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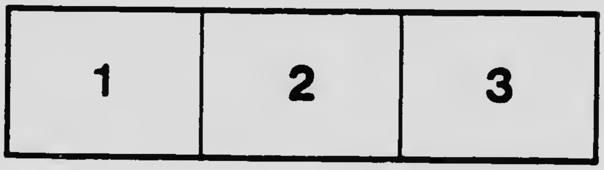
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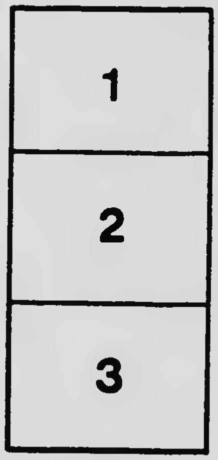
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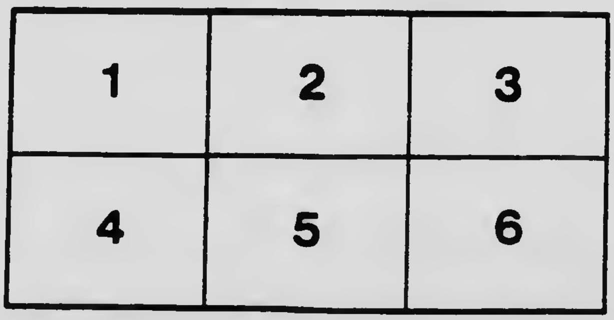
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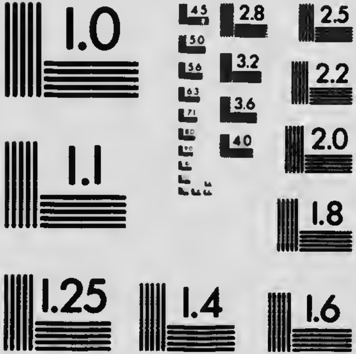

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CUSPATE FORELANDS ALONG THE BAY OF QUINTE

ALFRED W. G. WILSON

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INTRODUCTION—THE BAY OF QUINTE.

THE flat-lying limestone regions immediately to the north and east of the east end of Lake Ontario are traversed by a number of deep valleys with graded side slopes on their lower courses. These valleys are probably of preglacial origin, and were carved at a time when the relative altitude of the several parts of the Ontario lowland was different from what it is at present. The partial submergence of a number of these valleys, tributary to one another, has formed the water body known as the Bay of Quinte. This bay extends from near Kingston, at the east end of Lake Ontario, toward the southwest for a distance of over fifty miles, and nowhere has it a breadth exceeding two miles. A reference to the accompanying general map will show its remarkable zigzag course.[1] For purposes of study it may be

[1] For a discussion as to the probable origin of this valley see "The Trent River System and the St. Lawrence Outlet," *Bulletin of the Geological Society of America*, Vol. XV.

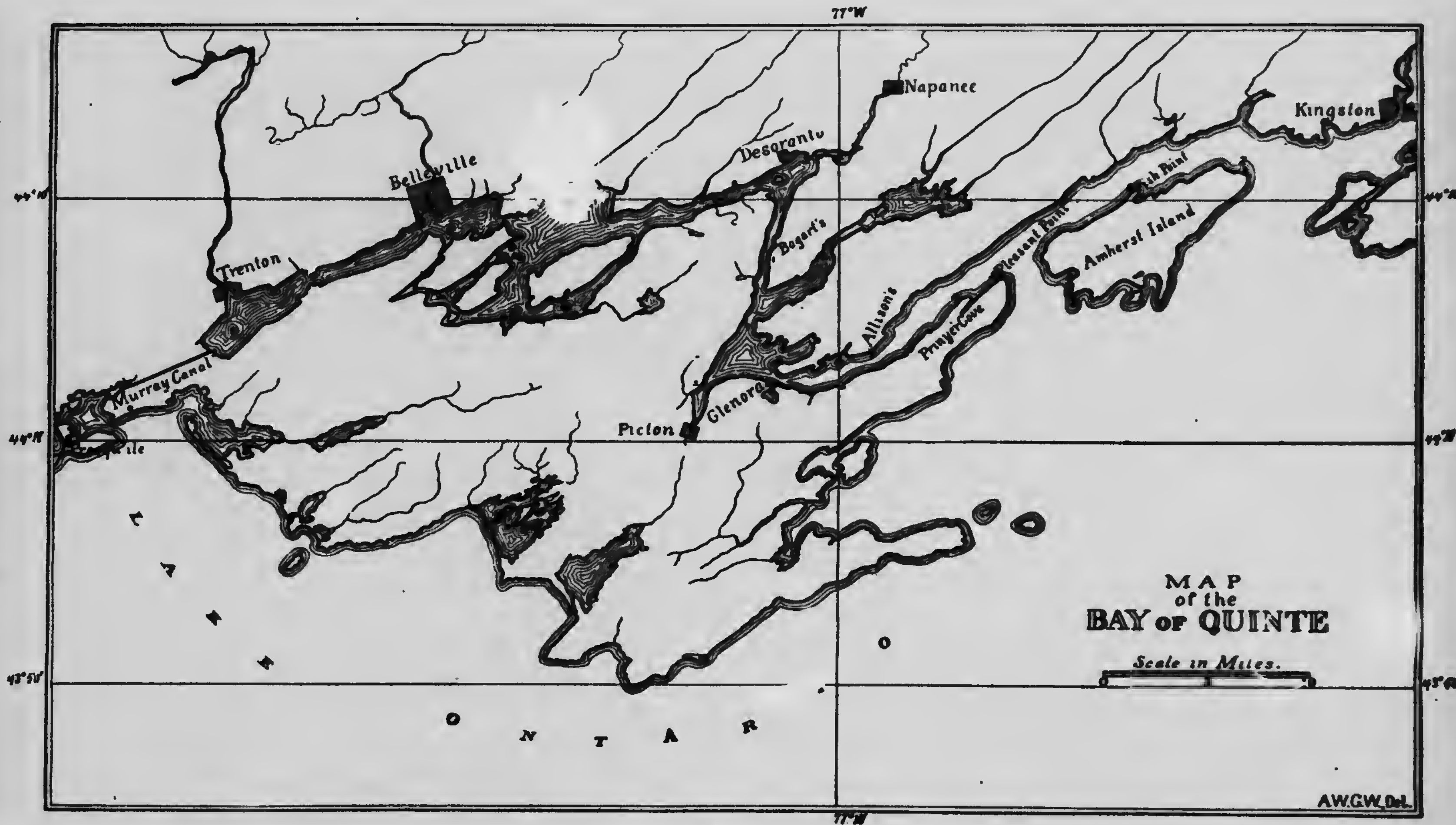

MAP
of the
BAY OF QUINTE
Scale in Miles.
Kingston
Napanee
Deseronto
Belleville
Trenton
Murray Canal
Picton
Glenora
Bogert's
Allison's
Prinyer Cove
Pleasant Point
Amherst Island
L A K E
O N T A R
O
77°W
44°N
A.W.G.W. Del.

FIG. 1.

divided into three parts: the Trenton-Desoronto section, trending a little north of east; the Desoronto-Picton section, trending to the west of south; and the Picton-Kingston section, trending nearly northeast.

The upper section is comparatively shallow; for the most part the shores are rocky; and no characteristic cuspate forelands have been noted along them.

The middle section, sometimes known as the Nine Mile Reach, has much deeper water, and the valley sides are steep, often inaccessible cliffs of Trenton limestone. The maximum relief is about 185 feet. Much of the shore is rocky, but along the east side there are, in places, small amounts of modified drift lying between the water's edge and the front of the adjacent escarpment. In one place, a short distance below Bogart's dock, shore drift derived from this material has formed a small foreland of fine sand which resembles the V terrace with the rimming bars which Gilbert describes as occurring on the shores of Lake Bonneville. On the west side of Picton Bay there are also two small spurs of shore drift which seem to be associated with talus cones from the face of the cliff.

Along the third section of the bay there are four excellent examples of the cuspate foreland and one long flying spit. Some of these cuspate forelands have a remarkably close resemblance to the V terraces and V bars of Lake Bonneville. Parts of the shores of this section of the bay are also rocky, but the amount of drift, both till and stratified material, is greater than elsewhere. Off the west end of Amherst Island the water has its maximum depth of 230 feet. The valley reaches its maximum relief of 284 feet near Glenora. The south shore is bordered by the steep escarpment of a cuesta which rises about 200 feet above water level near Glenora. The height gradually decreases eastward, and in Amherst Island it is only about 50 feet. The north shore rises gently inland. On the south shore rock exposures are numerous; on the north shore glacial drift frequently occurs, bed-rock less often. Of the four cuspate forelands to be described, three occur on the south shore; the flying spit is located at the extreme eastern end of Amherst Island, also on the south side of the bay.

The material which forms the loose débris of the shore is in part derived from the wasting of the cliffs, in part from the glacial deposits. The material which forms the single spit which occurs on the east side of the middle section, and also that of the spit which occurs on the north side of the eastern section of the bay, seem to be wholly of glacial origin. The materials of the three forelands and the flying spit which occur along the south side of the eastern section of the bay are largely derived from the bed-rock where it outcrops along the shore, but there is a slight admixture of gravels derived from the glacial deposits.

MOVEMENTS OF THE WATERS OF THE BAY OF QUINTE.

Currents.—Before describing each of the spits in detail, and discussing the question of their origin, it is considered advisable to say a word about the movements of the waters of the bay. As is well known, there are no appreciable tides on the Great Lakes; hence tidal currents do not enter as a factor in the distribution of shore waste. The volume of water discharged by tributary streams into the upper part of this bay is considerable, but its ratio to the total amount of water in the bay is so small that no appreciable outflowing currents are set up. It is altogether doubtful that any portion of the bay water below Deseronto has a normal current from this cause of over a mile per day.

The seiches of Lake Ontario periodically affect the height of the water of Kingston. Accurate data are not at hand to permit of any statement of their exact periodicity, but by calculation it should be about sixteen hours between wave-crests. The change at Kingston ordinarily does not exceed a foot and a half, except during and after exceptional storms, when it is much greater. The water that is backed into the bay at the time the crest of the seiche-wave is at Kingston must theoretically cause an oscillatory movement in the bay, as the crest and trough of the seiche-wave travel up the bay. At Napanee, at the head of the navigable portion of the Napanee River, about seven miles above Desoronto, this seiche-wave often makes a difference in water level of about 3 feet. Here, however, the water is backed into a narrow funnel-shaped opening. Out on the open bay very slight changes in level are occasionally noticeable, but no records of their amounts are available. It may, however, be stated that they are very slight, and at no time, except at the upper part of the Napanee estuary has the writer been able to determine the existence of any noticeable current due to this cause. It may be stated that the currents in the bay produced by this cause are not capable themselves of transporting any of the material which is moved along the bay shore. It is true that they may slightly accelerate or retard the currents which are concerned in the active transportation, but they are much too weak to be in any way considered as active and effective agents in transportation. Where they have been observed at their maximum the water is perfectly clear, although the bottom is covered with a fine mud which settles rapidly when stirred.

Approximate estimates as to the strength and importance of the seiche currents can also be made at the Murray Canal. This canal is four miles in length and connects the upper end of the bay with Presqu'Isle Bay, this latter bay connecting directly with the open lake. The crest of the seiche reaches Presqu'-Isle Bay some hours before it reaches Kingston. Consequent on the rising of the waters at Presqu'Isle Bay a current sets in eastward through the canal to the head of the Bay of Quinte. Some hours later the crest of the wave advancing from the Kingston end of the bay, having had about 110 miles farther to travel, reaches the head of the bay, and occasionally may start a current through the canal in the opposite direction. Unfortunately, it has not been possible to carry on simultaneous observations at several points on the bay, nor at any one point continuously for a long enough period to establish the time relations of these oscillations. The existence of the currents through the canal has been established. These currents in the canal are farther complicated by wind-action which generates surface currents. From observations made during periods of calm weather the author would infer that the current to be attributed to the seiche alone rarely exceeds five miles per day. It must be noted that until careful quantitative observations are made there can be no definite statement, for even during calm weather the momentum of wind-generated currents causes them to continue for a considerable period, and it is difficult to distinguish positively between these residual currents and the true seiche current.

In the absence of accurate observations of the time of oscillation of the seiche, we have no means of knowing whether the crest of one wave starts the currents through the canal from one direction at the time when the trough of another is at the opposite end of the canal; in other words, we do not know whether the current periodically reaches its greatest possible maximum value. Assuming a mean depth in Lake Ontario of 65 feet, and making some allowance for retardation of the advance of the wave-crest up the narrow bay, a calculation of the time of oscillation of the seiche along the line of direction of the most prevalent storms suggests that the periodicity of coincidence of crest and hollow at opposite ends of the canal will not be the same as the period of the seiche.

The mean depth of the canal is 11 feet; the breadth at the bottom, 80 feet; the breadth of the water surface, 125 feet. It may be inferred from the small volume of water moved through the canal by the seiche current that in the much broader, deeper bay the actual currents generated by the seiche oscillation must be very slight.

Waves.—The effective agents in the transportation the shore débris are wind-waves, and the longshore currents which are associated with them. The size of the material transported and the rate at which it travels must necessarily depend upon the strength of the waves; these in turn depend upon wind velocity, and, in the Bay of Quinte, upon wind direction. Observations which have extended over a considerable period have shown that resultant effective transportation along the shores of the Great Lakes depends in part upon the direction of the most prevalent winds, in part upon the length of the stretch of open water across which the acting wind has come. The larger storms usually determine the resultant direction of transportation. Now, in the case of the Bay of Quinte, the steep sides of the valley in which the waters of the bay lie so guides and controls the winds that we find that the efficient wave and wave-current work in shore transportation is done by those winds whose direction conforms nearly with the axial direction of the several sections of the bay. The narrowness of the bay, coupled with the depth of the valley, is such that even violent storms blowing across it can do less efficient work than is done by the much gentler local breezes blowing up or down the bay.

In this locality the prevailing direction of the wind during the summer is from the southwest; but, in spite of this, it is found that, because of the considerations to be noted below, there is virtually no continuous transportation eastward except along parts of the lower portion below the Upper Gap. There seems rather to be a constant oscillation to and fro. Because of the shape of the bay and its position the directions from which efficient winds and their accompanying waves can come are the northeast and the southwest.

The material which forms the forelands varies from fine sand in one example to large rock plates weighing over four pounds each. All the spits but one are built of coarse and fine gravel or shingle. In most cases the material is almost all so coarse that its transportation must be attributed to the wave itself, rather than to the action of any longshore current during the intervals that the wave may have raised it off the bottom, though no doubt these currents assist in that transportation to a small extent. It is moved in part by rolling along the bottom, but even some of the largest fragments are frequently lifted clear of the bottom and carried along with the wave. The shape of the oblong or rhomboidal plates (rarely over an inch thick, and with an area on the flat side, varying from ten to thirty square inches) materially facilitates this mode of transportation.

THE FORELANDS AND BARS.

1. *Sand spit below Bogart's dock.*—This is a small spit which consists wholly of fine sands derived from the adjacent cliff cut in modified drift. The spit measures about 245 feet across the base and extends about 100 feet out from the shore line. The normal width of the beach between the cliff front and the water

is about ten feet. In its present attitude the axis of the spit inclines toward the southwest or slightly down the bay. A reference to the accompanying sketch plan will show the present existing conditions. There is a central triangular terrace at water level, marshy, but filling with sand which drifts in or is washed in by rains or waves. Bordering this are two distinct sand ridges rising about 2 feet above water-level. The outer ridge has imponded a small amount of water between itself and the inner ridge. A third ridge has been begun on the outside of these two.

Referring to the general map, it will be seen that effective

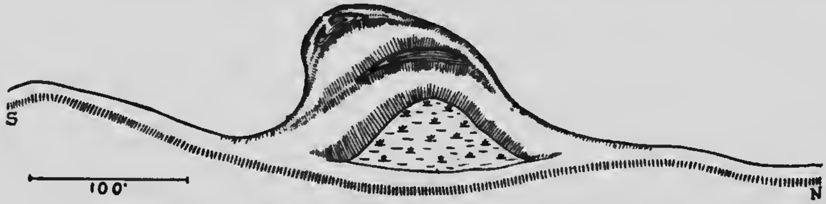


FIG. 2.—Small sand spit below Bogart's dock, June 1, 1903.

transportation must always be by winds blowing nearly parallel to the axis of the middle section of the bay. The present shore line, both above and below, is certainly just as irregular as it is here—it would be described as slightly wavy. There is no stream discharging near here, and there is no evidence of a local landslip having modified the shore line in such a way as to cause the beginning of the building of the spit at this point. In the field it was at first very difficult to see in this case why it should have happened to be formed here and not at a half-dozen other apparently similar places. It happens, however, that there is a very slight, though noticeable, difference in the curvature of the shore line at this place, and it seems as if, under certain special conditions of wind-action from the east of north, the longshore wave and wave currents first started to build a terrace and later a bar outward from the slight salient in the shore line of this point, and that the *same* waves gradually turned the end of this free bar as it reached deeper water, giving it its curved form, and finally tying it on to the shore again. This bar was subsequently modified and its curves readjusted by waves coming up the bay. At a later period the second bar was built outside the first, under a similar succession of conditions, the waves most actively concerned in its construction coming from the southwest. The third portion was in part built during the summer of 1903, under the action of a series of storms from the northeast. During the process of its building the waves cut into the earlier bars on the north side, producing the concave curve in the shore line at this point, and depositing the eroded material nearer the apex of the spit on the far side of the axis of the initial form, producing the asymmetrical form shown in the plan. If their action continued long enough under the conditions existing at the time the observations were made, the bars would be extended in a very much larger loop and would inclose a very much larger lagoon. The rounding of the end of the spit and the shaping of the convex and concave curves on the south side were actually done by the same set of waves which brought the material to form the outer cap of the spit. In this, as in several other cases, even where the material was coarse gravel, the apex of the spit lies so far off-shore that waves curving obliquely toward it from either direction will only have their shoreward ends retarded as they advance obliquely on the shore. The off-shore portions advance in the deeper water virtually unretarded, and thus the wave front is rapidly curved around the end of the spit. Material moved along a side of the spit toward the end, when discharged at the apex, will often be carried around the end by the more vigorous unretarded portion of the same or the next following wave to that which accomplished its final discharge at the point.

This sand spit seems to be rather an evanescent than a permanent feature of the shore. The present spit is, from the character and size of the sedges growing in the lagoon area, inferred to be several years old, probably not more than five.

2. *Grand bars on Picton Bay.*—On the west side of Picton Bay, nearly opposite the west end of the third section of the Bay of Quinte, are two peculiar bars forming two distinct loops, convex outward, joining the shore by two short concave curves of adjust-

ment. The beach between the cliff-foot and the water is here quite narrow, usually less than 6 feet in width. Above and below the two-loop bars in question the shore line is slightly sinuous, but the beach is of very uniform width. Between the two bars there is a stretch of 78 feet where there is not enough beach gravel to cover the bed-rock, and the cliff rises directly from the

FIG. 3.

water, here about a foot in depth at the shore line. The south loop is 220 feet in length, and the north one 280 feet. The north loop holds a long, narrow little pond between it and the old shore. The low area between the south bar and the old shore was above present water level, and was nearly filled with gravel.

The sudden departure from the normal conditions along this shore to form these bars is difficult of explanation. In the pres-

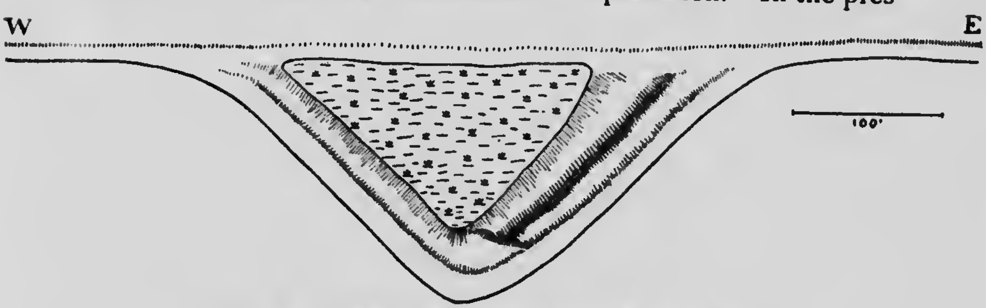


FIG. 4.—Foreland near Allison's dock, May 22, 1903.

ent instance it is possible that a small landslip from the cliff may have temporarily changed the shore line in such a way as to necessitate readjustment by the waves. On the other hand, they may have been formed under the action of the waves alone on the normal shore line, under conditions referred to below in a general discussion of the origin of the forms here described. In this latter case they represent initial stages of a form which reaches its perfection in the V terrace and V bar.

3. *Terrace and bar near Allison's wharf.*—On the north shore of the eastern section of the bay at Allison's dock, there is a sea-

cliff 25 feet in height, cut in till. To the east the cliff becomes much lower. About half a mile east of the wharf occurs one of the most perfect examples of the V-bars. The sea-cliff of till here has a height a little under 5 feet. There is a narrow beach about 20 feet in width. The front of the cliff behind the foreland is more subdued than elsewhere; it is graded, and is covered with sod. The bars which inclose a triangular lagoon are built of gravel and sand. The material of the east arm is chiefly a coarse gravel; that of the west is gravel with a much larger percentage of finer material and some sand. On the inner side there is a small amount of clayey soil which has gradually been blown or washed into the lagoon. The bars are of at least three periods of formation. The oldest rises 3.2 feet above water level the next oldest 4 feet, and the present one about 3 feet. The older beaches have been in part cut off by the newer, as shown in the plan.

The inclosed lagoon is triangular in outline, with rounded corners. The base on the old shore measures about 210 feet, the apical distance along the axis is about 135 feet. The depth of water is about 18 inches. It is more or less grown over with water plants and grasses. The east arm of the triangle measures 144 feet; the west, 165. The apex of the spit is rounded and the nearly straight sides join the shores with short concave curves of adjustment. The east arm of the bar is much higher and wider than the west arm, and its outer end has several times been truncated by stronger storms from the east. The present form of the spit is thought to be due to the activity of the waves, chiefly from the east. The western arm has been straightened and smoothed off at frequent intervals by the less violent, but more constant waves from the southwest. The bottom on which the terrace rests here slopes rapidly downward under the bay, the 100-foot contour lying less than a quarter of a mile off shore.

A reference to the general map shows that this spit is located very near one of the most salient points of the north shore of this section of the bay. On the ground its actual location is about a quarter of a mile to the east of this point, and hence it is sheltered by the point from the storms which blow directly down the bay from the southwest. Waves which travel up the bay from the east would apparently have their maximum effect on the beach at this point. A little farther east there is another minor point, too small to show on the plan Beyond this toward the large point (a drumlin) shown on the plan, about a mile and a quarter east of Allison's wharf, the shore débris is very much coarser. Both to the west and east the rawness of the shore cliffs and the coarser beach débris show that there is much more active erosion going on there than in the immediate vicinity of the

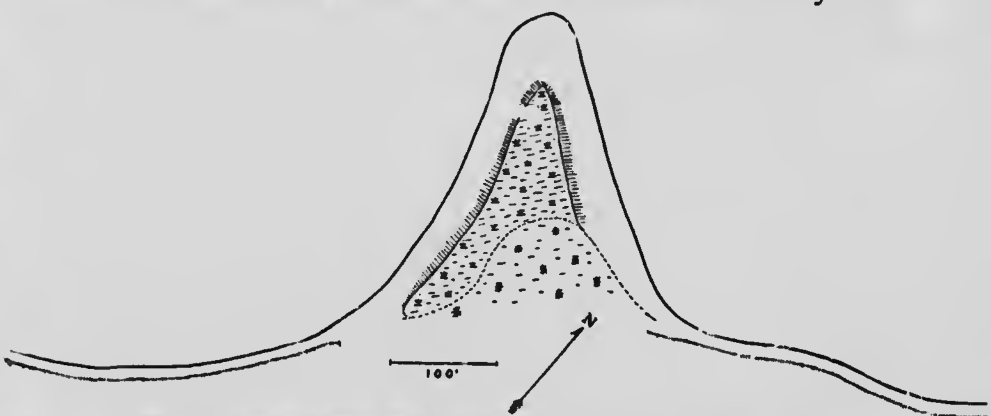


FIG. 5.—Foreland about half a mile west of Prinyer Cove, June 1, 1903.

spit. The inference there seems to be that just at this locality we have a region of relatively quiet water and less activity, where material eroded by the waves acting alternately at different intervals tends to accumulate.

4. *Prinyer Cove spit.*—About a mile west of Prinyer Cove there is a slight salient on the shore line which is tipped by a small V terrace and rimming bars inclosing a triangular lagoon. The axis of the spit lies nearly at right angles to the trend of the shore line. The spit is 275 feet in length and measures about 300 feet across the base. The sides are nearly symmetrical, and the inclosing bars are built of gravel. The inclosed lagoon is in part filled up with rank marsh vegetation; near the edges are some large trees. The apex of the spit shows the lines of successive additions on alternate sides. Inside the present beach only one of the earlier beaches is well preserved. This has been in part

cut into during the readjustment of curves when the present beach was built. The land behind the shore is overlaid by a thin sheet of till. It slopes gently bayward, and the inner margin of the lagoon gradually merges into the mainland. Both on the east and west there is a low cliff above the beach having a height of about 2 feet. The cliff and beach that must have existed behind the lagoon have long since disappeared. The gravel bars on the sides rise about 3 feet above water level. That on the east is a little larger, and consists of coarser material than the one on the west. Almost all the gravel composing the bars is derived from the adjacent bed-rock—a nodular shaly limestone of Trenton age.

5. *Pleasant Point spit.*—This is the largest and the most interesting of all the forelands on the bay. The general form of the foreland is shown by the accompanying plan. The material of which it is built is almost wholly gravel. The eastern side consists of very coarse shingle containing numerous flat plates of all sizes up to three or four pounds in weight. The west arm, on the other hand, consists chiefly of smaller rounded pebbles, rarely over an inch in diameter, and there is also a certain amount of fine gravel and sand.

To the west of the foreland there is a shore cliff about 20 feet in height, of which at least the upper 5 feet are glacial till. The base of the cliff is shaly limestone, and the width of the normal beach is between 6 and 10 feet. It is strewn with coarse cobbles, there being very little fine material such as is found on the arm of the spit a few yards away. The old cliff runs behind the spit; twice it changes its direction, recording significant changes in the growth of the spit. Its height at the base of the eastern arm is only about 5 feet. It continues as a low bluff for some distance to the southeast. The drift varies in thickness, but near the spit its thickness is about 2 feet.

The original foreland so far as it can be traced, lay a little farther to the west than the present one, and was very similar in shape and size to that near Prinyer Cove. At the present time there are seven distinct beaches. Counting east from the inner triangular lagoon, the first three of the beach mounds or ridges each rise only about a foot above present water level. They are nearly parallel, and between them we find two long, narrow ponds. The fourth beach, the largest and highest of the series, extends nearly the whole length of the spit. The next two are also of considerable height and breadth, and are best preserved near the outer end. In the readjustment of the curves during the formation of

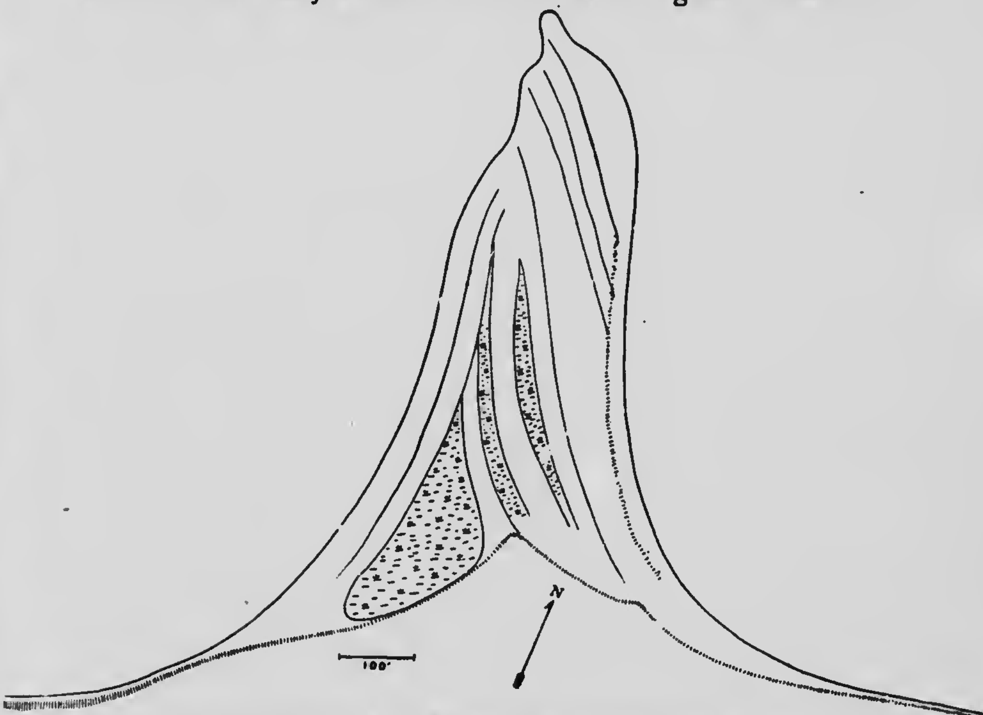


FIG. 6.—Sketch plan of Pleasant Point Foreland, May 23, 1903.

the seventh or modern beach the waves have cut through the sixth and fifth, and are now acting on the fourth near its shore end. On the west side traces of only one ancient beach could be found between the present modern beach and the triangular lagoon. It is assumed, in the counting, that this is the correlative of some one or more of the first six of the earlier beaches found on the east side. Both the beaches on the west side cut across the ends of the first three of the earlier beaches, and the modern one cuts across the ends of the other three as well. The fourth beach on the east, the highest and broadest of the series, rises about 6 feet above present water level, or at least 8 feet above the bottom of the lagoon. The beach on the west is only about 2 feet high, except near the apex of the spit.

A reference to the general map will show that immediately to the east of the point we have a gap—the Upper Gap—in the side of the Bay of Quinte valley, through which storm waves from the open lake can have access to the bay. The waves which will have most effect on the shore are those coming from a little to the east of south, although the waves of a storm from the east or south will also be capable of effective work. On the other hand, the spit is exposed on the west only to waves traveling up the bay before a wind having a very limited distance in which to act. Hence we find that the larger waves from the open lake have been steadily carrying material around the point, and depositing it in the slack, but very deep, water behind. The point of the spit is now out as far as the 70-foot contour. The much larger size of these waves has been the important factor in determining the coarseness of the material of the eastern part of the spit, in piling it so high, in determining the amount which has been brought here, and in causing the spit to travel slowly eastward. The material which forms the west arm is in part derived from that brought by the bigger waves to the east side and subsequently carried around the point, partly by the same system of waves which brought it, but chiefly by the waves coming up the bay from the northeast at other times. Some of it is brought from the shores to the west. One record of the changes which take place at the apex of the beach under the action of

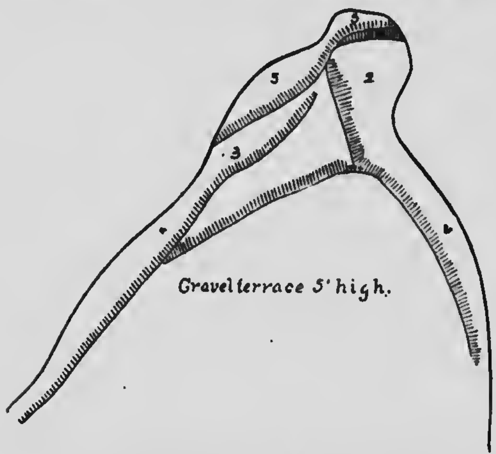
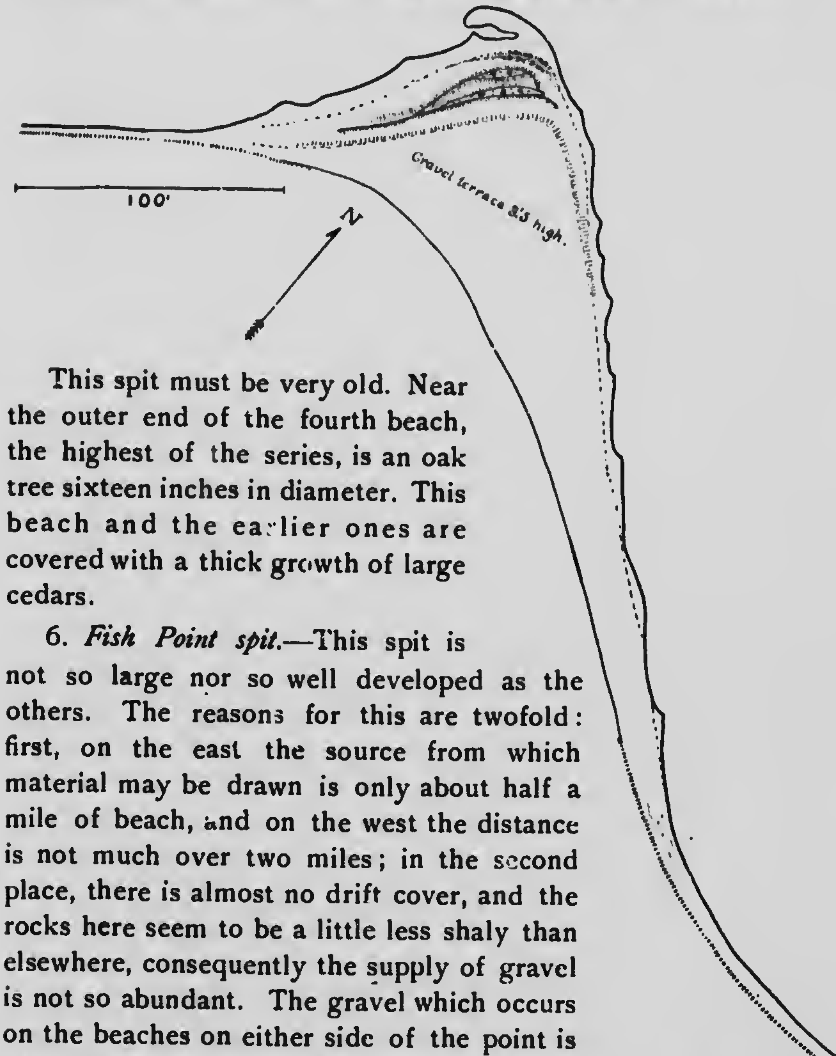


FIG. 7.—Sketch plan of about 100 feet of the apex of the Pleasant Point spit, May 23, 1903, showing the shifting beach ridges and terraces.

different storms is shown in the accompanying sketch. Material is transported very rapidly along the eastern side of the beach, in spite of its coarseness. Along the west the travel seems to be much slower because of the relatively small size of the waves.



This spit must be very old. Near the outer end of the fourth beach, the highest of the series, is an oak tree sixteen inches in diameter. This beach and the earlier ones are covered with a thick growth of large cedars.

6. *Fish Point spit.*—This spit is not so large nor so well developed as the others. The reasons for this are twofold: first, on the east the source from which material may be drawn is only about half a mile of beach, and on the west the distance is not much over two miles; in the second place, there is almost no drift cover, and the rocks here seem to be a little less shaly than elsewhere, consequently the supply of gravel is not so abundant. The gravel which occurs on the beaches on either side of the point is very coarse, many of the rounded pebbles exceeding two inches in the longest diameter, and there are numerous large plates up to ten pounds in weight. The gravel at the spit is smaller than elsewhere, that on the east

Fig. 8.—Fish Point Foreland, May 24, 1903.

side probably a little coarser than that on the west. The spit, as a whole, resembles a cap which has been built by the gravels on the end of a minor salient of the mainland by the waves when readjusting the shore curves. The main portion of the spit consists of a large irregular or wavy topped terrace of coarse gravel, built out in front of the mainland. For the most part the earlier beaches have lost their individual identity. At the outer margin several of the later ones are still persistent, inclosing shallow lagoons.

The spit was particularly interesting as it exhibited several features, which are described in detail because it is thought that their mode of formation is an index of the way in which the large V bars and V terraces were built up. The eastern side of the spit at the water line had a serrate margin, there being ten distinct, well-marked minor cusps, which for convenience in description may be called cusplets. Each of these had a long, gently curving shore line on the side toward the advancing waves. The free end of the cusplet was joined to the main shore by a short, abrupt, concave curve. Sometimes the free end of the cusplet was drawn out into a sharp, well-developed point. The best-formed cusplets had a sharp median ridge extending down the axis, and often prolonged as an apical spine at the free end. The outer slope, toward the water, was very steep, at first almost a straight line, and then gradually curving around to the normal subaqueous beach curve. The inner slope was much flatter. The curve of the shore line of the individual cusplets was approximately adjusted to the curve of advance of the front of the waves which were building and shaping them (see Fig. 9). The finer gravel lay on the longer back slopes, the coarser fragments, often small plates rather than rounded pebbles, were concentrated on the steeper frontal slopes.

These serrations on the side of the spit seem to owe their origin to the attempt of the waves of a particular series of storms, coming from a nearly constant direction, to readjust the curvature of the shore line to the curvatures of their own fronts. Off shore the waters are very deep, and the shore line of the bay is yet in a very young stage of its development; consequently the waves traveling obliquely toward the shore are not symmetrically and systematically retarded. The wave does not advance on the shore parallel to its front but comes up obliquely (see Fig. 9). The result is that the gravel was moved obliquely up the slope of the beach, and then obliquely downward with the return of the wave, but always with a resultant in a direction

FIG. 9.—Showing the relation of the wave-fronts to the serrate margin of the east side of Fish Point Foreland.

parallel to the shore. During the period of observation the débris moved along the long curve of the cusplets very rapidly, and then, when discharged into the deepest water at the free end, would either fall at once to the bottom, or might happen to reach the end just in time to be carried across the intervening space by the rush of the less retarded part of the wave which had not yet reached shore. Material would thus be rolled along the long slope by the breaking edge of the wave, but, when discharged at the free end, it was often bodily carried several feet past the spine of the cusplet and up to the main beach by the more powerful, less retarded portion of the waves—there to be rolled slowly or rapidly along the long slope of the next cusplet, where the process was repeated.

The size of the cusplet in some cases seemed to be increasing, but several seemed to have reached a maximum stage. Given a constant material, the limit of size seems to depend upon the size of the waves and their periodicity.

These little cusps are formed during the period of a single storm, or series of storms, when the waves advance in an oblique direction on a previously evenly curved shore. Their formation and their symmetrical arrangement seem to be due to two factors. In the first place, very frequently the undertow is able to carry material down the slope of the beach a little farther than the front of the wave can move it up, within certain limits. Consequently, although some of the material moved up the slope by the front of the wave lodges, some of it moves down with the undertow, and a small percentage of this latter material may move out beyond the zone at which the next oncoming waves can move it up the beach. Hence there will be a slow but gradual accumulation just beyond this line, which in time will even modify the direction of the long shore currents. A second and more important factor in the production of these serrations along the shore is the development of nodal lines along which material tends to accumulate. Where the waves are advancing at an angle to the shore there will be a number of waves breaking at the same time at different points along the shore. As the spacing of the waves is nearly uniform, if the shore line were perfectly straight, these points of simultaneous wave-breaking would be equidistant from one another. On a curved shore the spacing will be systematic, but the distances between breaking points will not necessarily be equal. Now, the undertow which flows out from one wave as it breaks will interfere with the advance of the next following wave, if it meets that wave on that part of the shore where the orbital motion is nearly a straight line up the beach. This happens very frequently where part of a wave is retarded by a cusplet while the other part passes the free end with little retardation. The result will be a tendency for the material moving down the slope with the undertow, and up the slope with the advancing wave, to be dropped at a symmetrically arranged series of points. The obliquely moving waves also move débris along the shore in the resultant longshore direction of the wave advance.

The result of the combined action of these different factors is that gradually a little bar is built out from the shore by which the waves attempt to readjust the curvature of the shore line to a curvature appropriate to their direction of advance. Because of the nearly uniform spacing of the waves, these bars will begin at a number of symmetrically arranged points. Because of the normal, uniform slope of the subaqueous floor, the maximum distance from shore at which the undertow can materially interfere with the advance of the next wave will be located at a nearly uniform distance off the initial shore line, and this will tend to limit the size of the individual cusplets. The size is also limited by the distance between the crests of the waves. The building of the cusplets further modifies the form of the shore line, the slope of the bottom, the direction of the advance of the waves, and the direction of the longshore currents; but with waves of constant size an equilibrium will be established, at which time the cusplets will have their maximum size. If the waves are irregular, cusps may not be formed at all.

The same waves which had built the serrate margin along the eastern side of this foreland had built a small flying spit at the apex. Between the free end of this small flying spit and the main beach a very small Λ-shaped point was also gradually built up. The waves coming from the east in the direction indicated by the arrow (Fig. 10) swung around the point, giving it the form shown in the figure. The fronts of the waves assumed the form of a series of helicoidal curves as they swung around the point as if on a pivot. As many as eight waves could be counted swirling around the west end of the flying spit at the same time, the moving crests looking not unlike the spokes of a gigantic horizontally rotating wheel. The relative positions of the successive wave-fronts are shown by the dotted lines in the figure.

Material which had rounded the extreme tip of the flying spit was actually carried across the narrow water space between the flying spit and the little conical point being deposited on the outside of

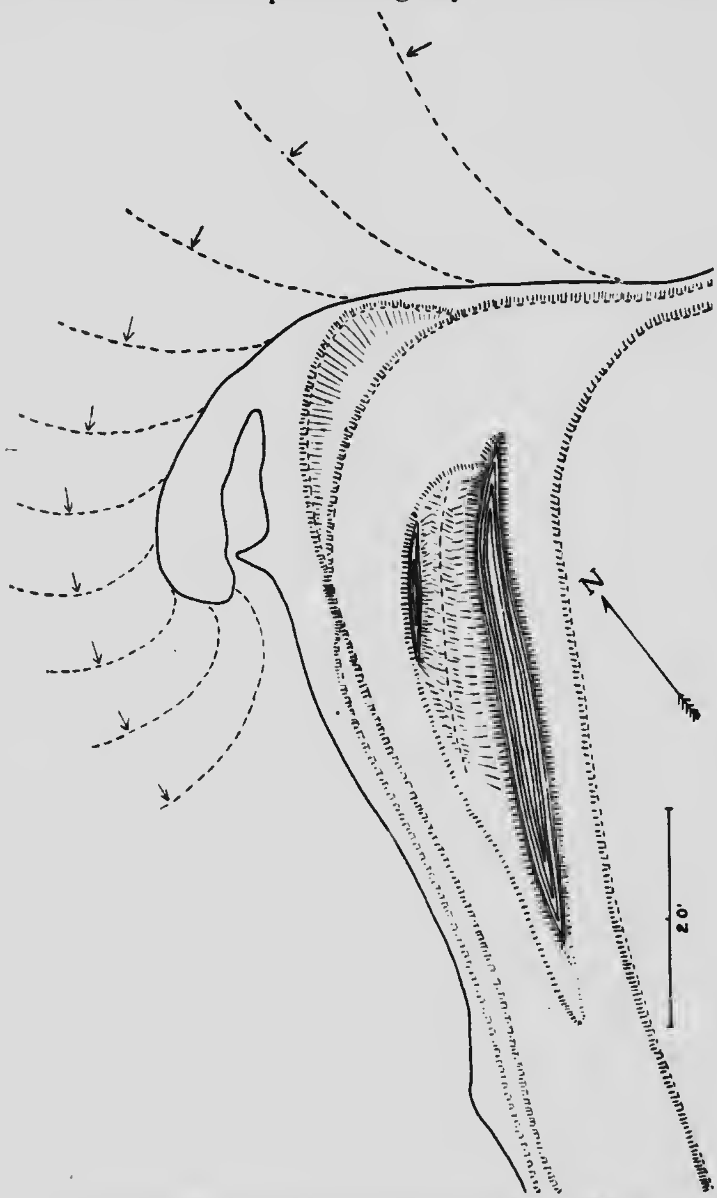


FIG. 10.—Sketch plan of the apex of Fish Point Foreland, May 24, 1903.

the cone. As each wave came in, the water in the small lagoon rose and fell. The outflowing current seemed to be the control which shaped the inner curves of the cone. A little farther to the west the same waves were increasing the size, rounding the ends, and otherwise modifying the two larger cusplets (Fig. 11), which,

FIG. 11.—Two well developed cusplets in the foreground, the apex of the small loop spit appears in the background. North side of Fish Point Foreland.

judging from their initial forms, had evidently been built some time before by a storm blowing from the west.

7. *Amherst bar.*—Waves rolling into the bay through the lower gap from Lake Ontario have built a long gravel bar off the east end of Amherst Island. This bar runs nearly north from the end of the island and is nearly two miles in length. Most of it is submerged, but near the island a portion rises as a sharp ridge several feet above water level. The eastern end of Amherst Island is low, and the shore is rocky. Most of the gravel forming the bar has been moved along the south shore of

the island by southwest storms off Lake Ontario. The portion of the bar that is above water level has a peculiar curved form, due to the many complex modifications which such a bar may undergo under the influence of minor storms. Some of these are well shown near the free end of that portion of the bar which rises above water level. On the south side of the free end we find two large, well-developed, south-pointing cusps, bounded by curves which are concave lakeward. These cusps seem to owe this form to the action of waves advancing from the southeast and the southwest at different times.

8. *Calf Island loop bar.*—Although not in any way associated with the Bay of Quinte, it seems desirable to include in these descriptions a reference to the loop bar off the east end of Calf Island. The island lies about four miles northwest of Stony Point, and half a mile to the west of Stony Island. Storm waves blowing down the lake naturally divide at the island and pass on either side of it. Coarse gravel derived from the limestone rock, by which the main island is underlaid, has been piled in two high ridges, one leading off from either side of the island. The two unite in a rather sharp point about 350 yards from the east end of the rocky part of the island. The crests of the bars are about 9 feet above water level, and between them is a deep, narrow pond. The south bar is about 60 feet wide, and has equal slopes on either side; the north bar is a little wider and more irregular.

Similar forms are to be looked for off the northeast ends of several of the other rocky islands in this part of the lake. Off the east end of Grenadier Island two long flying spits have formed, inclosing between them a shallow bay known as Basin Harbor. This bay is gradually filling up. The free ends of the two spits are curving toward each other, and, given time enough, we would expect them to unite. In the meantime, the inclosed basin will be partly filled by sand either washed in by the waves or blown in from the bars. The outer slope of the bars will still have the steep gradients of such forms; their height will depend upon the depth of the adjacent water. In time there will thus be formed off Grenadier Island a huge terrace, with running bars, which in form will approximate in shape to the typical V-terrace and V-bar.

THE ORIGIN OF THE V-TERRACE AND V-BAR.

Four of the forms which have been described in the preceding paragraphs agree very closely, both in form and location, with Gilbert's description of the type examples in Lake Bonneville.[1]

In his descriptions of the type examples Gilbert notes that:

> They are built against coasts of even outline, usually but not always, upon slight salients, and they occur most frequently in the long narrow arms of old lakes.

In discussing the origin of the form he states:

> In some cases the two margins appear to have been determined by currents approaching the terrace (doubtless at different times) from opposite directions; and then the terrace margins are concave outward, and their confluence is prolonged in a more or less irregular point. In most cases, however, the shore drift appears to have been carried by one current from the mainland along one margin of the terrace to the apex, and by another current along the remaining side of the terrace back to the mainland. The contours are then either straight or convex.

The bars which border the terraces he attributes to a later period during a slight deepening of the waters of the lake, after the terraces had attained their full size. While the lake stood at the higher level, the linear embankments were built at the outer margins.

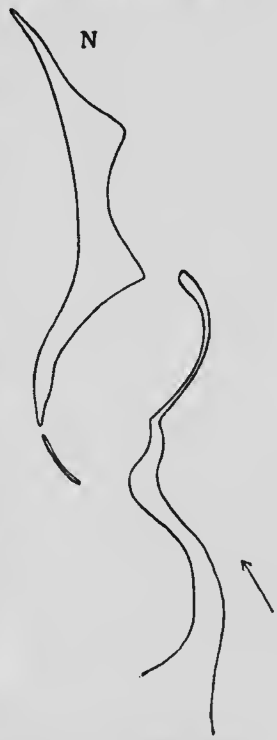


FIG. 12.—Sketch plan of about 500 yards at the apex of the portion of Amherst Bar above water level on May 25, 1903. Direction of wave advance shown by the arrow.

The author's studies of the forelands in the Bay of Quinte lead him to suggest the following hypothesis as to the mode of origin of the forms here described. In the first place, it must be noted that the level of the water in the bay varies

[1] U. S. Geological Survey, *Fifth Annual Report*, 1883–84, p. 98.

considerably with the seasons, being a little higher in late spring or early summer than at any other time. The level of Lake Ontario also changes considerably during a season. Both of these factors may have some bearing on the formation of the terraces and bars. The changes in level due to the larger seiche waves must occasionally be even greater than these seasonal changes. None of the forms show any evidence which could be interpreted as being due to these seasonal or periodical changes in level.

In a previous paragraph a detailed description was given of the process by which small cusps were produced along a shore. Under the continued action of waves of moderate amplitude the dimensions of these small forms would gradually increase, and eventually they would reach a size which could easily control the shore currents and wave direction of even moderate storms. In the present instance the bay is completely frozen over from about the middle of November until the first of May. During the season of open water the only effective storms are those which chance to be blowing up or down the bay. To be effective, they must have a constant direction, for a considerable interval of time. Hence, while moderate breezes which generate small waves are frequent, violent storms which can modify the work of all previous lighter winds and waves are rare. When they do come, their first work would be to readjust the shore curves developed during the previous interval. The chances that they would preserve a suitable direction long enough to efface the work of the previous, more or less contsant, but less energetic, storms are very slight. The construction of the small triangular terrace may in part be attributed to the leveling action of some such storms as these. In all observed cases, although the terrace under the triangular lagoon had a slight slope outward, its slope was not so great as that of the adjacent shore a little distance on either side of the sand spit; from which it is inferred that there had been some filling. Whether such a process could produce a very much larger terrace than those noted is uncertain. In other cases the portion of the terrace included between the bars may have been partly filled in by the waves themselves after the formation of the bars. Such a terrace is in course of construction off the east end of Grenadier Island. A similar process is causing a great deal of inconvenience at several harbors along the north shore of Lake Ontario, where two artificially constructed bars in the shape of piers inclose a harbor which periodically fills with sand that has to be removed by dredging.

In some cases the inner lagoon may have been filled after the bars were formed, by ordinary processes of transportation which tend to fill hollows and lessen the grade of steep slopes.

The size of the terrace would also depend upon the size of the water body, and upon the character of the material. The tendency will always be for the waves bringing the supplies of material to heap this up in the form of a bar. In the later stages, when the accumulation has become considerable, the larger storms would not be able to efface these bars, though they will reshape them and pile the material higher on the outer margin. On the outer side of a bar, below water level, the material has a gentle slope to below wave base. Beyond this the inclination of the front slope will be the angle of repose for material of the kind. In the case of all the forms on the Bay of Quinte, where the water drained off it would be found that the forelands would have steep frontal slopes, with an elevation in several cases of about 60 feet. The top would be a nearly flat terrace, with gently curved edges, and rising above it at a little distance from the margin would be the sharply defined rimming bar.

In the smaller examples the same waves which build the one side of the foreland carry material around the end of the spit and distribute it for a shorter or longer distance, according to their size, on the other side. On some occasions the same waves may shape both sides at the same time, but usually it is found that the adjacent sides are shaped alternately. In some cases the greater proportion of the material comes from one side, and its redistribution on the opposite side of the spit is effected by other waves from a different direction and at another time. In the case of Point Pleasant spit it seems to be slowly shifting eastward, as material brought from the southeast accumulates on that side. At the same time less rapid erosion is taking place on the west side under the action of less violent waves.

CONCLUSIONS.

In conclusion, it may be stated that the forelands here described seem to have been built wholly by the action of waves acting either directly or indirectly in association with longshore currents which were intimately associated with them.

The location of the forelands is associated with some more or less salient feature of the coast which has influenced the direction of wave advance and the course of longshore currents, and has localized the effective transporting action of both.

Their formation is due to the control exercised on wind direction and on wave direction by the form of the bay. The form of the forelands is due to the peculiar character of the long, narrow water body on which they are situated, the conditions being such that only certain classes of storms can be effective agents in the shore transportation. The immature character, and consequent imperfect adjustments of sub-acqueous portions of the shore is an important control in wave-work.

The V-terrace and the associated V-bar upon it, in the instances here studied, are regarded as products of the same agent, and do not necessarily imply a change in water level. The evidence from Point Pleasant spit implies that there has been no significant change in level during the long period of growth of the greater part of the spit.

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