of ice would suddenly change the position of the glacial front.

The most peculiar feature of the southern plains is found in certain broad channels extending from near the foot of the sand hills to the ocean shore. These channels are digitate in form; the depressions are from 200 to 800 feet in width and from 5 to 20 feet in depth; their bottoms are very flat, exhibiting no trace of a stream-bed. They slope toward the sea, with an irregular descent of about 5 feet in a mile. Their seaward extremities are in all cases below the level of the ocean and so contain more or less considerable lagoons or ponds which are barred from the ocean by a wall beach of sand through which their waters percolate and at times break their way. In some cases these lakes are very small; this is particularly the case with those on the eastern extremity of the island. West of the meridian of Nantucket village they become larger and, in the case of Hummock Pond and Long Pond, they occupy nearly the whole of the depression in which they lie. It can not be said that any of these troughs extend across the whole line of the hills, but at their head there is in some instances a nearly flat surface in which they are lost. The lake which fills the trough of Hummock Pond (see Pl. V) extends up to the foot of the hills. Its depression is continued to the north shore by a series of ponds, four in number, which are separated by low sand-hills and which indicate the persistence of the excavating action which produced the valleys across the island. The valley of

Long Pond constitutes a depression extending to within one-third of a mile of the northern shore, very nearly sundering the island, and the trough may be faintly traced across this remaining space of land. (See Fig. 7.)

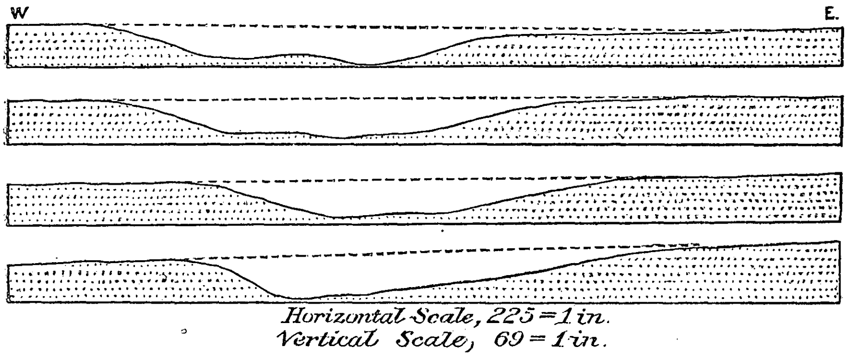


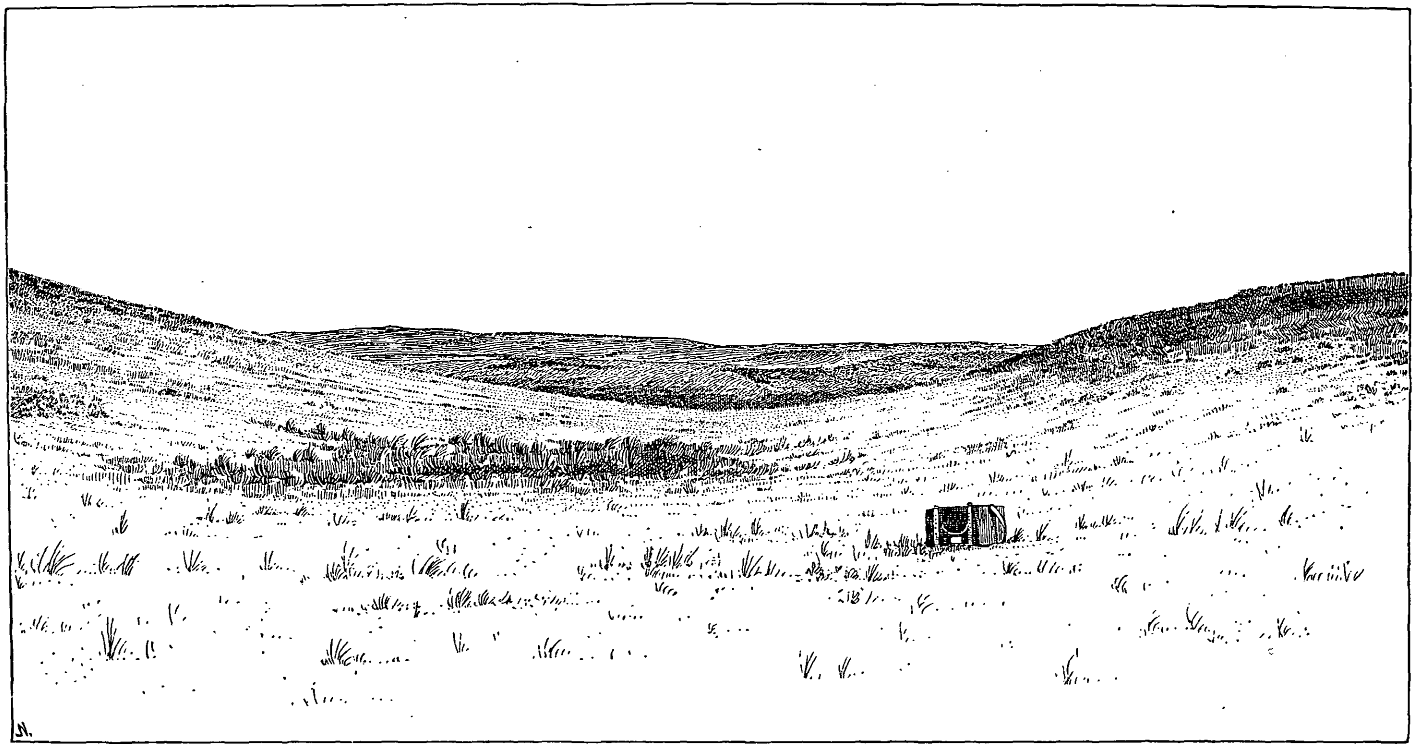
FIG. 7. Diagrammatic section across valleys in sunken plain.

At the point where these hollows originate in the sand hills, the hills are generally lower than elsewhere and have a more or less washed-away appearance. This is especially the case just east of the village of Nantucket, where two of the largest of the troughs head against the axis of the sand hills. At this point the hills themselves are in good part wanting.

West of Long Pond the troughs have been to a good extent destroyed by the invasion of the sea, but we may trace them in the valleys of Hither Creek, Broad Creek, Narrow Creek, and Further Creek to the western extremity of the island. They reappear on the island of Tuckernuck, there being two distinct trough-like furrows of this nature on that island. Counting these on Tuckernuck and reckoning all the depressions on Nantucket which can be put in this category, we have in all 23 of these remarkable depressions along this shore, or an average of about two to a mile of its east and west length. Some of these, particularly in the eastern end of Nantucket, are very small and do not distinctly extend up to the foot of the range of sand hills; still, all of them are manifestly of the same type and must be explained in the same way.[1]

We turn now to the internal structure of the sand belts and terraces. The sections through the sand belts are few in number and imperfectly reveal the structure of the mass. Where seen in section these deposits present a curious mixture of stratified and unstratified materials. In most cases the mass is throughout irregularly stratified, by far the greater portion of the materials consisting of sand and small pebbles accummulated in irregular layers. At a few points they contain, especially near their bases, materials huddled together in the manner of glacial till. It is noteworthy that wherever we find a section giving a

[1]A further discussion of these peculiar topographical features may be found in my report on the Island of Martha's Vineyard, Seventh Ann. Rept. U. S. Geol. Survey, p. 314 et seq.



TOPOGRAPHY OF KAME MORAINE IN CENTRAL DISTRICT, NEAR NORTH END OF LONG POND, LOOKING NORTH.

view of the stratified beds with the adjacent till, the gravels are found to contain a considerable mixture of clay, which appears to have been derived from the grinding up of the till upon which they lie and the mingling of the waste with the stratified kame deposits. Although there are occasionally large angular bowlders in the stratified deposits they are much less common than in the surface of the hills. On a section following the contour of the surface and ten feet below its level there will probably be not as much as one-fourth the number of large bowlders that are contained on the terraces or on the surface of the hills. This indicates that the bowlders were brought to their present positions by other agents than those which accumulated the heaps of gravel and sand. The contact of these bowlders with the surface in many cases seems to indicate that they have fallen with some violence to their present positions and have not been conveyed along the surface by glacial ice or currents of water. Here, as elsewhere in southern New England, these erratics often lie slightly embedded in the subjacent sand and gravel. It seems clear that they were brought to their present positions by floating ice. The greater number which are or were found on the surface when compared with any section of the subjacent deposits seems to indicate that the ice-rafting action continued for a considerable time after the glacier retreated from this vicinity. (See Fig. 8.)

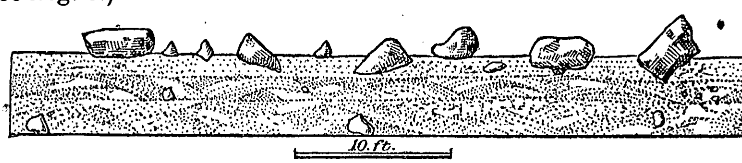


FIG. 8. Diagrammatic section—position of bowlders on glacial plain near Gibb Pond. *a*, horizontally stratified sand; *b*, somewhat irregularly bedded sand; *c*, very irregularly bedded sand.

It may be incidentally noted that if these bowlders were brought to their present positions by the ice we have from them evidence to show that this region was submerged during the accumulation of the kame deposits. Furthermore, from the fact that there are no evidences of the grounding of ice rafts on the delicately molded kames we may presume that this surface was deeply depressed beneath the sea at the time when the icebergs floated above it. In the kame hills scratched pebbles are of rare occurrence, and where found they have but faint traces of their original grooves.

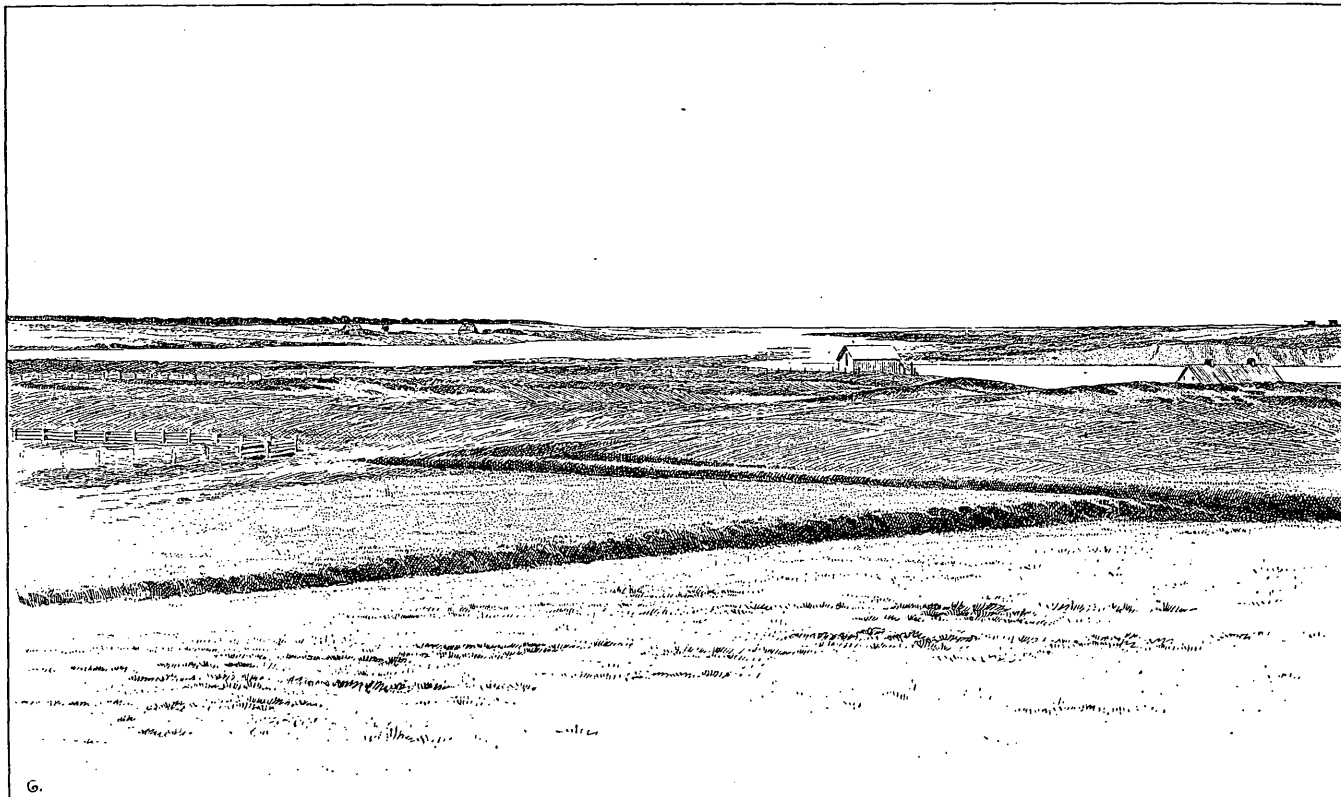
Perhaps the most noteworthy feature in these deposits of drift is the very extensive decay to which the pebbles and sand have been subjected. Some of the consequences of this decay will be noted below. In their form and structure the drift deposits differ in no distinct way from the similar accummulations found in the region a hundred miles farther north, but in their state of preservation they present important differences. The decay which has attacked the pebbles is exhibited in the following ways, viz: (1) By the interstitial decay of the stone, which manifests itself in the crumbling of many of the varieties of crystalline and fragmental rocks; (2) by the dissolved look of the surface of the rocks which resist the interstitial decay; and (3) by the development of the incipient joint planes in the pebbles, so that, though they may be but little decayed, they often split into fragments on being removed from their bed.

The interstitial decay is best shown in the pebbles of crystalline rocks where there is no magma, or base, to bind the separate crystals together; in certain varieties of syenite and in the hyperite pebbles, which not infrequently occur in some parts of the drift, this decay is most complete. It is also manifest in the numerous fragments of sandstone and in many of the conglomerate bowlders. Compared with the pebbles in the drift in the region about Fall River, Mass., these Nantucket fragments exhibit at least twice as much of this interstitial decay.

The superficial dissolving of the pebbles is a much more conspicuous and peculiar feature than the interstitial disintegration. It must be an inattentive eye which does not mark the effect of this peculiar form of decay in the erratics of the drift on this island. In appearance the pebbles subjected to this decay may be compared to crystals of rock candy partially dissolved away. The surface of the bowlders becomes very smooth, though uneven; in some cases pebbles or crystals contained in it are left as rounded projections on its face. This decay is observable in a great variety of specimens, but it is most conspicuous on the siliceous pebbles and appears to be limited to those which lie near the surface of the soil. In no case have I observed it at the depth of ten feet below, but my observations are hardly sufficient to warrant an opinion as to the depth below the surface at which it occurs.

It seems likely that this peculiar form of corrosion is due to the action of the surface waters, which, by the carbonic dioxide they obtain from the decaying vegetation, are able to effect a certain amount of solution of the more soluble stones. A trace of this action may be observed in the gravels on the southernmost part of the mainland north of Nantucket, but it is only in this island that it is a feature which quickly attracts the eye. In amount it is at least three times as great on this island as in the more northern localities. In some cases the pebbles on exposed portions of the surface show a small amount of erosion from the action of blown sand. These effects are not conspicuous and would hardly deserve mention were it not for the fact that it is worth while to discriminate between the considerable corrosion due to leaching and the inconsiderable amount effected by the erosive action of moving grains of sand.

In connection with this subject it should be noted that the bed-rocks of the mainland often exhibit a notable amount of decay which has taken place since the close of the Glacial Period. The amount of this corrosive action varies greatly according to the constitution of the rock and the extent to which it has been protected by the covering of



EAST BRANCH OF HUMMOCK POND, LOOKING SOUTH.

the drift; but when the rock has been to any considerable degree exposed to the action of the waters corrosion has generally affected it to the depth of a foot or more. This process of decay is traceable in the northern part of New England, though in that section it is relatively very slight, requiring close observation to detect it. In the region about Boston it becomes much more evident, the diabasic rocks of that vicinity having been decayed to the depth of twenty feet or more. Along the shores of Narragansett Bay the decay has penetrated less deeply, but more generally, into the rocks, none, except those which have been deeply covered by till, having entirely escaped the corrosive action. Where the bed rocks have so far suffered from this corrosion it is to be expected that the pebbles in the kame and terrace drift will be found even more extensively altered.

The third evidence of decay is that afforded by the splitting of the pebbles contained in the drift. This is a tolerably conspicuous feature in all parts of the deposits above the level of the lower till. The fractures are of two kinds: those which have taken place in pebbles as they lie, the fragments remaining connected, and those which have taken place in a remote period before the last movement to which the gravels have been subjected. This recent splitting is observable in all the glacial drift of New England. It is especially marked in the kame deposits, because the agents of decay penetrate more readily into the débris of this description than into the less porous till. On Nantucket it is, however, much more conspicuous than elsewhere, so far affecting the pebbly beds of the island that a large part of the fragments fall to pieces on exposure and many others are readily shattered by a very slight blow. The greater prevalence of this manifestation of decay seems to show that these beds have been subjected to weather for a much longer period than the gravels of the region to the northward.

The other group of split pebbles, of which the fracturing was done before the fragments came to their present position, is more puzzling. Pebbles of this class present distinct fracture faces, which are usually in joint planes. These fracture faces are a little rounded, the rounding being about what is found in unpolished paleolithic implements, or that measure of rounding which comes from a small amount of friction. In no case are the fragments which are separated from the slightly rounded pebbles found in connection with them. In some cases the edges of the stones are slightly chipped, making them appear like the secondary fractures which the savage implement-maker formed on the stones (Pl. X).

At first sight a large number of these faceted pebbles look like imperfect stone implements; to my eye they closely resemble the interesting implement-like stones from the gravels near Trenton, N. J. It is often, indeed, difficult to resist the conviction that some selected specimens are the result of human labor. A careful inquiry, however, has led me to the conviction that they are all natural products. This inquiry was conducted in the following manner, viz, gathering an extensive collection of these stones it was observed that they were far too common in the drift to make it reasonable to suppose that they had been the work of man. It was also evident that the range in size of these fragments was far too great to justify the supposition that they were of artificial origin. Specimens weighing 20 or 30 pounds were not infrequently observed; these were evidently too large to have been used as implements; others were found not exceeding an inch in length, which were clearly too small to have served any useful purpose.

Moreover, out of a hundred specimens, on the average not over one or two were chipped in a way which it would be reasonable to suppose a savage would have chosen to adopt in order to bring the stones into a shape suitable for any of his limited needs. The gradation between the specimens, which are so like unquestionable stone implements that they would readily be accepted by the collector as the work of the human hand and those which would be unhesitatingly rejected, is singularly complete and well calculated to persuade the unprejudiced observer that all the artificial-looking fragments from the kames and terraces of Nantucket are of natural origin. It is clear that the occurrence of such chipped and polished fragments resembling works of art shows us how careful we should be in classing as man's work fragments of stone which have been selected from a great many chipped pebbles.[1]

These chipped and somewhat polished stones may be accounted for in a natural way, thus: Let us suppose that the pebbles were formed and transported to near their present position by the glaciers during the first part of the ice age and left in the form of kame and till deposits for a long period during which they were exposed to the influences of decay. In this period of repose their incipient joints were developed, as the joints are now developed everywhere in the pebbles buried in the kame deposits. Next, in a readvance of the ice, these pebbles were forced forward and thereby submitted to strains which separated the fractured portions from the mass of the more or less chipped fragments; the transportation led to the rounding of the exposed edges and to the partial polishing of the fractured surfaces. We would then have the pebbles in the shape in which we now find them; and the enthusiastic collector, selecting one in a hundred of these fragments, would suppose that he had discovered implements which were accumulating on the ground during the glacial period.

The full bearing of these observations on the discoveries made by Dr. C. C. Abbott in the region about Trenton, N. J., can not be discussed

[1] It seems to me that we may for the criticism of such materials make a simple rule, based on experience, which is as follows: Where the stones appearing to be artificially worked are mingled with many similarly chipped stones which can not be regarded as artificial, we probably have a case similar to that above cited. Where the supposed implements are not so mingled with similar pebbles evidently of natural origin we shall run little risk in classing them as artificial objects.

in this memoir. It still seems likely that the collections of chipped pebbles gathered from the Delaware drift contain a large number of fragments which have been worked by human hands. However, on comparing the large and fairly representative collection of these pebbles contained in the Peabody Museum, at Cambridge, Mass., with specimens which abound at Nantucket, I am convinced that the whole problem requires a very careful discussion from the point of view of the geologist, as well as from that of the ethnologist.

These artificial-looking stones are found in relatively great abundance in all the pebble-drift sections exposed at Nantucket. At Sankaty Head they occur at a depth of 25 feet or so at the crest of the cliff, in positions which seem to indicate that they could not have slipped down from the surface. It is hardly possible to explain the occurrence of these fragments on the supposition that they are artificial in any way that is consistent with the demonstrated facts concerning the history of the Glacial Period. The pebbles themselves must have been formed during the glacial period, for the whole of this upper or kame drift rests upon a layer of till produced during the first great advance of the ice, and they are overlaid by what appears to be till of a later age. Apparently all the work of man on these materials, if indeed any such work has been done, must therefore have been accomplished in the interval between the retreat of the glacier after the first part of the ice epoch and the second advance of the glacier. We have to suppose that in this relatively brief interval savage men strewed the surface with chipped stones in a measure unknown in any part of the earth's surface, however long occupied by primitive people; otherwise, when the surface was swept by the readvancing ice sheet and the superficial material commingled with that which was below, forming the vast kame heaps which the glacier pushed forward to its front, these chipped stones would not have abounded in it as they do on this island, at Trenton, and probably at other points on the ice front.

Let us imagine the glacier to return to the present surface of New England, sweeping away all the superficial materials now resting upon it, and accumulating along a new ice front the débris which was not ground up in transportation. What would be the chance of finding in this deposit any remains of the Indians who lived during the Glacial Period? Manifestly their remains would be almost inconceivably rare. The explorer would be probably well rewarded with a single find in a lifetime of search, so slight would be the chance of a fragment of art work surviving the accidents of a glacial journey.

The worked stones and the other substantial elements of our modern arts in New England would afford thousands of times as many fragments as all the stone hatchets and similar tools which the aborigines left on the surface of this country, and yet I doubt if the remains of our arts would be as plenty in the frontal moraine of a new glacial period which should overtake us as these implement-like fragments which are now found at Nantucket.

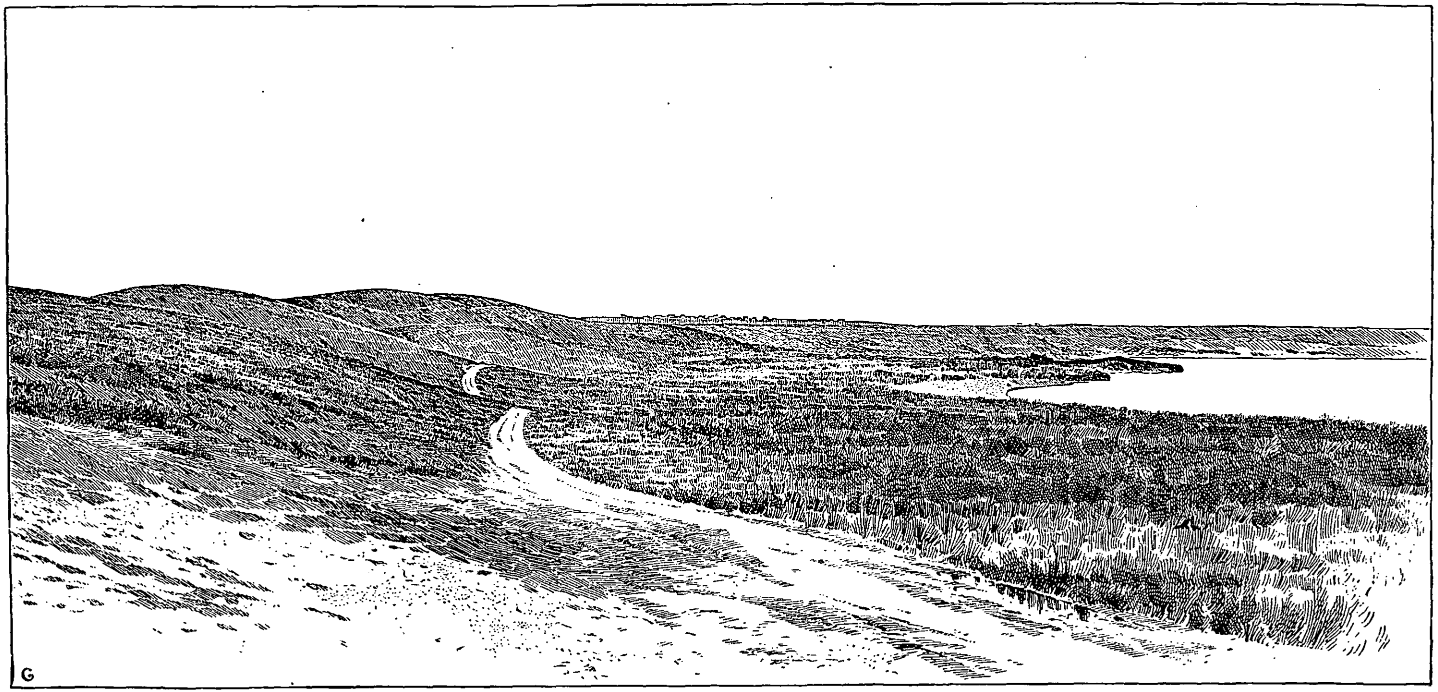
One of the considerable difficulties which we encounter in assigning an artificial origin to these frontal drift fragments arises from the fact that none of them appear to be worn on their cutting edges. It may be said that they were used for striking blows and not for cutting bones, sinews, and other hard substances. If this were the case we should find other forms of implements which were so used, for we can not believe that there was ever a tribe of savages making stone implements for the single purpose of striking blows, who neglected the equally serviceable uses in which the edges of the stone would have been worn.

ORIGIN OF THE DETRITAL MATERIALS.

The mineralogical features of the pebbles of the drift in this region have especial interest, inasmuch as they afford some information concerning the nature of the rocks which lie to the northward of Nantucket but which are deeply covered by the mantle of detrital material. About all we may ever know concerning these deposits we shall learn from a study of the drift materials derived from them. On this account I have paid especial attention to the pebbly deposits of the island. The exposures of the underlying till are so scanty and the pebbles contained in the exposed portion so few and small that no effort has been made to ascertain the variety of rocks represented in this portion of the ice-borne material. The only examination has been of the stratified gravels.

It should be noted that the distance to which the fragments contained in the bowlder clay have been carried is much less considerable than that to which the stratified or kame gravels have been conveyed. In the valley of the Taunton River, which is the nearest considerable basin on the mainland, the average distance to which the kame fragments have been carried is at least three times as far as that to which the till materials have traveled. The result is, that the kame or stratified gravels give us information of a less accurate because less localized nature than we may obtain from the study of the fragments from the till.

The pebbles of the stratified gravels on Nantucket are in large part derived from the group of granitic rocks known on the neighboring mainland; probably nearly one-half of the whole mass is of this nature. Of the remainder a considerable part is composed of felsites and felsite porphyries such as are common in the region of Boston, Mass. On the eastern end of the island these porphyrite and felsite materials are much more abundant than on the western portion. In the region about Sankaty Head these porphyritic pebbles are plentifully intermingled with somewhat angular fragments of volcanic breccias of a type unknown to me in any part of southern New England, though they much resemble the ash beds and breccias of the eastern portion of the shore of Maine, especially those found near Eastport. Although the felsites



JUNCTION OF KAME MORAINE AND TERRACE PLAIN ON GIBBS POND; SIASCONSET IN THE DISTANCE.

near Boston are only 60 miles away, I am disposed to believe that these fragments of porphyry found on Nantucket are derived from localities which are much nearer this island. The very angular nature of some of the fragments leads me to believe that they are from a field not more than 30 miles to the northward of the place where they are now found. There is a variety of stratified rocks, clay, slates, and sandstones and conglomerates in this drift material. The conglomerates and sandstones have the aspect of the deposits found in the Narragansett Coal Measures, especially those near Taunton, Mass. No distinct plant fossils or other organic remains have been found in these fragments, but several of the best of them show traces of carbonaceous matter, and in one instance a large bowlder lying near the village of Siasconset was found to contain faint traces of fossil plants.

Some of the bowlders of conglomerate have their pebbles much compressed, as is often the case in the mill-stone grit bed of the Narragansett coal fields, but only rarely so in the conglomerates near Boston. Mingled with these coal-measure pebbles is an abundance of large bowlders of white quartz, such as plentifully occur in veins in the much altered coal measures about Narragansett Bay, but which are rare in other parts of southern New England. Knowing that these materials are from a coal basin, the question arises whether they are derived from any part of the Narragansett field. Assuming as before that the direction of carriage of this drift was from the northwest, we find that the only part of the Narragansett basin lying in the path traversed by the glacial stream which brought the pebbles to Nantucket is in the narrow strip of those rocks extending northeasterly from Taunton through Bridgewater up to and a little beyond the village known as Queen Anne's Corner, a district which lies about 50 miles from Nantucket. The considerable size and the nature of many of these fragments are much against the supposition that they have journeyed so far. I am inclined to believe that they are from some area of carbonaceous rocks not farther away than the southern shores of Cape Cod.

If we assume that the direction of the ice movement at the time when the Nantucket moraine was formed was at right angles to the frontal line of that moraine, then these materials derived from the volcanic and the Carboniferous rocks probably could not have come from any part of the Narragansett field; they must have been derived from deposits of that age which lie either below the surface of Cape Cod or under the ocean to the north or south of it. The extreme western limit whence they could have journeyed must have been a meridional line lying at least ten miles to the east of Boston. In general it is a tolerably fair assumption that an extended moraine front was formed by an ice stream which moved down at right angles to the line of the accumulations. I am therefore disposed to believe that all the glacial waste of Nantucket, except perhaps the bowlders transported by icebergs, came from far east of the Narragansett basin.

Besides the above-mentioned stratified rocks there is a considerable amount of clay slate in the pebbles of Nantucket. These slates are represented by small though numerous fragments. A careful search failed to show any distinct fossils in them; in their physical condition they are more like the Carboniferous deposits of this section than any other deposits of this nature known to me in southern New England.

At no point on Nantucket have I found any distinct evidence of detrital matter such as might have been derived from Tertiary deposits like those which occur on Martha's Vineyard. This should not be taken as evidence that the Tertiary strata do not exist beneath this section. It may be that the beds of that age are deeply covered by the blue till, and that the last invasion of the ice was thus fended from them.

FOSSILIFEROUS DEPOSITS.

The fossil-bearing deposits of Nantucket are confined to two small groups of strata; one of these consists of fresh water peats, the other of areas of stratified sands containing a variety of marine species.

The fresh water marsh deposits are found, here and there, over the whole surface of the island. They consist of ordinary peats, and at first sight appear to have no special geological interest. On the shores of the island, however, there are, at several points, deposits of these peats which at present lie several feet below the level of high tide. These submerged fresh water peats appear to be particularly abundant in the sections from Tom Never's Head to Squam Head. Every heavy storm throws up considerable quantities of this peaty matter. The largest fragments are found on the beach a little south of Siasconset, but they may be observed at any time of storm along the whole of this eastern shore. The material, though not in any way changed from its original character, is interesting for the reason that it lies below the level of low tide, and also from the fact that it contains many beetles and other insects. There is another locality where the peats appear below the high tide level; this is on the north shore, about one mile west of the harbor of Nantucket, not far from the pumping station which supplies the town with water. At this point the peat is disclosed at low tide,

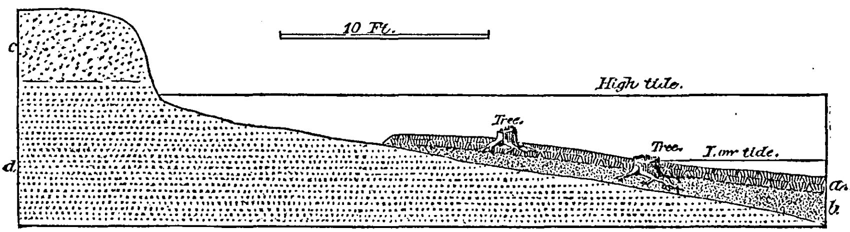


FIG. 9. Section of submerged swamp, north shore.
a, swamp; *b*, ferruginous sand; *c*, dune sand; *d*, stratified drift.

and is there seen to cover an area of several thousand square feet. (See Fig. 9.)

These submerged peat deposits contain abundant remains of insects. These are most plentiful in the deposits which occur along the eastern face of the island.

At first sight it appears as if these submarine peats might have been formed at their present levels in pools which were originally at a distance from the sea, but to which the sea has attained by the recession of the shores. There can be no question that this is the way in which the sea has come to invade these peaty deposits, but it seems doubtful whether we can explain their present elevation without supposing that the deposits have been somewhat depressed since the time of their formation. Ordinary spongy peat is now forming in many existing pools of the island below the level of high tide for the reason that the bottoms of the pools of fresh water are a little below that level; but the crowns of living trees never lie below the high tide mark, and even the rushes which grow on the margins of the swamps rarely, if ever, have their roots as low as the tide line. In these peat deposits on the north and northeast shores not only are the crowns of the rushes below the high tide line, but at one point we find the crowns and roots of a tree ten inches in diameter standing in the natural attitude about two feet below the highest tides and in a position where it is covered by the sea water. The roots of this tree were sufficiently exposed to view to make it clear that it was in the position where it had grown. It is not possible from fragments to determine its species in a clear way, but it is probably a variety of oak.

It is not admissible for us to assume, as we may in some other cases where trees grow below high tide mark, that this marsh deposit has been depressed by the local erosion of the base on which it stands. The area of swamp in which it occurs has the basin shape proper to the bottom of the basin-shaped pools found elsewhere on the island. A section excavated through the swamp shows that it rests upon the clay underlying all such accumulations, and that below the clay there are deposits of ferruginous sand. It would have been impossible for the waves to cut under this section in such a manner as to lower it gently beneath the sea. It is equally impossible to believe that the crown of any of our northern species of trees would have grown below the level of the water. I am therefore compelled to assume that this area has subsided since the above mentioned tree grew. The amount of the subsidence can not be less than two feet, that being the height to which the tides sometimes rise above the present level of its crowns. The roots of this specimen or those of a similar tree are found at least another foot further below the level of tide line. Moreover, as the existing swamps of the island which have or very recently had trees about their shores lie two or three feet above the sea level, it seems safe to assume that the tree when it grew had its crown at least five or six feet above its present altitude.

So far as I am informed this is perhaps the clearest evidence which has been obtained showing recent subsidence along this part of the New England coast. As to the date of the subsidence no evidence seems obtainable from this locality. The peaty matter has a very fresh and unconsolidated aspect. The roots of the rushes which it contains are singularly recent-looking; they are little decayed, and indeed seem to retain some part of their color and odor.

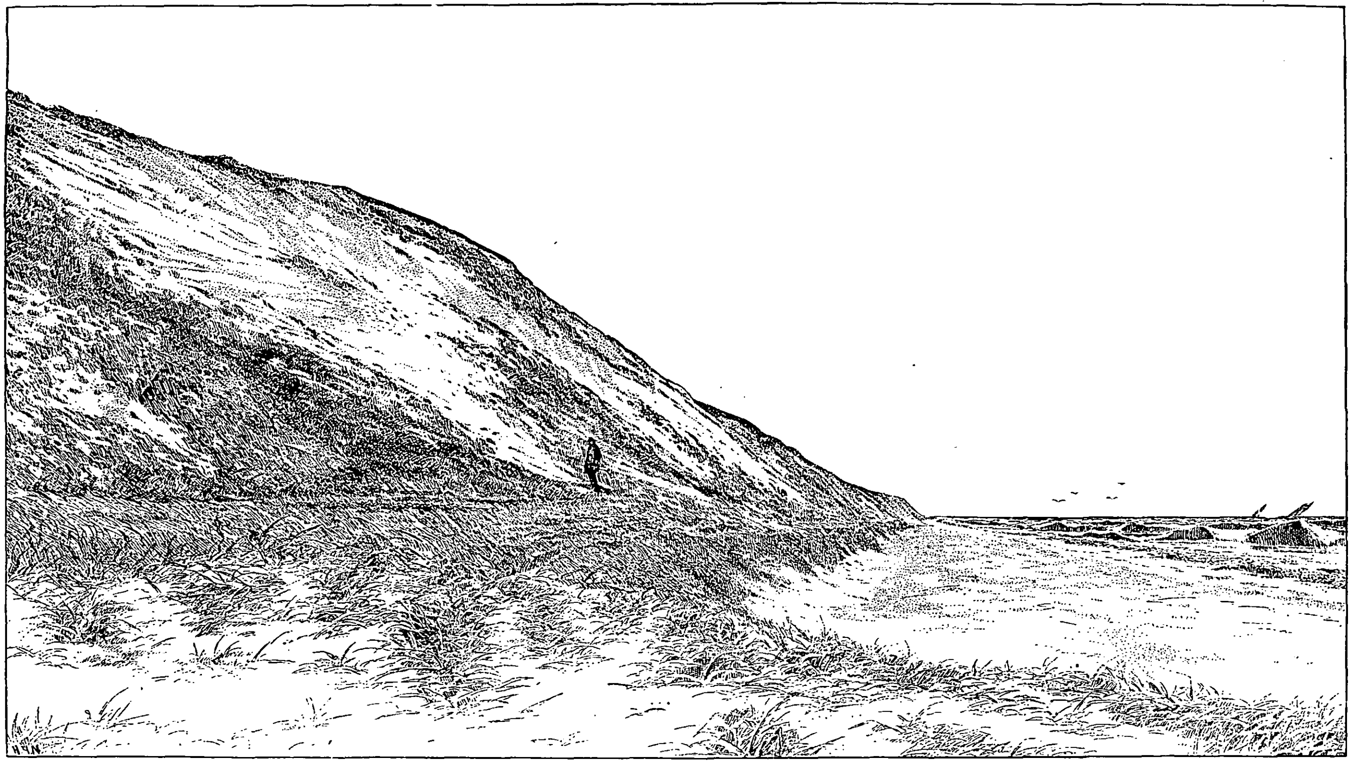
No other of the depressed fresh-water peats of this island exhibit their beds in place even at the lowest tides. They appear elsewhere than on the north shore to be covered by the deposits of sand, or are perhaps too deeply submerged to be exposed at the lowest stages of the tides. Still they contain fragments of roots of trees of considerable size, which may belong to some of the many species of shrubby plants which are tolerant of fresh water.

The evidence of marine deposits above the present level of the sea is, as has been long known, abundant on Nantucket. These deposits, so far as exhibited by natural sections, are limited to the east side of the island. This apparent limitation is probably due to the absence of natural sections elsewhere than on that part of the shore, for it is only on this eastern face of the island that we have any very extensive sections which clearly expose the stratified sands to a considerable depth. I am informed that at various points in and about Nantucket village deposits of shells have been encountered in digging the shallow wells, which never descend below high-tide mark. I have been unable to obtain any specimens of these fossils; but, as their presence is attested by Prof. Henry Mitchell, there can be no doubt that sands and gravels of the last stage of the Glacial Period containing scattered patches of fossiliferous beds, probably of the same age as those exposed at Sankaty Head, exist in other parts of the island.

FOSSILIFEROUS DEPOSITS OF SANKATY HEAD.

These fossiliferous beds of Sankaty Head appear in a cliff which has a height of about eighty feet above the high-tide mark. This cliff is cut through a portion of the kame gravels, which form a sort of elevated rolling terrace near the southern border of the true frontal moraine. The top of this terrace has a broadly rolling surface, and may be regarded as forming the zone of passage from the frontal moraine to the plain which lies on the southern part of the island. (See Pl. VII.)

The section at Sankaty Head is at present almost entirely hidden by the thick growth of grass and other plants, which have found a hold upon the surface since the sea has been fended from it by the considerable northward extension of the Siasconset apron-like beach. This is to be regretted, for the reason that it is from a geological point of view by far the most interesting section of the island and one of the most important found on the New England coast. It has been the ob-



SANKATY HEAD, LOOKING NORTH FROM A POINT 150 YARDS SOUTH OF LIGHTHOUSE.

ject of considerable study by several distinguished naturalists. In 1849 Messrs. E. Desor and Edward C. Cabot published in the proceedings of the Geological Society of London a short paper giving an account of this locality. At that time and for many years afterwards the continued inroads of the sea preserved a fresh face on the escarpment.[1]

The section as given by Messrs. Desor and Cabot is shown in Fig. 10. It differs from any I have been able to obtain in the present condition of the escarpment in certain important parts. It will be observed that at the base of the section the above-named authors indicate a bed of brown clay of unknown thickness which rises for 20 feet above the sea level. Above that point to the height of 33 feet they place successive layers of sand, gravel, and clay containing fossils, still higher in the section for a distance of 52 feet successive layers of sand and gravel without fossils, then a thin layer of peat one foot in thickness capped by six feet of dune sands, the whole forming an escarpment which rises 92 feet above the beach. The total height of the cliff as given by them is at least 15 feet greater than its actual altitude. It will be noticed also that the lower stratum of brown clay, which according to this section extends to a height of 20 feet above the sea level, is shown to be unconformably related to the gravelly layers which appear above it. It was the opinion of these observers that this lower clay belonged to the series of deposits which appear at Gay Head, and on this hypothesis they construct a highly ideal section, shown in Fig. 2 of their report, in which the Gay Head clays appear in the form of a syncline, the trough of which includes all the area between Sankaty Head and the western extremity of Martha's Vineyard. There is at present no trace of this brown clay at any part of this escarpment, nor was the thin layer one foot in thickness of tough clay, occurring according to their section at the height of 26 feet above the water line, found in my examinations. (See Fig. 10.)

The exhibition of this lower clay at the time Messrs. Desor and Cabot made their examination must have been clear, and the unconformity which they note was probably evident, as will be seen from the following extract from their report:

> The strata thus enumerated seem at first horizontal, but in digging along their edges we soon ascertained that they all dipped to the west, their inclination varying from fifteen to five degrees, the upper beds being generally less inclined than the lower ones. The inferior clay stratum, however, was found to differ considerably from the others, its dip being nearly thirty degrees to the southwest, and in some places even as much as forty degrees.
>
> These circumstances induced us to examine this lower clay stratum more carefully. Having made out a spot where the overlying gravel bed was seen in immediate contact with the top of the clay, we could distinctly trace its unconformable deposi-

[1] On the Tertiary and more recent deposits in the Island of Nantucket, Messrs. E. Desor and Edward C. Cabot, in a letter to Sir Charles Lyell, president of the Geological Society: Quart. Jour. Geol. Soc. London, vol. 5, 1849 (proceedings), p. 340.

tion, the gravel being seen dying out towards the more inclined clay stratum, as shown in the above section taken on the side of a gully in the cliffs. * * * A

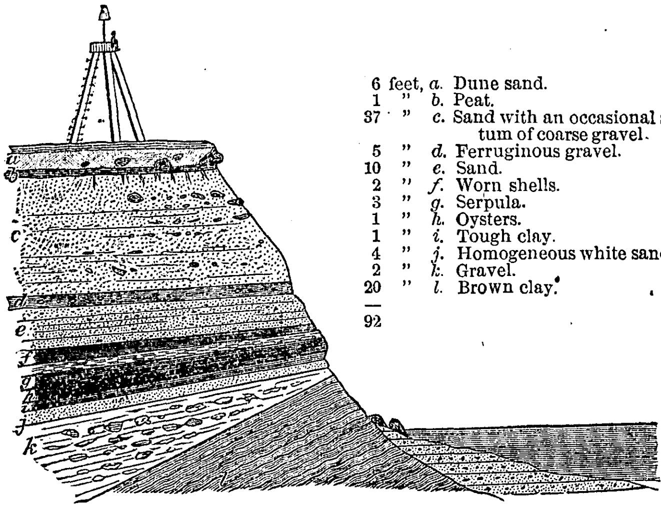


Fig. 10. Section at Sankaty Head.

considerable change of level must have taken place between the deposition of the clay and that of the gravel.

This statement compels us to believe that the lower clay was exposed to view at the time when Messrs. Desor and Cabot made their examination. This was probably in the year 1847. It will be noticed, as is indicated in the section, that a slight recession of the cliff in the direction in which it was then rapidly wearing would carry the shore-line across the exposure of the brown clay, and that a wearing back of 20 feet would in good part, if not entirely, destroy the exposure. It is not improbable that this recession has taken place and that this bed has disappeared from view.

This hypothesis is borne out by the results of a study of this section made in 1874 by Mr. S. H. Scudder, which is contained in a memoir by Prof. A. E. Verrill, On the post-Pliocene fossils of Sankaty Head, Nantucket Island.[1] At the time when Mr. Scudder made his observations the clay described by Messrs. Desor and Cabot was still visible. As his observations differ in an important way from those made by the above-named gentlemen, I give his note in full:

The sands and gravels forming the bluff at Sankaty Head, Nantucket, rest at base upon a thick bed of light-brown sandy clay of uncertain thickness, but extending upward to about 20 feet above the sea level. As the beds which rest upon it dip to the southwest, and as the anchor brings up clay from Sankaty Head eastward for half a mile, this clay bed is probably of great thickness.

The brown clay is overlaid by 4 feet of gravel and coarse sand, the coarser parts mostly confined to three or four inches of the uppermost levels; the upper bed is more or less ferruginous, and hardens on exposure into a rather compact conglomerate.

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[1] Am. Jour. Sci., 3d series, vol. 10, 1875, pp. 364–375.

To this stratum must doubtless be referred a single specimen of a bivalve (probably a mactra), with valves half open, picked up on the bluff, embedded in a gravel conglomerate, and like it strongly impregnated with iron. The gravel is followed by about four feet of sands, subdivisible into separate beds, viz: At base, an inch or two of a very fine loose white sand, followed by nearly two feet and a half of a little less fine, closely packed, white sand, with irregular ferruginous streaks through its mass; this is covered by 9 inches of a coarse beach sand, with a still coarser sand in pocket; and this again by 9 inches of a very fine white sand. Above this comes a foot of ferruginous sand closely packed with masses of tough blue clay, much exceeding the sand in bulk, and forming the floor of the fossiliferous beds.

These consist first, at base, of 22 inches of coarse sand, in which the oyster, quahog, and common clam are the prevailing forms, the first predominating to such a degree as to make the name of oyster-bed the most appropriate. This merges into a serpula-bed, about 28 inches in thickness, made up almost altogether of large masses of serpula packed in sand and almost wholly devoid of other fossils. The bed of worn shells superimposed on this is about 22 inches in thickness and closely resembles *coquina*, except in the entire want of adhesion between the fragments.

This bed is followed by about 10 feet of fine, white, thinly bedded sand, and this by the stratified drift of the island, to a depth, as estimated by Desor and Cabot, of 42 feet. The foot of peat mentioned by them is wanting at this exact locality (though present a few hundred feet farther south), leaving the drift covered by five or six feet of dune-sand, more or less intermixed with loam below.

On following the bed of broken shells along the face of the cliff it was found to thin out to about a foot in thickness 25 feet on either side of the most prominent point, where the section was made, and which has doubtless been longer protected than the other parts of the bluff by the former presence of a great mass of clay next the water's edge, called "Antony's Nose;" beyond these 25 feet the bed of broken shells becomes more or less obscured by an admixture of sand, gravel, and serpula, and is entirely lost at 40 feet distance on either side.

The strata, from the lowermost clay to the bed of worn shells, all dip to the southwest. The uppermost beds incline along the face of the cliff three degrees to the south, while the inclination to the west (along the section dug out of the cliff) is eleven degrees, making a dip of nine degrees to the southwest. All the beds below this also incline eleven degrees to the west, but the inclination of their face toward the south increased gradually in passing downward until that of the upper edge of the lower clay reaches eleven degrees, making a southwesterly dip of this bed seventeen degrees to the southwest. There is no evidence of any thinning out of the gravel-bed, as stated by Desor and Cabot, nor of any unconformability between this bed and the underlying clays; but, on the contrary, every appearance that the latter belong to the same continuous series as the former.

It is worthy of note that the fossils of this locality lie above the clays instead of in the clays, as in most of the New England localities of post-Pliocene marine shells.

It will be clearly observed that Mr. Scudder seems to have seen the clay, or rather sandy clay, found by Messrs. Desor and Cabot, but he failed to find any evidence of unconformability between this clay and the overlying fossiliferous sands. It is likely, however, that the aspect of the section had changed a good deal in the score of years which had intervened between these two observations. I think it probable that the observations made by the earlier geologists were good in the conditions of the cliff at the time when they were made.

I am disposed to believe that this lower sandy clay is not related to the deposits at Gay Head, but that it represents the upper portion of the lower till at Nantucket, which, as is shown in some parts of Squam Head, in the neighborhood of Polpis Harbor, on the north shore, and in the village of Nantucket, often contains very few pebbles, and presents in general the appearance indicated by the terms applied to it by the above-named observers. It is possible, however, that although not synchronous with the Gay Head deposits, it may be of the same age as the clays which occur on the southern shore of Chilmark.[1]

The most interesting portion of Professor Verrill's important memoir concerns the distribution of the fossil contents of this section. He divides this section into an upper and lower series of strata, between which there are considerable differences as to the character of their fossil contents. The exact line which separates these two portions of the section is not indicated save in the description given by Mr. Scudder. Inasmuch as this list of fossils is of great value to those who may be engaged in the study of quaternary fossils we give it in full.

List of species from the lower shell-bed.

MOLLUSCA.

Tritia trivittata Adams. Common.

Florida to Gulf of St. Lawrence; low water to 40 fathoms. Fossil in the post-Pliocene of Point Shirley, Gardiner I., Virginia, and southward; in the Miocene of Maryland, South Carolina; etc.

Ilyanassa obsoleta Stimpson. Common.

Florida and Gulf of Mexico to southern Maine; local in the southern part of the Gulf of St. Lawrence; littoral to 2 fathoms. Fossil in the post-Pliocene of Point Shirley, Virginia, South Carolina, etc.

Urosalpinx cinerea Stimpson. Common.

Tampa Bay and eastern Florida to Massachusetts Bay and local farther north to Gulf of St. Lawrence; littoral to 10 fathoms. Post-Pliocene fossil at Point Shirley, Gardiner I., Virginia, and southward; in the Miocene of Maryland.

Eupleura caudata Adams. One fine specimen.

Gulf of Mexico and eastern Florida to Cape Cod; low water to 8 fathoms. In the post-Pliocene from Virginia to Florida; Miocene of Maryland and South Carolina.

Astyris lunata Dall. One specimen.

Alabama and Florida to Massachusetts Bay; low water to 14 fathoms. Fossil in the post-Pliocene of Gardiner I. and South Carolina.

Cerithiopsis Greeni Verrill. Four specimens.

South Carolina to Massachusetts Bay; 2 to 10 fathoms.

Crepidula fornicata Lamarck. Abundant.

Gulf of Mexico to southern Maine, and local in the southern part of the Gulf of St. Lawrence; low water to 15 fathoms. Post-Pliocene fossil at Gardiner I., South Carolina, etc.; and Miocene in Maryland and South Carolina.

Crepidula plana Say. Common.

Distribution same as the preceding, from which, however, it is very distinct.

Crepidula convexa Say. Not common.

Distribution like the two preceding, from both of which it is perfectly distinct (although confounded with *C. fornicata* by Tryon and others). Fossil in the post-Pliocene of Virginia and South Carolina.

Odostomia trifida Gould. Common.

New Jersey to Massachusetts Bay: low water to 5 fathoms.

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[1] Geology of Martha's Vineyard: Seventh Ann. Rept. U. S. Geol. Survey.

Odostomia impressa Stimpson. Common.

South Carolina to Vineyard Sound: low water to 5 fathoms.

Turbonilla interrupta Adams. Several specimens.

South Carolina to Cape Cod; local farther north to the southern part of the Gulf of St. Lawrence, near Prince Edward Island; low water to 15 fathoms. Post-Pliocene fossil at Gardiner I. and in South Carolina.

Saxticava arctica Deshayes. Rare and small.

Arctic Ocean to Georgia; local and rare south of Long Island; low water to 50 fathoms. Fossil in the post-Pliocene of Maine and everywhere northward.

Mya arenaria Linné. Abundant.

Arctic Ocean (lat. 78° N.) to South Carolina; low water to 40 fathoms. Post-Pliocene fossil from South Carolina and Virginia to Greenland and northern Europe.

Corbula contracta Say. One valve.

Florida to Cape Cod.

Ensatella Americana Verrill. Common.

Labrador to Florida; low water to 25 fathoms. Fossil in the post-Pliocene of Portland, Me., Point Shirley, Gardiner I., Virginia, and South Carolina; Miocene of Maryland, etc.

Angulus tener Adams. Several specimens.

Florida to Gulf of St. Lawrence; low water to 12 fathoms.

Cumingia tellinoides Conrad. Common.

Florida to Cape Cod; 3 to 12 fathoms. In the post-Pliocene and Miocene of South Carolina, etc.

Petricola pholadiformis Lamarck. Rare.

Gulf of Mexico to Massachusetts Bay; local in Casco Bay and southern part of the Gulf of St. Lawrence; low water to 4 fathoms. In the post-Pliocene and Pliocene from Florida to Virginia.

Venus mercenaria Linné. The variety abundant; a nearly typical form not uncommon.

Florida to Massachusetts Bay; local on the southwestern coast of Maine and southern shores of the Gulf of St. Lawrence and Bay of Chaleur; low water to 8 fathoms. In the post-Pliocene of Point Shirley, Gardiner I., Virginia, Florida; Miocene from Maryland to South Carolina.

V. mercenaria, var. antiqua Verrill. By this name I propose to designate the unusually massive and strongly sculptured variety to which most of the fossil shells belong, and which has been discussed on a previous page.

The shell is rather obtusely rounded posteriorly, and is thickly covered with prominent concentric lamelliform ridges, which mostly extend entirely across the shell, but are often reflexed, appressed, and more or less confluent over the middle region, where the ordinary variety is nearly smooth (except when young). The violet color can still be traced in some specimens entirely around the inner margin, as in many recent Nantucket examples.

Tottenia gemma Perkins. Few specimens obtained.

South Carolina to Labrador; low water to 4 fathoms.

Gouldia mactracea Gould. One specimen.

Florida to Cape Cod; 3 to 15 fathoms.

Scapharca transversa Adams. Very abundant and large.

Florida to Cape Cod; low water to 15 fathoms. In the post-Pliocene of Cape Cod, Gardiner I., Virginia, South Carolina; Miocene of Virginia and North Carolina.

Mytilus edulis Linné. Common.

Circumpolar; Arctic Ocean to North Carolina; littoral to 50 fathoms. In the post-Pliocene from Florida to Greenland and northern Europe.

Modiola hamatus Verrill. Common.

Gulf of Mexico to Long Island Sound and Narragansett Bay; littoral.

Crenella glandula Adams. Few specimens obtained.

Labrador to Long Island; 5 to 60 fathoms. In the post-Pliocene of Montreal.

Anomia glabra Verrill.

Florida to Cape Cod; and locally farther north to Nova Scotia; littoral to 20 fathoms. In the post-Pliocene and Pliocene of South Carolina.

Ostrea Virginiana Lister. Abundant and well-grown.

Gulf of Mexico to Cape Cod, and locally farther north, at Damariscotta, Me., and in the southern part of the Gulf of St. Lawrence; low water to 5 fathoms. In the post-Pliocene of Point Shirley, Gardiner I., South Carolina, etc. Both the short, rounded specimens and the much-elongated and narrow forms occur, as well as all the intermediate states, just as in many modern oyster-beds, showing that in post-Pliocene times the same kind of individual variations prevailed that have perplexed many modern systematists, but they have not yet become specific, nor even definite varietal characters.

BRYOZOA.

Hippothoa variabilis V. (*Escharella variabilis* Verrill, in Report on Invert.) Common on *Serpula*, etc.

Florida to Massachusetts Bay; low water to 20 fathoms.

Biflustra tenuis V. (*Membranipora tenuis* (Desor); Verrill, in Report on Invert.) Common on shells.

Delaware to Massachusetts Bay; low water to 15 fathoms.

Membranipora catenularia Smitt. Common on shells.

Arctic Ocean to Long Island Sound; low water to 50 fathoms. Northern Europe.

CRUSTACEA; ANNELIDA; PORIFERA.

Panopeus sp. Several claws were found.

Eupagurus pollicaris Stimpson. A claw, probably from this bed, is recorded by Desor.

Florida to Massachusetts; 2 to 15 fathoms.

Balanus eburneus Gould. Common.

West Indies to Massachusetts Bay; littoral to 3 fathoms.

Balanus crenatus Bruguiére. Common.

West Indies to the Arctic Ocean; 3 to 15 fathoms.

Serpula dianthus Verrill. Very abundant.

North Carolina to Cape Cod; low water to 15 fathoms.

Cliona sulphurea Verrill. The excavations are abundant in oyster-shells.

Florida to Massachusetts Bay; 1 to 15 fathoms.

List of species found only in the upper shell-bed.[1]

MOLLUSCA.

Buccinum undatum Linné. Common.

Arctic Ocean to New Jersey; northern coasts of Europe; low water to 100 fathoms. In the post-Pliocene, Maine to Labrador and northern Europe.

Neptunea curta Verrill. Several specimens; one of large size.

Labrador to Massachusetts Bay, and in deep water farther south to Long Island.

Lunatia heros Adams. Common, but badly broken.

Georgia to Gulf of St. Lawrence; low water to 40 fathoms. Post-Pliocene, Canada, South Carolina; Pliocene, South Carolina; Miocene, Maryland to South Carolina.

L. heros, var. triseriata. One specimen occurred.

Neverita duplicata Stimpson. One broken specimen.

[1] A valve of *Saxicava Norvegica* was found after this list was put in type. Arctic Ocean to Massachusetts Bay.—*Foot-note in Am. Jour. Sci.*

Yucatan to Massachusetts Bay; low water to 10 fathoms. Post-Pliocene, Virginia to Florida: Pliocene, South Carolina; Miocene, Maryland to South Carolina.

Crucibulum striatum Adams. One large specimen.

New Jersey to Bay of Fundy; low water to 40 fathoms.

Scalaria Grœnlandica Perry. Recorded by Desor, and doubtless from this bed.

Arctic Ocean to Block Island; 10 to 109 fathoms; northern Europe. Fossil in post-Pliocene of northern Europe.

Diodora Noachina Gray. Two good specimens.

Arctic Ocean to Cape Cod; 8 to 70 fathoms. Northern Europe.

Mya truncata Linné. Several large specimens.

Arctic Ocean to Nantucket Shoals; low water to 10 fathoms. Northern Europe. In the post-Pliocene, Maine to Labrador.

Thracia truncata Mighels and Adams. A few valves, special bed not indicated.

Greenland to Long Island; 10 to 60 fathoms.

Clidiophora trilineata Carpenter. One valve.

Florida to Gulf of St. Lawrence; low water to 30 fathoms.

Macoma fragilis Adams, var. fusca (Say). A few valves.

Greenland to Georgia; littoral to 6 fathoms. In post-Pliocene from South Carolina to Greenland.

Ceronia arctata Adams. Abundant and large.

Gulf of St. Lawrence to Long Island.

Mactra solidissima Chemnitz. Common, fragmentary.

Florida to Labrador; low water to 12 fathoms. Post-Pliocene of Point Shirley, Mass.

Cyclocardia borealis Conrad. Common.

Labrador to New Jersey; 3 to 80 fathoms. In the post-Pliocene of Gardiner I., Point Shirley, Labrador.

Cyclocardia Novangliæ Morse. A few valves.

Gulf of St. Lawrence to Long Island Sound; 3 to 40 fathoms.

Astarte undata Gould. One worn valve.

Long Island Sound to Northumberland Straits in Gulf of St. Lawrence; low water to 100 fathoms. In the post-Pliocene of Gardiner I. and Point Shirley.

Astarte castanea Say. Abundant.

New Jersey to Nova Scotia; 5 to 40 fathoms. In the post-Pliocene at Point Shirley.

Modiola modiolus Turton. Many worn valves.

Circumpolar; Greenland to New Jersey; low water to 80 fathoms. In the post-Pliocene of Point Shirley, Canada, and northern Europe.

Anomia aculeata Gmelin. Common.

Arctic Ocean to Long Island Sound; low water to 100 fathoms.

BRYOZOA.

Eschara verrucosa Esper. On shells of Ceronia.

Arctic Ocean to Nantucket Shoals; 3 to 45 fathoms. Northern Europe. In the fossil examples the surface of the cells is covered with radiating ridges, often rising into an eminence in the middle, and is perforated with numerous pores in the grooves. Orifice somewhat semicircular, with a median avicularium in front of the proximal edge.

Celleporaria incrassata Smitt ?. Several.

Off Martha's Vineyard to Spitzbergen; 10 to 160 fathoms. The specimens are thick, irregular masses. The apertures are small, rounded, oblong, constricted on the sides by small points projecting inward near the middle, and sometimes with a small proximal spine.

CRUSTACEA AND ECHINODERMATA.

Balanus porlatus. Very abundant and large, but broken.
Arctic Ocean to Long Island Sound; 2 to 90 fathoms.
Strongylocentrotus Dröbachiensis A. Agassiz. Spines only.
Arctic Ocean to New Jersey; circumpolar; low water to 430 fathoms. Post-Pliocene of Maine and northward.

List of species found in both shell-beds.

Species.	Lower bed.	Upper bed.
Urosalpinx cinerea	Common	One.
Tritia Trivittata	Few	Common.
Ilyanassa obsoleta	do	Few.
Crepidula fornicata	Abundant	do.
Crepidula plana	Common	do.
Ensatella Americana	Abundant	do.
Mya arenaria	do	do.
Saxicava arctica	Few	Common.
Venus mercenaria	Abundant	Few.
Scapharca transversa	do	do.
Mytilus edulis	Few	Common.
Crenella glandula	do	Several, large.
Ostrea Virginiana	Abundant	Few.

Professor Verrill is of the opinion that—

The fossils of the lower bed indicate, for the water, a summer temperature of 70° to 75° Fahr., while those of the upper bed correspond to a temperature of 55° to 60°, thus showing plainly the influence of the Arctic current along the coast. All the species still inhabit the waters of southern New England, except *Diodora Noachina*, found in the upper bed, but this occurs in Massachusetts Bay, and will probably be found hereafter in the deeper channels among the Nantucket Shoals.

All the species found in this section appeared to Professor Verrill identical with those now found along the shores of this region except the quahog (*Venus mercenaria*). In these shells he notes certain slight but apparently unimportant peculiarities. It does not seem possible to conclude from the difference in the character of the shells in the upper and lower parts of the section that any general climatal change in the temperature either of water or of air took place at the time when these two portions of the section were formed. The result may have been due altogether to changes in the direction of the ocean current, changes dependent on geographical modifications, which may have occurred at considerable distances from this point.

A diagrammatic section of the cliff, as far as it is determinable in the present condition, is given in Fig. 11. It will be seen that, as shown at present, the fossils occur at various levels in the bed, some of the species occurring as much as fifty feet above the surface of the water. The deposit is, throughout, composed of alternating layers of sand and pebbles. Save in the upper fifteen or twenty feet of the section, the pebbles are rather small, few exceeding three inches in diameter; near the top they are coarser and more angular, resembling the matter of a frontal moraine which has been stratified. In this uppermost section the fossils are wanting.

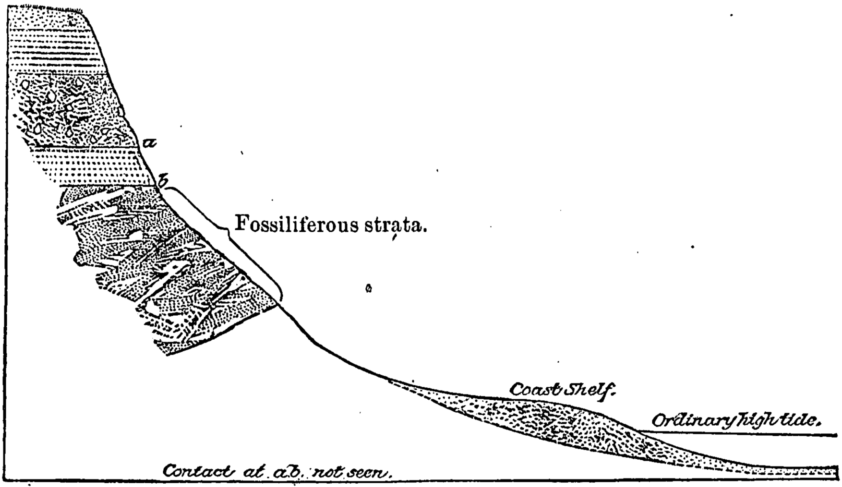


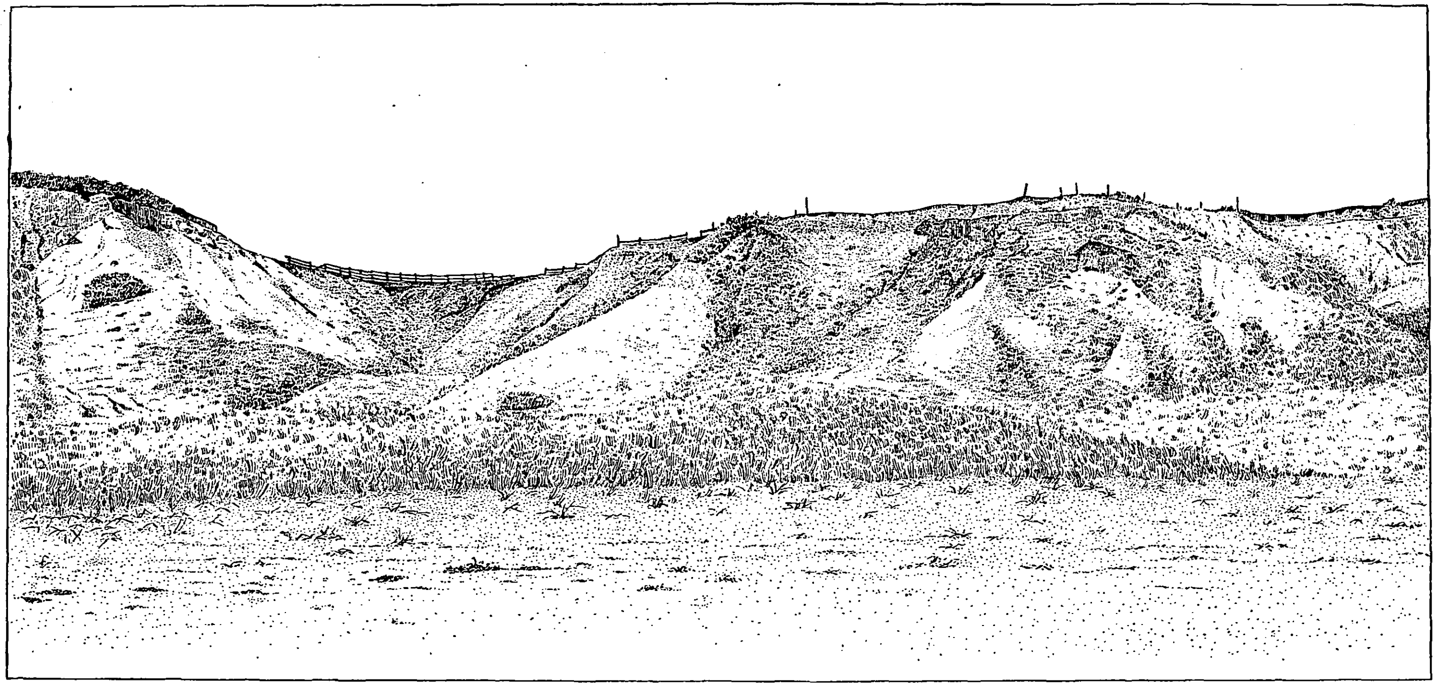
FIG. 11. Diagrammatic section of beds at Sankaty Head.
a, peat beds; *b*, tops of glacial drift.

The distribution of the fossils in the part of the section where they are found is extremely curious; they occur as small isolated patches, lying generally at a considerable angle, dipping in most cases to the southwestward. The specimens are usually in a fragmentary condition and are packed together as if by the action of waves or by motion of swift currents. It is evident that a larger part of these remains were not formed just where they lie, but were swept into their position after having been comminuted by the waves. As will be seen from the list of fossils given above, the species are all those which belong to shallow water in the parts of the shore which are open to the wide sea. This leads me to the belief that the fossiliferous deposits now exhibited at Sankaty Head were formed along an old beach line. The considerable thickness of the section in which they occur, which is 50 feet or more in depth, makes it necessary to suppose that the shore line remained near this place for a considerable time.

The upper part of this section for ten to twenty feet is pretty sharply divided from the lower fossiliferous portion, not only by the absence of fossils in its strata but by the disposition of its materials. The bedding from the base to the height of about fifty feet is, wherever observable, of the irregular, stratified type characteristic of the shore. Above that point, where the fossils cease to appear, the bedding becomes more horizontal, in this resembling our ordinary terrace drift, such as is found on the main-land and is exhibited in the terraces on the southern part of the island. Here, as everywhere else, so far as observed, these regular stratified terrace deposits are devoid of organic remains. Above this last-named deposit lies a mass of apparently unstratified coarse pebbles, which, though wanting the clay element so generally found in the till, probably is of that nature. This is capped by a layer of blown sand of very recent origin.

At a point about five hundred yards south of Sankaty Head lighthouse there is a section exposed which differs in an interesting way from that on the higher and more northern section of the cliff. The escarpment has a height of about thirty feet. The general nature of the ore deposits, which are fairly well disclosed, is indicated in Fig. 12. It will be observed that besides the variation arising from the presence of peat deposits and layers of bog iron ore, which may be fairly considered unimportant, the section departs in essential regards from that figured in the section given by Messrs. Desor and Cabot and that which represents the present condition of the higher cliffs. The till-like deposit near the top of the main section has apparently become in a southward extension of a few hundred yards a stratified clayey sand with angular pebbles. The sands next lower in the sections are apparently alike in thickness and character. But the fossiliferous sand is entirely wanting, unless it be represented by some small fragments of shells found on the talus at the point indicated in Fig. 12. The lower greenish gray clay appears to be identical with the deposit which I have considered as till in other parts of the island, where its character is much more distinct than at this point. I am disposed to believe that this blue clay may be the equivalent of the deposit which Messrs. Desor and Cabot considered of Tertiary age. In color and character it closely resembles the clay which overlies undoubted till at other points on the island. The contact between this stratum of clay and the overlying sands has not been seen, but from the imperfect indications I am inclined to believe that it is probably irregular, i. e., that the surface of the clay was, to a certain extent, eroded by the action of water or of ice before the sands were laid down. (See Pl. VIII.)

This sudden change in the character of the section is possibly due to the fact that within the interval which separates it from that at Sankaty Head we pass from the southernmost limit which the ice sheet attained in its last advance to the region where the sea-floor received the deposits of sand and gravel which came from the subglacial streams. It is likely that during the second stage of the last Glacial Period, the ice for a time extended beyond the southern shores of Nantucket. This is indicated by the rounded character of the mass of till which lies between the two arms of Hummock Pond, as well as by the extensive deposits of apparently morainal matter which exist in the ridges of Nantucket Shoals. But in its retreat the glacier made a considerable pause, in which the ice-front lay near the line of the center ridge of this island. The southernmost point occupied by the ice-front during this division of the period was near the portion occupied by the sections shown in



VIEW OF COAST ESCARPMENT, 500 YARDS NORTH OF SANKATY LIGHT.

Figs. 10 and 11. The section shown in Fig. 12 lies about four hundred yards south of the morainal accumulations.

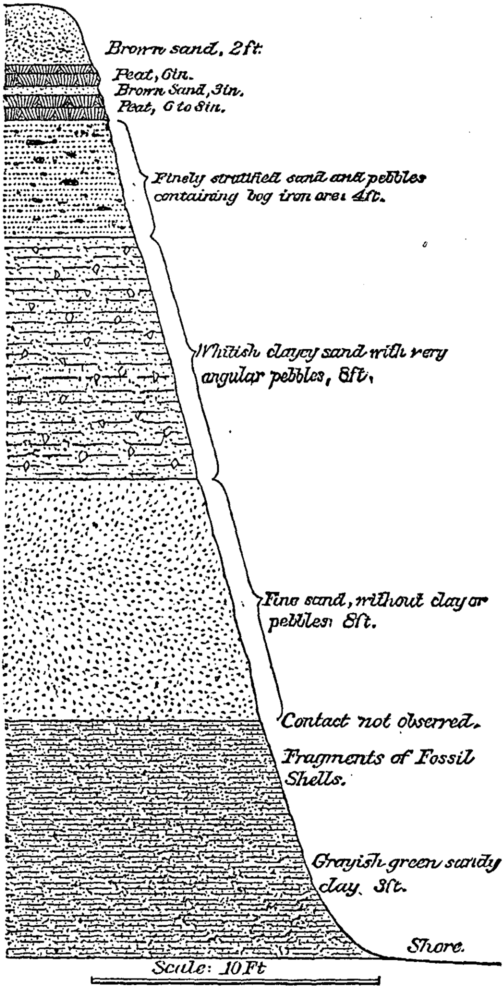


FIG. 12. Section south of beds at Sankaty Head.

In my opinion the history of this Sankaty Head section is as follows: After the first advance of the ice and its subsequent retreat, a movement which left the underlying till of the island in its present position, there was a considerable period in which this part of the shore was occupied by the sea. During this time the Sankaty beds were deposited, the sea shore probably sinking as they were formed; when, with the readvance of the ice, the organic life was expelled from these waters and the terrace deposits were formed above the level of the fossil-bearing beds. The passage from the obliquely stratified to the horizontal drift is so sudden that it must be taken to indicate a rapid change in the conditions which prevailed on the sea-shore at this point. This horizontal stratified drift, which contains no fossils, is capped on the top by irregular patches of bowlder material, which seem to me to be essentially till-like and to indicate that after the period of the fossil-bearing sands the glaciers again eroded this surface. It is, however, likely that only the extreme and thin edge of the ice attained to this point in its re-advance. This description of the section at Sankaty Head applies to the higher part of the cliff alone; a little to the southward the section changes greatly, as is shown in Fig. 12.

SUCCESSION OF GEOLOGIC EVENTS.

We are now in a position to consider the general history of this island during the Glacial Period, the only chapter of the geologic record which we can trace in its structure. First in this history is the series of events which led to the formation of the blue, pebbly clay or till, which, as before shown, appears to underlie the island, though it occasionally rises above the level of the sea. This deposit apparently must have been formed during the stage of the Glacial Period when the ice sheet was over this section. The unstratified nature of the mass compels us to believe that it was formed as ground moraine beneath the surface of the ice sheet, or immediately in its front. There is no evidence that this deposition continues to any distance south of the present shore of the island, but the occurrence of the mass on the ridge between the branches of Hummock Pond makes it clear that it extends about as far south as the southern shore. It does not appear possible to determine whether this region was above or below the level of the sea when this deposit was formed.

After the deposition of this mass the ice sheet retreated from the district and the climatal conditions became such as admitted the return of the marine life to the shore line, which must have been near its present position. This was certainly the case if the broken shells and coarse bedded sands at Sankaty Head be properly taken as evidence of sea-shore action. The level of this shore at one time must have been at least fifty feet below the present high tide mark. This condition in which the region was reoccupied by a marine life must have continued for a considerable period. After the fossiliferous beds were formed the ice again advanced until its southern front came at least to the middle of the island. The first result of this readvance of the ice was to erode the surface of the till and of the stratified deposits which had been formed above it. At certain points, probably over the greater part of the district, the beds were eroded all the way down to the till, as for instance at Pocomo and at some points in the center of Nantucket village. At other points, as on the north shore near the water-works, the stratified clays, which rest directly upon the till and which were probably deposited while the retreating ice front was still near the island, were not altogether removed by the later incursion of the ice.

At Sankaty Head, where the ice appears to have acted with much less energy than on the north shore, the fossiliferous beds, which doubtless lie at a considerable height above the surface of the till, and the stratified clays and sands, which normally covered it, were not removed, though they doubtless lost a portion of their thickness. As a result of this erosion by the second advance of the ice the beds containing the fossils, which possibly at one time covered the whole of the island, were left as separated patches.

During this readvance, or, perhaps, in several successive readvances, were accumulated the existing heaps of stratified and amorphous sand, gravel, and bowlders as well as the southern sand plains which constitute the principal features of the island. The conditions of their accumulation are, as far as determinable from the evidence, as follows, viz:

(1) The surface was below the present level of the sea. This is shown by the fact that there are no drainage channels leading out of the many valleys between the sand hills, such as would have been formed if the masses had been accumulated above the level of the sea, as are moraines at the front of a land glacier, as well as by the numerous bowlders apparently dropped from icebergs.

(2) The drift materials were partly shoved forward by the glacier and partly deposited by the streams which escaped from beneath the ice. This is shown by the intermingling of confused or amorphous drift with large bowlders and with stratified deposits of fine sands.

(3) The existence of considerable streams rising from the ice front and extending to the south is shown by the numerous deep channels which are excavated in the southern terrace or sand plains. These valleys originate in the hills and extend southwardly as distinct channels. They are comparable to the channels which are cut through sand deposits below the level of the water at the mouth of estuaries where considerable streams escape into the sea. It should be observed that all these valleys do not clearly head up against the base of the sand hills, though all of them trend in that direction. It appears likely, from what we know of the tendency of subglacial streams to change their position, that all of these streams may not have been flowing at the same time; indeed, they may have been made in succession by the changing direction of a few of these rivers which emerged from beneath the ice. The irregular accumulation of débris near their points of escape from beneath the ice sheet would of itself have a tendency to direct these streams to new channels. Clearly, we can not suppose that these channels were formed after the ice left this region, for there is no form of water action disconnected with glaciation which can be imagined to have produced them.[1]

(4) The sand plains on the southern part of the island, which exist nowhere else upon its surface, were deposited during the time when the

[1] Geology of Martha's Vineyard: Seventh Ann. Rept. U. S. Geol. Survey.

detrital hills of the northern section were being accumulated. This is shown by the fact that they at some points pass by gradual changes of form into these hills. The fact that they are intersected by the ancient valleys which originate in the morainal hills is evidence that the plains were here before the glacial sheets formed the hills or that they were formed at the same time as those elevations. The shape of the valleys, as is shown in the section (Fig. 7) and on the map, is best reconcilable with the hypothesis that they were formed as the sands of the plains were deposited. The whole of this work of deposition appears to have taken place beneath the surface of the sea, for, as before remarked, the whole character of the topography is inconsistent with subaërial action.

(5) After the foregoing stages of the re-advancing ice the glacier appears to have again retreated to the northward for the last time. During or after the process of retreat the surface must have been suddenly elevated above the level of the sea. Probably this process of reëlevation was extremely rapid, for unless we suppose that there was at that time some barrier on the south to protect the coast from the waves of the Atlantic, a barrier which has since been swept away, these delicate hills of sand and gravel would have been subjected to swift destruction by the action of the sea. The supposition that such a barrier ever existed finds no support from the facts.

This sudden uplift of the moraines and kames of this coast after the ice sheet went away is the most puzzling feature of its history. The evidence of this uplift seems to me ample; it does not rest upon the evidence presented on this island alone, but on the proof of the same nature afforded by the coast line from north of Boston to New York City. Everywhere along this part of the coast we have the same series of delicately molded kames that occurs on this island. We are compelled, therefore, to believe that they were formed below the surface of the sea and uplifted above its surface after the last retreat of the ice. I can not here discuss the whole array of evidence on which this assertion rests; that evidence will be considered in a special report on this subject, but one consideration in addition to those already adduced in this memoir will serve to show most essential grounds for this opinion. On the mainland, where there are extensive terraces of stratified drift—deposits clearly formed beneath the surface of the sea,—we often find these terraces passing gradually into sand hills or kames, the tops of these hills being on the same level as the upper part of the terrace. Now, these terraces were certainly formed below the level of the sea. The kames lying upon and inclosed within them must have been formed at the same time; for, if formed before, they would have been effaced in the construction of the terraces. They could not have been formed afterward for they are often completely inclosed in the terrace deposits.

Accepting, then, the hypothesis that these drift hills of Nantucket were accumulated below the level of the sea and afterward lifted above its surface, it is evidently very important to determine whether there was any action of the waves on their surface during the process of uplift. We may be sure that if they were exposed even for a few days to the action of the Atlantic surf and tides they would bear the unmistakable marks of water action. If we could plant these hills in the open sea on Nantucket Shoals, for instance, they would in one month have benches cut in their sides and a detrital apron formed on their front which would endure even longer than the delicate curves which now characterize their forms.

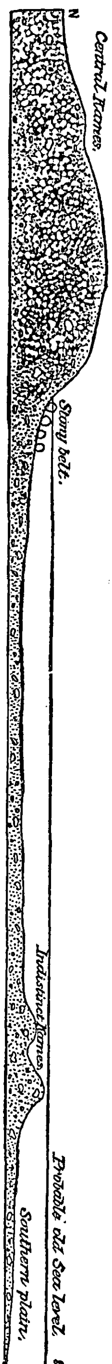


FIG. 13. Section showing apparent beach line near Gibb's Pond.

On the south side of the kame ridges between Nantucket village and the east end of the island where the hills are highest there is a faintly indicated shelf which possibly marks the action of the sea during a very brief period. (See Pl. VI.) This scarf is only a steeper slope of the hills and a faint terrace of sands with an inclined surface at its base. Although this may possibly indicate a temporary pause in the process of uprising which brought this surface from the bottom of the sea to above its level, it does not relieve us from the need of supposing that the elevation was really paroxysmal in its suddenness; for the fact that the summits of the sharp sand hills have not been planed down to the level is still before us. At one stage in the inquiry it seemed to me possible that these kames might have been worn down on their tops and become again pointed by the action of the rain; but a careful examination of the circular valleys between these ridges shows this not to have been the case, for these depressions

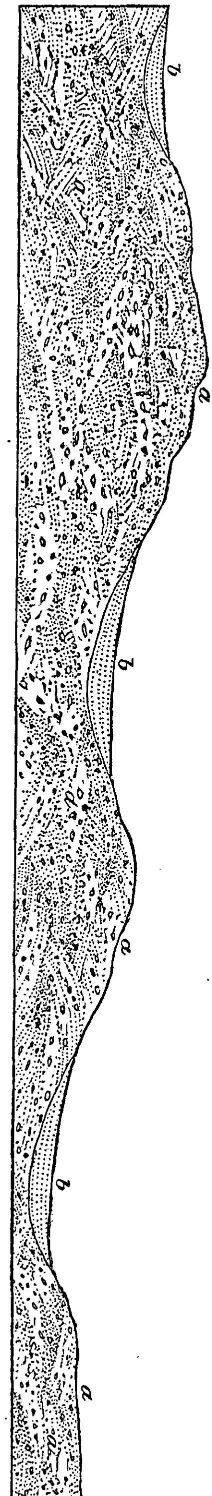


FIG. 14. Kames east of Nantucket village. *a*, *a*, *a*, cross-bedded glacial sands; *b*, *b*, *b*, sands deposited since the glacial period.

do not contain any such mass of débris as would have been swept into them by this process. It is true that the bottoms of the depressions often contain a small amount of sand, such as could be washed into them by torrential rains. These deposits are not disposed in the form of a flat-surfaced mass of stratified sand and gravel, as would have been the case if they had been formed by ocean waves, but they are made of fine sand which slopes gently toward the center of the pit. (See Fig. 14.)

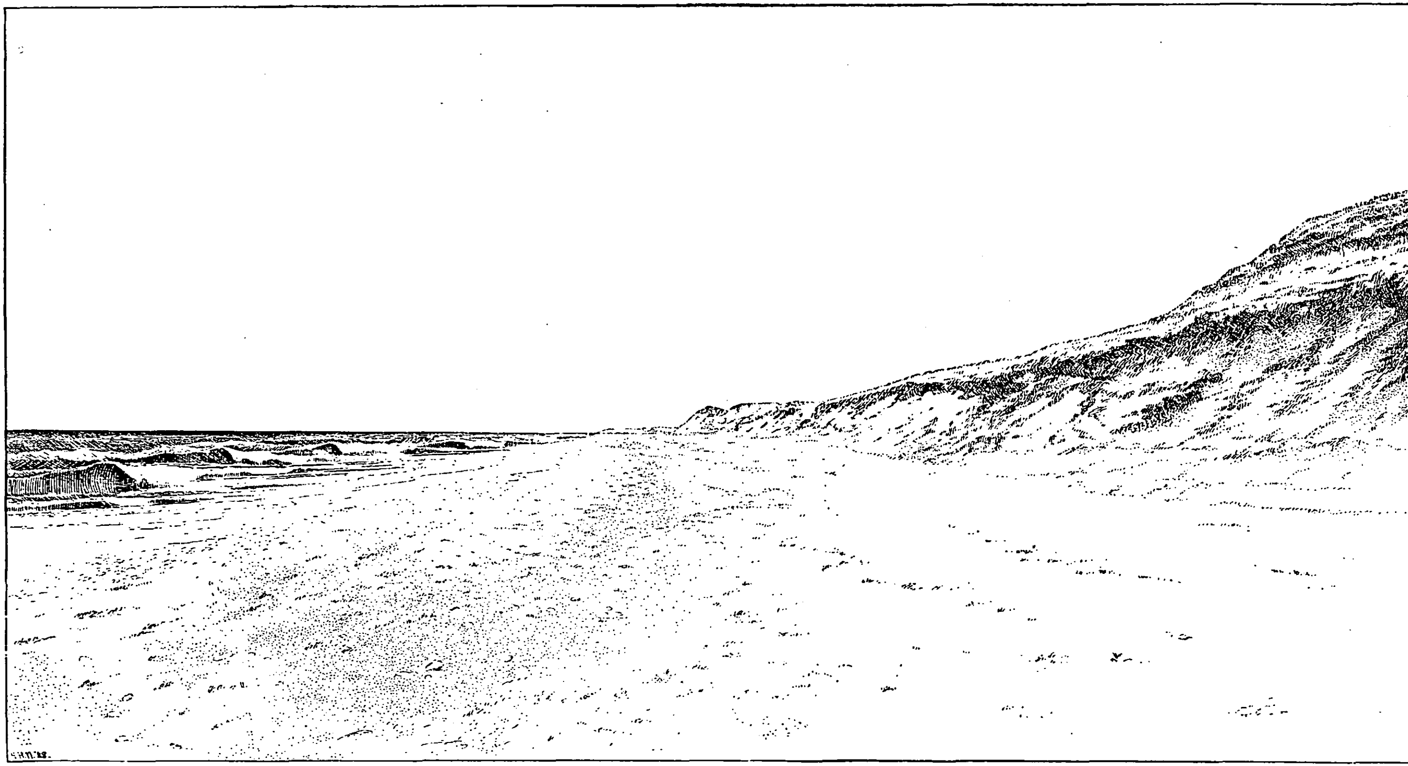
In a word, we can not believe that ridges of sand and gravel, with the accompanying sand plains, having the delicacy of outline which marks the contours of these great morainal accumulations could have been formed except beneath the sea. We are also forced to the conclusion that these deposits escaped from the water through the surf by a very sudden movement. In a report on the geology of Mount Desert, Maine,[1] I show that we have other evidence leading to the conclusion that the recovery of this shore from the deep subsidence that attended the Glacial Period was extremely sudden.

At this point we may discuss the peculiar compass course of the Nantucket moraines. So far as we can determine the matter the front of the ice during the formation of the Nantucket moraine lay in a nearly east and west direction. The exact alignment is not determinable from the direction of the separate mounds of drift, which are too isolated and irregular to afford any indication of the movement of the glacier. But considering these morainal masses as a topographic whole it is clear that their extension is within 5° of an east and west direction. This course is a wide departure from that of the other similar moraines of this district. The Elizabeth Islands frontal moraine has a nearly northeast and southwest trend, both in the islands whose name I have given to it and in its obscurer extension on the mainland of Cape Cod. It preserves this northeast and southwest course for a distance of over 40 miles without showing at any point a departure of more than 8° from the average direction of the line. The older moraine on the northern shore of Martha's Vineyard, although much shorter, evidently has the same direction. So far as I have observed, the moraines on Cape Cod, which, it is true, are very fragmentary, have the same general alignment.

On the other hand, the moraines of Long Island, New York, have a general course which is intermediate between those just noted and that of Nantucket. Their course is about N. 70° E. and S. 70° W. It is thus evident that there is a considerable range in the direction of these frontal moraines within 200 miles of distance on the southern shore of New England.

The wide difference between the direction of the ice front on Martha's Vineyard and that on this neighboring island of Nantucket may be due either to the existence of a great loop in the ice front at this point or to the fact that this Nantucket moraine, being the outermost of the frontal

[1] Eighth Annual Report U. S. Geol. Survey.



ASPECT OF NORTH SHORE FROM NEAR UPPER END OF LONG POND, LOOKING EAST.

deposits on this part of the continent, had a direction different from the later formed moraines on Martha's Vineyard and Elizabeth Islands.

The existence of such great loops in the frontal moraines has been made clearly evident by the labors of Professor Chamberlin and his assistants in the northern part of the Mississippi Valley. They may be therefore reckoned upon as possible accidents on all parts of the ice front. So far, however, I have not been able to reconcile the facts presented by the Nantucket moraine with the hypothesis that it is a part of a loop in a frontal moraine of normal direction. There is no trace of curve in its considerable length and it is not possible to connect it with any of the existing moraines by any hypothesis of form which I have been able to apply to it. Moreover, there is the important fact to be considered that we have as yet no evidence of any loops in the moraines in this part of the continent. In favor of the view that it is the fragment of a moraine older than any other occurring along this part of the coast, we have the important fact that the pebbles are much more decayed than they are in any of the morainal accumulations which lie to the northwest of it. It may reasonably be asserted that this difference in the measure of decay amounts to as much as one-half of the total oxidizing action which has been applied to this drift material.

The difference in orientation of this and other moraines may possibly be explained by the supposition that in the time when the glacier had its furthest extension, the movement of the ice was along the north and south line; while when the ice began to retreat the direction of the flow was gradually changed, the movement in the end being from the northwest. There is a good deal of evidence to support this view which can only be suggested in this memoir. The most important part of this evidence is found in the direction of the troughs excavated by the ice during the glacial period. These troughs probably owe their formation in the main to the force exerted in that part of the glacial epoch when the ice was deepest. The general trend of these troughs is from north to south. Although the cutting action which formed this valley has been in part guided by the positions of the rocks, that is, by their strikes and dips, it is clear that it was more generally determined by the direction of the ice movement. I therefore think it possible that the ice during the period of its greatest extension moved in a more meridional direction than during the period of its decline.[1]

POST-GLACIAL CHANGES OF NANTUCKET.

We shall now consider the changes which have taken place in this district since the last retreat of the glacial ice. These changes may be

[1] I venture in passing to call attention to the fact that this change in direction may be due to the very great extent to which the ice overlapped the shore during the time when it was thickest, when it probably had its front far out on the relatively level surface of the continental submarine shelf. It probably moved southward rather than toward the deeper sea on the east. As it shrunk, the eastern movement became more evident.

grouped under three heads, viz, changes of level, changes due to the alteration of the surface, and changes due to the wearing action of the sea.

The principal change of level was that which brought the sand and gravel hills and the fringe of lower land on the south above the surface of the sea. The amount of this elevation can not be accurately determined, at least from the evidence afforded by this island; still we may fix the minimum amount of the change in a rough way. Assuming that the sand hills were formed on the sea-floor at the front of the ice, we must suppose that they were originally at a depth which protected them from the action of the ocean waves. This requires us to suppose a submergence of their summits to a depth of at least 200 feet below the level of the sea, and even at that depth it is difficult to see how their easily moved sands remained undisturbed by the waves of great storms, which at the depth of two or three hundred feet produce a considerable motion in the water. As the highest of these sand hills now lies about 90 feet above the level of the sea, it is evident from our premises that the post-glacial uplift was not less than 300 feet and may have been much greater. This estimate, it may be remarked, is quite consonant with the evidence which is afforded by the other parts of the shore in this district.

After the first elevation there came at least one other movement of this shore, this time in a downward direction, which brought the fresh-water peat deposits beneath the sea-level. This last movement possibly did not change the level of the land to more than ten feet of altitude, though the alteration may have exceeded this amount.

There is another feature in the structure of the island which seems to afford some evidence of the recent subsidence of the shore. It will be seen from the map that the portion of the northern shore of the island which lies inside of Coatue Beach has a very indented shore-line, while the coast to the west of the harbor has a shore which has the outline proper to all coasts where soft materials have been subjected to the long continued action of the waves. The interpretation of this peculiarity seems to me to be as follows, viz: This shore after the post-glacial elevation must have been much farther to the northward than it is at present; then came the subsidence indicated by the submerged peats, as before described, which brought the land to about its present level. The beach of Coatue was rapidly formed in front of a portion of the north shore, and has since served as a protecting barrier against the assaults of the vigorous waves which form in Nantucket Sound. If this part of the shore had long been exposed to the action of the open water it would certainly have a different contour from that it now exhibits. The failure to form a similar barrier along the shore to the west of the harbor is probably due to the originally deeper water on that part of the coast, or to the absence of the supply of detrital material necessary for the formation of a barrier beach.

It must remain an open question whether these last described elevations and subsidences were local or general in their nature, or, in other words, whether they are in consequence of a general continental movement or were due to forces affecting only the district in which the island lies. Still further we are left in doubt whether these changes in level were of equal amount in all parts of the island. A comparison of the evidence attainable in this area with that which may be found on other parts of the neighboring land must be made before these points can be decided. So far as I have been able to compare the facts with those which are evident on the shores of Martha's Vineyard, the following results only have been found: On that island, as set forth in my memoir in the Eighth Annual Report of the U. S. Geological Survey, conclusive evidence of extensive subsidence is wanting. The conditions there are unfavorable for the preservation of such evidence. Still, we note the fact that on both these islands there is a remarkable correspondence in the height of the southern glacial plain above the level of the sea; in both islands the altitude of the southern escarpment along the Atlantic shore is essentially the same, and the channels which extend from the frontal portion of the moraine to the sea are about the same height above the tide-level. If there be any difference it is that these channels on Nantucket are at a slightly lower level than those on Martha's Vineyard. On the assumption that these frontal aprons were originally formed at the same height, the island of Nantucket has not been lowered more than 10 feet below the level to which the southern shore of Martha's Vineyard has attained since the close of the Glacial Period. It is not positively certain that these frontal aprons were originally formed at the same depth beneath the sea, yet the equal elevation of these two fragments of the coast is, considering the small distance which separates the two islands, a fair basis for believing that they were formed at about the same depth beneath the sea, and that they have since retained their positions relative to each other during the process of elevation which brought them to their present altitudes.

RECENT CHANGES ON THE COAST OF NANTUCKET.

The recent changes on the coast of Nantucket have a special interest, for the reason that they include some very curious horizontal modifications. (See Pl. IX.) While the larger part of the coast of Martha's Vineyard is now wearing away with considerable speed, rather more than the half of the periphery of Nantucket is at the present time not only exempt from wear, but exhibits a gradual accretion (Fig. 15). The gain of land on the sea is at present most conspicuous on the southeast section of the shore from Tom Never's Head to Siasconset. Along this portion of the border of the island the sea no longer attains the bluffs at any point, being shut out from them by a strip of sand which forms the crescent-shaped apron extending, at its widest part, about one-third of a mile from the shore. These sands have apparently been derived in part from the erosion of bluffs to the north and west of the site where they are accumulated, but perhaps in larger measure they may have been washed in from the floor of the sea. The formation of this extensive deposit appears to indicate a recent change in the regimen of the currents along this part of the coast; for it is evident that the coast-line was rapidly working inland until this apron began to form. It has evidently been but a short time since the sea beat against the cliffs inside of this protecting accumulation. These cliffs retain in good part the original shape given them by the erosive action of the waves. I have not been able to obtain any satisfactory information as to the growth of this apron within the historic period, but I am inclined to believe that it has been largely, if not altogether, formed since the settlement of the island by European population.

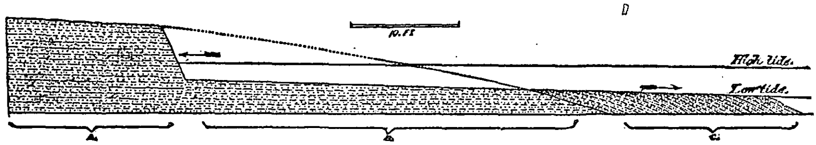
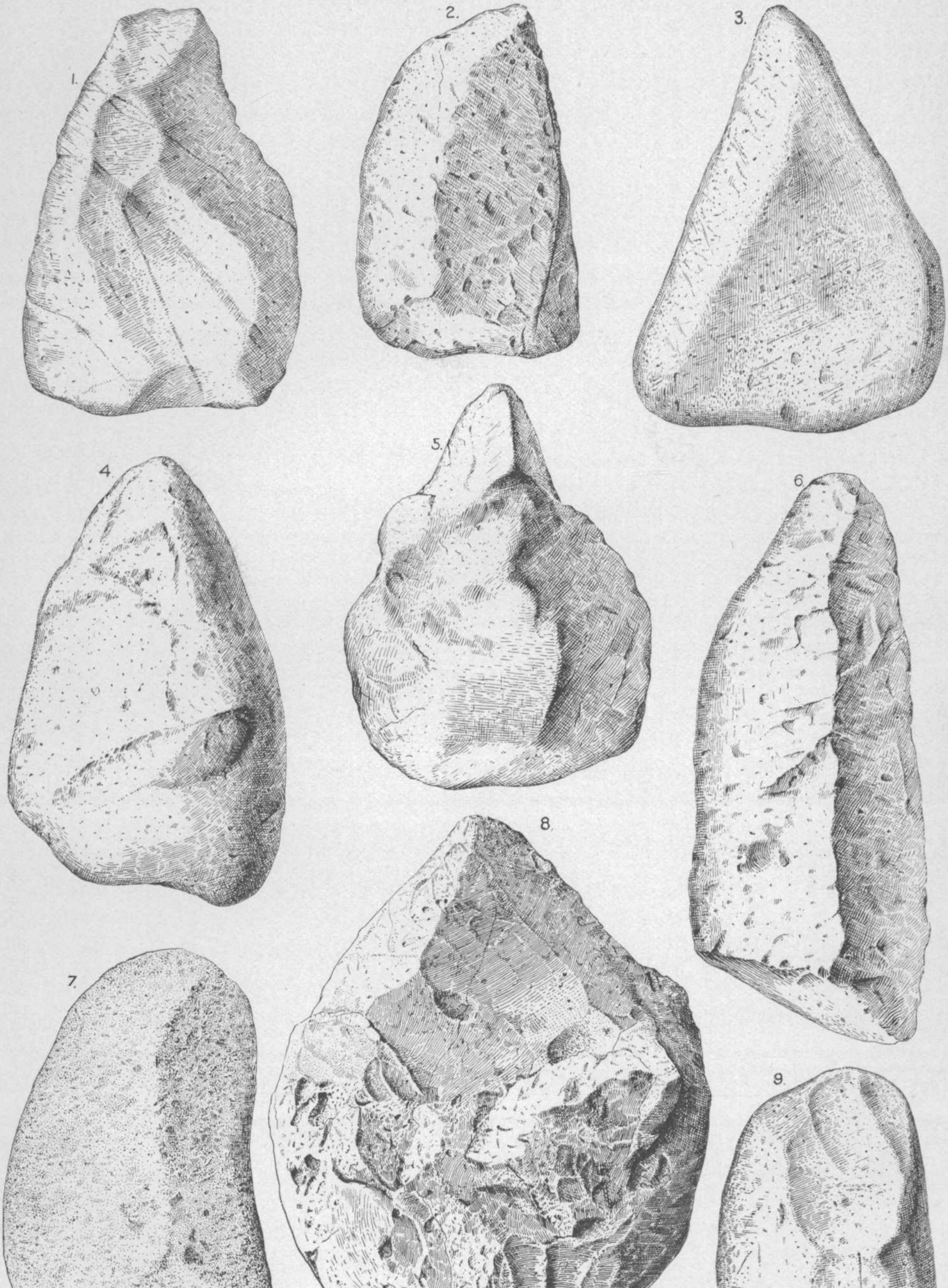


Fig. 15. Section of shore east of Surf Side.

I have also been unable to determine the nature of the alteration which led to the construction of this apron. The currents of these waters depend upon so many conflicting conditions that it does not seem possible at present to say to what this change is due. It appears, however, to have been connected with an alteration which seems to be now going on in the channels immediately to the eastward of Siasconset. It is a common opinion among seafarers of Nantucket that this channel is now less obstructed by sands than formerly; at present, ships venture through this passage, where of old, on account of its shoals, they did not dare to sail. If we may assume that such changes in this channel have really occurred we might suppose that the greater scour of the tidal currents in this water has removed from the bottom of the channel a quantity of sands and accumulated them in this shelf, which would afford not unnatural lodgment for them. It is evident that this apron of sand is extending its extremities to both the north and west. In the former direction it is affording some protection to the steep bluffs at Sankaty Head; although yet not a complete barrier to the action of the sea, it has diminished the wear on the shore bluffs in a noticeable way. Within a few years this escarpment has become in part grassed over. To the westward this apron is extending with considerable rapidity, as is indicated by the fact that the bluff still retains the marks of sea action at points where it is now completely defended by the protecting apron.

Another region of extensive accumulation in very modern times is that part of Great Head which extends from the apex of the triangle in which lies Croscaty Pond and forms a remarkable promontory (Fig. 16).



SPLIT PEBBLES, RESEMBLING STONE IMPLEMENTS.

This accession is evidently of less recent origin than the Siasconset apron. It consists of extensive sand dunes and beaches, the sand of the dunes having been borne to them by the winds. Although these dunes are frequently much wasted by the action of the same force which brought them to their present position, they are still very remarkable examples of wind blown sands. The extremity of this cape is now separated by a channel having about four fathoms of water at mean low tide from the point of the rip shoal, on parts of which there are not over four feet of water at low tide. Within the last century the extremity of this cape has fallen back southward for the distance of 1,400 feet, as noted by Prof. Henry Mitchell. This recession of Great Point has probably been a consequence arising from the rapid extension of the promontory of Monomoy, which, according to his determinations, has extended southward two miles during the past century.[1] It is possible that a portion of the material wasted from this point has been contributed to the Siasconset apron.

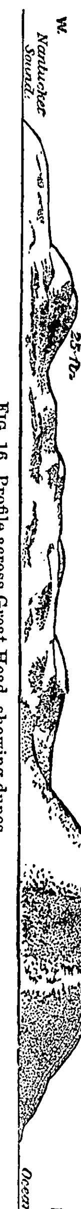


Fig. 16. Profile across Great Head, showing dunes.

The most extensive of these modern contributions to the shore of Nantucket is found in the mass of Coatue Beach, which contains a larger body of recently drifted sands than all the other similar deposits found along the shores of this island. If we consider the submarine portion of this peninsula as well as the emerged part we find it to contain a mass about equivalent to a layer a hundred and fifty feet deep occupying a square mile of area. A part of this material appears to have been derived from the bottom of Nantucket Bay by the action of the waves; a portion of it may have come from the recession of Great Head.

About one-third of the coast-line of Nantucket appears now to be undergoing erosion. At the eastern extremity of the island the erosive action appears at present to be limited to the section from the southern end of the Sankaty bluffs to a point just beyond Haulover Beach at the head of Coatue Bay. In 1873 Prof. Henry L. Whiting found by a resurvey of this portion of the shore that the eastern or sea side of the coast at the Haulover had receded by an average of about one hundred feet since 1846. Between Sachacha Pond and the Haulover, especially at Squam Head, the wasting is evidently at this day quite rapid, probably amounting to at least a foot a year.[2] The southern coast westward from Tom Never's Head, especially the section west of

[1] Monomoy and its shoals: Annual Report of the Harbor and Land Commissioners of Massachusetts, Boston, 1887, p. 42.

[2] Report of Harbor Commissioners of Massachusetts, 1873, p. 109.

Weedweeder Shoal, is also the seat of a considerable, though apparently inconstant, wear. A remarkable but probably temporary change has recently taken place in the long spit which forms the western extremity of the island as it is delineated on the Coast Survey maps. Twenty years ago this spit at low tide constituted an almost complete bridge extending from Nantucket to Tuckernuck Island. Of recent years this point has in good part been washed away almost down to its base near Further Creek. It seems possible that the existing separation of Tuckernuck from Nantucket may have been brought about by the action of marine currents within a relatively short time.

VEGETATION OF NANTUCKET.

The present condition of the flora of this island deserves some notice in this memoir, for the reason that it throws light upon its geological history. At present this is the most treeless area on the eastern coast of the United States. There are no traces of original forest upon its surface. About the borders of the smaller ponds, especially where these pools are well sheltered by the kame hills, there are a few stunted oaks and other forms of our ordinary New England trees, but in no case do they give the conditions of a forest. None of the specimens of this natural growth exceed 20 feet in height. On certain parts of the central region of the island artificial plantations of pines exist, but the trees, though in some cases nearly half a century old, have never attained a height of more than 20 feet and survive with difficulty, in the existing conditions of the climate and soil. Although the greater part of the surface of the island has remained entirely wild there is no trace of a tendency to return to the condition of forest.

There is a tradition, not, so far as I have been able to find, supported by any trustworthy records, that this island when first occupied by the European settlers was generally forest-clad, and that the trees of oak and pine were sufficiently large to afford ship-timber as well as material for edifices. Those who have had occasion to examine traditions as to the nature of forest-covering of a region now deprived of trees, know how untrustworthy such reports frequently are. At a number of points along the eastern shore of the United States where the poverty of the soil is very great and the timber extremely stunted we hear the same vague account of vanished woods. Nevertheless, though such traditions are open to suspicion, I am inclined to believe that when this island was first settled the greater part of its surface, at least that portion of the area north of the southern plains, was covered with a forest growth which afforded some architectural timber. As soon as this covering was removed, as it was before the middle of the last century, without any effort to restore its forest coating, the soil came to its present treeless state.

The failure of these woods to recover possession of the earth demands an explanation. This explanation we may find in either of two ways. We may suppose that there has been in modern times a change in the climatal conditions affecting this portion of the continent which makes it impossible for forests to be reestablished. Or we may account for the nudity by supposing that in the earlier day the island was very much more extensive than it is at present and that the climate was so far locally modified by the greater land area that the timber was enabled to gain a foot-hold. This latter supposition appears to be the most consonant with the known facts. It seems to me tolerably clear, from the topography of Nantucket as well as that of the sea-bottom north and south of it, that the island has not lost much of its surface for a considerable time in the past; but if we go back to the time when the last subsidence of this shore took place—the subsidence which lowered the peat deposits before mentioned below the level of the sea—we may be able to assume a reduction in the area of the land resulting from that down-sinking sufficient to account for the required change of the climatal conditions.

That there has been a general change of climate on this part of the continent sufficient to account for the failure of these woods to repossess the surface of the island appears to me an unreasonable assumption, because on the mainland we find no evidence of such a modification of climatal conditions. I am, therefore, disposed to believe that the forest-covering of Nantucket was established at a time before the last subsidence of the shore, and that this subsidence so far reduced the area of the land that the well-known influence of the sea air penetrating to the central portions of the island served to prevent the restoration of the timber after it had been removed.

The present flora of Nantucket, though it wants the larger trees, is extremely rich and varied. The absence of a forest-covering has enabled a host of low-growing plants to establish themselves upon its surface and to develop with a luxuriance which they do not attain on the mainland. The interaction of these plants in their unwonted freedom of development affords many problems of interest to the botanist which deserve more attention than they have yet received. It would be particularly interesting to consider the differences in the vegetation determined by the peculiarities of the soil in the various parts of the island, were it not that these problems lie beyond the scope of this report. I venture, however, to note for further inquiry on the part of those who may take up the question, that the differences between plants growing on the sand hills on the southern plains and in scanty areas of clay soil which exist on the surface of Nantucket are very great; and, furthermore, that very large areas of the southern plains, where the soil is composed in the main of quartzose sand, are occupied almost exclusively by mosses and lichens.

A peculiar feature in the botany of the island is found in the presence of cacti in the region north of Coatue Sound. Along Coatue Beach and in the district about Croskaty Pond, as well as on Great Head, one or two species of *Opuntia* are extremely abundant. This is certainly the easternmost and possibly the northernmost station in the region east of the Appalachians attained by any part of this interesting group of American plants. I have been unable to ascertain when this form appeared upon the island, whether it has been introduced by human agency or has come to its position in a natural way. It seems clear that it has been upon the island for a long time. If it be true that there are two distinct species present on this shore, then it is most likely that the introduction took place in the natural way. The field now occupied by these cacti has a length of about four miles and a width near Croskaty Pond of about a mile. It is a singular fact that, although within this area the plants abound and apparently find the circumstances well suited to their needs, the species has not extended to the southern portions of the island. Apparently the great beach apron at Siasconset affords a site equally well suited to these plants, but a careful search of this field, made in 1875, failed to show a single specimen of the genus upon it. Within the field occupied by these cacti they never depart from the areas of blown sand. The hummocks of kame drift which rise within this field do not seem to afford conditions for their development.

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