THE OUTLINE OF CAPE COD.

BY

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[Reprinted from the Proceedings of the American Academy of Arts and Sciences, Vol. XXXI., 1896.]

XVI.

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Presented March 11, 1896.

Summary.

This essay attempts to restore the original outline of Cape Cod by reversing the processes at work on the present outline (p. 308). In order to gain good understanding of these processes, a review of previous accounts of the Cape is introduced (p. 304), a general consideration of the development of sea-shores is outlined (pp. 312–317), and the conclusions reached are applied to the problem in hand (p. 318). It is thus estimated that the land here once extended at most two or more miles into the sea on the east, and that perhaps three or four thousand years have been required for the retreat of the shore line to its present position (p. 326). This period cannot, however, be taken as a full measure of the time since the glacial deposits of the Cape were formed, for there is reason to believe that the land stood higher than now for an unknown interval between the building of the Cape and the assumption of the present attitude with respect to sea level.

The chief interest in the problem here discussed turns on the growth of the great sand spit of the "Provincelands" northwestward from the "mainland" of the Cape (p. 312), and on the protection thus afforded to the old cliffs of High head. Brief account is given of the growth and waste of the Provincelands (p. 323), and of the changes of the western shore line (p. 329). The essay closes with some practical suggestions regarding the protection of Provincetown harbor (p. 329), and some speculations concerning the future change of the Cape. The consumption of the north arm — from the elbow to the hand — will probably require about eight or ten thousand years (p. 331).

Introduction.

An excursion to Provincetown and the "mainland" of Truro on Capė Cod with the students of the Harvard summer course in Physical Geography, in July, 1895, brought to my attention a number of problems concerning the changes of outline suffered by the Cape. These problems had taken rough shape on the occasion of a visit to the peninsula several years ago. Supplementing the observations made on the ground by a study of the Coast Survey charts and by a review of what has been written on the subject, the following essay has gradually grown up. Its substance was presented before the Geological Society of America at the winter meeting in Philadelphia, December, 1895, and again before the Harvard Geological Conference in April, 1896.

The end of the Cape is pleasantly reached by a four-hour run in a steamboat from Boston across Massachusetts bay to Provincetown, in whose neighborhood the most significant of the features here described are to be found. By driving to High head, the northernmost point of the "mainland," a general view of the peninsula of Provinceland may be gained: thence driving or walking to Highland light, one may see a portion of the long harborless cliff that forms the "back" or eastern side of the Cape. Walking northwestward along the beach to Peaked hill life saving station, the action of the surf can be observed at leisure; and thence crossing the sandy belt to Provincetown, the varied forms of the dunes can be studied in detail. A second day may well include a visit to Race point, the northwestern extremity of the Cape, and a return southward along the wasting shore to Wood end, or Long point, whence the town can be regained by boat, previously arranged for.

Cape Cod is an excellent region for the study of shore forms in the light of their development from some antecedent outline, and their continued change towards some future state. Although the "mainland" of the Cape rises about two hundred feet above sea level, it is built of uncompacted clays and sands, with occasional boulders, and is therefore easily consumed by the waves. Standing far out beyond the general shore of New England, it receives a violent attack from storm waves, which alter the shore line so rapidly that the changes are measurable even in the short time covered by our records.

Extracts from Previous Writings.

The following extracts summarize a number of previous references to the Cape.

In the Geology of Massachusetts (I., 1841), E. Hitchcock makes brief mention of the erosion on the eastern coast and the growth of the Cape into Massachusetts bay (323), the southward growth of Nauset beach, a mile in fifty years (324), the dunes of Provincetown (325), and the "diluvial elevations and depressions" of Truro (367); Provinceland is "alluvial; that is, washed up by the ocean" (371).

Lieut. (afterwards Admiral) C. H. Davis wrote a "Memoir upon the geological action of the tidal and other currents of the ocean" (Mem. Amer. Acad., Boston, 1849, IV. 117–156), in which he called attention to the repeated occurrence along our coast of bars built northward from coastal bluffs, such as Sandy hook, N. J., and Cape Cod, and suggested that "a generic term" should be applied to these forms. He mentioned a place of division of the tidal currents on the east side of Cape Cod, near Nauset inlet, from which the flood tide flows north and south.

Thoreau's narrative of his excursions on the Cape in 1849, 1850, and 1855, tells of various changes in the coast line known to the people there. A log canoe, buried long before on the inner side of the bar that forms the eastern wall of the marshy East harbor at the north end of the mainland, was found many years afterwards on the Atlantic side of the bar; that is, the bar had been pushed westward over the buried canoe as the sea cut away the outer beach. Swamp peat was sometimes found on the exposed beach, although it was originally formed undoubtedly on the inside of the bar. Stumps had been seen off Billingsgate point; the implication being, not that the land had been depressed, but that it had been washed away, leaving the stumps mired in their native soil.* A writer in the "Massachusetts Magazine" of the previous century is quoted to the effect that an island, called Webbs island, formerly existed three leagues off Chatham, containing twenty acres of land; the people of Nantucket carried wood from it; but in the writer's day a large rock alone marked the spot, and the water thereabouts was six fathoms deep. (Cape Cod, in New Riverside edition of Thoreau's works, 1894, pp. 182, 183.)

Freeman's History of Cape Cod (1860) attributes much wasting of land to reckless cutting of the trees, — a doubtful conclusion as far as it refers to shore work, although probably applicable to the interior district of the dunes. He says: "The work of devastation was too extensively accomplished; as is seen on the shores of the Cape since washed away by tides aided by the force of the winds, so that vast flats of sand extend in some places a mile from the shore, now, at low water, dry, or nearly so, and in some instances these flats disclose large stumps of ancient trees embedded in their native peat" (752).

H. L. Whiting prepared a "Report on the special Study of Provincetown Harbor, Mass." (Rep. U. S. Coast Survey, 1867, pp. 149–157). He distinguishes Truroland, the mainland of the Cape, "by the

* I have found this explanation of the occurrence of tree stumps on the shoals off Chatham current among the fishermen of the Cape. See Proc. Bost. Soc. Nat. Hist., 1893, XXVI. 173.

existence of clay and of boulders, and by the peculiar form of the 'bowl and dome' drift"; and Provinceland, "of sand only, — so free from all earthy matter that it will not even discolor water, — while the forms which the dunes and ridges here assume are mainly characteristic of wind drift" (155). He concludes that "the outer ridges of the peninsula of Provincetown were the earliest in date, and that the flats, marshes, and ponds now existing are subsequent accumulations and accidents, which have taken place under the shelter and eddy influences of the outer hooked bar or beach" (155). The narrow outer bar that connects the cliffs of Highland light with the Provincetown peninsula is described as wasting back with the cliffs, and is said to be in danger of breaking through at two points.

H. Mitchell wrote a "Report . concerning Nausett beach and the Peninsula of Monomoy" (Rep. U. S. C. S., 1871, pp. 134–143). Monomoy is described as built of sands derived from the bluff of Cape Cod during northeast storms; it grew southward into Nantucket sound at the rate of 157 feet a year from 1856 to 1868. The changes in the beach near Chatham are particularly described. The same author submitted an "Additional report on the changes in the neighborhood of Chatham and Monomoy" (Ibid., 1873, pp. 103–107).

W. Upham published some notes on Cape Cod in the Geology of New Hampshire (1878, III. 300–305), and a more extended essay on "The formation of Cape Cod" a year later (Amer. Nat., 1879, pp. 489–502, 552–565). He described the moraine extending eastward from Sandwich and entering the sea at Orleans (494); north of this point, the Cape consists chiefly of modified drift, rarely containing boulders (537). When the drift plains were deposited, the land stood somewhat higher than at present (561). Provinceland consists of sea sand, supplied by erosion on the east side of the Cape (564).

Chamberlin makes a brief reference to Cape Cod in his essay on the "Terminal moraine of the second glacial epoch." "The great northward hook of Cape Cod is composed of plains and rolling hills of sand and gravel, which resemble accumulations that often accompany the morainic belt on its interior side, and suggest the thought that the hook may be the modified inner border of the moraine which enters the sea near Orleans, and may be presumed to curve northward concentric with the hook, forming thus a loop enclosing the basin of Cape Cod." (Third Ann. Rep., U. S. G. S., 1883, p. 379.)

H. L. Marindin studied the "Encroachment of the sea upon the coast of Cape Cod, Mass." (Rep. U. S. Coast Survey, 1889, pp. 403–407, chart 28). From Highland light to Nauset lights, the average recession from 1848 to 1888 was 128 feet, or 3.2 feet per annum. The face of the cliff, whose average height is 50 or 100 feet, has thus lost a total of 30,231,038 cubic yards, or 755,776 cubic yards per annum. The bar south of Nauset, enclosing the north side of Pleasant harbor, extended its length southward some distance in the same period. The same author has made a detailed report on the changes in shore line and anchorage areas of Provincetown harbor in Appendix 8, U. S. Coast Survey report for 1891, with an elaborate chart.

K. Weule has, in his "Beiträge zur Morphologie der Flachküsten" (Kettlers Zeitschr. wiss. Geogr., 1891, VIII. 211–256), discussed Cape Cod at some length (232–238). The tidal currents are regarded as the most important factors in its shaping. A misunderstanding of local conditions is implied when the author asks how "the narrow mainland of uncompacted materials can remain intact in an exposed situation, when even so resistant landmasses as rocky Nantucket and Martha's Vineyard suffer great loss" (232). The present preservation of the Cape is ascribed to the beach sand, brought from the shoals on the southeast by the flood tide. Weule follows Whiting in attributing a greater age to the outer than to the inner side of Provincetown peninsula (234). The existing mainland is regarded as only a remnant of a great extent of drift land (233); this opinion being taken from a report by A. Agassiz.

A brief article of my own, describing "Facetted pebbles on Cape Cod" (Proc. Bost. Soc. Nat. Hist., 1893, XXVI. 166–175), argued from these evidences of æolian action that the plains of gravel and sand were deposited under the air rather than under the sea.

A "Report of the Trustees of public reservations on the subject of the Province Lands" (Mass. Legislature, House, Pub. Doc. 339, Feb., 1893, p. 6) states that "there is evidence that the tides and waves have built one beach after another, each farther north than the last, and that the so called Peaked hill bar is a new beach now in process of formation." The report contains an elaborate map of the sandy peninsula by J. N. McClintock, on a scale of about five inches to a mile, with ten-foot contours. The manner in which the outer beaches overlap the inner ones is very clearly shown. Five photographic illustrations present characteristic views of the dunes.

A general work on coastal forms — "La géographie littorale" — by J. Girard (Paris, 1895), briefly compares Sandy hook and the end of Cape Cod, classifying them with spits formed by littoral currents, but giving no specific description.

Review of Previous Writings.

The structures of the "mainland" of Truro and of the peninsula of Provinceland are so unlike that their different origins have long been recognized; the former being attributed chiefly to diluvial or glacial and aqueo-glacial agencies, the latter to marine agencies acting on the former. The general character of existing processes by which the shores are undergoing change, and the present rate of action of these processes have been carefully examined by various observers; but no systematic attempt has been made to trace the processes and the changes that they have produced backward to their beginning. This task is therefore attempted here.

Reconstruction of the Original Outline of the Cape.

The development of the existing outline of Cape Cod must be traced backward to the original outline. The initial form that it had before the present cycle of cutting and filling began along its shores may be roughly reconstructed by reversing the marine processes now at work and following them until they lead back through earlier and earlier conditions. The restoration may be regarded as complete, when the reconstructed forms are everywhere of non-marine origin. Then, reversing the order of study, the normal operation of cutting and filling processes should lead forward again to the existing outline of the Cape, and should even allow a reasonable prediction of future changes for some time to come.

Provinceland, the Chatham bars, and Monomoy, and a few small bars near Wellfleet, must first be removed, as they consist wholly of sea-carried materials, their arrangement being closely accordant with action at present sea level. The tidal marshes north of Wellfleet, along Pamet river, and elsewhere, should be excavated. The "mainland," chiefly of glacial and aqueo-glacial deposits, will then stand out alone, as indicated by the outline NBHQPTC, Figure 1. It descends to the shore on nearly all sides in steep cliffs of moderate height; long, straight, or gently curving beaches running along the base of the cliffs. Exceptions to this rule are found almost exclusively on the shores of protected bays, such as those north of Chatham and about Wellfleet. The cliffed descent of the mainland to the smooth beaches is manifestly an indication of destructional retreat from a formerly greater extension seaward, just as the gentle slope of the land to the irregular shore line of the bays is an indication of small change from constructional form.

Although no close accuracy is to be expected in restoring the seaward extension of the cliffed mainland, there are nevertheless some simple principles that will at least serve to guide us towards a not altogether imaginary reconstruction. First, it must be remembered that general subaerial denudation has not effected significant changes in glacial topography during postglacial time. Second, the restored outline should possess irregularities of pattern comparable to those in the protected bays of to-day, advancing from the headlands and retreating towards the troughs or "valleys" in the high ground. Third, the amount of land restored should be much less on protected shores than on exposed shores. Fourth, cliffs that are now protected by forelands of marsh and bar must not be built out so far that their recession could not have been accomplished before the bars began to grow in front of them.

Possible Changes of Level.

These four guiding principles do not include reference to the effects of change of level, because, if any change has occurred since the time of accumulative construction of the mainland, it has been of small amount, and it has, to my mind, acted on the whole in favor of decreasing the land area by submergence, thus co-operating with the destructive action of the sea. This view is in accord with that expressed by Upham, who thinks that, when the drift was deposited hereabouts, the land stood somewhat higher than at present, and that the numerous small indentations or re-entrants of the shore line, such as occur along the south side of the Cape, are results of a slight submergence of trough-like depressions or valleys. The digitate bays of Martha's Vineyard would seem to lend support to this view; but they are otherwise interpreted by my colleague, Professor Shaler, who regards them as having been formed by subglacial streams acting on sea-floor deposits that had been strewn in front of the ice margin when the sea stood higher than now, although he suspects also that "at the close of the glacial period this region was considerably higher than at present" (Geol. Martha's Vineyard, 7th Ann. Report U. S. Geol. Survey, 1888, pp. 318, 319, 350). The latter view is further supported by the small amount of erosion — about three miles — suffered by the low sandy southern shore of Martha's Vineyard (Ibid., p. 349) since the present level of the land was assumed.

Without undertaking to determine precisely the original level of the Cape mainland, the most plausible explanation of the facts seems to me that the washed gravels and sands correspond to the supermarine *sandr* of Greenland and Alaska; that the troughs, by which the plains of washed sands are trenched, result from the channelling by streams when they carried less waste than while they were previously aggrading the plains; and that the indentations of the shore line are the result of slight depression, whereby the troughs were partly drowned. The reconstruction of what I have above called the "original outline," will therefore not necessarily lead us to the shore line that obtained at the close of the time of accumulative construction, if the land then stood higher than now; but only to a contour line drawn on the original constructional mainland at present sea level. However, between the actual original shore line and the reconstructed contour line, there must have been a difference of degree rather than of kind; the latter embracing a smaller land area than the former, but the general outline and disposition of the land areas probably being of much the same style in both cases, except for the indentations of drowned valleys after submergence. For this reason, no further especial attention will be given to depression in its effect in altering the outline of the Cape.

A proposed reconstruction of the outline of the Cape has been drawn, with the four guiding principles above stated in mind. Trifling additions are made in the bays; none more than 2,000 feet. Significant additions are made on the west side of the Cape; some of these measure 4,000 or 5,000 feet. Two miles or more of land are added on the east side, or "back," facing the broad Atlantic. The margin of the restored outline is indented toward the various troughs and valleys that break the general surface of the mainland. About High head, the northern point of the cliffed mainland, the fourth of the guiding principles comes into play; and hereabouts the most interesting problem of the Cape is found. The view of the peninsula of Provinceland from this commanding point is therefore particularly instructive.

The Problem of High Head.

The cliffed margin of the mainland at High head, H, Figure 1, is notably even both on the northern and western sides. At present, the head is protected both on the west and north by forelands of marsh and bar, the bars springing tangent from cliff fronts farther south or southeast. The bar, QR, on the west, is part of a long concave shore line, TPQR,—the "west concave" shore,— whose excavated curve is manifestly dependent on the existence of the peninsula of Provinceland to the northwest. Before this concave curve was cut, a nearly straight shore line, CTYQH, — the "west straight" shore, — had been made, as indicated by its remnants now seen on the west marginal cliff, QH, of High head, and again about six miles to the south, TC, on Boundbrook, Griffins, and other islands. The cutting of the west straight cliff, QH, must have continued until the peninsula of Provinceland began to project northwest to High head. Then, as the movement of the shore currents was somewhat changed by the interference of the peninsula, the middle of the straight cliff was excavated more rapidly,

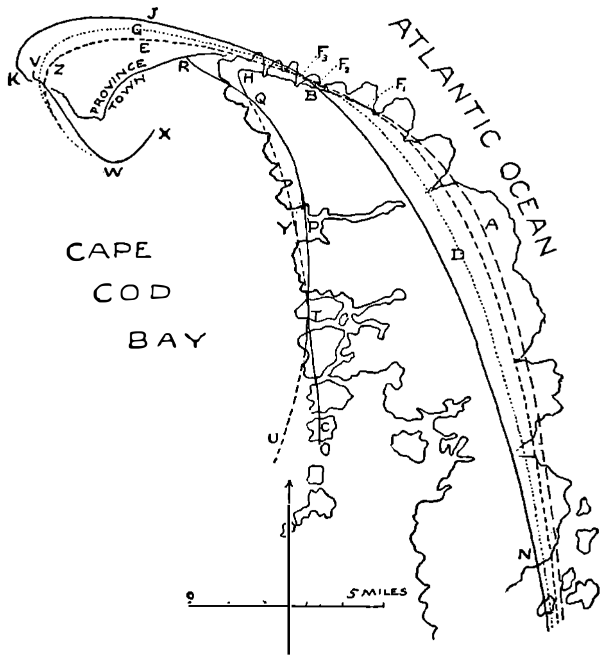

FIG. 1.

forming the west concave shore, TPQ, and the northern part of the straight cliff on High head at the same time came to be protected by the outspringing concave bar, QR, that now encloses East harbor and its marshes on the southwest side.

The bar, BJ, on the north of High head, is part of the long eastern convex shore line, NBJK, whose form is determined by the masterly Atlantic currents. It is along the outer beach of this bar — or of its representative in former days — that the sands of the peninsula have been transported from the southeast; this being the conclusion of all observers, unless perhaps of Hitchcock. Now it follows from the relation of this northeast bar to the peninsula of Provinceland, and from the relation of the peninsula to the western bar, that a somewhat shorter time was allowed for cutting the north cliff of High head than for cutting its west cliff; but inasmuch as wave energy was greater on the north than on the west, time and energy varied inversely, and hence about the same amount of lost land may be added to each cliff. The amount of reduction suffered on either side of High head is therefore roughly proportional to the time before the bar was built in front of the north cliff.

The north bar, BJ, that for this reason takes our attention, is one of the class built by marine action, as recognized by Admiral Davis. It springs tangent to the curve of the long convex cliff and beach, NB, on the east side or "back" of the Cape. As the retreat of the margin of High head is measured by the time before the north bar was built, the question arises whether bars of this kind are built in front of straight cliffs early or late in the attack made by the sea on the land. This question may be divided into two; the first considering the development of the cliff; the second considering the stage in the development of the cliff when the protecting bar would be likely to grow out in front of it.

Development of Shore Profiles.

Let the activities of the sea be resolved into two components; one acting on and off shore; the other along shore; and let the effects of the first of these components be now examined alone, postponing consideration of the effects of the second component to the next section.

On some young coasts, the on-and-off-shore movements of the sea carry out to deep water all of the waste that is abraded from the land and its submarine slope, leaving the shore line bare.* The rocky floor seen at low tide on the coast of Brittany illustrates this condition. Here the sea is able to do more work than it has to do. Its action is like that of a young river, whose ability to carry load is greater than the resistance of the load that it has to carry, and whose valley floor is therefore attacked and deepened. But as the valley is deepened, the slope, velocity, and carrying power of the river are all decreased; at the same time the load, derived chiefly from the valley slopes, is increased: thus ability to do work gradually falls into

* The problem of flat coasts, with shallow off-shore waters, is so different from the problem here considered that it will be treated independently in a later section.

equality with the work to be done. When this happy condition is reached, the river may be said to have graded its channel. Youth then passes into adolescence.

A comparable series of changes may be detected in studying the profile of a seacoast at right angles to the general shore line. As the sea can at first usually dispose of more waste than it gathers, the coast is energetically attacked and forced to retreat, and sea cliffs are thus produced. But in virtue of the changes thus brought about, the energy of on-and-off-shore attack decreases, while the waste coming from the growing cliffs increases; thus ability to do work approaches equality with work to be done, and the sea-floor profile, like that of the valley floor, may be said to be graded. When a graded profile is attained, the adolescent stage of shore development is reached.

The amount of retreat necessary before a graded profile is attained varies with the texture of the coast, and with its exposure to the sea. A coast of unconsolidated deposits will soon supply a large amount of waste from its cliffed margin, while the cliffs of a rockbound coast will shed waste slowly; hence, on coasts of given exposure, grade will be assumed with a less amount of cliff-cutting where the rocks are weak than where they are strong. This recalls the behavior of rivers in regions of weak and resistant rocks; in the latter, they may assume gentle slopes; but in the former, rather steep slopes are necessary to carry off the freely offered waste; and gentler slopes can be assumed only as the whole surface is worn down: this general relation having been pointed out some years ago by Major Powell (Uinta Mountains, 194). Moreover, inasmuch as a greater amount of waste can be handled on exposed coasts than on protected coasts, a considerable retreat may develop high cliffs on the former before enough waste is shed from the cliff face to give the shore waves all the work they can do; while on protected coasts a moderate retreat, producing low cliffs, will supply as much waste as can be handled by the sea.

The under-water form of a graded profile, when first developed, also depends largely on the violence of the on-and-off-shore movements of the sea. On a protected coast, the bottom will be degraded so as to descend from the shore line by a gentle slope to an eroded platform of moderate depth; but on an exposed coast, the bottom will be degraded so as to descend from the shore line by steeper slope to a platform of greater depth.

Typical Shore Profiles.

A graded profile being once attained, its graded condition will be preserved through all the rest of an undisturbed or normal cycle of shore development; shore profiles and river profiles being alike in this as in so many other respects. Before grade is assumed, the ability of the sea may be so far in excess of its load that it undercuts the shore and forms sea caves at tide level, as in profile 1, Figure 2. When grade is first assumed, the coast is usually cut back to a steep cliff, like profile 2. Much later, when the sea has cut back the shore so that the waves must transverse a submarine platform before attacking the land, their strength is thereby so much lessened that the cliff leans back to a moderate slope, as in profiles 3 and 4, and even then supplies enough waste to keep the waves at its foot fully occupied.

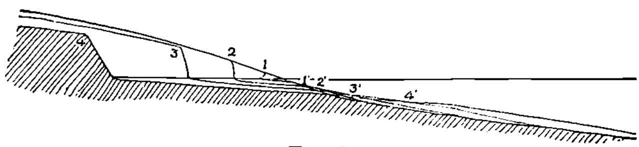

Fig. 2.

There is something more than analogy in the comparison that may be drawn between the longitudinal profile of a stream and the transverse profile of a shore. In youth, each usually has its torrent or upper portion, where ability to carry load is greater than load to be carried; but as development progresses, the graded condition of midstream extends headward, and after a time reaches all the way to the headwaters. At the same time, the lower or floodplain-delta portion extends seaward, its grade being rather steeper in adolescence, when much material is brought from the headwaters, than later, in maturity and old age, when the supply of waste is very slow. The critical point, where marine action changes from degrading the near-shore bottom to aggrading the off-shore bottom, migrates seaward, as 1′, 2′, 3′, 4′, in Figure 2. At the same time, the seaward extension of the bottom deposits increases. Furthermore, the comparison between stream and sea suggests the need of examining that process on the sea floor, which corresponds to corrasion in the stream bed. Sea-shore profiles make it clear that a considerable deepening is accomplished on the floor of the platform, landward from the critical points, 1′, 2′, etc. Off the eastern cliff of Cape Cod, this deepening can hardly have been less than fifteen or twenty fathoms: off the Chalk cliffs of Normandy, a similar scouring and deepening of the bottom may be inferred. We are accustomed to study transportation and deposition as submarine processes, but little attention has been given to decomposition, disintegration, corrasion, or any other process by which the sea floor is degraded. The subject deserves careful investigation.

It is manifest from the preceding paragraphs that a graded profile may be attained much earlier on one part of a shore line than on another; for the texture, the original profile, and the exposure of a coast all vary from place to place. But in a region like Cape Cod, where the original shore line consisted wholly of uncompacted materials, this aspect of the problem need not be considered further.

Development of Shore Outlines.

It is not, however, only in on-and-off-shore action that a close comparison may be drawn between the operations of marine and fluviatile agencies. The 'long-shore action of the sea also is in many respects comparable to the down-stream action of rivers. Beginning on an unevenly deformed land surface in a region of moderate rainfall, where there are many heights and hollows, the drainage will at first consist of many small independent systems, each one transporting waste from the initial divides down the initial slopes into the initial hollows. Every stream proceeds, by degrading and aggrading its course, to develop a line of slope on which its ability to do work shall everywhere equal the work that it has to do. As the eminences are worn down and the hollows are filled up, local systems that were at first independent become confluent, and the drainage of the higher ones is discharged to the lower ones. Every change of this kind will call for rearrangement of the degraded and aggraded slopes in the confluent basins. Ultimately, all the separate systems will, in one combination or another, find outlet to the sea, and the waste will be carried a long distance from the main divides to the main river deltas.

It is much the same with the action of the sea. Leaving the on-and-off-shore action out of consideration for the moment, let us view only the 'long-shore action, as determined by the dominant rather than by the prevailing movements of the littoral waters. The projections or headlands of the constructional shore line act as so many divides, on either side of which the 'long-shore currents flow away from the apex, as in the uppermost outline in Figure 3. The re-entrants or bays are so many basins into which the 'long-shore currents converge from the adjacent headlands. The headlands are slowly worn back, and the waste is carried along their sides into the bays, where it forms aggrading pocket beaches or bridging bars, as in the second and later outlines of Figure 3. The initial irregularity of shore outline is thus replaced by a graded outline; grade being first attained in the bays, and last on the headlands, much as was the case with stream action. As the headlands are cut farther back and beaches are formed at the base of their cliffs, then the 'long-shore action is more and more thrown into one direction or the other from the chief headlands, transportation is carried on past many of the subordinate headlands, and much of the waste finds its way into the chief re-entrants of the shore line, as in the lowermost outline of Figure 3. We should expect to find

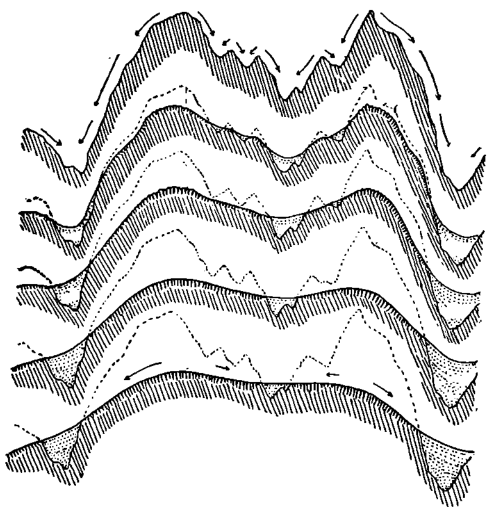

FIG. 3.

inside the long-sweeping curve of the aggrading shore line of the chief bays more or less distinct record of the sharp-curved pocket beaches of an earlier stage.

However irregular the initial shore line was originally, and however many divisions were then made in the direction of the 'long-shore currents, the time will come when only a few of the most prominent and resistant headlands survive, as in the later outlines of Figure 3; elsewhere the 'long-shore action is developed into a continuous movement. Truly the direction of transportation along the graded shore line is sometimes one way, sometimes the other, according to the sweep of storm winds; but if the dominant currents alone are considered, the movement is essentially constant. The graded condition, first reached on the pocket beaches, comes to prevail all along the shore; ability to do the work of transportation is everywhere equal to the work of transportation to be done.

In the river problem, the number of independent river systems that occupy the originally deformed surface varies with the strength of the initial relief and with the rainfall. A light rainfall and a strong, rapid-growing initial relief of resistant rocks produce many independent river systems, and a long time must elapse before a general grade is attained. The early stage of this condition is illustrated in the lava-block mountains of southern Oregon, so well described by Russell (4th Ann. Report U. S. Geol. Survey, 435). But a heavy rainfall and a faint, slow-growing initial relief of weak materials may allow the immediate development of a single river system, soon attaining grade over the whole area concerned. So with the sea. Moderate 'long-shore action and strong initial irregularity of resistant rocks break up the 'long-shore currents into many systems at first; the grading of the shore line and the union of the many currents can be accomplished only after a long time of endeavor. But strong 'long-shore action and moderate initial irregularity of weak materials may permit continuous 'long-shore movements for a long distance on well graded beaches almost from the very first.

Both in valleys and on coasts — in rivers and on shores — the graded condition will be reached sooner on certain stretches than on others; and just as an alternation of rough rapids and smooth-flowing reaches indicates a youthful stage of river life, so an alternation of ragged headlands and smooth-beached bars indicates a youthful stage of shore line development. But in time even the more resistant parts will be trimmed off so as to accord with the less resistant, and then down-stream transportation — or 'long-shore movement — is well developed; the adolescent stage is reached. From this time forward, on a shore as in a river, the grade is normally changed only where and when a change of load calls for readjustment; the readjustment necessitating an aggradation or degradation of the valley floor, or an advance or retreat of the shore line, as the load may increase or decrease.

It should of course be understood that comparisons of this kind are not formal comparisons in which the condition of one member may be inferred immediately from those of its analogue. The purpose of the comparison is not to compel explanation, but chiefly to borrow illustration of the systematic processes of land sculpture from the better known examples of river action, and apply them to the less studied examples of shore action; less studied certainly in this country, where our great interior areas have for some decades past absorbed the attention of geologists; more studied than river action in Great Britain, but not from the point of view here taken.

Under favorable conditions, irregular shore lines may be smoothly graded early in their cycle of development. This is well illustrated in the case of Martha's Vineyard. Here an extremely irregular constructional shore has been reduced to a remarkably even and well graded outline in a relatively early stage of the attack of the sea on the land; for although a matter of two or three miles of the southern headlands of the island have probably been cut away by the sea,* a good part of the original shore line still remains in the branching bays behind the bridging bars. The straight-cliffed headlands stand perfectly in line with the bars across the bays. The later stages of outline on graded shores are considered in the third section below.

Application of the Foregoing to Cape Cod.

The foregoing account of the development of shore lines is perhaps an overlong preparation for the application of the simple principles that govern shore changes to the case of Cape Cod; but the excuse for the details into which I have entered is the desire to show good ground for the conclusion which they support; namely, that on a coast as weak as the mainland of Cape Cod, any originally irregular shore line would soon be reduced to grade by the action of a sea so energetic as the Atlantic, with its frequent southeast and northeast storms. Only a moderate time and a moderate recession is therefore necessary for the production of the even northeast cliff of High head. It does not, however, follow from this that only a short time actually elapsed in this work, for as far as has yet been stated, the High head cliff that we see may have been cut far back from the first position of an even cliff on this part of the coast line. Whether the time was long or short can be best determined by examining into the conditions which determine the development of the bar by which the cliff is now protected, this being the second problem announced above.

It should be noted that when the northeast cliff of High head formed the open shore line of this part of the Cape, the outline must have extended in a sympathetic curve, HBF_1A, for some distance southeast of its present limit; and from this early form there must have been a gradual change to the shore line of to-day. At some time during this change, the protecting bar, BJ, must have been built out

* Shaler, *loc. cit.*, 349.

to the northwest. The problem is to determine at what stage in the history of a cliffed shore line such a bar or spit might grow out from one part of its face and protect another part.

OFF-SHORE BARS.

In order to avoid misapprehension, it is advisable to make careful distinction between those bars or spits which spring as tangent attachments to a cliffed shore, often extending into comparatively deep water, and those off-shore bars which are built up from the bottom in shallow water, not immediately connected with the mainland. Exam-

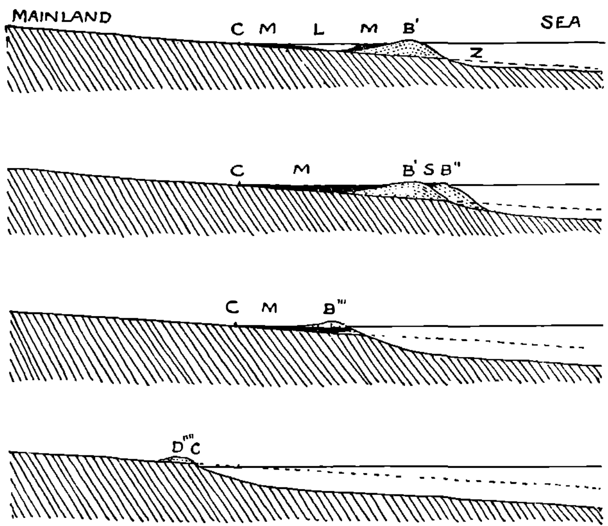

FIG. 4.

ples of the latter class are common along a great extent of our southern coast, especially where the tides are weak. Briefly stated, their history seems to be as follows. When waves roll in upon a shelving shore, as in Figure 4, much of their energy is expended on the bottom. Between the line of their first action far off shore and their final exhaustion on the coast, C, there must be somewhere a zone of maximum action. This zone must lie farther seaward when large storm waves roll in than when the sea is slightly ruffled in fair weather. Let the zone of maximum action for storm waves be shown by **Z** in profile. Here the bottom is deepened; the coarser particles are moved landward, forming a shoal and in time a bar, B′, enclosing a lagoon, L; while the finer particles are moved seaward, beyond the limits of Figure 3, where they are distributed in moderate thickness over a considerable area. During this process, we may imagine the storm waves to say: "We cannot to advantage attack a coast where the off-shore water shoals so gradually; let us therefore first deepen the off-shore bottom, so that we may afterwards make better attack on the coast." So saying, a preliminary off-shore bar is built up by the storm waves in position B′; and afterwards, at times of exceptional storms, successive additions may be made on its outer side, as B″. Wind action builds the bar up with dunes, and carries much sand over into the lagoon. But a time will come when the bottom farther to seaward has been deepened enough to enable even the greatest waves to act severely on the outer slope of the bar, taking from it more than they bring to it; then the outward advance of the bar is changed to a landward retreat, and it is pushed back to such a position as B‴. This change in behavior may be taken to separate the stages of youth and adolescence in the development of a shore line of this kind.

Young bars that are advancing or that have advanced seaward may often be recognized by belts of dunes, B′, B″, roughly parallel to the shore, enclosing lines of marsh or "slashes," S, as they are called on the coast of New Jersey. Adolescent bars, retreating landward like B‴, may be distinguished by the exposure of the dark mud of the lagoon marsh, M, on their outer slope, as is sufficiently explained by the diagrams. Many examples of this kind might be cited. In time, the retreat of the bar will carry it back to the mainland; then, as long as the marginal cliff is not too high, the dunes, D⁗, will be heaped directly on the land slope, and the mature stage of shore development is reached. In this stage, the depth of water near the shore is much greater than it was originally; degradation of the sea floor reaching to depths much below low tide.

An interesting variation on this type of coastal forms is found on coasts whose submarine slope varies, so that off-shore bars are formed in one district, but an immediate attack is made on the land in a neighboring district. The coast of New Jersey gives a standard example of this kind. About Atlantic city the bars are built off shore; about Long Branch, the land is cut back in a retreating cliff of moderate height. Although now generally retreating and exposing marsh mud on their ocean side (Ann. Report N. J. Geol. Survey, 1885, p. 80 *et seq.*), the bars frequently possess dune ridges and slashes, as if they had once advanced seaward. Somewhere in the earlier history of this coast, there must have been a point or fulcrum of no advance or retreat between the advancing bars and the retreating cliff. It should not be overlooked that 'long-shore action has a share, often a large share, in the development of compound forms of this kind; but it is quite conceivable that they might be developed essentially under the control of on-and-off-shore action alone. A second example of this kind is perhaps to be found in the combination of the bars from Chatham to Nauset with the cliffed margin of the Cape mainland farther north; but into this problem it is not desirable to enter further at present. The origin of tangent bars or spits, built out into comparatively deep water, may now be taken up.

TANGENT BARS OR SPITS.

In order to understand more clearly the conditions under which tangent bars would form, it is necessary to return for a few moments to the problem of the varying outline of a graded shore as dependent on an increase of load. It is advisable to enter this phase of the problem through comparison again with the development of rivers and valleys.

In the case of adolescent rivers, the increasing dissection of the drainage basin by growing headwater branches may frequently cause the load to continue to increase after the first attainment of a graded slope along the trunk river. As a consequence, the trunk river must aggrade the valley floor, forming a flood plain, until the load begins to decrease later on in maturity. Much in the same way, 'long-shore action of the sea on a coast of graded outline may gather an increasing load as the cliffs retreat and become longer and higher; and with this increase of load, certain parts of an early-graded outline may have to be built forward into the sea. But on pursuing this comparison a step further we find here, as in some earlier cases, a contrast replacing the agreement thus far traced between the river and the 'long-shore action. Not only the load, but also the volume of a river increases from youth to maturity by reason of the better development of stream lines all over the drainage basin; and this increase of volume tends to prevent the aggradation asked for by the increase of load. Similarly, the volume of water involved in the 'long-shore movements becomes greater as the inequalities of a young shore line are reduced to the smooth curves of adolescence and maturity; but here the increase of volume causes the shore waters to move in curves of larger radius than before, and this change may require the beaches to grow forward on certain concave or incurved parts of the shore line. In such case, increase in the volume of 'long-shore water movements may co-operate with the increase of load in tending to build the land out into the sea. Here rivers and 'long-shore currents have unlike behavior.

One of the best examples of this kind that has come to my notice is found on the coast of Georgia and Florida, where the better adjustment of coastal bars to shore currents and the consequent increase in volume and strength of the latter seems to have led to the out-building of the several bars that are involved in the southward migration of Cape Canaveral.* The accompanying digaram, Figure 5, illustrates the essential features of the changes here inferred. The general attack that is at first made nearly all along the ragged coast soon comes to be resolved into two diverse actions; a persistent attack on the chief medial headlands, while the subordinate headlands are protected by the growth of off-shore bars. Let the ragged outline of Figure 5 represent the original shore line of an uncompacted land mass. The general attack by the sea first cuts off all the headlands, forming cliffs 2, 3, more or less connected by bars. When longer and higher cliffs, 4, are developed, they supply so large an amount of waste and allow the movement of so large a volume of water along shore that the less exposed cliff of earlier intention in the upper part of the figure is no longer attacked, but is protected by a spit, 4′, that springs out from the main cliff, prolonging its curve in one direction or the other, — here, upward, — according as the tides and the on-shore winds determine the direction of the 'long-shore movement. In this case, on-and-off-shore action and depth of water have little to say. Wherever the dominant 'long-shore movement advances, there the tangent bar must grow, whether the water is shallow or deep.

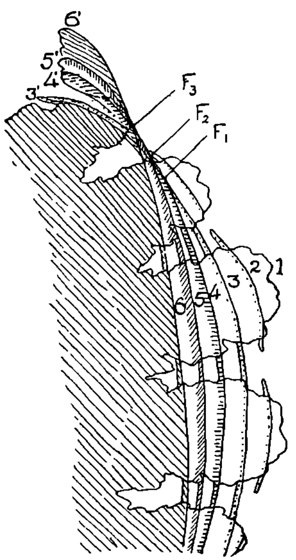

Fig. 5.

* This peculiar change in the situation of the cuspate foreland known as Cape Canaveral was briefly stated by the writer in Science, 1895, I. 606. It has later been found that Weule had previously noted the fact of migration (*loc. cit.*, p. 253), although not mentioning the cause here suggested to account for it.

Illustration from the Coast of New Jersey.

An example suitable for illustration of this case is found in the relation of Sandy hook to the Long Branch cliffs on the New Jersey coast, as exhibited on the excellent topographical maps of that State. Although now protected by the spit of Sandy hook, both Rumsor neck and the Highlands of Navesink are truncated by sea cliffs. The truncation must have been accomplished before the spit was built, and therefore before the Long Branch cliff had been pushed back to its present position. Stage 3, Figure 5, essentially represents this relation. In the change from earlier stages to the present, the 'long-shore action has increased in consequence of the general smoothing of the outline, and the direction of 'long-shore movement has been somewhat changed; so that now instead of carrying the waste from the Long Branch cliff directly to the truncated headlands next north, it is carried along an independent path forming the spit of Sandy hook outside of the line of truncation. It is interesting to notice that the Long Branch cliffs were evenly graded, and that the spit was formed rather early in the general attack of the sea on the land hereabouts, and that a very slight change in the outline of the chief cliff sufficed to cause the growth of the spit outside of the subordinate cliffs further north. The various fluctuations in the growth of the spit and the intermittent destruction of its slender bar are described in the Annual Report of the New Jersey Geological Survey for 1885, p. 78.

The Long Branch cliff has for some time been retreating under the blows of the Atlantic breakers. The farther it retreats the longer the stretch of cliff becomes; it is undoubtedly much longer now than formerly. It may be fairly inferred that the two great spits, to the south as well as to the north of the cliff, have always been, as now, essentially tangent to the cliff front. It follows necessarily that the point of the attachment of the spits to the mainland has shifted, and that the spits have also been pushed backward at equal pace with the retreat of the cliff. With these conclusions in mind, the problem of High head and the northeast bar may at last be taken up.

Growth of the Provincelands.

There is good reason to think that the analogy between Sandy hook and the Provincelands pointed out by Admiral Davis may be carried much further than he suspected. The great convex cliff line on the back of the Cape corresponds to the slightly convex line of the Long Branch cliff; the northeast cliff of High head is the counterpart of the protected cliff of the Navesink highlands; the slender bar that springs tangent to the curve of the back of the Cape and runs to the broad peninsula of the Provincelands is essentially a repetition of the slender bar that springs north from the Long Branch cliff and runs to the broadened peninsula of Sandy hook. The point where the bar now springs northwestward from the long convex back of the Cape is not the point where the bar first began to grow. Its original point of attachment must have been southeast of the present point; and in the change from the original to the present arrangement, both the cliff and the slender bar must have been forced back, in the very manner already described for the example in New Jersey. Marindin's report gives precise data for the retreat of the cliff; and the story of the buried canoe, recorded by Thoreau, gives support to the retreat of the bar near its point of attachment. In both examples, the farther part of the great spit has grown by addition to its seaward side in order to keep the outline in a curve sympathetic with the retreating cliff; the outward or eastward growth of Sandy hook being described in the Annual Report of the New Jersey Geological Survey for 1885, p. 77; the similar growth of the Provincelands is more fully stated below. As a result of the outward growth of the spit while the cliff is retreating, there must be a neutral point or fulcrum of no change somewhere on the connecting bar: and with the further straightening of the cliff front, the position of this fulcrum must generally shift toward the spit, as shown by F_1, F_2, F_3, Figure 5.

The original point of attachment of the connecting bar on Cape Cod must have been at the intersection of two converging lines determined by the northeast cliff of High head and the innermost or oldest of the bars in the Provinceland peninsula. The first of these lines is well defined, HB, Figure 6; the second is less distinct, but appears to be recorded in a sand bar on the line EF_2. The form of this bar has probably been somewhat changed by wind action, yet the trend of its inner margin along the shore of East harbor is comparatively straight, as if it had not been much altered from the form given when it was built. Its trend departs slightly from the direction of the adjacent Atlantic shore, as if had been determined by conditions now vanished.

The intersection of the two guide lines, HB and EF_2, when prolonged to the east-southeast, is found at a point F_1, about 4,000 feet off the present shore, and about a mile and two thirds east-southeast from the present point of attachment of the springing bar. Judging by the present rate of retreat of the cliff line, this outer position must have been occupied about 1,200 years ago. These figures are of necessity only approximate, but they are believed to give a fair indication of the order of magnitudes involved, both in space and time. We may then infer that when the general outline of the back of the Cape had assumed the position of the line AF_1BH, the shore was well enough graded to supply material for the building of a spit; and that the curvature of the shore at the point F_1, assigned for the beginning of the spit, was such that the dominant 'long-shore currents, moving from south to north in flood tide or under southeast storms could no longer

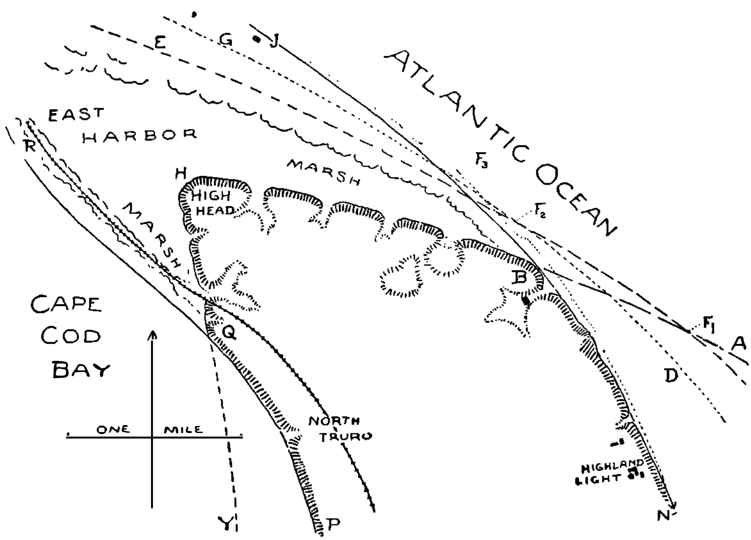

FIG. 6.

follow the shore, but departed from it outwardly by a small angle. Thus the protecting bar, F_1E, began to grow in front of the High head cliff.

At an earlier stage the 'long-shore currents must have been much interrupted by the irregularities of the original shore line. No large and well developed current could at that time follow these irregularities. But as the headlands were cut back and the bays bridged across, and the shore assumed the outline ABH, then the resistance to the development of the current became less and less; thereby the current became stronger and stronger, and desired a straighter and straighter path for its movement. At the same time, a greater and greater volume of waste was supplied from the growing cliffs. As long as the back of the Cape projected farther into the sea than now, the northward shore current may have swung pretty well around the mainland, as sketched in line ABH. But as the east side of the Cape was cut away and straightened, and as the shore current grew stronger and stronger, it became increasingly difficult for the waters to turn the curve that led to High head; and at last, when the turning was impossible, the spit began to form on the line F_1E. As the change progresses, the current swings on a fulcrum, F_2; the spit broadens by the external addition of new bars, F_2G, as well as by the formation of sand dunes inside of the curve; and the fulcrum shifts along the shore to the northwest, as indicated by the points F_2, F_3, Figure 6, in the manner already explained for Figure 5.

The important point to note is that here, just as on the New Jersey coast, the grading of the initial irregular shore line into a curved cliff shore, and the straightening of the curved cliff shore enough to require the growth of the tangent bar, must have been accomplished early in the development of so weak a land mass as Cape Cod in face of waves so strong as those of the Atlantic.

Dimensions of the Original Cape.

Now inasmuch as no very long time can have been required for the Atlantic waves to wear back the original shore line of the Cape to a graded outline, ABH, of which the High head cliff is a part, and inasmuch as the growth of the springing spit must have been begun soon after the grading of the shore, it follows that the original constructional outline of the land in front of the High head cliff cannot have extended far into the sea. I have given it an extension of 3,000 feet in Figure 1. A similar original extension of all the mainland of the Cape may be assumed outside of the graded shore line ABH, that existed before the springing spit was formed; and thus the original outline of the eastern side of the mainland has been roughly sketched in. As drawn in Figure 1, the greatest retreat from the original shore to the present shore is nearly two and a half miles, and at the present strength of wave action, 3,000 or 4,000 years may be roughly taken to have sufficed for the accomplishment of this change. This time is probably too long rather than too short, for the retreat now must be slower than when the cliff was lower.

It should be carefully understood that the period here computed does not measure postglacial time; for, as already stated, it is believed that the land hereabouts stood somewhat higher than now during the accumulation of the stratified sands, and that only after the time of accumulation were the valleys and low grounds slightly submerged by a moderate depression of the land, and the work whose duration is here computed begun. The time that passed while the sea was at work on some lower shore is not measured. There is no indication of a recent elevation of the land hereabouts, as far as the shore features testify: even the protected cliffs of High head are cut down to present sea level.

The Nauset bar extends southward from the cliff at the point N. The earlier positions were prolongations of the lines A, D. The point of attachment must therefore have migrated to the southwest; the retreat of the cliff front determining the retreat of the bar that stands in line with it. How the problematic islands off Chatham affected the behavior of the bar is not here inquired into.

Inasmuch as the recession of the eastern shore is believed to have been of moderate measure, the loss on the western shore must have been still less. This is considered in a later section.

The Origin of Race Point.

Two important consequences follow from the swinging of the shore current on its movable fulcrum. The first gives explanation of the overlapping of the newer shore lines outside of the older body of the peninsula, as stated in the Report of the Land and Harbor Commissioners, quoted above. This is only a repetition of the process by which the spit first departed from the beach on the back of the Cape itself. The outer margin of the Provinceland peninsula is therefore its very youngest part, and not its oldest, as supposed by Whiting. The long bar, F_3JK, ending in Race point, is a distinct external addition to the older body of the Provincelands, and a long narrow "slash" is included behind it. It has grown out into comparatively deep water, for the 20-fathom line lies only 1,700 feet off shore to the northwest. Peaked hill bar may be, as the Commissioners have plausibly suggested, the embryo of still another external bar.

It may be noted that small spits departing tangentially from curved beaches are not uncommon. The map accompanying Whiting's report shows two of them near Wood End, one pointing east, the other north, from the sharp curve of the bar, as if determined by a strong southwest storm, whose waves worked eastward and northward from the apex of the curve at Wood End. A minute spit of this kind is shown on the chart of Cape Cod bay (Coast chart 110, printed 1890), a little northeast of Race point; but a later edition of the chart (1892) carries a smooth curve around the point. Small examples of these forms, trending eastward, were seen on the south shore near Long point light, at the time of my visit to the Cape last summer.

The Wasting Shore from Race Point to Wood End.

The second consequence of the outward deflection of the current around the peninsula is the rapid consumption of the bar, VW, that extends south from Race point inlet to Wood End, the long "finger" at the end of the Cape. This suggests a preliminary digression. Wonder is often expressed at the ability of sand bars to withstand the violence of the surf that breaks unceasingly upon them. The sands are entirely unconsolidated, and their surface layers are moved by every surge of the waters. Yet the form of the bar changes very slowly. The reason for this must be found in the continual feeding, from the cliffs and from the bottom off shore, by which the volume of the bars is sustained. The bars of our southern Atlantic coast presumably receive much of their sand from the bottom. Sandy hook receives much of its supply from the retreating cliffs at Long Branch. If the supply be withheld, the bar will be rapidly swept away. It may not be that the grains of sand are actually ground to dust, but that they are brushed along, and when no followers come to take their place, it is left vacant, and the face of the bar retreats; its dunes are cut back, and a low cliff-shore is formed.

As long as the outside of the peninsula formed a continuous curve, sand was carried along it in plenty from the cliff and the sea floor on the back of the Cape, and probably also from the shoals where Webbs island and its vanished mates once stood off Chatham. This condition is represented in line DGVW. But as the cliff from Nauset to Highland was cut farther back, and the shore current became unable to follow its earlier path along the margin of the peninsula, the additional bar, ending in Race point, was laid out, and the long marshy "slash" was enclosed behind it. From the beginning of this additional bar until the present time, the supply of sand carried around the western curve of the peninsula was greatly reduced; at times it may have ceased entirely. The supply being thus reduced or cut off, the bar southward from Race point inlet nearly to Wood End rapidly wasted; and the sand taken from it by northwest gales went to supply the correspondingly rapid growth of Long point, WX, into Provincetown harbor, which Whiting shows to have extended many feet eastward in the fifty years past. Like Race point, Long point has advanced into comparatively deep water; the 20-fathom curve lies only 600 feet off shore; the same depth is not found for almost three miles off the cliffed shore of the "back" of the Cape.

The Western Side of the Cape.

The western side of the Cape offers simpler problems than those of the eastern side. The first task here attempted by the waves was the development of the long west straight shore line, HQTC, of which only the extremities now remain. This does not seem to have required anywhere a greater recession than 3,000 feet. It must have been accomplished chiefly by northwest gales and north-to-south shore currents, by which the waste gathered from the more continuously cliffed shore was carried southward to tie together the several islands below South Truro. If southwest gales and south-to-north shore currents had been dominant, an acuminate spit should have been formed in prolongation of High head, where the waste would have been supplied from both sides of the Cape; but of this there is no sign.

The modification of the west straight shore line by the excavation of the present concave shore line, QPT, undoubtedly results, as has already been stated, from the disturbance of antecedent conditions that was caused by the growth of the Provincelands to the northwest. The northwest gales gradually came to have less and less influence; for some time past, they must have ceased to be dominant; the chief control of shore movements now seems to be in the hand of the weaker southwest gales; for both the offsetting spit at the mouth of Pamet river, P, and the outspringing bar, QR, that protects High head on the west, imply a northward transportation of sands. Some southward movement, however, still occurs, as might be expected; for at the faint angle, T, where the older straight shore line, HQTC, is now cut by the concave shore line, QPT, a spit projecting to the southwest seems to have been begun, and its continuation under water is indicated by a shoal of sympathetic curvature, TU, some five and a half miles in length. How far this shoal may be a new feature, originating with the excavation of the concave shore line, or how far it may be of much greater age, dependent on the extensive Billingsgate shoals, where outlying islands are thought to have originally stood, is for the present an undecided question.

Protection of Provincetown Harbor.

A matter of considerable economic importance turns on the changes experienced by the "wrist" of the Cape, the narrowest part of the bar that connects the mainland or "forearm" of the Cape with the peninsula or "hand." The people of Provincetown feel anxiety lest the sea should breach the bar and wash a great amount of sand westward past High head into their excellent harbor. The records of changes in the bar that connects Sandy hook with the Long Branch cliffs give ground for this anxiety. The point that I wish here to call attention to is that the only part of the northeast shore that is liable to be broken through lies on the stretch, BF_3, between the point where the connecting bar springs northwest from the great cliff and the point where the "fulcrum" is at present located. Within this stretch, the bar is generally retreating, being cut on the outer side, and reconstructed on the inner side.

Two safeguards may be suggested. One would cause the fulcrum to migrate southeastward, thus diminishing the length of the narrow and breakable bar, and at the same time increasing its breadth and strength. This would be accomplished by the construction of bulkheads along the outside of the narrow bar, or wrist, so as to catch the drifting sand instead of allowing it to pass by; thus the bar might be broadened and strengthened. Judging by the rapidity with which the body of a wrecked vessel causes an accumulation of sand on its southeastern side, a significant addition to the narrow bar might soon be made in this manner. Manifestly, the greatest economy in the use of the drifting sand requires that the bulkheads should be continually built out so as always to project a little beyond the aggrading shore line. There are indications that this very result is at present being accomplished by natural process, for the beach in the narrow stretch, BF_3, is now notably broadened in front of its former line at the base of the surmounting dunes.

A more economical and enduring protection of Provincetown harbor than the above plan suggests has been already secured by completing the extremity of the bar, QR, that some years ago almost enclosed East harbor; so that if storm waves should temporarily breach the narrow connecting bar on the ocean side, — the "wrist" of the "hand" of Provincetown at the end of the "bended arm of Massachusetts," — all the sand that was carried through the breach would settle in East harbor, and thereby strengthen the embankment against further encroachments. A second protecting dike has been built across the marsh, northeastward from near High head. The fear that, in case the narrow connecting bar or "wrist" should be breached, the whole action of the Atlantic 'long-shore currents would thereafter be directed through the breach into Provincetown harbor, is groundless. The whole history of the growth of the peninsula demonstrates that the 'long-shore currents must continue to swing in long curves of large radius in the future, as in the past.

The danger of silting up the Provincetown harbor by drift coming from the west concave shore line along the west protecting bar of High head does not appear to be imminent, for the processes of transportation are comparatively slow on the inner side of the Cape; but the danger is nevertheless real, and nothing but an extensive and expensive system of bulkheads from North Truro northward, on the stretch PQ, appears to be sufficient to avert it.

The destruction of the narrow strip of sand-bar shore, VW, between Race point and Wood End seems to me to threaten Provincetown harbor with a greater danger than any that it is exposed to from the east. This shore is now wasting rapidly. Once broken through,* the currents driven by northwest gales, as well as by the rising tide, would no longer have to swing around Wood End, W, and deliver their load of drifting sand to Long point, X; they would in all probability invade the harbor directly, cutting away the low-tide flats that now expand south of the village, and throwing the detritus thus gained into the harbor. Attention has been called to this danger by Marindin in the Coast Survey report for 1891, Appendix 8. While bulkheads may delay the destruction of the narrow bar, they can hardly preserve it even through a brief historical period. It has been proposed to abandon the wasting bar to its fate, and to protect the harbor by building a dike from the west end of the village across the flats to Wood End. A partial protection might be gained by building bulkheads on the northern shore of the peninsula, two or three miles east of Race point, K. Drifting sand from the east would then be stopped there. Race point, no longer so well supplied with sand as now, would be wasted by the northwest storms, and the sands carried from it would go southward to repair the shore towards Wood End. The protection of the bar northeast of High head near F_8 would, to a certain extent, work in the same direction by diminishing the supply of sand for the Race point bar; but a considerable time might elapse before any advantageous effect from this cause would be felt.

The Future of the Cape.

The encroachment of the sea on the back of the Cape is undoubtedly destined to continue until the Truro mainland is all consumed north of Orleans, the " elbow " of the bended arm. At the present rate of recession — 3.2 feet a year — eight or ten thousand years will be required for this task; and this without considering the aid given by the

* A small breach has been made in this bar during the past winter, as I have learned from a recent visit to Provincetown.

waves of Cape Cod bay, whose concave sweep along the Truro shore shows their competence to do no insignificant share of the work.

It does not seem at all likely that, while the rest of the Truro mainland is wearing away, the spit at Race point will of itself curve around to the south, and thus save from destruction the narrowing bar which encloses Provincetown harbor on the west. A great volume of transported sand would be needed to continue the bar in the deep water through which its present curve would lead. Moreover, the shoal known as Peaked hill bar may, as has been suggested, mark the beginning of a shore line exterior to that of the present Race point curve. It is possible that as additional tangent spits are lapped on the outside of the curve, Race point will be cut back by a current from the northwest, working opposite to the great current that rounds the peninsula from the east; a cuspate or acuminate spit being then formed in the angle between the two, such as now exists at Great point, Nantucket. There, the transportation of shore waste is northward on the east shore and southward on the west shore, according to the memoir by Admiral Davis; this being proved by the drift of coal and bricks from vessels wrecked on the east shore (*op. cit.*, 139). The occurrence of these "cuspate forelands," as Gulliver has called them (Bull. Geol. Soc. Amer., 1896, VII.), is not so much of a rarity in nature as might be imagined from the little that appears about them in books; their growth being sometimes attributable to accordant currents that flow towards the point on either side; sometimes to opposing currents, one flowing inwards, the other outwards. Good reasons have been given by Abbe for believing that Cape Hatteras and the other cuspate capes of the Carolina coast have been built between opposing currents (Proc. Bost. Soc. Nat. Hist., 1895, XXVI. 489).

The Provincetown peninsula may be expected to outlast the Truro mainland; for as long as the latter exists, the former must receive contributions from it. But when the mainland is washed away, — ten thousand years hence, at the present rate of wearing, — then Provinceland must rapidly disappear. Sable island, a long sand bar off Nova Scotia, is perhaps to be regarded as the vanishing remnant of a destroyed drift island (see Trans. Roy. Soc. Canada, 1894, XII. pt. 2, pp. 3–48; also, note in Science, 1895, II. 886). It may in this sense be taken to represent a future stage in the destruction of Cape Cod. All these changes are rapid, as changes go on the earth's surface. The Truro mainland will soon be destroyed, and the sands of Provinceland will be swept away as the oceanic curtain falls on this little one-act geographical drama.