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INLAND LAKES OF MICHIGAN

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CHAPTER V. INTERIOR LAKES OF THE SOUTHERN PENINSULA WESTERN INTERLOBATE AREA

The lakes discussed so far in this report lie near the borders of Lakes Michigan and Huron, and the majority have been connected with them at some time during the past. Furthermore, a rather simple grouping of these lakes suggested itself. The interior lakes are much more numerous and are smaller in size, therefore a relatively smaller number was selected for detailed study. Undoutedly a more extensive study of our lakes would bring to light relations which would serve as a basis for grouping but for the present this is not at hand. Fortunately we are able to determine more or less accurately the relative time of formation of these lakes and may use this as a natural order for discussion, even though other relationships may be very remote.

The fact that the glacier receded from the Southern Peninsula in a general northeasterly direction and that great interlobate areas were first uncovered between the Michigan-Huron-Saginaw lobes and the Saginaw-Erie lobes has been mentioned previously. For convenience we may term, the interlobate areas as the eastern and western, although they merge in the southern part of the Peninsula. In general, for each of these areas the relative age of the lakes is determined by their position, the more southerly being the older. However, within the moraines which border the interlobate areas the older lakes necessarily lie nearer the interlobate and it is only by a consideration of both of these factors that the chronological order may be determined. Uncertainties exist as to the correlation of the glacial deposits and, therefore, the order here presented is tentative and open to revision.

LAKES OF ST. JOSEPH COUNTY

Probably the first part of the Southern Peninsula to be uncovered by the ice is a small triangular area included largely in St. Joseph County. Within this county the glacial formations consist of two morainic tracts, one in the eastern part and the other crossing the northern part of the western boundary, and a large area of outwash which stands between and around the northern borders of the morainic areas. A number of small lakes occupy pits in the outwash and basins in the moraine in this region. The more numerous, however, lie in the morainic basins and several of these were examined by the writer, namely, Corey, Clear and Long hikes in the western morainic area and Klinger in the southeastern district. No careful attempt was made to determine the relative age of these lakes and the order of their discussion is of no significance.

KLINGER LAKE. Klinger Lake is the largest of a group of small lakes which are aligned in a northeast-southwesterly direction in the south-central part of St. Joseph County. These basins are morainic in character but that of Klinger Lake is much larger than is usual for this type of basin. It appears to be a depression that is almost surrounded by a narrow zone of moraine, which extends as a spur in a southwesterly direction from the main moraine, and is probably more closely related to lakes situated in basins of till plains than to those found in simple morainic basins. The morainic topography about its shores is the cause of varied shore conditions and the sandy nature of the glacial deposits has been conducive to shore adjustments to a degree unusual on a lake of less than two square miles in area. The many bluffs and clean sand beaches have been instrumental, to some extent at least, in making this lake one of the most popular in this section of the State.

From the map, Fig. 63, it will be noted that the shores of the present lake are relatively free from prominent irregularities. The elongate form is rather noticeable,

and the direction of the longer axis is such that some of the strongest winds, notably those from the southwest, have full sweep of the lake. The adjustments, although stronger along the east and northeast shores, are, nevertheless, distributed about the shores rather consistently.

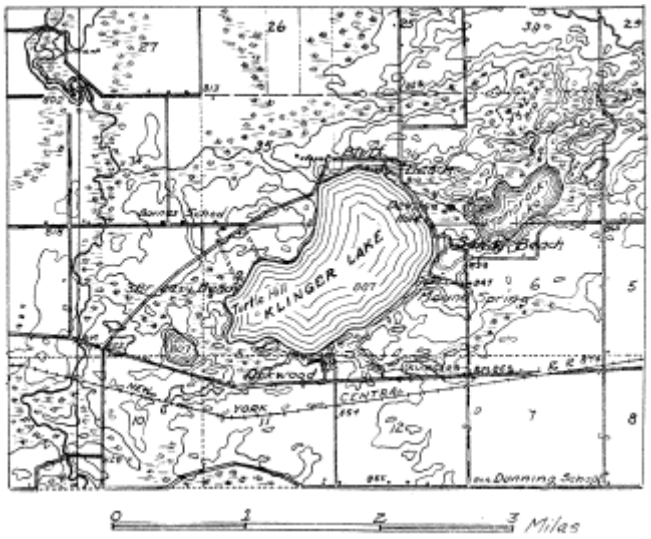

Figure 63. Topographic map of Klinger Lake and surroundings. (From U. S. G. S. Three Rivers Quadrangle.)

The lake is easily reached by the Toledo, Adrian, Hillsdale and Elkhart branch of the New York Central Lines which runs within a half mile of the south shore of the lake. Arriving by train one approaches the lake at Oakwood. This thriving summer resort is beautifully located on high ground that commands a view of the entire lake. Fresh cliffs rise from the excellent sand beach which lines the shore. Westward, cliffs face the shore for about one-half mile with the single exception of a marshy lowland just west of Oakwood. This lowland stands less than three feet above the present lake level and is very suggestive of a higher level. If such were the case, one might expect to find this depression bridged by a bar but none can be definitely recognized. Yet the presence of a road along the natural course of such a bar is at least significant. This lowland proves to be a narrow neck connecting with the flat marsh which borders the southwestern end of the lake and extends westward to the Fawn River. A single depression drops below the level of the marsh, forming a small, unnamed pond west of Klinger Lake, and several island-like hills stand above its surface. Such a hill causes the broad projection of the shore west of Oakwood. In the amphitheater-shaped northwestern side of this hill an exposed terrace of a former level is easily recognized and, in addition, a bar extends westward from the western point of the hill. Thus, it seems clear that the lake has stood at a higher level. Also .since the bar and the terrace stand above the marsh, it is evident that the lake flooded this lowland, including the unnamed pond and possibly extending to the Fawn River. Another hill stands near the present shore at the head of the bay. A small spit runs eastward from this "island" but does not connect with that extending towards it from the hill to the east, so that the shore line was not completely straightened in this locality. However, on the west side a complete bar extends to Turtle Hill which was also an island during the higher level. The greater development of the bars towards the west is readily accounted for by the great reach of the waves and currents from the east.

Turtle Hill comes to the lake with gentle slopes which have been cut into low cliffs. The material derived from these cliffs was shifted in both directions along the shore, but the greater part seems to have been carried northward and deposited in a well-defined spit which extends from Turtle Hill towards Breezy Beach. The development of the spit was interrupted by the lowering of the water level before the opening was completely closed, and the form changed somewhat by recent ice action. Much of the west end of the lake is shallow and the bottom covered with marl near the shore. In places the submerged terrace of the present level is clearly definable and drops into deep water at about five feet.

At Breezy Beach the land rises slightly above the level of the former lake bottom and is dry. The shore line was somewhat more irregular during the former stage but currents do not appear to have been effective along this shore. Northeast of Breezy Beach low hills slope gently to the shore and a low cliff and narrow exposed terrace of the higher level are present. The cliffs vary in height and where highest show fresh cutting. Around the broad point the submerged terrace is very decided and drops at thirty inches within one hundred feet of the shore, indicating much less powerful wave action here than on the south .shore west of Oakwood. A well-developed, but local, ice rampart was noted near the end of the point.

To the north, wave activity seems to be greater and the exposed terrace has been completely removed, the cliffs rising directly from the beach. Also the submerged terrace widens gradually towards the outlet where it reaches a width of more than one hundred yards. The lowland through which the outlet flows was nearly closed by a bar which developed from the south and forced the stream to the slopes of the hills at the north end of the lake. This bar is obscured by the road but the smooth curvature, the tree growth rather than swamp vegetation, and the dry ground make its presence certain.

From the outlet to Bluff Beach continuous cliffs are evidence of strong wave activity. Between Bluff Beach and Sandy Beach a swamp borders the lake. This swamp was clearly a part of the lake during the former level, and from the elevations we may deduce that both Tamarack and Thompson lakes were also included. It was stated earlier that the form of the lake was conducive to strong activity at the northeastern end of the lake. The almost continuous cliffs and well-defined submerged terrace along the shore southwest of Sandy Beach are evidence of powerful wave action due to westerly winds, even though their reach is less than those from the southwest, and in this locality the shore adjustments are of the greatest magnitude on the lake. The most noteworthy change took place during the

former stage across the lowland between Sandy and Bluff beaches and was brought about by the development of a great bar of more than a half mile in length, which practically separated the northeastern portion of the lake (Thompson and Tamarack basins) from the present Klinger Lake basin. The position of the inlet from Tamarack Lake near Bluff Beach shows clearly that the bar developed from the cliffs near Sandy Beach towards the northwest and that the material must have been derived almost exclusively from the cliffs below Sandy Beach. Ice action exerts a strong push along this bar but the ramparts are of moderate strength on account of the sandy character of the material.

East of Oakwood the bluffs drop to a low marsh above winch rises a small hill near the present shore. A bar at the level of the former stage extends from this hill to the bluffs to the west but no such form was noted on the east side. From this it is clear that the marsh was formerly an arm of the lake and that the hill was a land-tied island. Also westerly winds were the more effective in this locality since the material for the bar must have been derived from the bluffs at Oakwood.

From the physiographic viewpoint Klinger Lake is most interesting in its past. Clearly it has stood at a level approximately three feet above the present and at that time was part of a lake of much greater area, although shallow for much of its extent. No attempt was made to trace the old shore lines where they deviate greatly from the shore of Klinger Lake, but from the topographic map some conception of the former extent of the lake may be deduced. The elevation of Klinger Lake is given as 807 feet above sea level. At the former level, then, it must have stood at about 810 feet. At this level, marked extensions of the basin existed at the southwestern end, at the northeastern end, including Tamarack (808 elevation) and Thompson (809 elevation) lakes, and possibly at the outlet. The latter is moist interesting, since there is a possibility that the lake spread over an area of more than five square miles to the north, and is well worth the effort necessary to trace this out.

The adjustments of the Klinger Lake basin were accomplished largely during the former stage and, although not completed in many cases, they determined to a large extent the present outline of the lake. The activity of all the forces acting on shores excepting that of ice, is excellently shown. Ramparts are present but are not exceptional in development. This is due to the prevalence of sandy material which is unfavorable to the development of strong ramparts. This lake is within the limits necessary for ice expansion but the testimony of observers is that the push is exerted by ice jams. They are especially effective on the east and northeast sides, because of the presence of an open zone of water which is maintained throughout the winter by the many springs near the shore.

As regards extinction, the greatest effect has been produced by the lowering of the water level. Little has been accomplished within the present lake basin either by vegetation or sedimentation.

At the present time the adjustment of the shores of the lake is not marked. There is little work for currents except the distribution of material derived in small amount from the cliffs which show fresh cutting in a few localities only. Probably the principal adjustment taking place is the remodeling of the submerged terrace to conform to present conditions.

COREY LAKE. Within the morainic tract in the southwestern part of St. Joseph County are a number of lakes occupying morainic basins of which Corey, Clear, Long, Kaiser, and Mud Lakes were examined. The latter two were dry at the time of the writer's visit and are too small to show decided shore features.

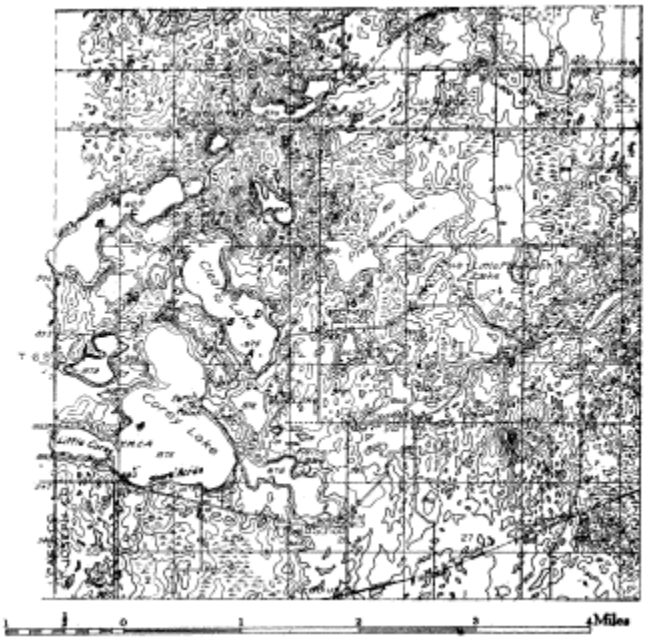

Figure 64. Topographic map of Corey, Clear and Long Lakes and surroundings. (From proofsheet of Three Rivers quadrangle U. S. G. S.)

Corey Lake, Fig. 64, is the largest of those examined and lies at the edge of the moraine. Its shores are bounded by morainic material with the exception of about one-half mile on the south side. It is the only one of those mentioned which is at all popular as a summer resort and may be reached by a short drive from Three Rivers. On first impression one might expect insignificant shore adjustments on this small lake of hardly more than one square mile in area, but a study of its shores quickly dispels the notion. The lake lies in several connected basins and the shores are not only irregular in contour but varied in relief as well. Furthermore, the material is sandy and easily worked, so that the shore features are exceptional for a lake of this size.

At present, the lake flows into Kaiser Lake which has no outlet. Formerly when the lake stood at a higher level the water escaped southward through an extended swamp, eventually reaching Mill Creek. An exposed terrace of the higher level stands below the cliffs at the southeastern shore of the lake but is somewhat

obscured by the numerous cottages. Further west, a flat caused by the recession of the high ground furnishes the key to the former condition of the lake. The most noticeable feature is a sand bar of smooth curvature, which stands nearly four feet above and about thirty feet back of the present shore. This bar at present incloses a lagoon of approximately three hundred feet in greatest width. Closer examination reveals the presence of a spit attached to the east side of this indentation farther inland and at a level still higher than that of the bar. From evidence found on other parts of the shore the highest level stood seven feet above the present and the spit just mentioned was in an early stage of development.

West of the lagoon cliffs again line the shore and the terraces of both of the former levels are readily distinguished. The terrace of the four foot level reaches a width of twenty feet and supports ice ramparts locally. An especially well-developed rampart has been formed under present conditions on this terrace just west of the lagoon. Similar conditions persist to the entrance of Little Corey with the exception of a sag at Shore Acres. This sag dropped nearly to the level of the four foot stage and was artificially deepened some sixty or seventy years ago to allow the water to flow southward. The writer's information concerning this channel is none too reliable but it seems certain that the lake stood at the four foot level at that time, and it is presumed that the channel was dug to accommodate the water under flood conditions. Since that time the ground water table has sunk; Corey Lake has dropped to its present level; and Kaiser and Mud lakes have dried up.

The point on the south side of the entrance to Little Corey is composed of sand and swings northward from the cliffs in an even curve. It is clearly a current deposit which developed largely during the highest level, and the lagoon on the west side is therefore dry at present. Indications point towards a continuation of its growth but at a very slow rate.

In addition to the forms described, a well-defined submerged terrace follows the south shore. As a rule it drops into deep water within one hundred and fifty feet of the shore but swings outward to double this width in front of the lagoon. The change in color at the "drop off" was very marked near the entrance to Little Corey and the writer had the good fortune to succeed in registering this on a photographic plate, a reproduction of which is shown in Plate X, B.

A narrow morainic depression extends westward from the south: western part of the main lake and is composed of two basins, both of which are filled with water. The more westerly, not shown on the map, forms a small pond which drains into Little Corey, situated in the easterly basin. The two basins are separated by a swamp which rises scarcely above the present lake level. Both exposed terraces are continuous below the cliffs around the depression, showing that the entire depression was connected with Corey Lake, as represented on the earlier maps. A sharply defined submerged terrace follows the present shore of Little Corey and supports a heavy growth of vegetation and a deposit of marl as well. Within the depression the waves have been the most active agent and have accomplished the most work on the south side, due to the greater .strength of winds having a northerly component. Some deposition by currents may have taken place at the west end of Little Corey but the presence of a road across the flat makes this uncertain.

However, an easterly drift along the north shore of Little Corey cooperated with a southerly drift along the west shore of the main lake to form a V-bar with characteristic central depression at the north side of the entrance to Little Corey, the point occupied by the Y. M. C. A. camp. This V-bar stands fully eight feet above the present level and is considered to have been a fully developed form during the highest stage of the lake, that is, stood slightly above the water level. At present, the currents on the main lake predominate and the V-bar is extending southeastward as a spit. This extension is not in line with the spit on the south side of the entrance but there is, nevertheless, a likelihood that the channel will be closed, as indicated by the very shallow water between the two spits, which, in addition, receives each year the deposits from a heavy growth of rushes.

North, of the Y. M. C. A. camp the terraces of both of the former levels are present on the cliff-lined shore either side of the point opposite the island. This was the scene of strong wave action which accomplished most during the highest stage, since that terrace is the better developed. Part of the material derived from the cliffs was distributed on the terrace but a considerable portion was carried along the shore in both directions. Thus, at the point opposite the island, currents from both the north and the south left the shore but, instead of forming a simple spit or V-bar, tied a small island to the mainland by spits which developed in accordance with the shores on both sides. See Fig. 65. The currents were unable to continue to the island or else were entirely depleted of their load, for the shallow water between the island and the mainland is due to the natural configuration of the bottom, as shown by the clay bottom upon which rest many large boulders.

Figure 65. Sketch of small island tied to the mainland by two bars or tombolos.

The island is an oblong "sugar loaf" with steep cliffs on all sides but the north. The shores show the effects of the activity of waves rather than currents, and the exposed terraces of the former level are the predominant features. Slight activity is manifested on the north side but the well-developed terrace, formed at the highest level on the remainder of the shore, has been largely cut away on the exposed south and east sides.

Cliffs line the greater part of the shores of the bay north of the island and usually are notched by the terraces of the higher levels. Near the head of the bay and on the north shore are indentations which were completely cut off by bars at the highest level. At the sharp headland on the west .side of the entrance to the north arm of the lake, the effects of strong current action are again evident. This headland is caused by the projection of the hills into the lake but is so sharp that the currents were unable to follow the shore. The current-borne material was deposited in the form of a spit which runs to the northeast and has a length in excess of three hundred feet. The spit began its growth during the highest level and has continued to develop during the succeeding stages, including the present, but at less rapid rate. Clearly the southerly winds are the most effective here on account of their long reach and the deep water over which they pass.

The west shore of the north arm is lined by a continuous low cliff below which stands the four foot terrace. The bay is shallow and vegetation is encroaching along the shore. This is especially noticeable at the north end where rushes extend from two hundred to three hundred yards off shore. On the east shore wave action proceeded to an advanced stage of adjustment, as shown by the current deposits about midway between the head of the bay and Perch Point. In this locality a slight bend in the shore line of the highest level was sufficient to throw the currents off shore, forming a complete bar across a narrow lagoon. Likewise at the four foot level the currents swung away from the shore and built a hook from the east in front of the bar of the highest level. The lagoon in the latter case does not exceed two hundred feet in width. The lower bar shows clearly that the effective currents drift northward along this shore and that reach of the wind is again the determining factor.

Between the bars just described and Perch Point the cliffs are less prominent and the exposed terraces are better developed. Perch Point is almost a duplicate on a larger scale of the point opposite the island. The bars which connect the low island to the mainland were built at the highest level. The bar on the south side connects with a well-defined terrace at the seven foot level, which soon merges into high cliffs. The absence of the highest terrace along these cliffs, which are continuous to the outlet, is due to its removal during the four foot stage. This shore is exposed to the strongest winds of maximum reach, and the obliteration of the shore features of former levels is to be expected here if anywhere on the lake. The material quarried from these cliffs has drifted in large part towards the south and was deposited across the low ground at the outlet which was formerly flooded. The bar developed during the highest stage and nearly separated Corey Lake from Kaiser.

It remains to point out briefly some of the more important episodes in the history of this lake. At its inception the lake stood at a level approximately seven feet above the present. At this time it flooded all of the depression at the southwestern end of the lake and connected with Kaiser, Mud, and possibly Clear Lake. The adjustments of the shores during this level were carried to an advanced stage and in some cases the currents completed their work before the level dropped. The four foot level was in existence a relatively short time ago and the adjustments followed along lines determined during the previous stage. In general, however, they were less extensive. Within recent years the levels of all the lakes mentioned have dropped several feet, which has caused the extinction of Mud and Kaiser Lakes. The adjustments at present are slight, the one of greatest consequence being at the entrance to Little Corey which may become closed.

CLEAR LAKE. Clear Lake lies within a half mile of the north end of Corey Lake, see Fig. 64, and runs parallel to the northeastern shore. As in the case of Corey Lake, this small body of water, which has a length of somewhat more than a mile and a width of less than one-third of its length, is surprising in the number and extent of the adjustments of its shores. The surrounding land rises well above the level of the lake except at the south end. Inasmuch as the Mud Lake basin, now dry, lies but a few hundred feet to the south, this low divide is a favorable locality for beginning our study. At this locality it is evident that Clear Lake has stood at a higher level than the present, and from the elevation of the divide it seems probable that the two lakes were connected with each other and with Corey Lake through Kaiser Lake. Conditions are favorable here for the formation of a bar along the south shore of Clear Lake but the presence of a road along the logical position of such a bar makes its identity uncertain. Very often, however, advantage has been taken of the higher ground along the course of a bar in the building of roads and such an occurrence may serve as indirect evidence of the existence of the bar.

Northward along the west side of the lake, the slopes are gentle and little adjustment of the shore has taken place. Proceeding along the shore one notices evidence of an increase in the activity of the shore forces. The first definite feature to be found is a small spit which stands three feet above the present level and points southward from the point designated A on the map, Fig. 64. This spit protects a narrow lagoon which is merely a continuation of the shallow, mud-covered lake bed adjacent to this shore. Vegetation has established itself off shore but is especially abundant in the lagoon which is rapidly being filled. North of the spit the slopes increase in steepness and the activity of the waves becomes evident. The wave cut cliffs increase in height

to a maximum just south of point B and, where well developed, rise from an exposed terrace rather than from the present beach. This terrace corresponds in elevation with the spit at A and is further evidence of a former level of the lake. The cliffs and hills are wooded but the terrace supports only a limited growth of bushes and young trees; consequently one may conclude that the drop in the water level has been of recent occurrence. The material derived from the cliffs between points A and B drifted in both directions, inasmuch as a current deposit was formed at B as well as at A.

The deposit at B is a typical V-bar with characteristic central depression. Its greatest development was from the north west, due to the greater power and reach of the winds from that direction and to the abundant material quarried from the cliffs which are more prominent on this side of the point. During the former stage of the lake, the north side of the V-bar attained the greater development, and, in addition, a considerable part of the current-borne material was distributed off shore, forming a submerged terrace of greater width and gentler slope than on the south side. At the present time, a small hook pointing northward indicates that conditions are reversed and that the greater growth is from the south side. This reversal was brought about by the general reduction of the activity of waves and currents, caused by the lowering of the water level. Under the present condition of reduced activity, the submerged terraces are more effective than formerly in reducing the size, and therefore the power of the waves passing over them, and the wider the terrace the greater its effect. In this case the broader terrace on the north side so reduces the power of the incoming waves, and therefore the currents, as to render them less effective than those passing over its narrower counterpart on the south side.

North of point B the cliffs which face the shore indicate the source of material forming the north side of the V-bar just described. The presence of an alluvial fan and a fossil delta along this shore are of interest although not formed by the agents active on the lake shores. The delta was built by a small stream which entered the lake at the time of the higher level, but the waves and currents were able to distribute the material as fast as supplied, so that the shore line was not affected. The exposed terrace of the former level is a consistent shore feature as far as the north end of the lake. Its elevation with reference to the present level was measured in several places and found to be within a few inches of four feet. This means that many of the deposits formed during this stage did not extend above the water level. Near the north end of the lake the side slopes are gentle and the exposed terrace is wide. An interesting change has been produced at this end of the lake by the lowering of the water level. Areas formerly covered by open water are now swamps filled with rank growth of vegetation. One such was a bay just south of the end of the lake. Currents from the south made some headway in cutting off this indentation but succeeded in building only a submerged bar, now clearly outlined by a row of willows.

The muddy-north shores of the lake show little adjustment aside from the exposed terrace. The absence of any indication of a bar between the small island, not shown on the map, and the mainland is evidence of the feebleness of the currents.

The east shore is lined with cliffs which are continuous along the northern half of the lake. Below the cliffs stands the exposed terrace of the higher level, and so uniform are the shore features that any deviation is very noticeable. Thus, the current deposits at either end of the cliffs are readily detected. At the sharp bend near the north end of the lake a small hook is indicative of currents driven by southwesterly winds, and at C a spit shows the effectiveness of the winds from the northwesterly quarter. The reach from both quarters is approximately the same, so that the size of the deposit is an index of the strength and frequency of the winds. The greater development of the spit at C shows conclusively that the northwesterly winds are the more effective. In each case the deposits were built during the former level and are not growing at present.

The turning of the currents from the shore at C has prevented the formation of a spit on the west side of the nearby point to the southeast but some such activity might be expected on the east side. This, however, is not the case and it is due to the topographic features of the southern half of the east shore of the lake. Instead of the continuous cliffs of the shore north of C, which furnished a maximum of material, there is an alternation of cliffs and lowlands. In addition to the smaller amount of material furnished by the cliffs, many of the lowlands extended below the water level during the former stage of the lake and were areas of deposition. Thus, the material, relatively small in amount to start with, was further depleted by deposition at the mouths of indentations. The absence of any deposit at the end of the point indicates that the currents not only were weak but practically without load by the time they reached this locality.

The first indication of the work of currents along the southeastern shore was found in the bay east of the point just discussed. The head of this bay consists of a hooked spit which came within thirty feet of completely cutting off a narrow lagoon. This spit developed from the south and at the former level of the lake. A hundred yards or more to the southwest the cliffs are again interrupted by a small triangular indentation which was completely isolated by a bar. Beyond this bar cliffs again line the shore as far as the depression at D. The mouth of this indentation was broad but, nevertheless, was completely bridged by a bar, forming a lagoon of several acres in extent, which is still wet. To the south, the cliffs are less prominent and gradually give way to gentle slopes. Yet currents, probably from the north, were active and succeeded in cutting off two small indentations between D and the south end of the lake.

From the discussion above it should be evident that Clear Lake has stood at a level some four feet higher than that found by the writer in the summer of 1914. The presence of only very young vegetation on the exposed terrace is evidence that the lowering of the level was of recent occurrence. This was fully corroborated by information obtained from residents of the locality. Practically all of the adjustments of the shore have taken place at the higher level and the indications are few indeed that they are continuing at the present time.

The adjustments are very pronounced for a lake of this size and include those due both to wave and to current action. In general, the eastern shore was most affected, and this is shown by a less abundant growth of vegetation along the shores as well as by more prominent shore features than on the opposite side of the lake.

At present the lake has no surface outlet and no inlets of importance. Since there is little adjustment of the shores, extinction is the active physiographic process and this is being accomplished by vegetal accumulation. Little has been said of the submerged terrace in the description above. The reason for this is that it is impossible to determine its limits on account of the heavy growth of vegetation, not only on the surface of the terrace but on the lake bottom as well. Over much of the bottom a complete carpet of vegetation may be seen through the transparent water which gives the lake its name.

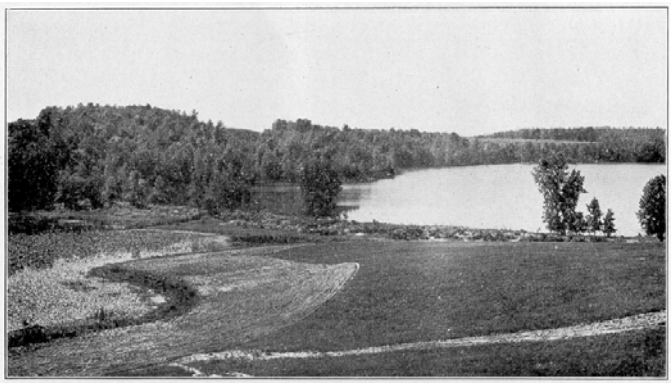

Plate XI. Bar, Long Lake, St. Joseph County.

LONG LAKE. Long Lake lies less than a half mile northwest of the north end of Clear Lake and resembles the latter closely in size and form. This lake is also surrounded by moraine and is without outlet or inlets of consequence. The greatest difference is in the direction of the longer axis which runs at right angles to that of Clear Lake. Inasmuch as the contour of the bottom is not known, it is not possible to determine whether this basin is a simple elongated depression or a series of connected morainic basins. The morainic material in this locality contains a large percentage of sand and the shore adjustments are of the same order as those found on the other lakes of the group.

In Plate XI is shown the adjustment of the northeastern end of the lake, which is not only the most pronounced on this lake but is one of the most perfect of its kind found on the inland lakes of the State. As may be seen from the plate, the north end of the lake has been cut off by a complete sand bar, perfect in development and preservation. This bar stretches from the cliffs on either side of the lake in a beautiful curve and stands slightly more than five feet above the present level. Inasmuch as there is no sag in its crest, this bar was fully developed and extended above the water level which prevailed at the time of its formation. This bar, then, establishes a former level of the lake which probably stood somewhat less than five feet above the present stage. The lagoon of about ten acres in extent is still wet and in late summer is literally crowded with lily pads which are rapidly converting it into a peat bog.

The continuous cliffs which face the shores of the southeastern side of the lake rise from a well-defined exposed terrace which varies in width from forty to sixty feet. The lake level indicated by this terrace stood more than four feet above the present level and, thus, is in agreement with the level deduced from the bar at the end of the lake. The presence of coarse material on the terrace is an indication that it was formed largely by wave cutting, furnishing the material for the bar above. Along the northwest shore the cliffs are less prominent west of the blunt projection and become insignificant to the south, where the slopes are gentle. A wide exposed terrace is the predominant shore feature, although currents were effective in closing two small indentations in the vicinity of A, see map, Fig. 64, and another near the southwestern end of the lake.

West of the broad point on the south, shore, the side slopes are gentle and the effects of wave action are not prominent. However, currents from the north were effective and built bars across the mouths of two small indentations which existed during the higher level. The more westerly embayment was cut off by as perfect a bar as that described at the northeastern end of the lake but is less prominent on account of its smaller dimensions. Apparently the current-borne material was limited in amount and the greater part was deposited on this bar, since the deposit at the mouth of the embayment nearer the point is a spit attached to the west side. The broad projection on the south shore is caused by a low morainic knoll whose lakeward slopes were carved into the characteristic cliff and terrace profile during the former stage of the lake. The material from the cliffs drifted westward and was deposited on the east side of the knoll, forming a small spit. This spit would have cut off a large part of the swamp which borders the shore to the east had its growth not been interrupted by the sinking of the water level.

The west side of the prominent projection on the southeastern shore of the lake is exposed to the action of strong waves due to westerly winds, and the cliff and terrace of the higher level are continuous to the vicinity of point B. Here the velocity of the alongshore currents was reduced at a small indentation south of B, which was completely cut off. At B an unsymmetrical V-bar,

elongated on the south side, indicates that the currents from both directions left the shore but the more effective currents were from the south. This bar whose longer side has a length of nearly one hundred yards is an exceptionally strong shore feature for a lake of this size.

Between B and C cliffs are again prominent but at C another V-bar, which is a duplicate of that at B on a smaller scale, indicates similar conditions. Wave action. predominated along the shore from C to the northeastern end of the lake as shown by the well-developed cliff and terrace. An interesting break in the cliffs was found in the bay east of C in the form of a dry gully, at the foot of which stands an excellent example of an alluvial fan.

Long Lake also is interesting chiefly on account of its past. The water level formerly stood between four and five feet above the present and at this time prominent adjustments of the shore took place. Strong wave activity carved steep cliffs where conditions were favorable. Currents were also active in like degree, so that there are few localities where adjustments are not readily detected. Not only did the currents cut off indentations but also swung away from the lake shores, forming the interesting V-bars commonly found on the long and narrow lakes. Little activity is manifested at the present level and the important physiographic process of the future is that of extinction. Vegetation has become firmly established in the lagoons but the process is not so active on the main lake as was found to be the case on Clear Lake. Since there is no outlet the lake could not have been lowered by downcutting and the drop in level, therefore, must be referred to some other cause.

The lowering in level is shared by all of the lakes in this group, and the idea that it is connected with the pumping of water for the city of Three Rivers from the outwash plain six miles east of the lakes seems to exist. Therefore some pains have been taken to obtain information concerning the lake levels and the pumping operations since the installation of the plant. In particular the writer is indebted to Mr. Eugene A. Schall, City Clerk of Three Rivers, Mich., for collecting this information.

The levels of these lakes and also all other water-ways in the vicinity have fluctuated somewhat periodically during the last forty years at least, conditions previous to that time being unknown to the writer. Previous low water periods occurred in 1882-83 and 1895-96, and during intervening years the water came back to normal. The levels of the lakes during the low periods are not known to the writer and, therefore, cannot be compared with the present low stage.

The city of Three Rivers has been obtaining its water supply from nearby wells since 1876, the amount used increasing to 70,000 cubic feet (approximately 500,000 gallons) daily at the present time. Previous to 1896 a few small, flowing wells were utilized but since that time twelve six-inch wells have been installed, five in 1896 and seven in 1910. In 1915 six of these wells were reset about one hundred yards away and, although drilled to the same depth, tapped an entirely different source of supply. In some respects the lowering of the lake levels and the pumping operations are related, but it must be kept in mind that our record of lake levels does not antedate the installation of the water system. Also during the first known period of low water, which occurred soon after the installation of the water works, the wells were not pumped and the amount of water used was insignificant. The low period of 1895-96 occurred slightly previous to the driving of additional wells and could not have been caused thereby. The present low water stage follows the change in position of some of the wells, which tapped a new water-bearing layer, and shows a closer relationship than the previous stages. In addition to the discrepancies which appear in the statements above, the pumping operations have steadily increased and there should have been a gradual lowering of the levels rather than a periodic fluctuation. Also it is probable that the water pumped from the wells comes from a large surrounding catchment area rather than the local area occupied by the lakes, since all other water ways in the vicinity have been similarly affected. Thus, it appears from the data at hand that the wells have had little or no effect on the fluctuation of the levels of the lakes.

The cause is probably a natural one and may be related to periodic changes in climate which are none too well established as yet. Whatever may be the cause, the effects are very pronounced and a careful study of the problem promises interesting results.

GUN LAKE. Of the lakes included in this group Gun was the next uncovered by the retreating glacier. This lake is one of the largest of the numerous small, interior lakes which lie in the southwestern part of the State. It lies directly in the center of the western border of Barry County and crosses into Allegan County at the extreme western end of the lake. The lake is not readily accessible but may be reached either from Middleville or Hastings, both of which are on the Grand Rapids branch of the Michigan Central R. R. Nevertheless, the lake is a popular resort and draws a large number of summer visitors from both nearby and distant points.

This lake is almost rectangular in shape, see Fig. 66, but is nearly cut into two basins by Englands and Murphy points, which are attached to the south and north shores respectively. Numerous other points and bays make the lake most irregular in outline. This is better appreciated when it is known that, although the area is but slightly over four square miles, the shoreline measures more than seventeen miles. If Mud Lake is included, the area is 4.4 square miles and the shoreline nineteen miles (a perfectly rectangular lake of the same area would have a shoreline of eight miles in length). The reason for the complicated shoreline is apparent when the origin of the basin is understood. This basin lies on the western border of a strong morainic ridge, trending north-south. To the west is a triangular outwash plain which developed from the north and west and is very thin and

incomplete near the border of the moraine. In the vicinity of the lake fragments only of the surface of the outwash are present due to the fact that large ice blocks of irregular shape were present at the time of its formation and prevented deposition of the outwash material. It is doubtful if these blocks were entirely covered by the outwash material since till plain borders parts of the shore of the lake, even though its surface stands below the general level of the fragments of the outwash plain (see Chapter II on the formation of pit lakes). Thus, the lake may be classified as a pit of shallow depth but very complicated in outline. The basins represent the locations of the ice blocks and the points are spurs of the moraine, fragments of the outwash plain, or swells of the undulating surface of the till plain not covered by outwash. The varied conditions along the shore, both as to contour and material, are favorable to adjustments but, on the other hand, the shallowness of the lake and its partition into partially enclosed basins greatly interfere with normal wave development.

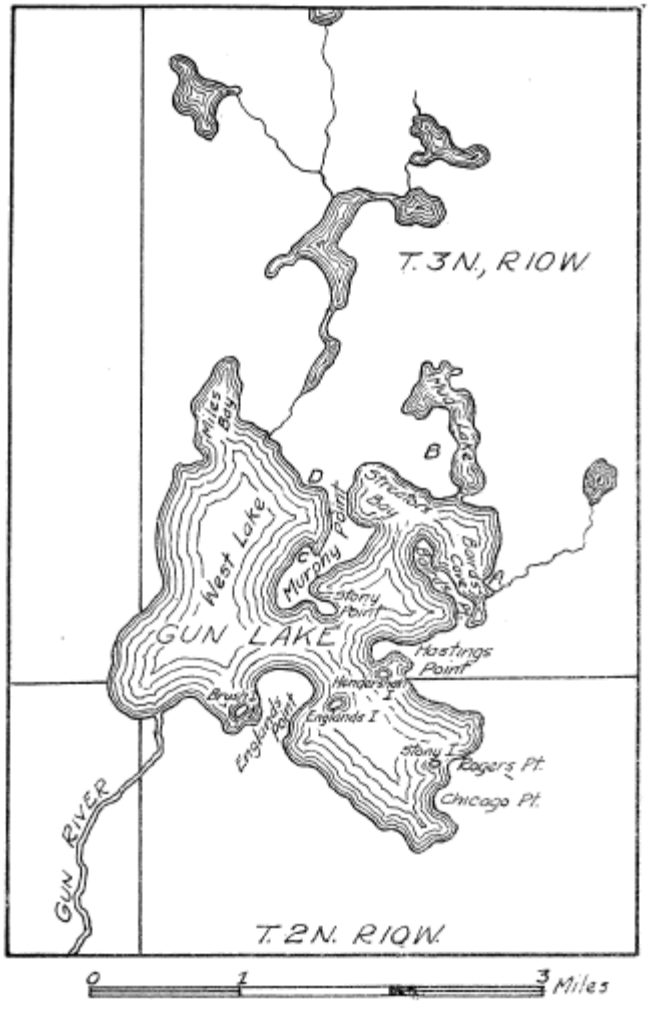

Figure 66. Outline map of Gun Lake, Barry County.

The outlet of this lake, the Gun River, flows from the southwestern end and takes a southwesterly course to the Kalamazoo. The gradient of Gun River is very flat, and the stream has cut a very shallow trench in the sand flat. Shore features are now exposed along certain parts of the lake which indicate a former level in accordance with the down-cutting of the outlet. There also exists a probability that at the higher level Gun Lake formed a part of a glacial lake known as Lake Dowagiac, a matter readily determined when the exact level of Gun Lake is known. Furthermore, the outlet gives us a clew to the small amount of variation in the level of this lake during the year. The writer was surprised to see the outlet almost filled with a heavy growth of lilies and rushes and realized at once that they must offer considerable resistance to the flow of water which might hold the lake at a higher level. An obstruction, natural or otherwise, in the course of the stream would cause a ponding of the water and the encroachment of vegetation in its channel would follow as a result, but the writer knows of no obstruction in Gun River, although a positive statement to this effect cannot be made. Assuming the absence of an obstruction, one might well conceive the encroachment of vegetation in a stream channel such as Gun River which has a very flat gradient and carries little sediment as it leaves the lake. In addition, it flows in an old river channel which is merely a veneer of alluvium over till and, after cutting through the sand, would pick up very little solid material from its bed. Thus, with few tools to work with, the abrasive power would be reduced and vegetation could take hold. It is also interesting to note that such interference with the outflow would take place mainly during the growing season and would tend to hold the lake level higher during the summer months, normally a time of low water. At other times, the dead parts of the plants would offer much less resistance and might be removed during the spring floods. Another possibility is that the dead parts may accumulate in the channel and gradually raise the lake level until a new outlet is found or the old one cut off during exceptional floods. The latter is known to have happened on at least one lake in our State.

Near the outlet the shores are bordered by a low, grass-covered swamp and have no definite beaches. This condition persists eastward until the low swells of the ground moraine which causes Englands Point are encountered. One of the smaller swells forms Brush Island, which rises barely above the surface of Pickerel Cove, and possibly is the cause of the blunt projection of the main shore at the head of the cove. The absence of wave action along this shore is probably due to the shallowness of West Lake which, although the reach is large, prevents the formation of large waves and also reduces materially the power of those formed as they approach the shore. Englands Point, however, runs out into the deeper water and has been carved into low cliffs on the north and northwest sides. Elsewhere the shores are low and the slopes are in places carved into a low terrace hardly two feet above the present level. Locally the shores have been pushed into low ice ramparts by the expansion of the ice during the winter. East of Englands Point another low swell projects above the surface of the lake and is known as Englands Island. Some planation of its surface by waves may have taken

place in the past, but at present it is covered with a black muck, an indication of vegetal accumulation.

The south shore of the large embayment, formed by Englands and Hastings points, is lined by a definite sand beach, and the shore features consist of alternating low cliffs and swales. The cliffs increase in height as the moraine is approached at the extreme southern end of the bay. At the swales a narrow but definite terrace of the upper level is present, fronted very commonly by low ice ramparts. Considerable adjustment of this shore has taken place, but the low areas were not cut off by definite bars. A single exception to the last statement was found in the embayment below Chicago Point where a sand bar developed across a triangular depression. The lagoon has been filled by vegetation so that the features are none too evident.

The broad projection which includes Chicago and Rogers points is due to morainic hills, and the shore features are those due to cutting. The boulder-lined strand is an indication of strong shove by the ice. Off Rogers Point another small island is appropriately named Stony, inasmuch as the finer material of the till has been removed by waves, leaving a mass of rocks standing slightly above the water level. It will be noted that this island is exposed to much stronger winds from the west and northwest than is Englands Island on the opposite side of the bay, therefore the greater amount of wave action.

At the head of the embayment north of Rogers Point, a sand beach of even curvature lines the shore and has been pushed up into a low rampart. The terrace of the upper level is distinct on this lowland but no evidence of a lagoon was found. Deposition has taken place, however, but has succeeded in building out a terrace rather than forming a definite bar. On the north shore of this bay wave action is slight, and the swamp vegetation of the swale grows to the water's edge. Northward, the shores are high but drop to a low swamp just south of Hastings Point. The swamp runs across the neck of this peninsula and may have been open water during the higher stage, thus making Hastings Point an island at that time. The point is a swell of the ground moraine rising ten to fifteen feet above the lake level. It is exposed to wave action from the west especially and considerable cutting has been accomplished. Thus the shores are faced by cliffs, and a rocky cut-terrace runs off the end of the point. The rocks on the terrace are an accumulation resulting from the removal of the finer material and many have been transported to the beach by ice action. The ice shove is strong on this point, for boulders up to five feet in diameter are now lined along the shore.

The division of the lake into east and west arms by Englands and Murphy points has already been mentioned. The east arm is similarly divided by Stony and Hastings points and the northern basin of this arm is likewise constricted by Bairds Point and a projection on the east side of Murphy Point. The bays on either side of Bairds Point are both shallow and the point itself is low with the exception of two knolls, one forming the end of the point and the other the expansion near the middle. The terrace of the higher level is distinct on all but the west side and, inasmuch as it extends between the two knolls and between the central knoll and the main shore, it is evident that Bairds Point was originally two distinct islands. Considerable adjustment took place along the island shores and also on the north shore of Hastings Point. Not only was the terrace well developed on the low slopes but, in addition, a bar developed across the head of the bay between Hastings and Bairds Points which connected the more southerly of the islands with the mainland. The material of this bar was derived mainly from the north side of Hastings Point, although some may have been added from the Bairds Point islands which are bounded by cliffs on the west side. The higher level terrace is well exposed on the east side of the point and in places reaches a width of one hundred feet. The development of the terrace on this side was due to favorable conditions of shore topography and material rather than to excessive wave action. The latter is much more effective on the west side because the winds from this direction have the advantage of greater velocity and reach and blow across deeper water. When the water level dropped wave activity was decreased in greater proportion on the east side, and sufficiently so that the terrace was preserved on this side but was cut away on the west. In fact, the south end of Bairds Cove is effectively protected from wave action and is being rapidly filled with vegetation. It is an excellent example of the encroachment of vegetation from the shore in the form of a floating bog, and the present area of open water is but a small remnant of its former extent.

The slight projection, A, on the east side of Bairds Cove is a small spit pointing southwestward and is the southerly limit of sand beach which lines the shore to the entrance into Mud Lake. At the northern end of this beach there is also a spit which is responsible for the isolation of Mud Lake. It is probable that the spit was complete, but conditions are somewhat obscured by the roadway built upon it. The entire east shore, including Mud Lake, is lined by moraine whose slopes were washed by the waves at the former level. Considerable adjustment took place at this time and, in addition to the spits mentioned, a terrace was formed which varied in width according to the slopes encountered. In general, the terrace was wider in the embayments and has effected a straightening of the shore line with the subsidence of the lake to its present level. At present, the morainic slopes come to the shore in one locality only, the attachment of the Mud Lake spit, and little material is being quarried from the cliffs at this point. It seems reasonable, then, that the active period of adjustment of this shore was limited, to a large extent, to the former level.

Mud Lake is well named and is a most uninviting place. Shore adjustments on this small lake were much less extensive than on the main lake, and the exposed terrace is not clearly defined. In its place are found bogs

and muck shores, in fact, there is scarcely a foot of firm beach on the lake. The lake is not over five feet in depth and the bottom is composed of soft muck. As may have been already inferred, the lake is in an advanced stage of filling by vegetation and this is being accomplished both by plants encroaching from the shores and by floating forms. On the west side the peculiarly shaped cove is caused by a narrow strip of boggy lowland which continues southwestward to the north shore of the east arm of Gun Lake. In the early stages of these lakes an open but shallow connection existed at this lowland as well as at the present outlet, forming an island of the present large point designated B on the map. This connection was not cut off by current action but was filled with vegetation and abandoned when the water level sank to its present position.

The shores of Gun Lake west of the outlet of Mud Lake are lined with low sand cliffs, alternating with patches of the terrace of the higher level. The cliffs are being washed to some extent under the present conditions, but the more prominent shore features are the ice ramparts which form in front of the fragmentary terrace. This condition holds until the former connection with Mud Lake is reached. Across this lowland the shores are mucky and have no definite beach. Beyond the lowlands the shores lie on the slopes of ground moraine whose southward extension forms Murphy Point. The swells of this moraine rise barely above the surface of the water and have been carved into low cliffs by the waves, while the sags form swampy shores. On the low shores the terrace of the former level is generally present, and in such localities ice ramparts are usually found. One of the most conspicuous of the morainic sags extends across the neck of the point near its attachment to the mainland. It stands slightly below the level of the higher stage of the lake and, therefore, was an open water channel separating the main portion of Murphy Point from the mainland at that time. This island was later tied to the mainland by a bar which developed on the east side and may now be readily traced across the swampy lowland.

The adjustments of the east shore of Murphy Point are the result of wave activity and consist of alternating low cliffs and flats which are characteristic of the shores in morainic material. Stony Point is a swell of the ground moraine that juts out into the lake and in this exposed position has suffered considerable dissection by waves. On the north shore the terrace of the former level is well developed but on the south this has been removed by the present activity of the waves. Also the waves have reduced the low neck which connected this point with Murphy Point, and it now stands as an island save for an ice rampart nearly three feet in height which was built during the former stage by material shoved up from both the north and south sides. The push from the south was the more powerful and the stronger rampart follows the south shore. Nearer the end of the point many of the boulders which line the shore have been forced into the base of the low cliffs by the expansion of the ice.

The south end and west side of Murphy Point are exposed teethe strongest winds, and the shore features are at first due to wave cutting. The material quarried from the low cliffs has been moved largely in a northerly direction along the west shore and deposited in a small spit at C, which has efficiently protected the partially enclosed lagoon to the rear so that it is now filled with vegetation. North of C the smooth shore is largely the result of adjustments at the former level, but no bar was noted crossing the swamp which forms the neck of the point. The absence of a bar in this locality is puzzling in view of the fact that a small indentation at D was completely cut off, evidently from the south.

The shores are low along the north side of West Lake, and the shore features are due to wave action of very moderate intensity on account of the shallowness of this arm of the lake. However, the sandy material was very easily worked, and a terrace was formed at the upper level which is distinct in places. It is best developed in Miles Bay which is a pit of considerably greater depth than West Lake. If currents were active we should expect results at the entrance to this bay, but there seems to be little or no indication of bars. The entrance is very shallow and is becoming more so, but this is due to filling by vegetation rather than by currents. This end of the lake supports a heavy growth of rushes and other water plants and much filling in the future may be expected in this way.

Farther south along the west shore the sand plain gives way to ground moraine and the land slopes gently to the shore. Where not removed the woods grow to the shore and have aided in the formation of the excellent ramparts which are the most conspicuous shore features in this locality.

From this description it should be clear that in the early stages of its existence Gun Lake stood at a higher level and covered a larger area than at present, including some of the nearby lakes. The shores of the upper level are well preserved and show adjustments which are less pronounced than might be expected from the size of the lake. This is due probably to the shallowness of a large part of the basin and to the irregular shoreline. Much of the work was accomplished by waves which succeeded in straightening some of the minor irregularities and forming a terrace of flat slope. Current activity played a subsidiary part but succeeded, nevertheless, in producing some important changes, such as the blocking of the channels to Mud Lake and the tying of some of the islands to the mainland. Ice was also very effective and the shove exerted produced many well-defined ramparts and boulder strands. The sinking of the level left some of these features within reach of the waves which have since removed them at exposed places. The activity at present, however, is very much less than at the higher level.

Vegetation has filled, or is in process of filling, the indentations and is now taking hold in the shallower parts of the lake. The outlet of the lake is especially interesting in this regard, since the growth of vegetation

appears to hold the level of the lake more nearly constant throughout the season. This, in itself, has to some extent the same effect as though the level were raised and may account for the slight recession of some of the shores. A continuation of this process will accentuate present conditions and may even raise the level of the lake.

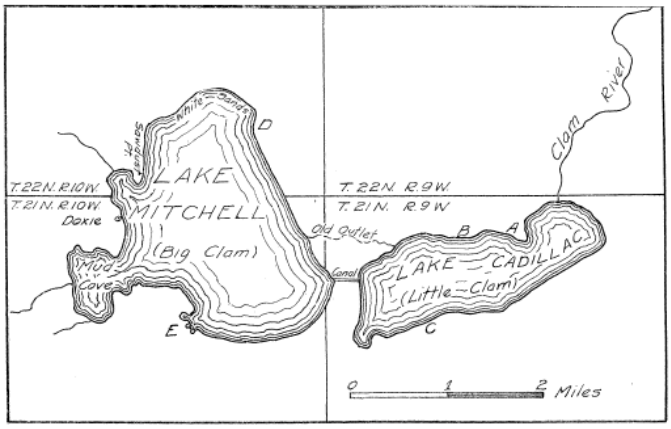

Figure 67. Outline map of Lakes Mitchell and Cadillac, Wexford County.

LAKES CADILLAC AND MITCHELL

Lakes Cadillac and Mitchell followed Gun in order of appearance and lie in a region which is most interesting from a physiographic viewpoint. The location of the city of Cadillac is especially fortunate. It is built at the junction of a large morainic tract on the east and an extended outwash plain on the west. The surface of the outwash plain is extensively pitted, but few of the pits hold water. However, two large ones are located just west of Cadillac and form the basins of Little and Big Clam lakes, or Cadillac and Mitchell lakes, as they are now called. These lakes, although not large, are well adapted to physiographic study on account of the adjustments in the easily worked material and, furthermore, are readily accessible, Cadillac being the junction of the Grand Rapids and Indiana, and Ann Arbor Rail roads. It is but a few steps from the railroad station to the shore of Cadillac Lake which extends for nearly three miles in a direction south of west. In width it is rather uniform and nowhere reaches one mile. Its area is 1.9 square miles, making the average width very close to three-fourths of a mile. Compared with its neighbor, Mitchell, it is very regular in outline, the main exceptions being the large projection on the north shore and a small bay at the southwestern end.

The outlet, Clam River, leaves the lake at the northeastern end and flows through a depression in the outwash in a broad curve convex northward to the Muskegon River in northwestern Clare County. It flows in a channel which has been cut a few feet below the level of the plain but has been obstructed by a dam of low head built by one of the numerous manufacturing plants in the city of Cadillac. The obstruction of the outlet leads at once to the expectation of flooded shores, which is fulfilled.

The shore facing the city is obscured by buildings and lumber docks and shore conditions are not well represented. Around the north shore, point A, see map, Fig. 67, projects into the lake and continues under water as a shoal of less than four feet in depth for a distance of three hundred yards or more. Little evidence of a distinct submerged terrace is present, and this point is considered as one of the less deep portions of the pit which has been exposed by a sinking of the water level. The swampy condition of the point furnishes early evidence of the flooded condition of the lake. The swamp continues along the shore westward to the vicinity of locality B on map, where the edge of the out wash comes to the lake and stands in a steep cliff. Between the foot of the cliff and the beach a narrow terrace stands about one foot above the present level. This terrace merges into the swamp just described and with its surmounting cliff may be traced to the northeast.

West of B the terrace widens and has been pushed into an ice rampart near the present shore, forming a foul lagoon which is rapidly being filled with vegetation. The rampart persists to the west end of the lake but the lagoon widens and extends through to Mitchell Lake along the course of the natural outlet of this lake. A canal, navigable for boats of light draught, was dug about 1870 through the narrow neck of land which separates the two lakes and has caused the abandonment of the outlet. This neck of land stands below the general level of the outwash plain with the exception of a small flat-topped mound, probably a remnant of the outwash, on the south side of the canal midway between the two lakes. On the Cadillac Lake side the neck has been carved into the persistent low terrace which widens south of the canal and runs to the embayment at the southwestern end of the lake. On this low flat the footpath follows a well-defined bar of the higher level from the low cliffs just south of the canal to the bridge which crosses the bay at the southwest end. Across the bridge the outwash and narrow terrace soon appear, and the latter is made use of for the roadway as far as locality C. East of this point the land is low and the terrace is not distinct for a short distance. East of the broad bend of the shore line the outwash again comes to the lake with the usual narrow terrace and continues thus until the shores are obscured by buildings or docks. Along this shore the effects of the artificial raising of the lake level are very evident. The terrace, which practically surrounds this lake, has been utilized for a boulevard but is quite generally being attacked by the waves, so that some protection is necessary. The pine stumps, so abundant in this region, have been used for a breakwater but have proved none too satisfactory, so that in addition to an unsightly shore, much repair work must be done.

From the above, it is evident that Cadillac Lake has stood at a somewhat higher level than at present and that the cause of the lowering of the former level was the

deepening of the outlet. During the higher level the main adjustment of the shores was the formation of a narrow terrace which is well preserved where natural conditions have not been disturbed. Current action accomplished little during this stage, the only characteristic form recognized being at the west end south of the canal. The condition of affairs previous to the artificial elevation of the water level has been obscured by the recent increased activity of the waves which are rapidly removing the former terrace, except where protected. During stages of high water this terrace is covered, and it may be considered that it merely represents the activity of the shore agents during such times. This argument would have more force were not the lake held abnormally high. Also the rounded, grass-covered slopes above the wide portions of the exposed bottom are an indication of a definite water level, long since abandoned.

Ice action is very effective wherever shore conditions permit and some well-defined ramparts are to be found. The process of extinction is making slow progress at present and little has been done in the past. At the abandoned outlet and in the bay at the southwest end, considerable filling has been accomplished by vegetation but the main body is still relatively clear. Filling by sedimentation is insignificant for the water comes either from seepage or flows from Lake Mitchell, which acts as a perfect settling basin. Undoubtedly an unobstructed outlet would continue to deepen but, since the depths of the lake were not taken, the final effect cannot be ventured.

LAKE MITCHELL

North of the canal on Lake Mitchell, the shore, as shown on the map, is particularly regular, but inferences as to the probable shore conditions based on this would be greatly misleading. As a matter of fact, the outwash plain is excessively pitted and the shore consists of a succession of flats interrupted by island-like mounds of outwash. Proceeding northward from the canal, evidence of a higher level for this lake is soon at hand. A low sand bar rises above the flat at a distance varying from twenty to fifty feet back from the shore and encloses a poorly drained lagoon behind it. On the gentle slope in front, faint beaches may be discerned which in places enclose small narrow depressions, now dry. These bars were probably formed as storm beaches during the gradual lowering of the level. Farther north, the waves at the higher level succeeded in cutting back the "islands" of outwash, while the currents distributed the material in a series of connecting bars which have been pushed up into ramparts in many places. These bars stand at a somewhat lower elevation than those found on other parts of the lake and it is probable that they did not extend above the water level. But, with the dropping of the water level, the bars were exposed and the shore line assumed its present regular contour.

Northward the lowland areas decrease in size and at the north end disappear, leaving a continuous cliff in the outwash. This, however, stands some distance back from the shore and the exposed flat below is a portion of the former shallow bottom. In order to get the full view of the flat it is necessary to stand on the embankment of the Ann Arbor Railroad which crosses in this locality. The beach of the present level, called the White Sands, swings around the north end in a perfect curve, see Plate XII, A, and is an exceptionally fine example of an adjusted sand beach. The flat adjacent to this shore swings far to the west and forms the so-called "Thousand Acre Swamp," above which rise outwash remnants similar to those on the opposite side of the lake. The perfection of the adjustments along this shore is again detected in the excellent bar which stands a short distance inland between the lake and the swamp. Ice has been particularly active along this shore and has piled up two distinct ramparts in front of the bar. At the present level a low rampart is in process of formation, making three in all, a rare occurrence. The continuation of the bar to the south forms Saw Dust Point which shows the direction of the prevailing currents at the time of formation. Thus, the material must have been derived from the cliffs at the north end of the lake.

Ice action on this lake is most interesting, not only on account of its effects but also because of the manner of its occurrence. Information from reliable sources makes it certain that both ice jams and expansion take place. At Doxsie's ice jams have shoved twenty feet on the shore and have piled up ten feet in height, a statement well within reason as may be seen from Plate XII, B, which is reproduced from a photograph of an ice jam on the north shore of this lake taken by Mr. W. E. Sours of Cadillac. Also at Doxsie's, the ice advances by expansion between four and five feet a season. The width of the lake at this locality is one and five-eighths miles and approaches the maximum limit for ice shove of this type.

Below the shallow bay back of Saw Dust Point the outwash, with cliff and terrace of the higher level, again appears and extends to the entrance of Mud Cove. From this shore the depths of the lake are readily distinguished when light conditions are favorable. The northern part is very shallow with the exception of a narrow channel in the middle running nearly north-south and appears as though it were almost possible to wade across. The southern lobe lies in a much deeper portion of the pit and is sharply contrasted in color with that on the north.

Mud Cove is a partially detached portion of the pit which continues to the west as an extended swamp. Currents have accomplished little or nothing at the entrance and there is little likelihood of its being isolated in this manner. Nevertheless, its existence as a body of open water is very limited on account of the rapid filling by vegetation. On the south side of the Cove, a case of complete extinction of a shallow part of this irregular pit is found. In this case the indentation was separated

from the lake by a narrow strip of outwash which, at first sight, appears to be a bar. The extinct part has an uninterrupted, flat surface composed of a black, peaty soil upon which a few shrubs are growing. An attempt was made to drain this for agricultural use but evidently was not an unqualified success.

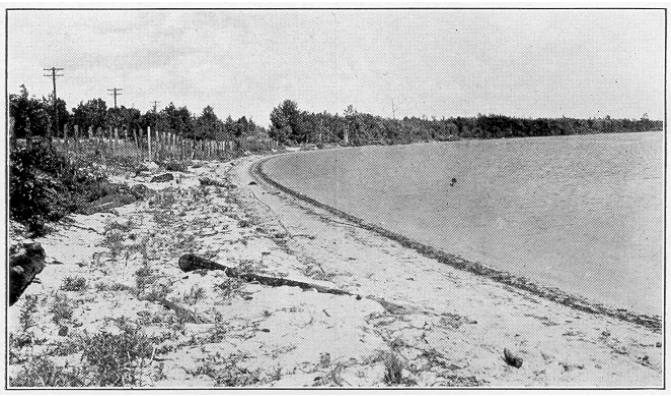

Plate XII, A. White sands, Lake Mitchell.

Plate XII, B. Ice-jam, Lake Mitchell. (Photography by W. H. Saurs.)

Plate XIII. Stream diverted by currents. Lake Mitchell.

East of Mud Cove the outwash, with cliff and terrace, lines the shore but soon drops to a small swamp which was cut off by an ice rampart about twenty feet inland from the present shore. The outwash again appears at the shore but finally gives way to a lowland which extends to the double bay at E. This bay is caused by two small pits which drop below the level of the swamp. It is set off from the main lake by very shallow water at the entrance. Currents undoubtedly flow across the entrance of the more southerly lobe but no bar is present, although the water is scarcely deep enough for rowboats to cross. This bay will eventually be isolated, however, by the deposits from the heavy growth of vegetation in the shallow water across the mouth.

From this locality eastward, the outwash cliffs face the shore but the terrace of the higher level is fragmentary. The northwest winds strike this shore with, full force, and the waves and currents have accomplished much in the adjustment of the shore. This is shown by the regularity of the beach, see Plate XIII, the well-defined submerged terrace, and the presence of cusps at low water. (See Douglas Lake on cusps.) Near the east side of the lake the outwash cliffs continue to the south shore of Cadillac Lake, and the shore of the higher level is well shown by a bar which follows the curvature of the southeastern shore towards the canal. The land separation between the two lakes stood somewhat above the water level of the higher stage and the connection was restricted to a narrow strait in the vicinity of the abandoned outlet.

Thus, in times past, a large lake of very irregular outline stood in this locality. The greatest variation from the present condition occurred in the Lake Mitchell basin which then included a great part of the swamp areas to the west. In the early stages, the shores were much more irregular than at present, due to the numerous shallow pits above which stood "islands" of the original outwash plain. At the higher level, important adjustments of the shores took place which resulted in the formation of a definite submerged terrace and the straightening of the shore line in many places, clue both to cliff recession and to the development of connecting bars. It is probable that many of the bars were not built to the water level but it seems clear that the "Thousand Acre Swamp" was partially cut off. The downcutting of the Clam River in the loose sands of the outwash lowered the level of this lake and formed two definite basins connected by an outlet, now abandoned. After the separation of the basins the further deepening of Clam River was felt directly by Cadillac Lake which stood at a lower level, while Mitchell was held up by its outlet. At this stage the adjustment of the shores of Lake Mitchell, accomplished during the upper level, became fully effective and are the cause of the long stretches of regular shore line.

Ice exerts a powerful shove on the shores of these lakes and is especially active on Lake Mitchell. Wherever vegetation served to bind the sand, ramparts have been formed and the multiple ramparts on the front slope of the bar at "Thousand Acre Swamp" are of exceptional development. The manner of the ice push may be studied to advantage on Lake Mitchell since both expansion and jams are active. We ore very fortunate in having a photograph of the latter in action.

The cutting of the canal between the two lakes has caused but little lowering of the level of Lake Mitchell, and its shores remain practically in their natural condition. However, on Cadillac Lake the interference of man has obscured a large part of the shore topography and initiated far reaching changes. Aside from the buildings and lumber docks along the east shore, the

raising of the level by a dam should be mentioned. The natural level of the lake has been covered and obliterated by subsequent wave action. Also a new cycle of shore activity has been brought about which is working havoc and has necessitated the novel but unsightly breakwaters.

The lakes are fed to a large extent by ground water and the few entering streams flow from swamps, so that filling by sediment is not of importance. Vegetation has made little headway except in the protected bays, and this may be due to some extent to the sweeping effect of the ice jams near the shore from which the plants usually encroach. This type of filling, however, may be expected to increase in the future and eventually will fill the basins. Little may be expected from deepening of the outlet as long as the dam is maintained, a condition likely to prevail.

CHAPTER VI. INTERIOR LAKES OF THE SOUTHERN PENINSULA, CON'T. LAKES OF THE WESTERN INTERLOBATE AREA AND OF ALPENA COUNTY

HOUGHTON LAKE

Of the interior counties of the Southern Peninsula, Roscommon is perhaps the most fortunate as regards lakes. Others there are which surpass it in number but none in respect to size. Houghton and Higgins lakes, the most important, are both of large dimensions as our inland lakes go, the former with an area of 30.8 square miles taking first rank in the State. They lie in the western and northwestern part of the county and, although not so readily accessible as many, are nevertheless very popular during the summer and fall months. Roscommon on the Michigan Central Railroad is the most convenient point of departure for these lakes, although Houghton Lake is frequently reached from the west.

A physiographic study of these lakes is most interesting and, in fact, surprising. Obviously, for such a study all the advance information possible proves of great service and much information is always obtainable. In this case, one may find that the glacial geology has been thoroughly worked out and described.* This region is a great interlobate area between the lobes of ice which filled simultaneously the Michigan and Huron basins. The outline of the Michigan lobe was relatively smooth at this stage and ran northeast-southwest in the northwestern part of the State. The Huron lobe, however, was noticeably irregular and extended far to the southwest into the Saginaw Lowland, forming a large subsidiary lobe, the Saginaw lobe. Thus, between the northeast side of the Saginaw lobe and the Michigan lobe is a broad interlobate area which extends northeast-southwest, see Fig. 3. The recession of the ice in this area was to the northeast, and somewhat fragmentary cross-morainic ridges were deposited at intervals in the region extending northeast from Cadillac to Roscommon. Three such ridges cross Roscommon County and in the troughs between them are located Houghton and Higgins lakes, see Fig. 68. This accounts for their northwest-southeast trend and similarity in size. With such information at hand one naturally visits the Jakes prepared to find other points of similarity but herein is the surprise, which may well be deferred until the lakes have been described.

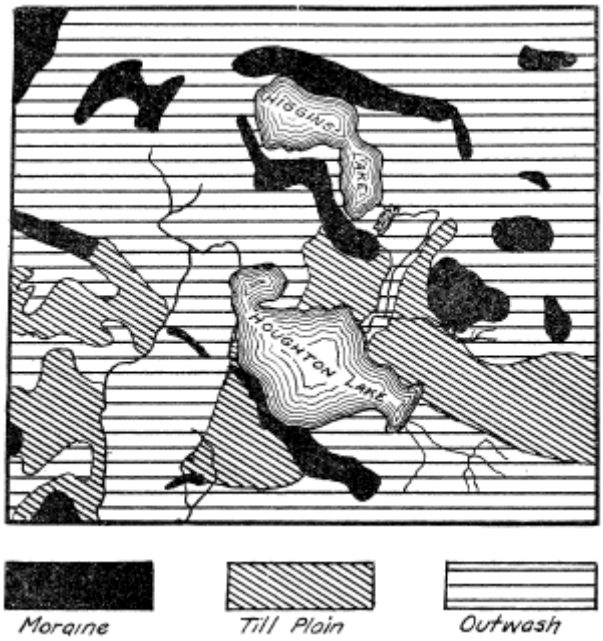

Figure 68. Map showing the distribution of the glacial formations in the vicinity of Houghton and Higgins Lakes. (After Leverett)

Houghton Lake is not a summer resort, strictly speaking. Its popularity is due to the excellent fishing and hunting and for this there is a geographic reason. This lake, although more than eight miles long and over four wide, does not anywhere exceed twenty-five feet in depth and is filled with an almost continuous weed bed, except in a zone about the shore. This is the lair of countless fish of many kinds and accounts in part for the attraction of this lake to sportsmen. Interesting and instructive though a study of the plants and animals of these waters might be to one capable of undertaking it, the writer must dismiss it with the mere mention of wild rice. This furnishes food supply to migrating birds which flock here in great numbers to feed and rest in the fall of the year, thus the attraction to the hunters.

As already mentioned, Houghton Lake lies in a trough between two roughly parallel morainic belts trending northwest-southeast but does not completely fill the depression. In reaching this lake from Roscommon, one crosses the northerly moraine just south of Higgins Lake, see Fig. 68, and drops down to a wooded lowland which becomes swamp within a half mile of the lake. This till plain borders the northeastern shore of the lake.

Outwash plains swing around the ends and border the southwest shore of the lake along the constricted portions at either end, with the exception of a small area of till plain near the northwest end. The main body of the lake, however, is retained on the west by moraine. From the shallowness of the basin and the presence of broad shoals in the main body of the lake, it seems clear that this body of water lies mainly on till plain, and is retained at the ends by outwash and on the southwestern side by a moraine. Such basins were classed as inter-morainic in Chapter I.

The first impressions of this lake depend very largely on the point of view. From the heights of the moraine on the southwest side, the broad expanse of water, fringed with forest on the opposite shore and with highland in the background, present's a pleasing landscape. From the east shore, however, conditions are very different. After a trip of a half hour across a low swamp, the first glimpse is caught through an opening in the trees near the water level and, while not so fortunate perhaps, gives the more accurate impression. The horizontal dimension is exaggerated at the expense of the vertical and things appear flat. The familiar fishing boats, which dot the surface during favorable weather, are enlarged by optical illusion and suggest at once the favorite recreation on this lake.

The road from the north reaches the lake at the inlet, or Cut, as it is called, see Fig. 69, and the initial observations here lead to the conclusion that shore action due to waves and currents is feeble, due obviously to the shallowness of the lake. The inlet, a rather sluggish stream in this part of its course, has, nevertheless, brought down considerable silt which has been carried out and deposited in parallel submerged bars on either side of the current, extending from the shore directly out into the lake for a distance of about one hundred yards. A considerable portion of the water of the Cut comes from Higgins Lake which serves as a settling basin, and the stream is not normally heavily laden with sediment. Since this material is not distributed along the shore, it is evident that the waves and currents are not only relatively, but actually, of little power.

The presence of a third bar, similar in form but located more to the south and in front of a recently abandoned stream channel on the flat adjacent to the inlet, shows that a northward shifting of the channel of the stream has taken place. Those qualified to know state that this was caused by a large, temporary increase in volume of the Cut, due to the removal of a dam at the outlet of Higgins Lake a few years ago, and that the more northerly of the two bars which formerly existed in front of the abandoned channel was removed as the channel shifted. Other evidence of the weakness of the waves and currents is the absence of a well-defined submerged terrace and the broad sinuosities of the shore line.

Some action has, of course, taken place and has formed a rather broad zone of sand off-shore in lieu of a terrace, which does not support the heavy growth of vegetation found farther out in the lake. Also there is an uneven beach of clear sand, which is receding at the present time and laying bare the roots of the trees growing at the high water mark. The recession of the shores is due to the obstruction of the outlet. In the lumbering days a dam of about four feet in height was constructed three-fourths of a mile below the lake and was used to retain the water in the spring. It is probable that the level of the lake was raised only a small amount, if at all, but it was held at the high water mark for a longer period than normally at least and the waves became relatively more powerful. The dam is no longer maintained but the same effect is sometimes produced by log jams.

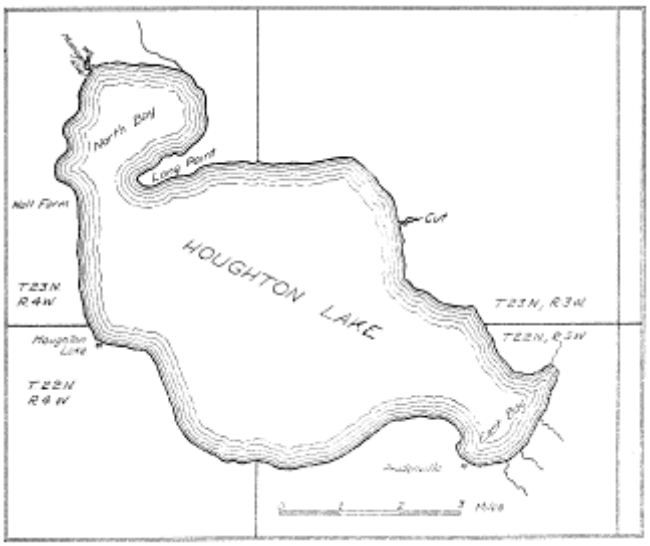

Figure 69. Outline map of Houghton Lake, Roscommon County.

Quite in contrast to the work of waves and currents is the effect of the ice on these shores. Ice jams, which reached a height of fifteen to eighteen feet at the Cut in the spring of 1913, are of frequent occurrence on this shore. The gentle slope and the sandy character of the shore are not favorable to the formation of ramparts, and the chief effect is exerted on the trees which often stand in water along the shore at this time of the year. Driftwood is piled high on the beach, live trees snapped off and overturned, and the bark is scrubbed from the trunks of trees still standing.

Shore conditions are so uniform on the northeast side of the lake from East Bay to Long Point that no detailed description seems necessary. Cusps, which are low water forms, are found on other parts of the lake and might well occur on this shore where not littered with driftwood. They are, however, very transitory and their occurrence in definite localities would be of little significance.

Long Point, although it extends more than half way across the lake, is, nevertheless, an extension of the outwash and not a current deposit. However, shore action is somewhat more in evidence on the north side of this point than along the shore just mentioned. When this lake was visited by the writer some exceptionally well-developed cusps were present near the tip of the

point and a definite sand bar free from vegetation extended a short distance into the lake in line with the shore. Also, a very definite zone of sand off the entire north side of the point indicates an ineffectual attempt at terrace formation.

The land surface bordering the east side of North Bay has very low relief but portions of out wash, standing approximately three feet above a swamp which is at lake level, may be detected. In front of the swamp areas, bars have developed but at a level slightly higher than the present. These bars are probably a single discontinuous bar which becomes less distinct at the northeastern end of the bay but reappears along the swamp at the north end of the lake, the flat of the Muskegon River. It follows the present shore and swings in a gentle curve to the outlet. Across the outlet it continues to the low swells of the ground moraine nearly a mile to the south but stands a hundred yards back from the shore for most of its length. Along the present beach is a similar bar which ends abruptly at the outlet and stands at a slightly lower elevation than the bar farther inland. In general, the bars on the west and north shores are better developed than those in the vicinity of Long Point. The short stretch of low shore along the north side of Long Point furnished a very limited amount of material for the currents flowing eastward with the winds from the northwesterly quadrant. On the west side, however, a relatively large amount of material was quarried by the waves from the cliffs to the south and was deposited by currents first in the bar which stands farthest inland. This bar swung around the north end of the lake (the outlet was farther to the west at this time) and turned a small inlet to the east before merging into the undertow.

The altitude of the bar shows that the lake must have stood at an elevation at least two feet higher than the present high water mark and possibly more, since the bar may have been submerged. This higher level must have covered the flat adjacent to the outlet and extended some distance down stream. Also the low swamp bordering the northeast side of the lake was flooded at this time. The drop in level was due to the deepening of the outlet and was gradual. As the level lowered a passage was maintained by the outflowing water through the bar which terminates farther to the east. Eventually the currents were unable to continue along the bar, on account of the decreasing depth of the water, and took a course in the deeper water near the present shore. In this way the second bar was started but, with continued lowering of the water level, its length became fixed by the establishment of a definite channel by the outlet. Its subsequent growth was small but sufficient to force the outlet slightly to the north at its debouchure.

South of the grass-covered outwash lie the gentle swells and sags of the till plain which rises to the moraine near Houghton Lake village. The moraine borders the shore, as shown in Fig. 68, and then drops to the outwash plain which nearly surrounds the southwestern end of the lake. The prominent features along this shore are the wave-cut cliffs which rise from the high water mark and show no evidence of the higher level found near the outlet. Where the till plain and the moraine come to the shore, the cliffs are composed of boulder clay and are steep. The outwash is composed of unconsolidated sand but is covered with a close mat of grass so that the cliffs are somewhat steeper than is usual for this material. The different formations are also expressed in the character of the beach material which contains cobbles and boulders in front of the moraine but is of clear sand along the outwash plain.

In conclusion, it may be stated that shore agencies on Houghton Lake have been productive of meager results. Waves and currents, although rejuvenated to some extent at the present time, are of little power and this inactivity is due to the shallowness of the lake and the heavy growth of vegetation which effectively interfere with wave and current development. Shore adjustments have been of somewhat greater importance in the past when the lake stood at a higher level. At this time, currents showed their greatest activity in North Bay and succeeded in decreasing the size of this arm to a considerable extent. The greatest activity of the waves has taken place along the southwestern shore, as shown by the prominent cliffs. An index to the combined activity of waves and currents is the development of the submerged terrace and this is nowhere well-defined. Ice jams are of frequent occurrence and great intensity, especially on the northeast side of the lake, but shore conditions are not favorable for decided effects.

The lake is, however, an interesting example of one physiographic process,—that of extinction. Little sediment is brought in by streams and the outlet is deepening at a very slow rate. Yet the lake is filling very rapidly due to vegetation. Geologic processes are, as a rule, acting very slowly according to human standards of time but one may look forward to the extinction of this lake in the course of a few generations.

*Monograph 53, U. S. Geol. Survey.

HIGGINS LAKE

Higgins Lake is reached conveniently from Roscommon on the Michigan Central R. R. by stage and is well worth a visit. With an area of nearly fifteen and one-half square miles and a length of seven miles, this lake ranks among the larger of our inland lakes. Also it is one of the most beautiful. As seen from the summit of the moraine to the south, the lake consists of two broad arms which stretch west and south from a central constriction. The interesting island, the green slopes and the clear blue water blend into a most attractive landscape. From most points on the shore, however, the view is restricted but is sufficiently inviting to induce one to explore further. The clarity of the water is remarkable and might well have inspired a less prosaic name than Higgins. It is so clear that it looks cold and such is the case, for the lake is deep and is fed by springs. The change from the light color of the shallow water to the blue of the depths is sudden. So sudden, in

fact, that to float across this zone on a peaceful day gives one the indescribable sensations of sailing into space.

Likewise from a physiographic viewpoint Higgins Lake is most interesting. The general features of the region are quite simple as regards geology, see Fig. 68. Moraines border the north shore of the west arm and parallel the southwest shore of the entire lake. The morainic slopes on the southwest side do not reach the lake but are separated by a narrow zone of sand which widens into broad outwash plains at both ends of the lake. The outwash was formed when the ice border stood at the northern moraine, and covered the till plain between the two moraines, with the possible exception of the lake basin itself. Nearer the moraines the outwash merges into a terrace, and till is exposed beneath the sands on the southwest side of the lake.

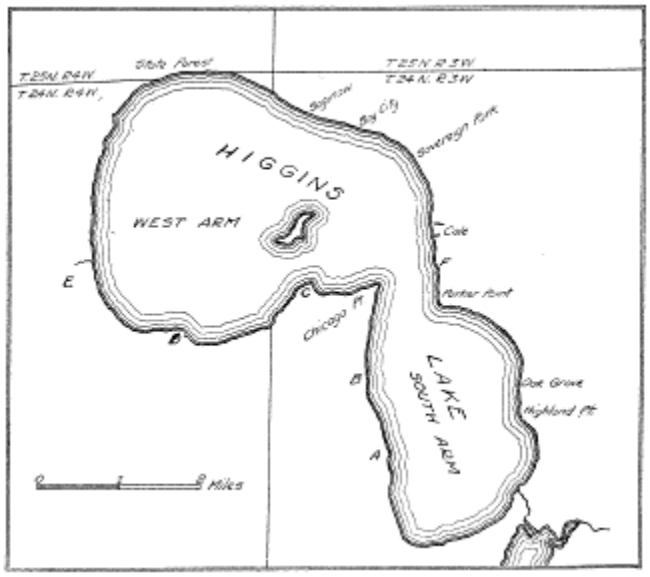

Figure 70. Outline map of Higgins Lake, Roscommon County.

Ideas are prevalent concerning remarkable depths of the water in this lake but the greatest depth reported from reliable sources is one hundred twenty-five feet. This depth makes it certain that the lake does not cover a till plain, as does its neighbor Houghton, or else the outwash is excessively thick. From the shape of the lake it seems probable that the basin is a large, irregular pit in the outwash formed by buried blocks of ice, as explained in Chapter I.

In addition, the history of the lake is as complicated as that of some of the lakes which were connected with the Great Lakes and is in itself an interesting story which could not be fully deciphered at the time this study was made. The former strands are very distinct and show a lake of much greater size at its maximum height. A careful mapping of these shores and the adjustments which took place at the various levels promises a most interesting and profitable study.

At the outlet of the lake natural conditions are somewhat disturbed by the activity of man. In the lumbering days a dam was constructed to retain the water for the log runs in the spring. The level was raised about forty inches but lowered rapidly during the runs, remaining low during the greater part of the year. With the passing of the forests the dam lost its usefulness and the lake assumed its normal level. The outlet was again obstructed in 1911 for the purpose of permanently raising the level of the lake. This caused a renewal of the activity of the waves, and the effects were sufficient in one year to convince those concerned of the inadvisability of such a condition, so that the dam was blown out. Such disturbances make the interpretation of conditions at the outlet somewhat uncertain but the significant facts may be ascertained.

The outlet, see Fig. 70, flows in a channel which has been cut approximately eight feet below the level of the sand plain. It flows in a southeasterly direction to the nearby Marl Lake and thence eastward for more than two miles before turning south through a low sag in the moraine which stands between Higgins and Houghton lakes. In the bed of the outlet and along the shore to the southwest a large number of boulders of considerable size are found. These boulders lie at the base of the sand plain which is relatively thin here and are washed free from the finer material by the movement of the water. Considering the outlet, it is obvious that down-cutting has taken place rapidly while the stream was running over the sands but was accomplished much more slowly as the boulders were encountered. Thus, from this limited locality one may hypothecate higher levels for the lake and be prepared to find conclusive evidence on the slopes adjacent to the present shores.

At the south end of the lake, the outwash soon gives way to a narrow flat which borders the shore to the west side. The even curvature of the shore and the clear sand beach are suggestive of current action and further evidence is found in two sand bars a short distance inland. These bars stand about two feet above the present lake level and parallel the shore from one side of the lake to the other. The lagoon, thus formed, was very shallow and is now dry. If these bars were formed by currents, their growth must have been from the west because shore drift on the east side of the lake could not well have passed the outlet. Undoubtedly currents brought much material to this shore from the cliffs along the west side of the South Arm, where an uninterrupted shore of nearly three miles in length is exposed to the northeasterly winds. In the early stages of this level, the currents did not leave the shore in this locality but, as the submerged terrace developed and widened, both the waves and the currents were retarded by its influence. Finally, the retardation was sufficient to exert a back pressure on the strong currents moving southward along the west side and they were forced from the shore. Thus the first bar (farther inland) was formed and a slight lowering of the level as the outlet deepened may have caused the second bar somewhat farther out in the lake. (See Crystal Lake for a similar occurrence.)

At the present level the submerged terrace is wide but not sharply defined. Soundings showed an exceptionally

wide terrace near the west side which extends into water nearly twenty-five feet in depth before dropping into deep water. The zone of sand, however, stopped at depths of ten to twelve feet, and this probably represents the greatest depth of the terrace, since the finer material is usually swept from the terraces in lakes of this size and may possibly be carried from one end of the lake to the other.

The west shore of the South Arm is bounded by low cliffs for most of its extent. In two localities only were the effects of current action detected. At locality A, see map, a small point breaks the regularity of the shore line, and currents have formed a small spit pointing southward, a fact in harmony with the view that the bars at the south end were formed by currents from this shore. Again at Chicago Point currents are active but this will be reserved for discussion later. The cliffs along this shore do not rise above six to eight feet and have been carved in the sands of the adjacent plain which is a terrace of a higher level. The material is homogeneous and unconsolidated and has been very uniformly worn by the waves, forming an exceptionally smooth shore line. A distinct submerged terrace drops at eight to ten feet but is of relatively narrow width. Off locality B a rock shoal comes to within six or eight feet of the surface. It is thus within the zone of action of the waves which have removed the finer material from the north end and deposited it in a bar at the opposite end. Clearly the northerly winds are the most effective in this locality.

Chicago Point has much of interest for the physiographer. In this locality, evidence of levels higher than the present is at hand and, in addition, changes are now taking place which are of great significance. Back from the shore stands a broad sand terrace which slopes very gently upward to the morainic hills in the distance. Its height was not measured in this locality but a similar terrace at the State Forest marks a level of the lake sixteen feet above the present. This terrace, which borders the shore of the south arm, drops to a lower one standing at an elevation of eight feet above lake level, formed probably at the time when the outlet flowed over the surface of the sand flat. The spit began its development at this time but, inasmuch as the outlet cut down through the loose sand rapidly, the growth was small. The outlet soon cut through the sand and encountered the boulders at its base which held the lake at a level two feet above the present for a considerable time. During this stage the spit increased in length more than two hundred feet. At the present level the spit is continuing its growth and, including the submerged portion, extends fully a quarter of a mile out into the lake. On the opposite side of the lake the submerge terrace is fully as wide as the length of the spit, so that the narrows is in reality much more restricted than appears from the map. An ice rampart borders the south side of the spit at the present level but its counterpart is not present on the opposite side. This decrepancy may be due to the destruction of the rampart on the north side. The material of the spit is not suitable for the formation of a permanent rampart and, if formed, it would be subjected to strong wave action, due to northerly winds of considerable reach.

West of Chicago Point the eight-foot terrace becomes faint and drops to the two-foot level in the vicinity of point C, see map. Off this shore the lake is shallow to the Island, due probably to the nature of the basin. The condition of the Island during the stages above the two-foot level cannot be determined but it is probable that its top was bevelled to some extent at the eight-foot level. During the two-foot level a much smaller area than the present stood above the water and was subjected to considerable adjustment by waves and by ice. Terraces and strong beaches were formed all around the island but were better developed on the northwest side throughout. In addition, the bouldery material was pushed up into ice ramparts which are very pronounced on the northwest shore. The expanse from the Island to the west shore, a distance of more than two miles, is generally considered excessive for the formation of ramparts by expansion, so that ice jams appear to be effective here. However, the maximum size of lake upon which expansion is effective is as yet uncertain and it is unfortunate that little could be learned concerning the manner of the ice push on this shore. At the present level the waves are active on the northwest side and much of the material quarried is transported to the point at the northeastern end of the island, where it is being deposited in a spit extending almost due east. Another spit was found, at the sharp projection on the southeast side, which was partially removed at the time of the writer's visit, due probably to the temporary rise in level a year previous.

Along the south shore of the West Arm the moraine lies nearer the present shore and the terrace of the sixteen-foot level is relatively narrow. The small terrace of the two-foot level is quite generally present but that of the eight-foot stage occurs infrequently. At the two-foot and present levels, the waves have removed the gravel of the higher terraces, and many of the boulders of the underlying till are concentrated on the beach at the projections. Ice action is of little importance on this shore. At point D, which is caused by an outlying morainic knob, the eight-foot terrace is well preserved but that of the two-foot level has been removed. The submerged terrace is well developed along this shore. The line of the "drop off" swings in a southward bending loop from the Island to point D where it narrows to a width of one to two hundred yards and continues thus around the west end of the lake with minor variations only.

About one-half mile west of point D, an indentation not manifest in the contour of the present beach is to be found. This was an embayment of considerable extent during the eight-foot level but was cut off by a low bar during the two-foot stage. The lagoon was a shallow portion of the submerged terrace and was readily drained by seepage through the sand of the bar when the lake level lowered. At E the waves have demolished both the two and eight-foot levels and are working on the

sixteen-foot terrace, having formed a cliff twelve to fifteen feet in height.

North of point E the moraine drops to the sand plains and there is a possibility that the lake extended considerably farther to the west when it stood at the level sixteen feet above the present. The two-foot terrace is well developd and in places reaches a width of over two hundred feet. This shore was badly cut during the temporary high water due to the recent dam at the outlet. Most of the beach has been worn away to the tree roots and the effects of a strong ice push are evident in places. The latter is said to have been caused by ice jams in the spring of 1913.

At the State Forest the moraine which borders the northern end of the lake approaches the shore and the levels are poorly defined with the exception of that at the two-foot stage. However, the sixteen-foot terrace is definable and has been accurately determined at sixteen and one-half feet above the present level of the lake. At the Saginaw Grounds the highest terrace is reached by a continuous cliff of about fifteen feet in height. Farther to the east at the Bay City Grounds morainic hills are being carved by the waves, forming cliffs up to heights of thirty-five feet. These two locations are well suited for resort purposes and afford an excellent view of the entire length of the lake. The only disadvantage is the excessive width of the present submerged terrace, the greatest on the lake. Inasmuch as it drops at six feet, the water is very shallow for a long distance off shore.

Sand plains again border the lake in the vicinity of Sovereign Park and continue along the eastern side of the lake to the outlet. The clump of pines at the Park gives some idea of the wonderful forests that formerly covered this region and adds to the attractiveness of the location. At the two-foot level the shore stood considerably farther back than at present. So much so, that the currents left the shore and deposited a bar nearly a mile in length in front of a very narrow lagoon. As is frequently the case on Higgins Lake, the lagoons of this level stood on the sandy terrace and were quickly drained when the water level lowered. Along the shore in the vicinity of Cole low hills come to the shore and have been carved into cliffs which step down to the two-foot terrace. This higher ground leaves the shore about one-half mile north of Parker Point, F on map, and swings back from the lake in a broad curve, reaching the lake again at Oak Grove. The lowland between this and the lake was flooded at the higher levels and was thus a shallow embayment whose bed was worked into a submerged, terrace of gentle slope. The change in direction of the shore line at the -sides of this embayment was abrupt and especially so at the northern end, F, where the angle was approximately ninety degrees. Currents must have left the shore at each side, but, strange as it may seem, accomplished little at the north side. However, on the south side a series of bars converging on the low cliffs above Oak Grove, stand at progressively higher elevations inland, or in other words, are arranged in steps. They sweep around the bay in broad, swinging curves and are truncated by the somewhat irregular shore north of Parker Point.

Apparently the bars did not begin to develop until the eight-foot stage, during which the outlet was being cut down rather rapidly. As the water level lowered at least four bars were formed, which may be readily distinguished along the road running east from the head of the bay. The individual bars were not traced through the swamp back of Parkers Hotel and there is the possibility that the number is increased in this locality by splitting. As the water subsided to the two-foot level, the embayment was drained with the exception of a narrow strip adjacent to the present shore, which was isolated by a low bar during this stage. The submerged terrace is very well defined along this shore but gradually decreases to a depth of about four feet and a width of less than fifty on the south side of Parker Point. Beyond the end of the point it makes a broad loop to the southward and also widens in conformity with the terrace fronting the east shore above the point.

In the development of the shore features in this locality several factors have been of importance. Obviously, winds with a westerly component are the only ones effective on these shores and those from the northwest are probably the more important both as to strength and frequency. That the currents caused by these winds have been powerful is shown by the development of the shore between Parker Point and the bluffs at F in accordance with that to the north, and by the southward extension of the submerged terrace off the east side of the point. Nevertheless, the deposits in the embayment have been made almost exclusively by northward moving currents in the South Arm and something other than the force and prevalence of the wind has been the determining factor.

From either direction the material is derived from sources which are practically equivalent but the waves have a slight advantage at Oak Grove on account of the narrower submerged terrace. This, however, is not sufficient to account for the great preponderance of the work of the currents in the South Arm and the explanation must be found in the form of the lake basin. The lake lies for the most part in a deep pit, but during the higher levels overflowed on the adjacent slopes, forming shallow embayments. Such an embayment is the one under discussion but off the point lies the deep water of the main basin. The currents from the West Arm left the shore at the abrupt turn, F, and ran directly into deep water, causing a rapid reduction in velocity and therefore deposition of the suspended load. This material was utilized in filling the deep basin and consequently was not localized in characteristic shore forms. However, on the south side of the embayment the currents flowed over shallow water after leaving the shore at Oak Grove and deposited their load in bars which crossed the bay and terminated at the shore north of Parker Point where the stronger cross currents of the West Arm were encountered.

The protuberance of the shore in the vicinity of Oak Grove is of higher ground and was the source of the materials of the bars in the embayment just discussed. Here the sixteen-foot level is well defined and the terrace is utilized as a building site for several summer cottages. The eight-foot level is not well defined, much of it having been removed at the lower levels. Recent cutting due to the temporary raising of the lake level is much in evidence along the low cliffs which line the shore. At Highland Point the land drops in elevation and the two-foot level is prominent as a wide terrace. Ice action has built a low rampart at the present shore but is of moderate intensity. Between Highland Point and the outlet a low sand fiat extends several miles to the eastward. This flat was covered by all of the higher levels but the borders of the sixteen and eight foot stages were not traced. During the two-foot level a low bar, conforming to the present contour of the shore, developed and definitely cut off this lowland from the lake basin.

In conclusion, it seems fair to state that Higgins Lake is one of our most interesting and instructive lakes. The history of this interior lake is exceptional and is merely sketched in this account. This phase of the work is left with reluctance for it is felt that a detailed study of the various levels would be productive of most interesting results. We may be certain of a much larger lake during the highest or sixteen-foot level. At this time, the ends were extended in broad, shallow embayments and the southwestern border reached to the morainic slopes. Much work was done by the waves, and broad terraces were formed which now appear as a veneer of sand on till adjacent to the shores. With the lowering to the eight-foot level, accomplished probably by deepening of the outlet, a new cycle was inaugurated. At this time the waves were working on the unconsolidated sands of the sixteen-foot terrace and quarried great quantities of material which was distributed by currents on the submerged terrace and in the embayments. The rapid deepening of the outlet through the sand caused a gradual depression of the level to two feet above the present stage. The adjustments at this level were mainly by currents which cut off numerous minor embayments, notably at the south and west ends. The slight drop to the present level served mainly to reduce the activity of the shore agents, a condition emphasized by contrast when the lake was held temporarily at a high level. A re-adjustment to present conditions is undoubtedly taking place but the results are not striking. However, a continuation of the development of the spit at Chicago Point will have far-reaching results, since it is growing across the narrowest part of the lake. Eventually, the lake must be divided in this locality, but much filling is necessary on account of the deep water and the progress will be slow.

The process of extinction has hardly started. Filling by vegetation and sediment is of slight importance at the present time on account of the great depth of the lake and the absence of entering streams. The deepening of the outlet will eventually drain the lake, but this process is making slow progress now that the stream is flowing over boulders. It seems reasonable, then, that the shores may become adjusted to a late stage of development before the cycle is interrupted. Ice push is not of great importance on this lake as regards effects but observational work on this phase of our study should produce interesting results, especially in the West Arm which is near the maximum limit for expansion.

Before leaving these lakes the writer wishes to point out the unexpected (to him at least) contrast between the two lakes in this region. Higgins Lake is deep; its limpid, blue water is derived from underground sources; the adjustments of its shores are numerous and varied; and its history is punctuated with interesting episodes. A few miles to the southwest Houghton Lake occupies a similar position with reference to the glacial formations, but is almost diametrically opposite in characteristics. Thus, it is shallow, its turbid waters, derived from surface drainage, are agitated throughout by every storm; it is choked with vegetation; the adjustments of its shores are infrequent and of little significance; and conditions have varied little in the past from those existent today.

PORTAGE LAKE, CRAWFORD COUNTY

Portage is a rather popular name for lakes and it seems necessary to state that the one under consideration is situated in the central-western part of Crawford County. It lies about eight miles almost due north of Higgins Lake, and, thus, came into existence at a later time. It is reached from Grayling on the Michigan Central Railroad by a short drive.

The best idea of the outline of this lake may be gained from the accompanying map, Fig. 71, drawn from the U. S. Land Survey map of the region. It is approximately three, miles long, less than a mile in width except across the broad embayment at the north end, and has an area of slightly less than three square miles, 2.96. It lies in one of the deeper pits of an outwash plain but at the border of a moraine which stands not far back from the south and west shores. Although within three miles of the Au Sable River it, nevertheless, is the source of one of the tributaries of the Manistee which leaves the lake at the northwestern end. The lake is best known on account of the location of the state camp of the National Guard on the west side.

The entire east side of the lake presents little of physiographic interest. Shallow depressions which sink below the level of .the outwash plain but stand above the lake level cause swampy shores for the greater part of the distance. The swamp condition is further accentuated by low ice ramparts of sand through which occasional small stream's break. Along the north shore the adjustments are better defined and the broad salient. Eagle Point, is the index of this work. A well-defined bar extends out into the lake from the end of the point and connects with the beaches on either side in unbroken curves. The low cliffs in the vicinity of McIntyres' west of the point have furnished a considerable portion of the

material for this spit. On the opposite side some material drifts in from the northeast, as shown by the turning of the stream courses towards the point before they cross the beach. The west side of the point is exposed to the strong westerly winds and the adjustments of this snore should, therefore, be more pronounced. This, however, is not striking and may be due to the formation of return currents on the east side during "blows" from the southwest in addition to the direct effect of the easterly winds.

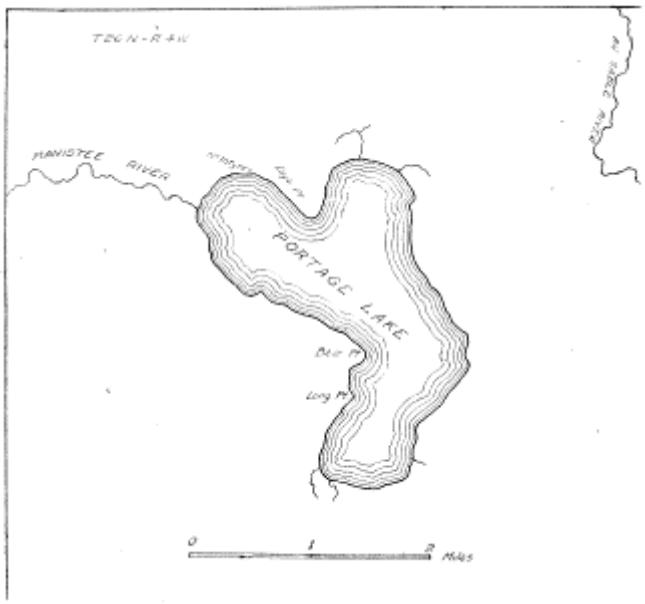

Figure 71. Outline map of Portage Lake, Crawford County.

At the northwestern end of the lake the land drops to a low swamp through which the outlet runs. A strong ice rampart follows the shore, but fails at the outlet and near the southern edge of the swamp. This rampart totally obscures any possible current deposits but, nevertheless, the fact that it plays out to the south suggests the possibility of its being a remodeled bar which developed from the north.

South of the swamp low, outlying knobs of the moraine relieve the swamp conditions. These knobs determined the position of currents along this shore and are connected in some cases by bars. In one locality a definite bar with a well-developed rampart on its front slope stands above the present water level. These forms, which show a higher level of the lake, are made more prominent by the presence of a second rampart at the present water level. Northwest of Bear Point the moraine comes to the lake shores and the slopes are cut into steep cliffs which rise from the exposed terrace of the higher level. At Bear Point the currents left the hills during the former level and built a strong bar in a southeasterly direction which now ends abruptly at the present shore on the south side of the point. The lagoon behind this bar is filled with vegetation. A rampart has been pushed up on the front slope of the bar but is being removed by waves under the present conditions. This material is being carried outward and deposited on a submerged bar in line with the northeast shore of the point, one of the few adjustments in process.

South of Bear Point the morainic topography has given rise to an alternation of cliffs and small swamps. The activity of the waves is unmistakably evident but the currents seem to have carried little of the material along the shore, for the swamps are not cut off except at the small indentation near the rifle range and this by an ice rampart. Near the south end the land drops to an extensive swamp which is separated from the lake by ice ramparts rather than by typical bars. Beginning at the western side two ramparts fringe the shore, the Inner rampart reaching a maximum height of live feet. They decrease in strength towards the east and die out before reaching the higher ground of the moraine at the south end of the lake. In this locality the slopes are gentle and an exposed terrace of the former level is present locally. Wave action seems to have been very slight for the cliffs are very low or are entirely lacking.

The shores of Portage Lake show a relatively small amount of adjustment and this was accomplished at a level somewhat higher than the present. The lack of well-defined shore features makes an accurate determination of the elevation of this former level somewhat difficult but it probably stood between two and three feet above the level of the lake at the time of the writer's study. The original lake was much more irregular in outline than the present and the opportunities for adjustments were numerous. Nevertheless, the greatest change was brought about by the draining of many of the shallow indentations when the level lowered. At the present level the adjustments in process are few in number and progressing very slowly.

It is interesting to compare the development of the shores of this lake with that of such lakes as Corey, Clear and Long in St. Joseph County. These lakes are much smaller than Portage and are surrounded by material which, although sandy, is probably more consolidated than the outwash sands along the east and north shores of Portage Lake. Nevertheless, the shore features are much more decided than those of Portage Lake and have been carried to a more advanced stage of development. In the absence of complete data one is inclined to infer that the greater age of the more southerly located lakes is the determining factor.

OTSEGO LAKE

Further retreat of the ice in the western interlobate area uncovered the region centering about Otsego County, in the southwestern part of which Otsego Lake is situated. This lake is nearly five miles in length but is scarcely a mile in greatest width. Its area is three and one-quarter square miles, so that the average width is approximately three-fifths of a mile. This lake is hemmed in on both sides by moraines for most of its extent, but the material at the shores is outwash sands, so that the lake may be classed as a pit. It is, however, somewhat exceptional in form and topographic location, and, therefore, some

discussion of its manner of formation may not be out of place.

The glacial deposits of this region lie south of a well-defined moraine which was formed by the ice of the Michigan lobe on the northwest and by that of the Huron lobe on the northeast, thus the right-angled bend. See Fig. 72. An extensive outwash plain stands south of this moraine and surrounds a number of morainic tracts which rise above the plain as island-like forms. The morainic tracts have a general north-south trend and are separated by narrow, sand-filled troughs, three of which, designated I, II, and III on map, are well defined. The central trough, II, branches northward and Otsego Lake lies at the north end of the eastern branch. Attention is called in particular to the eastern troughs, I and the Otsego Lake branch of II, which lie in the drainage system of the Au Sable River.

The drainage of these troughs divides near the north end, the major part flowing southward. The upper parts, however, flow southeastward around the morainic tracts and contain lake basins which are pits in the outwash. Thus, in accounting for these basins, and in particular that of Otsego Lake, the elongated form and the presence of divides in the sand-filled troughs must be considered.

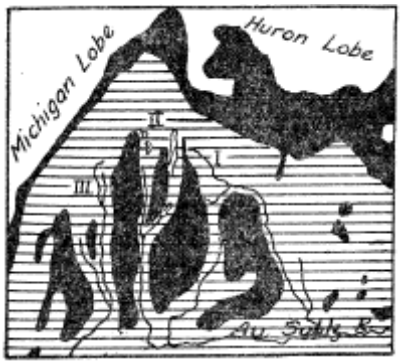

Figure 72. Map of the glacial formations in the vicinity of Otsego Lake. Solid black indicates moraine. Lined areas are outwash. (After Leverett.)

The recession of the ice border in this .locality was to the northwest within the Michigan lobe and to the northeast within the Huron. Thus, it is very probable that at one stage the ice front stood near the northern border of the morainic tracts and extended in narrow tongues into the inter-morainic valleys to approximately the position of the present divides. During this time, the drainage flowed southward and the valleys were partially filled with outwash material. As the Ice melted the higher elevations were completely uncovered, but parts of the tongues of ice in the depressions became detached and were buried by outwash from the ice front which was receding northward. At the same time a lower channel, parallel to the ice border, was opened to the southeastward which in the case of Otsego Lake crossed the northern tip of the moraine on the east side. Finally the melting of the buried ice block formed the depression in which Otsego Lake stands.

The loose surface material, the irregularity of the shoreline, and the elongated form of the lake, presenting a broad expanse of water to winds from certain directions, have caused numerous adjustments of the shores which are exceptional for a lake of this size. Many excellent beaches and cottage sites are, therefore, available but are most appreciated on the east side in proximity to the railroad.

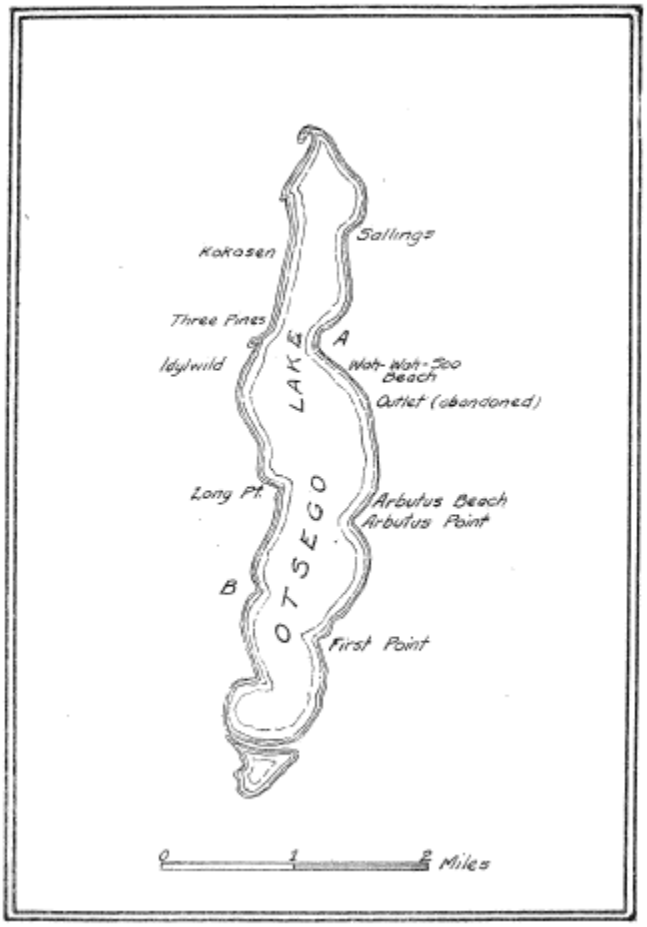

Figure 73. Outline map of Otsego Lake, Otsego County.

On a map one looks in vain for an outlet of Otsego Lake (Fig. 73) but may notice that the North Branch of the Au Sable River heads straight for the east side of the lake somewhat north of the center. It does not extend to the lake, however, and one interested in drainage problems naturally wonders what the conditions at the head of this stream may be. In this ease a trip is worth while, so we may advantageously begin our study at this place.

Back from the lake a dry channel, with even floor and gentle slope away from the lake, runs through a break in the hills and connects directly with the North Branch of the Au Sable. Nearer the lake the channel broadens to a low marsh in the sands of the trough and splits before reaching the lake shore, having formed an island in past times. At present the water stands four to five feet below the level of the outlet, long since abandoned.

The shores along the head of the broad embayment from which the outlet leads are bounded by cliffs of stratified sand which reach to the surface of the outwash

about ten feet above the lake. This unconsolidated material was easily quarried and was distributed in both directions by shore currents and offshore by the undertow. The relative importance of these agents is dependent very largely on the reach of the winds which may be rated in the following order: Southwest, northwest and west. Thus, shore currents developed at the expense of the undertow and the submerged terrace is poorly defined. In most places it is merely a zone of sand which shows a sharp line of demarcation from the muddy bottom of the deeper part of the lake. Of the shore currents those which develop under southwest winds have the advantage and the northward drift along this shore is the more powerful. Therefore, much of the material has been deposited along the south side of the broad point north of the outlet. The current action is first apparent at the outlet where a bar started to develop at a level four feet above the present and partially enclosed the small marsh bordering the outlet, which must have been a shallow arm of the lake at that time. At the present level ice-shove, probably of the expansion type, has formed a poorly defined rampart, although shore conditions are unfavorable. North of the outlet this upper beach extends to the broad point and is known as Wah-Wah-Soo Beach. The point is caused by an original irregularity of the basin and was almost obliterated by wave action during the early stages of the lake. Thus, in the background stands a cliff in the outwash and from the foot of this stretches the now exposed submerged terrace of that time. But with the subsidence of the water, caused by the downcutting of the outlet, the activity of the shore agencies was reversed and currents from the north deposited a bar almost in line with that shore, enclosing a very narrow lagoon just in front of the cliffs. Either during or following this period the currents from the south became effective and carried, the Wah-Wah-Soo Beach beyond the bar from the north and are at the present time flowing to the end of the point. This condition is expressed by a well-defined submerged terrace which drops into deeper water from a depth of two feet. This very shallow terrace in a locality favorable for its development indicates a poorly developed undertow.

From this point to the north end of the lake the land slopes gently to the shore and the only discernible adjustment of the shore has been the carving of low cliffs by waves of very moderate force. Some of the material which was removed from the cliffs has been transported to the north and deposited in a bar which stands slightly above the swampy lowland bounding the north end. This bar leaves the higher ground some distance inland but borders the lake at the north end. On the west side similar currents have built a strong bar at right angles to the one from the opposite shore which has partially cut off an extensive swamp and caused a peculiar gourd-like outline of the shore. These deposits were both formed at the higher level but probably were not above water for much of their extent.

The northward drift of the currents along the west shore is again evident at the narrow hook which has developed in front of a low exposed terrace a short distance south. In the early stages of the lake waves have been energetic along this shore, and the terrace of the higher level is well exposed, in places reaching a width of nearly one-fourth mile. At the higher stage this smooth shore was broken by bays north of Kokosen and in the vicinity of Three Pines. In both cases complete bars were formed across the mouths of these embayments, forming lagoons which are still swampy. Between Three Pines and Idylwild the same process is being repeated at the present level by the formation of a spit across the neck of the small bay. Below this bay the moraine recedes from the lake and the outwash is considerably wider. In places the waves have removed the higher terrace and are sapping the sands of the outwash. Ice-shove is effective in this locality at the present level and has formed ramparts at the edge of the exposed terrace which is, therefore, poorly drained. The greater part of the eroded material is carried by shore currents rather than by undertow, and the submerged terrace is poorly developed. Most of it drifts to the south and is dropped at Long Point where the currents are forced from the shore. The activity at this point began during the higher level and shows features similar to those found on the point north of the outlet. The main part of the point is an exposed terrace of this level upon which was built a strong bar from the north, indicating a reversal from wave to current action. The bar stands about twenty feet back from the present beach and is sharply truncated by the south shore. The revival of wave action, as shown by the removal of the tip of the bar, was due to the inauguration of a new cycle by the sinking of the water level and is still in progress at periods of excessively high water such as occurred in 1913. On the north side of the point, however, the currents are still active, the point having been extended approximately two hundred feet offshore below the water level. As is the case at many of the points, the submerged terrace is well developed on the side affected by currents, here the north, and drops into deep water at four feet at distances offshore which increase towards the ends of the points.

The shore from Long Point to the south end of the lake shows features very similar to those just described. The long stretches are generally regions of wave action which in many places has removed the terrace of the former level and is working in the sands of the outwash. Two strikingly similar points, B on map and point to the south, break the shore line. Both are V-bars which began their development at the higher stage and were interrupted by the drop in level. In each case the currents from the north were the more active and built strong bars which probably stood above water level. Likewise, on the south side bars developed which met those from the north, forming a more or less symmetrical triangular embankment with enclosed lagoon, but were not completed at the time of the sinking of the water level. However, at the present stage the triangular form is well shown and the lagoons are filled with water or are swampy.

The south shore of the lake is bounded by the so-called "beaver dam" which, local tradition to the contrary, is one of the best examples of a bar seen by the writer. This form, shown in Plate XIV, is composed entirely of sand and joins the east shore in an unbroken curve. Its crest stands slightly above the level of the higher stage, except for the last hundred feet at the west end, and supports a fringe of trees which accentuates the linear character of this bar. In the photograph, Plate XIV, a similar bar may be seen stretching across the triangular lagoon isolated by the "beaver dam." This bar, however, stands at a lower elevation and is poorly defined. Both of these bars were formed during the higher stage and obviously the outer bar developed first. For some reason the point of departure of the currents from the shore was shifted to the north before the outer bar reached the water level and remained in the position now occupied by the inner bar, the "beaver dam." The currents instrumental in their formation were those driven by northwest winds along the shore south of First Point. At flood stages of the present level waves have been active and have steepened considerably the front slope of the bar, which normally should be gentle.

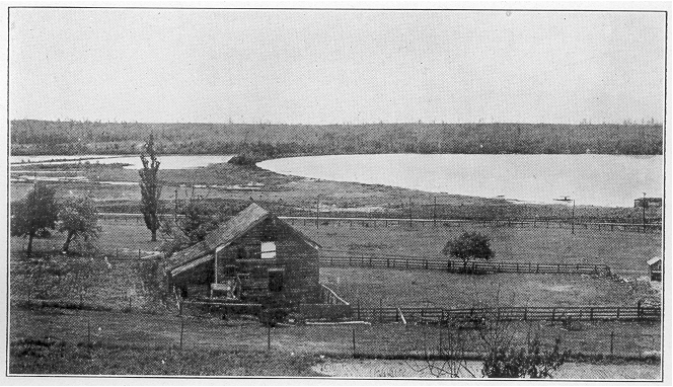

Plate XIV, A. "Beaver Dam," Otsego Lake.

Plate XIV, B. Ice-formed V-bar, Long Lake, Alpena County.

Along the east shore cliffs in the outwash reveal the source of the material of these bars. In places the cliffs show fresh cutting which may be laid directly to the excessively high water in 1913. Near First Point the cutting is less active and the terrace of the higher stage appears and widens towards the point. In the early stage of the lake this point was merely a blunt projection of the outwash which was carved into a cliff and terrace. Then followed a period of reversed activity, ascribed to the down-cutting of the outlet, during which currents predominated. The drift from both directions left the shore at this point but that from the south was the stronger. The material from this side was deposited in a strong bar which splits twice before meeting the single bar on the north side. Thus, on the south side of the apex there are three distinct bars separated by marshy lagoons. In front of the bars a triangular terrace of considerable extent developed, which was exposed by the sinking of the water to the present level. Since that time, the point has been extended under water for nearly three hundred feet and drops at a depth of four feet. The stretch of shore on either side of the point along which currents may develop is slightly longer on the north side while the northwesterly winds have quite an advantage in reach over those from the southwest. The greater effectiveness of the currents from the south is, therefore, somewhat unexpected. The determining factor seems to be a blunt projection just north of the point, which causes considerable deflection of the currents from this direction, as is shown by the distinct submerged terrace.

In the broad embayment north of First Point waves are again the active agent and sand cliffs are the conspicuous shore features. The terrace of the higher level has been removed except in proximity to the points. Arbutus Point is very similar to First Point and requires no special discussion except for slight modifications. The main episodes in its development are identical but the predominating currents came from the north. Instead of the split bars found on the south side of First Point there developed here a compound hook with several spurs recurving to the shore. In front of the hook on the north side is a series of parallel beaches which may mean a gradual lowering of the water level. This point is not growing at present and some cutting may take place at flood stages. However, a very well-defined submerged terrace has developed in conformity with the north side of the point.

As regards origin and general features, Otsego Lake presents many interesting features. The major shore adjustments have taken place when the water stood higher than at present and show many variations. The sandy material of the surrounding outwash has been easily eroded and each change of conditions is clearly registered. Although the full extent of the lake in the early stages was not determined, cutting by waves prevailed generally along the shores. The reversal of activity, making currents effective at the numerous points, is remarkably consistent and is ascribed to the downcutting of the outlet. Then followed a period of stability during which the points were increased by the development of bars. The drop in level to the present stage was probably accomplished slowly and allowed the growth of a series of minor bars on some of the points. Since the drop has caused the abandonment of the outlet, it must be ascribed to a decrease in the amount of ground water which is the main source of supply. The depressed level of the surface of the

ground water is a subject full of complications, but one important factor may have been a general drying-out following the disappearance of the glacier which supplied immense quantities of surface water in melting.

At the present level the adjustments are not striking and occur for the most part during stages of high water. No important changes are to be expected but minor adjustments may be accomplished by currents in a few localities. With wave action limited to exceptional conditions of infrequent occurrence, there is little probability of any extended growth of the points. Considering the amount of current action, the submerged terrace is of very inferior development. A more distinct terrace may have been formed at the higher level and is now being slowly adjusted to the present conditions.

Little sediment is being brought into the lake and filling in this way is a negligible factor. Vegetation is taking hold on the muddy bottom but has as yet made little growth on the off-shore sands. Fishing is the favorite recreation on the lake and this, with many sand beaches and excellent locations for summer colonies, has made Otsego one of the more popular of the interior lakes of the State.

HUBBARD LAKE

Hubbard lake lies in the drainage of the Nenelon River which flows almost directly north from the lake to the Thunder Bay River. It lies just south of the northern boundary of Alcona County in the central part and, thus, is not readily accessible from the railroad. Yet a lake of nearly thirteen and a half square miles in area ranks as one of our larger inland lakes and is well worth a visit, even though a ride of sixteen miles from Alpena is necessary. The ride, however, need not be monotonous for a variety of glacial formations are crossed and serve to hold the attention.

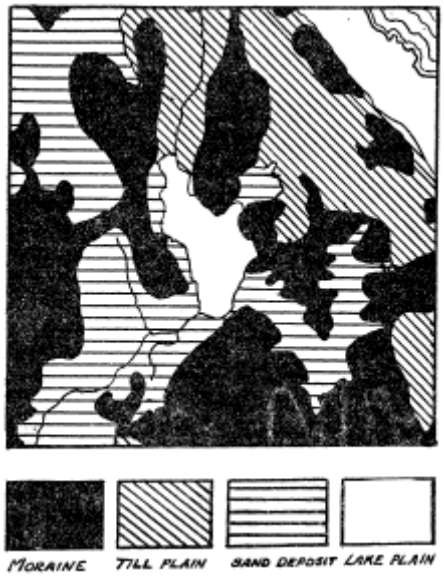

Figure 74. Map of the glacial formations in the vicinity of Hubbard Lake. Note: Hubbard Lake is the white area in center of map.

The first part of the trip is across the sandy lake bottoms of the forerunners of the Great Lakes but in the distance may be seen the strong relief of the moraines to the west and south. The moraines stand well above the lake beds and afford many opportunities for distance views of the neighboring region. It is impossible, of course, to get a comprehensive idea of all the glacial formations in a single trip across the region, but careful mapping of this locality has shown that the moraines are fragmentary rather than arranged in continuous belts. The fragments often cover large areas and are in a very general way aligned in a nearly north-south direction. Between the moraines are till plains or sandy deposits similar in topography but standing at a considerably lower elevation. The distribution of the various deposits is shown in Fig. 74 and from this it will be seen that Hubbard Lake is hemmed in by four patches of moraine. These come to the shores in two places on the east side but on the south and west stand back a short distance. The intervening lowlands determine the position of the larger drainage channels, including most of the inlets and the outlet at the extreme north end.

In a region of such complicated glacial deposits it is difficult to imagine the behavior of the ice. The irregular morainic tracts in themselves nearly enclose basins and show that during the melting the distribution of the ice was very complex and even fragmentary. Thus, it is probable that large masses of ice stood in the depressions after the moraines were free from ice. In the case of Hubbard Lake, it may be supposed that an exceptionally thick mass of ice covered a distinct basin which was uncovered by subsequent melting. The origin of the basin is, however, still a question, due to the lack of knowledge as to the form of the submerged portion of the basin and to the uncertainty as to the interpretation of conditions during the waning of the glacier.

The outlet, see Fig. 75, furnishes a good starting place for a physiographic study of this lake. At the time of the writer's visit a dam of nearly five feet head was holding the lake above its natural level. The present dam has been In for a few years only but the waters for some time previously were periodically held up by logging operations. The submergence and subsequent obliteration of the former shore makes the determination of the amount of flooding difficult, but it is quite evident that this has been sufficient to cause a decided renewal of the activity of the waves and currents, as will be seen from the description that follows.

The outlet flows northward through a narrow channel which has been cut from three to four feet below the level of the swampy lowland at this end of the lake. The outstanding feature in this locality is a strong bar composed of sand and gravel which separates the swamp from the lake. It stands well above the present level even under the flooded condition and indicates a higher level of the lake, which is amply confirmed at

other points on the shores. This former stage must have been the original level of the lake, during which considerable adjustment of the shores took place, and was interrupted by the deepening of the outlet. The bar at the outlet developed from the east side and partially cut off the swampy lowland which now lies adjacent to the stream. The material for this bar was derived from the almost continuous cliffs which rise from five to ten feet above the straight shore to point B, see map, Fig. 75. In one locality only, A, have the shore currents persistently deposited material. The deposit is in the form of a spit which swings outward with very gentle curvature for a distance and then continues parallel to the shore as a sharp spit. The partially enclosed lagoon is open at the north end showing unmistakably that the effective currents flow northward along this shore. The cause is the greater reach of the waves from the south. The presence of good-sized tree trunks standing in water along the bar may be taken as an indication that this bar developed during the former level and also that the lake has been flooded. The reason for the currents leaving the shore in this locality is obscure and must remain so until the configuration of the bottom of the lake is known.

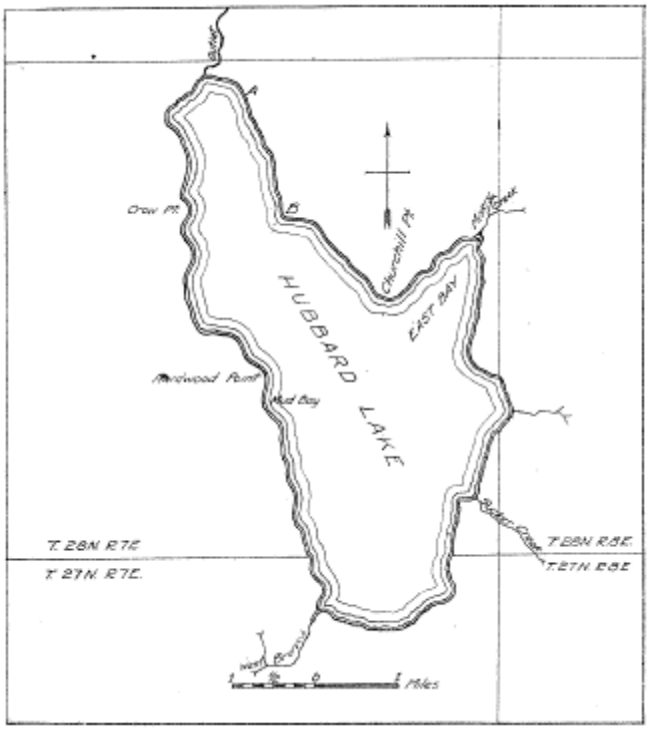

Figure 75. Outline map of Hubbard Lake, Alcona County.

Again at point B the currents have been active and the cause of their departure from the shore is obviously the abrupt bend in the shore line. In this case currents from both directions were involved and a V-bar which enclosed a triangular swamp was built at the former level. The currents from the southeast were the more effective and the bar is unsymmetrical, the sharper curvature occurring on the north side. From the map it will be seen that the shores from which the material of this bar may have been derived are about equal in length on each side. This balance is an apparent one, for the moraine which causes Churchill Point conies to the lake shores just east of the point and has furnished the greater amount of material, as shown by the height of the cliffs which exceed twenty feet in places. In addition, the reach of the southerly winds is much greater than that of those from the northwest, the only ones which could be effective in the formation of the north side of this bar.

Along the shore from B to Churchill Point considerable cutting has been accomplished by the waves and a distinct submerged terrace is present. The outside edge is found usually at about two hundred yards out and drops to deep water from a depth of from fifteen to sixteen feet. This seems rather excessive as compared with the depths found on other lakes of like size, but it must be remembered that this lake stands considerably above its normal level. The recent renewal of wave action is here attested by the fresh cliffs which frequently slump, carrying trees and sod to the beach.

Around Churchill Point the moraine drops to a till plain into which East Bay heads. This bay is exposed to waves of long reach from the southwest which, are intensified by the convergence of the shores, and the shore adjustments were, consequently, exceptionally well defined. The submerged terrace is wide and drops at a depth of twelve feet to the channel of deeper water. Also bars were formed at the higher level on each shore by currents running towards the head of the bay. As in the case of the outlet, these bars cut off the swampy lowland adjacent to Misery Creek, and the lagoon, as well as the exposed portion of the terrace, grew up to forest after the sinking of the level. Under the present flooded condition, the trees stand in water most of the time and are rapidly dying. The bar on the west side of the bay extends to the mouth of Misery Creek, which has some difficulty in keeping an open channel. But wave action is the predominant agent on this side and the bar is retreating landward in a very irregular fashion, due to the presence of the drowned trees. On the east side of the bay the bar is better preserved and terminates in a graceful hook at the entrance of the small embayment into which Misery Creek flows.

To the south cliffs prevail as far as Sucker Creek and reach a maximum height at the projection opposite Churchill Point, which is caused by a morainic fragment. The broad swells and sags cause an alternation of freshly carved cliffs and sandy beaches, which may be definitely described as bars only in the vicinity of the mouth of Sucker Creek. The shore-drift is here to the south as shown by the turning of the stream in this direction. This small stream has brought much material into the lake and has deposited it in a broad shoal, best described as a flooded delta. Ice-action has been powerful along this shore but the only locality where its effects may be observed is at the attachment of the bar to the cliffs north of Sucker Creek. It is likely that much more extensive ramparts or boulder-lined strands were formed but have been submerged or destroyed since the

flooding. The formation of strong pressure ridges on this lake in winter, one of which occurs regularly in this vicinity, makes it almost certain that the ice-push is exerted by jams rather than by expansion. Where the pressure ridge occurs, the lake is two miles in width as nearly as can be measured on the map, an observation of value to the physiographer interested in differentiating between the two types of ice-shove.

Below Sucker Creek cliffs again predominate to the south end of the lake, which is bordered by the undulating lowland through which the West Branch flows. The raising of the water level has flooded this lowland and caused wholesale destruction of the trees, except on low knolls which stand as islands above the swamp and are sharply set off by the green foliage. During the higher level, the flooding was even more pronounced than at the present time and a shallow embayment extended inland along the course of the West Branch. The development of a bar from the east forced the West Branch to the west side of the valley and cut off the embayment, except for the channel maintained by the stream. The bar is in process of destruction at present, due both to the wash of the waves and the spring freshets during which tile West Branch frequently inundates the lowland, including the bar. The current of the stream is especially strong near its channel and consequently the destruction of the bar has been carried farthest at the east end. In fact, this process in conjunction with the flooding of the lake has so far obliterated the end of the bar that the only surface indication is a row of dead trees standing in water.

Along the west side of the lake the lowland runs northward in a narrow strip as far as Mud Bay, where it is interrupted by a spur of the moraine which usually stands from one-fourth to one-half mile back from the lake shore. The lowland strip is somewhat higher than at the south end and, although swampy, has no marked shore features below Mud Bay. This broad bay is caused by a sag at the northern extremity of the lowland strip and was formerly more extensive than at present. The reduction in size was caused by the development of a complete bar which now forms the shore at the head of the bay. This bar is exceptionally well developed, due largely to its enlargement by subsequent ice-action.

Hardwood Point is being attacked by the waves to some extent and has furnished the material for the bar at Mud Bay. However, to the north ground moraine again borders the shore. This stands considerably higher than the lowland below Hardwood Point and low cliffs are the predominating shore features. In one locality only have the sags extended below the lake level and this was completely isolated from the main lake by a bar. As at Mud Bay, ice has succeeded in intensifying the bar and has remodelled it into an ice rampart which rises nearly five feet above the lake. Crow Point is another interesting locality because a considerable portion of the terrace of the former level is exposed here. The sandy material of the ground moraine in this locality was very easily eroded, and the low knob which extended well out into the lake at the former level was planed into a terrace of greater width than usual, so wide that it is not entirely flooded under present conditions. Ice-action is again evident in the series of parallel ridges which rise above this terrace.

From the above description it should be clear that but two stages stand out in the history of this lake basin. Of these, the latter is now submerged by an artificial flooding of the lake and we know practically nothing concerning the adjustments which took place at that time. Of those described all, except possibly some of the effects of ice-shove, have occurred at the higher level. However, the adjustments were carried to an advanced stage of devlopment which determined to a large extent the outline and the general character of the adjustments during the later stage. It is true that the shores were not completely adjusted to wave action and much material was therefore being distributed by currents. Nevertheless, much was accomplished and, in addition to the submerged terrace, the embayments were reduced by bars. In most cases the bars were completely developed and in numerous instances strengthened by ice-action. Among the notable changes accomplished in this way may be mentioned the embayments at the outlet, West Branch, Sucker Creek, and Misery Creek.

The lowering of the level was due to the downcutting of the outlet which was sufficient to account for a drop of about five feet. Judging from lakes whose main adjustments have occurred at higher levels, we may be reasonably certain that changes of a minor character only were in process previous to the flooding of the lake. When a considerable depression of the level of a lake has taken place, it frequently happens that the activity along a given shore may be reversed from cutting to deposition (see Otsego Lake). Such reversals are likely to take place where the terrace is locally wide and probably occurred on this lake at Crow Point and the delta of Sucker Creek. This, however, is conjectural and cannot well be substantiated under the present conditions.

The most striking thing of physiographic import is the renewed activity on the shores of Hubbard Lake, due to the artificial raising of the water level to within about one foot of its former position. The flooding of the adjacent lagoons, previously dry as shown by the forest growth, and the freshly cut cliffs are the more evident effects of this rejuvenation. In places, however, unexpected effects such as the degradation of the bars of the higher level are found, even though the water level stands lower than formerly. The sapping of cliffs and destruction of depositional forms of a higher level is due to the fact that the ponding of the lake by a dam holds the water at the flood stage for a longer period than normal each year and thus causes effects that are greater than would be the case if the lake were allowed its normal seasonal fluctuation.

Ice action exerts a powerful shove on the shores of the lake and mainly by jams, although some expansion may

take place in the narrower parts. In general, the effects are more frequently encountered and are better developed on the west side and consist almost exclusively of ramparts formed on the bars which cross the mouths of identations. Boulder-lined strands are not present, although conditions both as to material and topography are favorable for their formation. Ice jams are active on all shores of a lake but have a tendency to exert a greater push on the east side. Likewise wave action is more intense on the east side due to the prevalence of storm winds from the west, and it is possible that many of the features due to ice shove have been destroyed on this side while on the opposite side they are still preserved.

During the higher stage of the lake, its area was considerably reduced by the cutting off of indentations but the lagoons had not been filled when the level lowered. At present they are again flooded and are rapidly being filled with vegetation. As regards the main lake, little filling of any kind is taking place and, since the outlet is dammed, we may have little concern about the further extinction of the lake. Shore adjustments are far more important at the present and will continue to be so as long as the high level is maintained.

LONG LAKE, ALPENA COUNTY

This lake should not be grouped with the interlobate lakes nor was it ever isolated by current action from one of the former stages of the Great Lakes but is appended here for want of a better place. In the naming of lakes descriptive, terms are very often employed and those most frequently used are "round" and "long". This is especially true of the inland lakes of Michigan and, since these names are duplicated many times, it is necessary to add a statement as to their location. The lake under discussion crosses the boundary between Presque Isle and Alpena counties near its eastern extremity and is divided into two almost equal parts thereby. It extends seven and a half miles in a northwest-southeasterly direction and nowhere exceeds one and a half miles in width. The area is slightly greater than eight square miles, making the average width in excess of a mile. The basin lies on the exposed terrace of Lake Algonquin whose shore stood just west of the lake. The terrace in this locality consists of a' series of troughs and ridges which run parallel to the glacial striations found on the bed rock. It is probable that the ridge-and-trough topography existed previous to glacial times and was modified, but not obliterated, by the passage of the ice over it. As regards the troughs the modification where the ice moved parallel to the trend of the topography consisted mainly in a widening and deepening process, and the effects produced varied locally due to variations in hardness of the rock, fracture systems, and other factors. Where the erosion was greater the trough was deeper and this, in conjunction with the damming of the trough by glacial deposits may account for the Long Lake basin. Yet the irregularities of the shoreline and in the depth of the lake and the occurrence of numerous limestone blocks, both on the shores and the bed of the lake as well, lead one to believe that some other factors have been instrumental in the formation of this basin. Although positive evidence is not at hand, one cannot overlook the possibility of the effect of underground drainage and the resulting sink holes. It is certain that a considerable amount of the rainfall sinks below the surface in this region and flows to Lake Huron in subterranean channels. Sink holes and disappearing streams are numerous in the area from Thunder Bay to Black Lake in Cheboygan County, and the former are found within a few rods of Long Lake. Many of the smaller irregularities of the shore are due to the removal of blocks along the frequent joint planes but it appears difficult to account for the larger embayments unless the possibility of sinks is admitted.

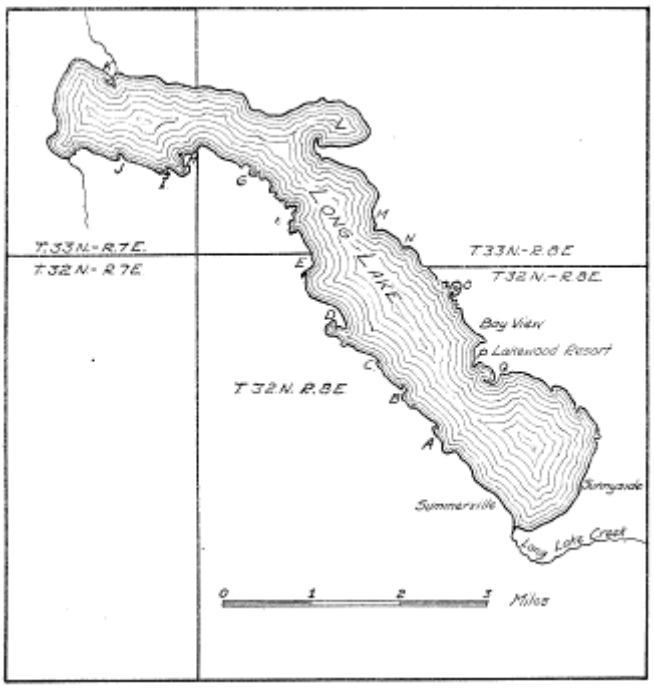

Figure 76. Outline map of Long Lake, Alpena County.

The surrounding region is very thinly drift covered and in several places the bed rock outcrops on or near the lake shore. These outcrops, however, are not numerous and have little effect on the general outline of the lake. The numerous large boulders are largely of local derivation, that is, are of limestone, and many have been pushed on the shores from the lake bottom by ice.

The lake is readied by a six mile drive from Alpena which brings one to the southwestern shore. The south end of the lake is held by a low sand plain which stands but slightly higher than the lake and is swampy during high water. The sand beach which forms the lower end of the lake is the best example of shore adjustment to be found on this body of water. Not only is the material well assorted and the curvature even but a well-defined submerged terrace is present which has a maximum width of one-fourth mile and drops at five to six feet. A low ice rampart skirts the present shore but evidence of a definite current deposit was not found. The rampart

may possibly be a remodelled bar but this is not certain. Yet the position of the outlet at the southwestern side and its turn to the east after leaving the lake indicate a drift from the east side of the lake. The adjustment of this shore is due to some extent to the topography and material but largely to the great reach of the prevailing storm winds from the west and northwest. The outlet has cut a shallow trench through the sand flat; a matter of importance in explaining the presence of shore features above the present level found elsewhere on the lake.

About a mile inland from the southwestern side of the lake the bluff of Lake Algonquin runs approximately parallel to the lake. The exposed terrace of this lake has a very thin surface cover near the southwestern end of Long Lake and in places the rock beds are exposed. At all outcrops the rock has been planed off and is marked with striations which run parallel to the lake basin. Such evidence shows the part played by the glacier in the formation of this basin.

The shoreline north of the outlet on the west side has few irregularities for about one mile and shows little adjustment. A broad bay at locality A, see map, Fig. 76, marks the beginning of a very irregular shore which persists nearly to the north end of the lake. At A the waves and currents have accomplished little but a small indentation on the north side of the bay has been isolated by an ice rampart and is now well on the way to extinction by vegetation. In fact, ice has been the most powerful agent on this shore and waves and currents have been effective only in the most favorable locations. Thus, ramparts are the common shore feature and in many places are strong ridges of coarse material. At B currents have turned from the shore and a well-defined, but small, hook pointing up the lake has been formed. Again at C the currents have deposited detritus but in this case the spit is turned to the southeast, showing a reversal in the direction of the effective currents.

Along the south shore of the bay below point D an excellent ice rampart of at least five feet in height and containing boulders of several tons in weight was found. The rampart diminishes towards the head of the bay and disappears at the low fat which continues to the northwestward more than one hundred yards. This lowland was formerly a part of the lake but has been partially drained and filled with vegetation. The bay is shallow and the muddy bottom contains a heavy growth of reeds. In places the shore and bottom are lined with a white sand which is found to be composed almost entirely of shells, indicating the active formation of shell marl. On the north side of the bay current action is well shown by the spit which has grown an appreciable distance across the bay. The material averages nearly three inches in size and indicates the presence of a powerful drift into the bay from this side. The presence of a rampart on the spit and the coarseness of the material leads one to conclude that ice has been of considerable importance in the building of this form. The spit is not increasing under the present conditions and its period of most rapid development must antedate the cedars of more than two feet in diameter growing on its crest.

On the end of point D, where one might expect current deposits, a submerged terrace, composed of rocks except for a sandy zone near its outer edge, is present. This terrace, therefore, has been swept free of finer material by the waves and undertow and has a comparatively narrow built portion. On the side of the point facing the lake a narrow, but distinct, exposed terrace upon which boulders are scattered is evidence of a former level of the lake between two and three feet higher than that at the present time and shows that the terrace was cut, wave activity having been the predominant factor in the adjustment of this point in the past. The tendency for the boulders to stand near the former shore shows, furthermore, that ice has been active during the higher level.

The broad embayment north of D is caused by an extensive sag in the Algonquin terrace. The present shores are composed of rubble and show little adjustment. For the most part the irregularities of this shore are due directly to variations in the Algonquin terrace and adjustments, if present, are found at the projections. One of the most interesting was found at F. The projection itself does not differ materially from those occurring so frequently along this shore, but the small point which runs to the northwestward from its extremity is of considerable interest. In all but one respect this minor feature resembles an unsymmetrical V-bar, see Plate XIV, B. Two bars meet in a blunt point and enclose a shallow depression. That on the east; or lake, side is the better developed and is fronted by a submerged terrace while that on the opposite side drops steeply below the water level. On the east side the bar has been remodelled in part into an ice rampart. The most interesting feature in connection with this point is the coarseness of the material of which it is composed. The smallest size of particles was not less than one inch but the maximum was as great as two feet in largest diameter. Also the rubble is for the most part angular in form rather than rounded, the form characteristic of water-worn material. Clearly this material has not been transported by waves and currents unaided and yet is not the typical ice rampart. It seems possible that stray blocks of ice in whose bases rocks have been frozen may have been blown against the point and upon partial melting dropped some of their load. The material was then worked over to some extent by the pounding of the ice blocks as they drifted with the waves, causing a spit-like form of very coarse material. The exposure of this point to the southeasterly winds which sweep up from the lower end of the lake accounts for the greater development on that side.

Beyond F the irregular shore shows little adjustment until the small bay designated as G on the map is reached. On the east side of this bay the terrace of the former level is present and is emphasized by ice ramparts at the shorelines of both the present and higher levels. On the

opposite aide of the bay, which has the advantage of a relatively smooth shore to the west, the currents, aided by ice, have succeeded in building a hook of coarse material similar to the form found at F. That the currents along this shore are reversed with the shifting of the winds is shown by the hook which is developing westward from the end of point B. The material of this hook is sand and extends under water as a shoal of considerable extent. The point has been abruptly turned by the westerly winds, giving the effect produced by tidal races in the ocean, as at the tip of Cape Cod. In the small reentrant at an interesting series of five parallel cusps pointing towards the middle of the bay was noted at the time this study was made. These low water forms are similar to those found on Douglass Lake, under which, their manner of formation was discussed. Just west of the indentation, a small projection of the shore is caused by an outcrop of thinly bedded limestone which shows some undercutting by the waves at the higher level. At present, however, the waves have not been able to keep the foot of the low cliff free from talus and the point is, therefore, receding at a very slow rate.

Westward to the end of the lake, the shore is relatively smooth and little adjustment has taken place. One rather prominent exception is the point at J which breaks the continuity of the currents along this shore. A spit of rubble up to six inches in diameter is growing in a southerly direction from the west side and may cut off a small bay in time. The contrast between the coarse material of the spit and the sandy bottom of the bay in process of inclosure emphasizes the importance of drifting ice as an aid to currents in the formation of such features. It is interesting to note that the northeasterly winds play the more prominent part in the shove exerted by ice on this shore.

Beyond J there is little of interest until the shore turns to the southwest to form the small bay at the end of the lake. Here two incipient spits are developing and the material is again coarse rubble indicative of ice-shove. The probability of these spits developing across the mouth of the bay is remote, for vegetation is well started in the bay and literally carpets the bottom. Lilies and rushes have also taken hold and extinction by vegetation before the spits are completed may be expected. Within the bay the noticeable shore adjustment is a well-developed ice rampart which stands just above the high-water strand. The west end of the lake is very shallow and is lined for most of the distance with a good sand beach.

In general, the northeastern shore of the lake is more regular in outline than the opposite shore and especially so from the west end to the large bay at L. Adjustments by waves and currents are very slight and are, therefore, very noticeable when present. Thus, the spit which has developed from the end of the narrow point at K stands out prominently and is an indication of the strength of the easterly winds which have a much greater reach than those from the west. But the relatively smooth stretch of shore to L is not without interesting features, for here are found some of the best examples of the effects of ice shove on the shores of the lakes of our State. Ramparts are the striking features of the shore and they are found in two almost continuous belts, representing the former and the present levels. As a rule the rampart of the former level is the stronger and stands from five to ten feet back of the one formed under the present conditions. The stronger rampart is a distinct ridge which frequently reaches five feet or more in height and contains boulders of several tons in weight. The offshore slope was not swept free of boulders before the water level receded and a quantity of material has been piled up since that time in the present rampart. Nor is the process complete at the present time for boulders are seen in the process of transportation across the terrace towards the rampart. Two such boulders are shown in Figs. 77 and 78 from which may be seen the trench along which the rock has moved and the rubble piled in front like the “bone in the teeth" of an ocean liner. Several of these boulders were seen on this shore and the paths, of all were found to be practically in' the same direction. This direction, moreover, was not at right angles to the shore but from southwest to northeast. These rocks were undoubtedly moved by the ice but the manner of shove has not been observed by the writer. However, the fact that large ice-jams occur on this shore of the lake and that the direction of the movement of the boulders over the terrace is diagonal leads one to believe that ice jams have been more effective than expansion, although the width of the lake is well within the limit for the latter.

Figure 77. Boulder pushed on shore by an ice jam, Long Lake, Alpena County. This boulder will travel up the beach in stages and eventually become a part of the rampart. (Sketch from photograph.)

Figure 78. Boulder pushed on shore by an ice jam. This boulder has nearly completed the journey to the strong ice

rampart which stands a few feet to the right and is hidden by the trees in the sketch. Long Lake, Alpena County. (Sketch from photograph.)

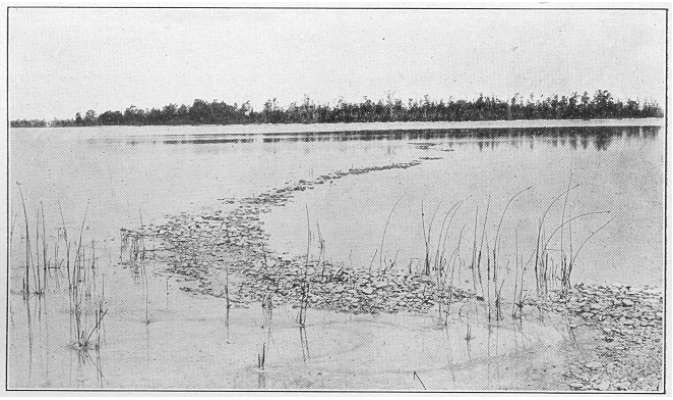

Plate XV, A. Ice-formed Spit, Long Lake, Alpena County.

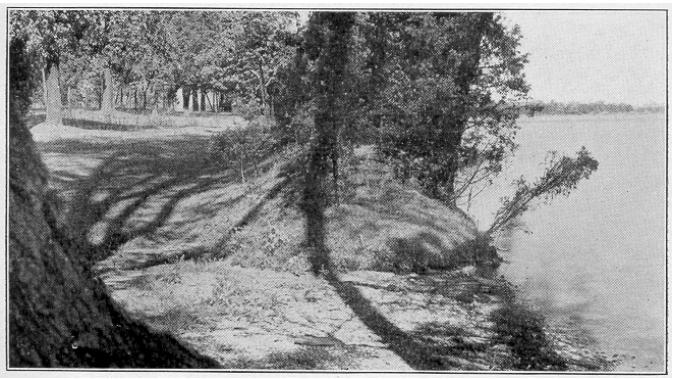

Plate XV, B. Ice Rampart, Apple Island, Orchard Lake.

The lake is very shallow off this shore and the bottom is composed of large angular boulders except for a zone of sand near the shore. No "drop off" could be detected but the sand zone is considered its equivalent, its outside edge marking the outer limit of the effects of the undertow.

The bay at L is shallow but, nevertheless, waves of considerable power have removed the thin drift cover and exposed the limestone on the west side. Vegetation is gradually taking hold and will aid in the extinction of this arm. Another factor of importance in this connection is the action of currents and ice off the point at the east side of the entrance. The greater portion of the point which separates this bay from the main lake was original with the lake basin, but the end has developed into a hook, typical in all respects except the size of the material, which is frequently as much as six inches in diameter. Thus, the beach is evenly curved, a depression stands to the rear, and the bottom slopes gradually off shore into the lake but drops steeply on the bay side. Currents have clearly been the important factor in its formation but the large size of the material leads to the conclusion that ice has been instrumental to some extent. However, near the end of the hook a peculiar offshoot, see Plate XV, A, has developed at right angles to the general trend of the shore. This spit, which is composed of large, angular material, is, furthermore, serpentine in form and could hardly have been formed by currents alone. One is compelled to account for its formation in a manner similar to that of the point at F on the opposite side of the lake. Currents are effective on the south side of the point also and have built a blunt spit of rather coarse material. Currents from both directions are contributing to this point but are making slow progress, due to the deeper water in this part of the lake. Ice push is very effective on the end of this spit and has piled up a rampart fully six feet in height.

To the southeastward the beach, although composed of rather coarse material, is of even curvature until the bluffs of the higher ground at M are reached. Considerable adjustment has taken place along this shore, as is shown at the small indentation just north of the bluffs which has been separated from the main lake by an ice rampart. It is probable that currents were instrumental in the isolation of this indentation in the early stages and that the bar thus formed has been remodelled by ice. The currents in this case came from the west and, after the completion of the bar, swung-around the apex of point M and were turned from the shore a little farther on. Currents from the opposite direction also left the shore in this same locality and as a consequence a blunt spit has developed which is similar to the V-bars already described. The material is large for such a form, the usual diameter being about one-inch with a maximum of four inches. Here also the ice has been effective and has formed a rampart comparable in size to that found on the point below bay L. When seen by the writer the currents from the southeast had the advantage and were building out on the north side, but this condition may have been temporary. In general, the symmetry of such a form is a safe indication of the strength of the forces which are active in its development. Shoals run out into the lake from two hundred to three hundred feet in front of the points along this shore and are sufficient to turn the currents out into the lake. In most cases the shoals are of rock, but at N a definite built terrace of sand which drops into deeper water at five feet is present.

To the southeast, the shore is broken by a number of small points and the shallow bay at O. A small spit on the north side of the bay indicates some current from the northwest but this is necessarily feeble due to the irregularities of the shore along which the currents develop. On the south, however, the currents from the opposite direction are much more powerful and have built a hook which, with its submerged continuation, extends two-thirds of the distance across the mouth of the bay. The shore to which the hook is attached has a very low slope and a broad flat is exposed during periods of low water. Much of the material on this fiat is coarse and several boulders were noted which had halted, in their journey towards the shore. These have undoubtedly been pushed by ice and, inasmuch as the direction of the paths agrees with that found on this shore near the upper end of the lake, ice jams are believed to have been the propelling force.

The shore to point P is more regular and shows little adjustment save for the assortment of the beach material which is relatively coarse for a lake of this size. At P currents, developed on both sides of the projection, have left the shore and built a blunt V-bars. This bar is, in reality, composed of two V-bars, one built outside the other. The one nearer the land is the older and the enclosed lagoon is now filled with vegetation, whereas the outer has developed subsequently and the wet lagoon supports a growth of rushes. It is probable that the older lagoon was formed at the higher level but not until a strong ice rampart had been piled up at the old shore. The outer lagoon is the result of the activity of currents under the present conditions and is developing most rapidly during high-water. Obviously, the currents from up the lake are the more powerful on account of the greater reach of the winds, the longer stretch of shore, and the protection afforded by point Q to the short strip of shore to the south.

Point Q is a peculiarly shaped projection which originally was a narrow strip jutting out into the lake. Strong currents evidently swing around this point from the southeast, and as a result the end is a well-developed hook whose point of departure from the original point may be readily detected by the ice rampart at the former shore. At present the hook is growing directly towards point P and may in the course of time enclose the narrow strip of water between the two points. The turning of Q to the northwest is interesting in view of the fact that the two points between this and the southeastern end of the lake are both spits pointing in the opposite direction. It appears, then, that the turning of Q is due to the protection of the shore to the northwest by P rather than to exceptionally strong currents from the opposite direction.

The first of the spits below Q was .caused by a bend in the original shoreline sufficiently abrupt to throw the currents from the shore. The material is coarse and has been pushed into a rampart on the lake side. The main shore protected by this spit is a smooth sand beach but gives way to coarser material beyond the end of the spit. Nearer the lower end of the lake a narrow strip of the lowland borders the lake and forms a fringe of swamp. The second point developed across a depression in the swamp during the higher level and enclosed a narrow lagoon which is now grown up to marsh grass and may be flooded during very high water.

The basin of Long Lake, then, may be assigned to glacial scour with the possibility of solution by ground water as an added factor. The irregularities of the shoreline furnished opportunities for numerous adjustments of the shores by waves and currents, and the abundance of coarse material as well as' the topography of the shores is favorable to development of forms due to ice push. The adjustments by waves and currents have seldom passed beyond the early stages but those due to ice have produced some very marked results. In fact, ice ramparts are by far the most pronounced of all the shore features on this lake and there is hardly a locality where they may not be observed. Both types of ice shove are effective but the writer is inclined to lay the greater stress on ice jams. Furthermore, floating cakes of ice seem to have played at least a subordinate role in the shaping of some of the depositional features.

The lack of adjustments by waves and currents may be assigned to several factors. Undoubtedly waves of considerable size run lengthwise of the lake but lose much of their force before reaching the shore on account of the uneven surface and the flatness of the off shore slopes. The greater part of the work done by the waves has been the assortment of the beach material, accomplished by the removal of the finer particles. The paucity of current deposits is due in part to the very irregular shore which prevents the formation of currents of sufficient continuity for large effects. In addition, the material upon which these forces are acting may be of some importance. In general lake clays, boulder clay, and limestone are the materials encountered. The disintegration of both the lake clays and the till furnishes little sand but rather a slimy mud which is carried out onto the lake bottom. This mud is very calcareous and may account for the lime deposits which accumulate on the pebbles near shore, although it is recognized that such deposits are formed by the action of lower plant forms.

The two stages in the history of the lake conform to the general conditions found on our inland lakes. The drop in level is due to the downcutting of the outlet and has occurred rather rapidly. If this is continuing at the present time, the process is a slow one and the probability of the lake being drained is remote. Vegetation has taken hold in a few localities and some marl is being deposited but it seems best to consider the lake in a youthful stage of development.

CHAPTER VII. INTERIOR LAKES OF THE SOUTHERN PENINSULA, CON'T. LAKES OF THE EASTERN INTERLOBATE AREA

ORCHARD LAKE

In a glaciated region the largest and most diversified deposits are found in the interlobate areas. As has been stated heretofore, in the reentrants between any two lobes of ice the rock debris is supplied from two ice fronts, and the accumulation is, therefore, not only much greater than that of a single front but also the forms are very Irregularly distributed. In such regions the continuity and arrangement of the deposits are greatly disturbed, or wanting entirely, and the topography consists of an intricate patchwork of the various glacial forms. Undrained depressions are, therefore, especially numerous but are usually small on account of the lack of

continuity of the deposits. In the interlobate area which stretches southwestward from the Thumb, the surface is literally dotted with lakes and from certain eminences as many as ten to fifteen may be seen. Oakland County is especially favored in this respect; more than one hundred named lakes appear on the Pontiac topographic map which represents about one-fourth of the area. The lakes are all small, ranging from a maximum of about two square miles down to insignificant ponds, and lie for the most part in morainic basins or pits in the outwash. Two of the larger of these lakes, Orchard and Cass, were selected for study on account of their size, popularity, and accessibility, but the writer realizes fully that the work should be extended to include groups of lakes, possibly on the basis of drainage systems.

These two lakes are part of a group which lies southwest of Pontiac and drains into the Clinton River. They may be reached via the Jackson Branch of the Grand Trunk R. R., the Detroit and Orchard Lake interurban cars, or by automobile over excellent roads. They both lie in rather large morainic basins and are, therefore, rather simple as to origin. The shores, bounded by moraine, are varied as to relief but uniform as to material. The stiff boulder clay is not readily eroded by shore agents, and on small lakes, such as Orchard and Cass, the adjustments of the shores are not on a large scale. Nevertheless, sufficient work has been done both at the present level and a higher level to make the study interesting.

Figure 79. Topographic map of Cass and Orchard lakes and vicinity, Oakland County. (From U. S. G. S. Pontiac quadrangle.)

The nearly circular form of Orchard Lake is emphasized by Apple Island which stands slightly north of the center of the lake. See Fig. 79. The lake is entirely surrounded by moraine which rises well above the water, dipping only occasionally to small undrained swales. The shores are well drained for the most part and advantage has been taken of the many excellent locations for summer homes. The lake is deep (reputed to be one hundred and seventy-five feet) but systematic soundings have not been made, so that the exact depths are not at hand. For our purpose it is sufficient to know that the waves may develop free from interference by the bottom except in the vicinity of the shores. The lake receives the water of Pine Lake, which stands to the west, through a small channel of very sluggish current as the lakes stand at about the same level. Orchard in turn empties into Cass Lake, which stands one foot lower, through a similar channel across the narrow neck of land on the north side. From Cass Lake the drainage passes through Otter and Sylvan Lakes to the Clinton River which is dammed a short distance below Sylvan Lake. The total fall from Pine to Otter Lake is about two feet, a fact which may be accounted for in part by the damming of the Clinton River. Yet, it is doubtful if the drainage above Cass Lake is affected by the dam, and the slight difference in the levels of Pine and Orchard Lakes, is due to the flat gradient and short course of the outlet.

The outlet of Pine Lake enters Orchard at the narrowest part of the land strip which separates them. This insignificant stream flows through a swamp which extends to the shores of Pine Lake. No indication of bars or ramparts was noted along the Orchard Lake shore but a well-developed bar crosses the flat on the Pine Lake side at a level slightly above the present. Thus, the two lakes were originally connected, forming part of a larger and very irregular lake which included Pine, Orchard, Cass, Otter, Sylvan, and possibly Elizabeth lakes. Also during this early stage Pine and Orchard were separated by the development of the bar just mentioned.

South of the outlet of Pine Lake the shores of Orchard are exposed to the powerful west winds and the waves have the full sweep of the lake. The land stands well above the lake level except for two small sags, so that the adjustment of the shore has been accomplished mainly by waves. They have formed a steep cliff in the compact till and a well-defined submerged terrace which reaches a width of one hundred to one hundred and fifty feet and drops into deep water from depths of five to six feet. The recession of this cliff straightened the shoreline to some extent but currents were also instrumental, as shown at the sags. In both cases the reentrants were cut off by bars which have since been remodelled into ice ramparts. The first sag, A on map, Fig. 79, is a small morainic depression which, since its separation from the lake, is filling rapidly with vegetation.

Around the south side the lakeward slopes are very gentle and the adjustments much less pronounced than on the east side. The submerged terrace swings In close to the shore and the cliffs are very low. The adjustment of this shore consists mainly in the

transportation and distribution of material from the east side by currents, forming a sand beach and built terrace. Between Orchard and Upper Straits lakes a flat saddle interrupts the uniform conditions of the south side, and the adjustments of the shores are negligible. The lowest part of this saddle stands about five feet above the present level of Orchard Lake and served as a very narrow divide between the two lakes during the higher level. The blunt point, B on map, is a part of the saddle and shows no current activity. North of this point the land rises to a rolling moraine and low cliffs of variable height face the shore. The absence of current deposits at B leads to the conclusion that the material from these cliffs has been transported northward. This material was deposited in two spits near the entrance to the embayment at the northwestern part of the lake. The first spit lies directly south of Cedar Island and is too small to be shown on the map. It is slightly recurved near the tip, almost enclosing a narrow lagoon, and has been converted into an ice rampart near its attachment to the shore. The second spit lies west of Cedar Island and is much the larger. The currents along the west shore continued beyond the first spit but were forced directly out into the lake at the second. Thus they dropped practically all their load and have built the larger spit in this locality. It is doubtful if any material was supplied from the west for the bay is small and the shores are mucky. In fact, the bay is being filled with vegetation at a rapid rate and the heaviest growth occurs on the south side.

The hills which form the west and north sides of the bay are separated by a low sag which extends through to the west end of Cass Lake. This channel is a swamp from Cass Lake to the road and stands less than three feet above, Orchard Lake at its highest point,—the road crossing. If allowance is made for some filling along the highway, it seems probable that a shallow connection formerly existed between the two lakes in this locality.

North of Cedar Island a small knoll forms a point on the main shore which was sufficient to turn the currents from the shore. The material transported along the north shore to this point is apparently very small in amount, since the spit has made little headway. However, it is pointing directly towards Cedar Island and its continuation would tie the island to the mainland. A contributing factor in this connection is the spit growing landward from the north end of the island but much is yet to be accomplished. Cedar Island is a low knoll which may serve as an excellent index to the activity of the shore agents in this part of the lake. The north shore shows no adjustment and the waves have not prevented a thriving growth of vegetation. On the south side the waves have carved the slopes into low cliffs, and the material has been transported in both directions by reversing currents, as shown by a spit at the west end as well as at the north. In addition to the waves and currents, ice has been effective and has pushed boulders into the cliffs and the landward portions of the spits into well-defined ramparts. The possibility of the island attaching itself to the mainland by the growth of the spits at either end suggests itself, but this is improbable on account of the limited amount of material in this small island.

The north shore is a succession of cliffs which drop to lake level In two places only. In both cases the low areas are channels which connected with Cass Lake during the early stages of the higher level. Bars developed from the west across both channels on the Orchard Lake side and were later pushed up into ice ramparts. The westerly connection was completely obstructed In this way and Beebe Lake was formed midway between the two lakes. The easterly channel was never .completely closed and Is now occupied by the outlet of the lake. In the vicinity of the Military Academy the adjustments are obscured by "improvements." One might expect at least the beginning of a spit where the land drops to the flat separating Pine and Orchard lakes but, if so, it has been covered by the highway.

Apple Island is a somewhat elongated cluster of morainic knobs that stand well above the level of the lake. Its location near the center of the lake exposes all of its shores to agents of approximately equal intensity, and differences in topography are, therefore, more important in determining the adjustment of the shores than the wind direction. Waves are very active and have carved steep cliffs along the entire southern and the greater part of the northern shores. At the blunt projections, however, the slopes were originally flatter and the effects were more pronounced in some respects. Not only were the waves able to cut a wider terrace but also currents were able to add to this, although no definite bars were formed. In such localities the sinking of the water level exposed relatively broad terraces which are excellently preserved and furnish the clearest evidence of the former level of the lake. The points on the west, north, and northeast shores are well worth inspection. The expansion of the ice during the winter is also effective on the shores of the island and especially so on the south and east sides, due to the greater expanse of the lake. On the east side the outer edge of the exposed terrace has been pushed into a rampart, see Plate XV, B, which obstructs the drainage and causes swamp conditions in places.

CASS LAKE

A convenient starting point for the study of Cass Lake is Dollar Lake. This little pond lies in a pit in a fragment of outwash that borders a part of the east shore of Cass Lake and is now a muck basin, rapidly decreasing in size on account of the encroachment of vegetation. Dollar Lake was formerly in direct connection with Cass Lake but the channel became so crowded with plants that it was necessary to open it by dredging.

With the exception noted, Cass Lake is surrounded by moraine, composed of broad swells and sags rather than sharp knobs and basins. Consequently the shores are either dry or are swampy for long stretches. The south

shore stands consistently well above the lake and the shore features are so uniform that the few exceptions are greatly emphasized. Leaving Dollar Lake, one's attention is at once attracted to the point across the bay. The major portion of the point is due to a knoll which juts well out into the lake but the narrow eastward projection is clearly a spit. The spit stands more than two feet above the present level of the lake and is covered with grass and trees. See Plate XVI, A. Near its attachment it has the characteristics of an ice rampart which continues along the edge of an exposed terrace surmounted by a cliff. The effects of waves, currents and ice may be seen within a short distance and indicate a higher level for this lake which corresponds exactly with the former level of Orchard Lake. The disturbing feature is the present activity of the waves which is removing the rampart and spit, laying bare the roots of trees. See Plate XVI, B. This is unquestionably a renewal of activity and is due to an elevation of the water level, probably a result of the obstruction in the Clinton River.

South of the spit the exposed terrace soon plays out and the shore is faced by a cliff which is continuous to the outlet of Orchard Lake, with the exception of a narrow gully about midway. This cliff, pounded by waves driven in from the west, has furnished the material for the spit above. The renewed activity of the waves is clearly seen in the fresh cliffs, landslides, and undermined trees and may result in further extension of the spit after it has adjusted its position to the new conditions.

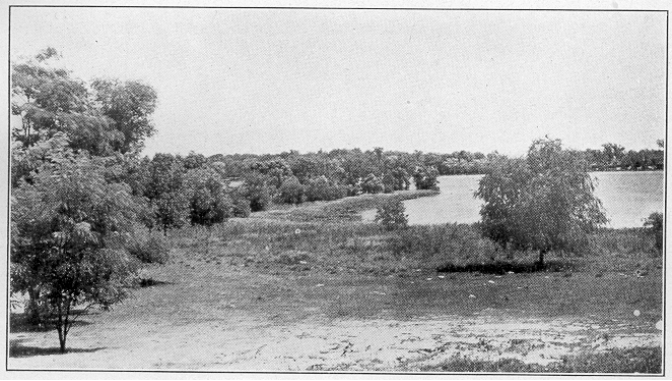

Plate XVI, A. Spit, Cass Lake.

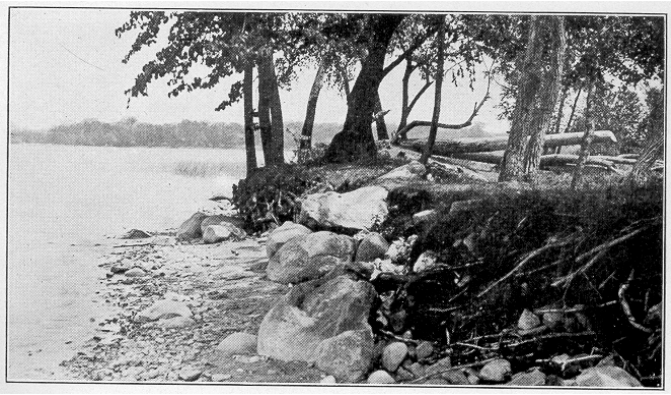

Plate XVI, B. Dissection of ice rampart, Cass Lake.

The outlet of Orchard Lake and the Beebe Lake channel interrupt an almost continuous cliff to the west end of the lake. Wave action is less intense along this part of the shore on account of the restricted reach of the waves and fresh scars are not abundant on the face of the cliff. Also a boulder-lined strand is still intact. Farther west wave activity is still less and two neighboring gullies are able to maintain a small delta in the lake. Strong currents are undoubtedly set up along this shore but conditions are unfavorable for deposition at present. During the former stage, the depressions at the Orchard Lake outlet and the Beebe Lake depressions were crossed by currents, but the latter only was obstructed by a bar. The position of the outlet of Beebe Lake near the east side of the depression shows that the bar developed from the west.

Near the west arm the exposed terrace of the upper level appears and widens towards the bay. It reaches its greatest width on the south side of the bay and then diminishes. Outside the bay on the west shore the cliffs rise directly from the beach. The presence of the exposed terrace in the more protected places leads to the conclusion that it was formerly continuous and has been removed subsequently to a very large extent. The cliffs extend to the neighborhood of Gerundegut Bay, which was formerly an extended but shallow arm of the lake. The dropping of the water level exposed more than one-half of its bed and the shores are consequently low and swampy at the present time. The entrance to this bay is restricted to a channel which does not exceed forty feet in width, the remainder, as shown on the map, being blocked by very shallow water grown up to rushes. The shallow water appears to be due to submerged terraces which were extended from either side by current action. The greater extension of the terrace on the west shows that the currents from this direction are the stronger. This may be due to more favorable shore conditions combined with the greater effectiveness of the southwest winds. Within the bay the adjustments are uncertain, for the shores are lined by swamp, and filling by vegetation is the dominant physiographic process. Between Gerundegut and Coles bays, the shores consist of the swampy terrace for the first half of the distance but beyond rise to cliffs which extend to the west side of Coles Bay. In contrast with Gerundegut Bay, Coles Bay is deep and has a relatively narrow entrance. A minor indentation just west of the entrance to the bay was cut off by currents but much more important adjustments are found at the bay and along the shore to the east. The small spit at the west side of the entrance to Coles Bay seems rather insignificant on first sight but closer examination discloses that its continuation under water nearly blocks the channel, the water above it nowhere exceeding three feet in depth. Furthermore, this bar rises to the higher level of the lake east of the bay and runs as far as the outlet, causing it to turn to the southeast. Near the east side of Coles Bay the bar stands at the present shore but is fragmentary and irregular in form, due to the renewed activity of the waves which is causing a recession of the shore. East

of the outlet the old lake bed extends towards Sylvan Lake but is dotted with small hills which stood as islands above the lake at its higher stage. In building the shore road advantage has been taken of a well-defined bar which extends southeastward from the outlet and connects directly with one of the "island" hills whose slopes were carved into a cliff and terrace during the higher stage. Farther south the old lake bottom connects with the Dollar Lake depression without definite shore features.

A study of the shores in the vicinity of the outlet shows that currents were the active agency in their development. The work was practically all accomplished when the lake stood at the higher level, but some deposition may now be taking place on the submerged portion of the Coles Bay bar. The most conspicuous adjustment was the building of bars across the flat now occupied by the outlet. They developed from both directions and would have met, if the currents east of the outlet had run a little farther to the south. As it is they dove-tail and Cass Lake was never completely isolated during the higher stage.

Briefly stated, the outstanding fact in the history of the lakes under discussion is the existence formerly of a large, irregular body of water which not only included the basins of Orchard and Cass lakes but of some of the neighboring lakes as well. During this stage considerable adjustment of the shores took place and, as a result, the present lake basins were at least outlined, if not isolated. If it may be assumed that the bars stood above the water level, Orchard and Pine lakes became definite basins and Cass nearly so. Many of the changes, however, were interrupted by the lowering of the level and little seems to have been accomplished during the lower stage. A renewal of activity, however, is clearly indicated at the present time, due probably to the interference with the flow of the Clinton River, and adjustments are beginning anew. It may not seem possible that the effects of an obstruction of the drainage would be so far-reaching but it must be kept in mind that an actual rise in the water level is not necessary to produce an increase in the adjustment of the shores. Small lakes vary considerably in level during the season and any cause which will prevent a fall during the dry season is equivalent to a higher level on the average. As has already been stated, this study was not complete but it is hoped that from what has been done the work may be extended by the reader to the other lakes of this group.

LONG LAKE, GENESEE COUNTY

In the discussion of Orchard and Cass Lakes the confused arrangement of the glacial formations of the interlobate area in the southeastern part of the State was mentioned. Outside this area on the Saginaw Bay side the deposits are. distributed with a regularity which, by way of contrast, is very pronounced. Morainic ridges, separated by till plains and occasional outwash aprons, form a series of wide, roughly parallel loops about the Saginaw Lowland, extending from Genesee County westward to Ionia County and thence northward to the southeastern part of Roscommon County. In many localities the streams follow the moraines for long distances but in others they flow directly across the trend of the ridges. Numerous small lakes occur in this region, the majority filling depressions in the till plains or morainic basins. A group of such lakes is located in southern Genesee County, north and west of Fenton, some members of which were examined by the writer. The most common type are the shallow basins in the till plain which often contain great quantities of marl, utilized in the manufacture of Portland cement, for example, Mud Lake. The larger lakes show the more interesting physiographic development and Long Lake, see Fig. 80, was chosen as more or less representative.

The glacial formations in this region have a general east-west trend but are less regular in their distribution than farther to the west. A high, strong moraine follows the southern border of Fenton Township, marking a decided halt of the ice front at this locality. The next halt of the ice is shown by a fragmentary moraine which crosses the region near the south end of the lake and was of short duration. Another moraine crosses the north arm of Long Lake but turns abruptly to the south just east of the lake, merging with the fragmentary moraine mentioned above. From this it appears that the ice front held its position east of the offset but receded to the westward and uncovered the southern part of the Long Lake basin. During the halt of the ice border which followed a local outwash apron developed, fragments of which surround the south arm of the lake. North of the outwash the shores are bordered by till plain, which may be interpreted as a fosse, followed by moraine along the northarm and till plain at the north end.

The orientation of the Long Lake basin transverse to the trend of the moraines suggests that a depression existed prior to the advance of the ice. Some scour by the advancing ice probably took place, deepening the depression somewhat to form Long Lake basin, in which case Orrs Point and Cranes Island were deposited later when the ice retreated. During the retreat of the glacier the ice persisted in the basin and upon melting formed the outwash about the south end of the lake.

Long Lake lies in the drainage of the Shiawassee River which now flows directly into the east end of Mud Lake through an artificial channel. From Mud Lake it follows the south side of a moraine westward for more than fifteen miles before crossing. On all maps which the writer has seen the outlet of Long Lake is placed at the north end connecting with a branch of Swartz Creek. This outlet undoubtedly functioned but was artificial. Discussion concerning the former natural outlet will be found below.

An excellent distance view of Long Lake may be had from the high kame south of Fenton and from this eminence the irregular outline of the lake is very apparent. From this view and a study of the map it is seen that the lake consists of three basins set off by Orrs

Point, and Log Cabin Point and Cranes Island. It also appears that the west shore is much more irregular in outline than the east, but this is less pronounced when the adjustments of the east shore are taken into consideration, as will be seen later.

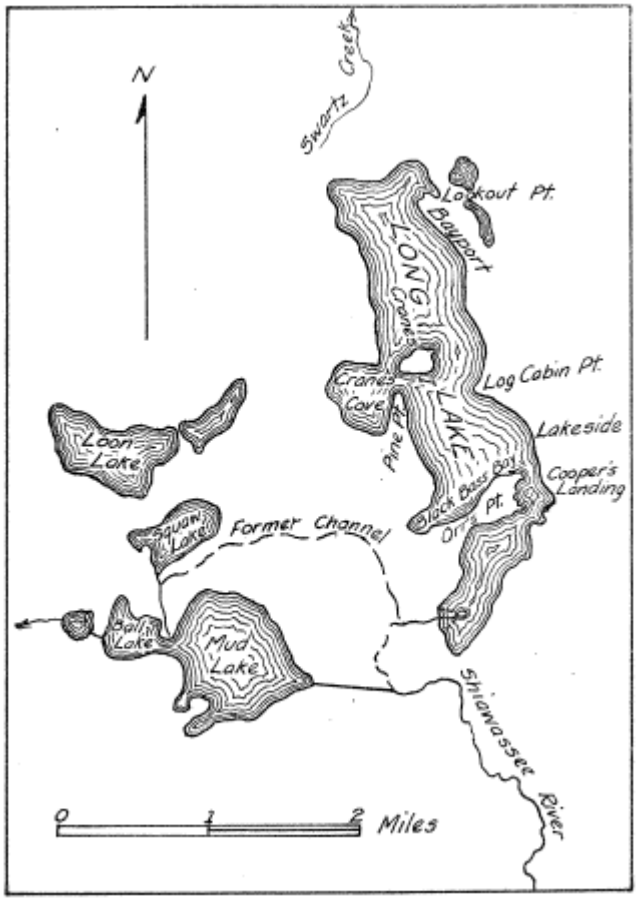

Figure 80. Outline map of Long Lake and neighboring lakes, Genesee County.

At the south end of the lake the low remnants of outwash slope gently to the lake and have been carved into a well-defined terrace which stands between two and three feet above the present level. Wave activity in this small arm of the lake is moderate and the shores are grown over with vegetation, consequently the beach is poor. Towards the outlet the land is higher and well-defined cliffs were formed at the higher level. In the neighborhood of the outlet a, low flat which stands below the former level of the lake extends westward and connects with the former channel of the Shiawassee River. The south arm of Long Lake now shows an interesting anomaly in that the outlet now leaves the lake across what appears to be a delta which extends to and includes the small island in this part of the basin.

If this formation is correctly interpreted, it is evident that the Shiawassee entered the lake at this point during the former level. At this time two outlets were possible, one just north of Orrs Point leading back into the present Shiawassee valley, and another at the north end of the lake. Of the three channels leading from the lake, the one now occupied by the outlet was the lowest and naturally accommodated the outflow when the lake level dropped permanently. Yet it is possible that it may have served as an inlet during the former level under flood conditions of the Shiawassee, at which time great quantities of material were brought into the lake and deposited, forming the delta. On the other hand, when the waters lowered during the dry season this channel may have served as the outlet which had a sluggish current so that the delta was left intact.

The south arm of the lake is relatively deep and a well defined off-shore terrace drops into deep water from a depth of four feet. This terrace has been remodelled under the present conditions to an uncertain extent and inferences from it as to the strength and work of the waves are of little value. As a rule the surface of the terrace is covered with heavy deposits of marl which is of commercial value on some of the nearby lakes.

North of the outlet the shores are low and in places the terrace of the upper level is exposed. Similar conditions prevail on the south side of Orrs Point, a morainic ridge which runs nearly to the east shore, forming a narrows of less than one hundred feet in width. During the former level considerable material was carried outward along the south side; of the point and deposited in a spit which threatened to close the channel. Under present conditions little work Is being done on this shore and the spit is not growing appreciably. A like condition exists on the north side but the spit, although possibly of greater extent than that on the south side, had accomplished relatively less in the filling of the channel. The north shore spit Is attached to a narrow terrace of the upper level which stood thirty inches above the water level at the time of .measurement. Ice shove is here evident ill the line of boulders along the shore and a partly demolished rampart at the outer edge of the terrace. Westward into Black Bass Bay cliffs rise from the present shore, showing that the waves not only have removed the upper level terrace but are still furnishing material some of which is being added to the spit at the end of the point. Thus, there is still a possibility of the isolation of the south arm.

Black Bass Bay stands on a till plain and is very shallow with the exception of a small hole near the west end. This probably was the location of an isolated ice block. Within the bay a slight swell near the north shore forms Duck Island. The low relief, as Indicated by the shallowness of the bay, extends westward from the lake to the old channel of the Shiawassee. This flat stands slightly below the level of the former stage and, if not an outlet, was a broad arm which connected this basin with the lake basins which lie to the west.

The west shore north of Black Bass Bay is lined with a gravel beach above which stands an almost continuous terrace of the upper level. Currents as well as waves are active along this shore and those from the south leave the shore at the end of Pine Point. Southeasterly winds are the only ones which cause northward drifting currents on this shore and, since these winds are not of long duration nor great intensity, the amount of material

transported Is relatively small. Nevertheless, a well developed spit was formed at the point during the upper level and is continuing its growth under the present conditions. Ice action is also effective near the attachment of the spit and has formed ramparts at both the upper and present levels.

Within Cranes Cove wave action is slight and the exposed terrace is well preserved. Near Crane's cottage ice has formed a rampart at the present shore which obstructs the drainage of the exposed terrace locally, forming a lagoon-like swale. At the head of the cove the terrace widens to a swamp which extends westward to the road and was a shallow arm of the lake during the upper level.

The shallow water between Cranes Island, or Cases Island, and the west shore establishes a close relationship between the two. The shallow water, however, is not due to current action, and any direct connection of the island with the mainland will be accomplished by filling, by vegetation which has already established itself. The island is a low knoll of nearly twenty-five acres in extent. The greatest activity along its shores at present occurs on the south side and Is due to waves. They have removed the terrace of the former level and are cutting back cliffs of from twelve to fifteen feet in height. On all other shores the exposed terrace is well preserved. The preservation of this terrace on the north side seems singular in view of the exposure of this shore to strong winds of considerable reach. It is due to the flatness of the off-shore slope, which has been intensified by the sinking of the water level and greatly reduces the effectivenss of the incoming waves. The adjustment of the shores during the higher level was accomplished mainly by the waves, as shown by the exposed terrace on all sides but the south. However, westward moving currents developed on the north shore and succeeded in building a small spit at the northwest corner of the island.

North of Cranes Island on the main shore, the terrace of the higher level, makes a slight notch in the gentle slopes and is continuous to the swampy depression which may have functioned as the outlet of the lake. This channel is partially closed by a strong ice rampart, the best example of this feature found on the lake. It is possible that this channel served as an outlet during the higher stage but, if so, was secondary to the Shiawassee River. In case both outlets functioned, the northern channel was abandoned by the deepening of the channel of the Shiawassee River.

Moraine borders the north shore and the slopes have been cut into almost continuous bluffs ranging from fifteen to twenty feet in height. The northeastern shore is low and the exposed terrace appears along the shores of the bay at the northeast end of the lake. High bluffs again come to the shore at Lookout Point but drop to a low sag near the end of the point. This sag stands slightly below the former level and the tip of the point was, therefore, a small island during that time. South of the point the bluffs recede and below Bayport a small crescent-shaped lagoon was cut off by current action during the higher level.

Between Bayport and Log Cabin Point the shores are faced for most of the distance by bold cliffs. A well defined "drop off" follows this shore and extends outward as much as two hundred yards in places, dropping at a depth of six feet. The depth of the "drop off", it will be noted, is greater than on the west side of the lake, and this is due to the greater power and size of the waves developed by winds from the westerly quadrant. Weves are active under the present conditions on this shore and breakwaters are necessary in places to prevent the recession of the cliffs. Sags in the cliffs are infrequent but where present show both current and ice action at the bars that developed during the former level.

Log Cabin Point is an extension of the moraine into the lake but originally had a, gentle slope. Consequently it now shows a wide terrace. The original slopes were much flatter on the south side of the point and the submerged portion of the terrace is, therefore, much wider on this side. A small embayment on the south side of the point was completely cut off by a bar at the higher level and this has since been remodelled into an ice rampart. Bluffs line the shore to the vicinity of the narrows with the exception of another indentation south of Lakeside which was cut off by the usual combination of bar and ice rampart at the higher level. This indentation runs back of the bluffs and appears again at the lake shore north of the narrows where it is similarly cut off.

The two small points on the east shore opposite Orrs Point are due to current and ice action during the former stage and were built of material brought in from the cliffs to the north. In this vicinity the shore consists of an alternation of cliffs and swamps, the latter being as a rule cut off. An excellent rampart-bar isolates a small swamp just south of Coopers Landing. In the same way a nearby swamp, which extends a considerable distance to the east, was cut off, definitely separating a small pond from the Long Lake basin. The point below the narrows consists of several small knolls surrounded by swamp on the east. This swamp was undoubtedly open water at the former stage but has since been filled to some extent by vegetation.

The east shore to the south, end of the lake is lined by low cliffs .and vegetation grows to the shore. The exposed terrace is not well developed and in many places is wanting entirety. Also the submerged terrace is but moderately developed and drops usually within one hundred feet of the shore. Vegetation is much more abundant along this shore than in other parts of the lake. In general, wave action is moderate in this part of the basin, due probably to the restricted reach of the waves.

There appears to be sufficient evidence to show that Long Lake has stood for a considerable period of time at a level about thirty inches higher than at present, an almost universal occurrence on the inland lakes of Michigan. When first formed the basin was connected

with those of Squaw and Mud Lakes and also included a number of small and large indentations which were either isolated by current action or drained by the sinking of the water level. That the former stage was of long duration is shown by the fact that practically all of the shore adjustments took place at that time. Thus, strong cliffs and an almost continuous terrace were cut by the waves. Currents succeeded in throwing bars across many of the indentations and added to the terrace formed by the waves. In addition, spits were started from some of the points, which show little growth under the present conditions. The greatest change has been the reversal of the Shiawassee drainage with the cessation of delta building. In general, the adjustments were carried to such an advanced stage that the present outline of Long Lake was determined at that time. At present, the waves are doing most of the work on the shores and in places are cutting back the cliffs, the exposed terrace having been removed. The change of greatest moment that one may foresee is the possibility of the growth of the spit at the north end of Orrs Point which will eventually isolate the south arm. Vegetation has taken a firm hold on the submerged terrace, following a more or less abundant accumulation of marl. Some of the shallower parts of the basin are in process of filling in this way, but a large part of the lake is too deep for such method of extinction. The absence of entering streams precludes filling by sedimentation.

CHAPTER VIII. LAKES OF THE NORTHERN PENINSULA.

BREVORT LAKE

Brevort Lake is one of the largest lakes of the Northern Peninsula and lies approximately twelve miles northwest of St. Ignace and within one mile of Lake Michigan. Allenville on the Duluth, South Shore and Atlantic R. R. is the nearest stop and a short drive brings one to the east end, of the lake.

The lake is five and one-half miles long and nearly two and one-half miles in greatest width. See Fig. 81. The south shore runs nearly parallel to that of Lake Michigan, that is, northwest-southeast, but the north shore takes a nearly east-west direction so that the lake tapers towards the west in general outline. It covers an area of 6.7 square miles and its average width is about one and one-fourth miles.

The lake lies in a shallow basin surrounded by low ground for the most part. Near the southeastern end two low knolls rise above the sandy plain. These knolls are of hard rock thinly covered with glacial material. They are surrounded by a sand plain which formed a portion of the bed of Lake Nipissing and now borders the east end of the lake. On the north side a flat swamp extends from the lake shore northward to the Carp River. This swamp closely resembles outwash in that its surface is flat and the material is sand, but stands somewhat lower in elevation than the outwash plain at the west end of the lake. The south shore from Luepnitz Bay to the west end is bounded by a belt of sand dunes which rise nearly one hundred feet above the lake and are the highest land in the vicinity. These dunes form the inner border of a narrow sand strip that separates this lake from Lake Michigan. Beyond the dunes is a series of bars, parallel to each other and the Lake Michigan shore, which are separated by shallow troughs grown up to swamp grass. Near Lake Michigan another belt of dunes is found. From the elevation of the bars it is clear that Brevort Lake was a part of Lake Nipissing in its early stages but was cut off by a bar which stood near the location of the inner belt of dunes. This stage was of relatively long duration and the constant addition of sand to the shore by currents furnished the material for the dunes. Then followed a recession of the shore accompanied by rapid encroachment of vegetation on the exposed bars and dunes, which fixed their position. The final belt of dunes probably represents another halt in the recession of Lake Nipissing but may belong to the present stage. Just what may have been the cause of the depression in which Brevort Lake lies is not clear at present but it is certain that the lake has been isolated by current action and thus may be classed as a lagoon.

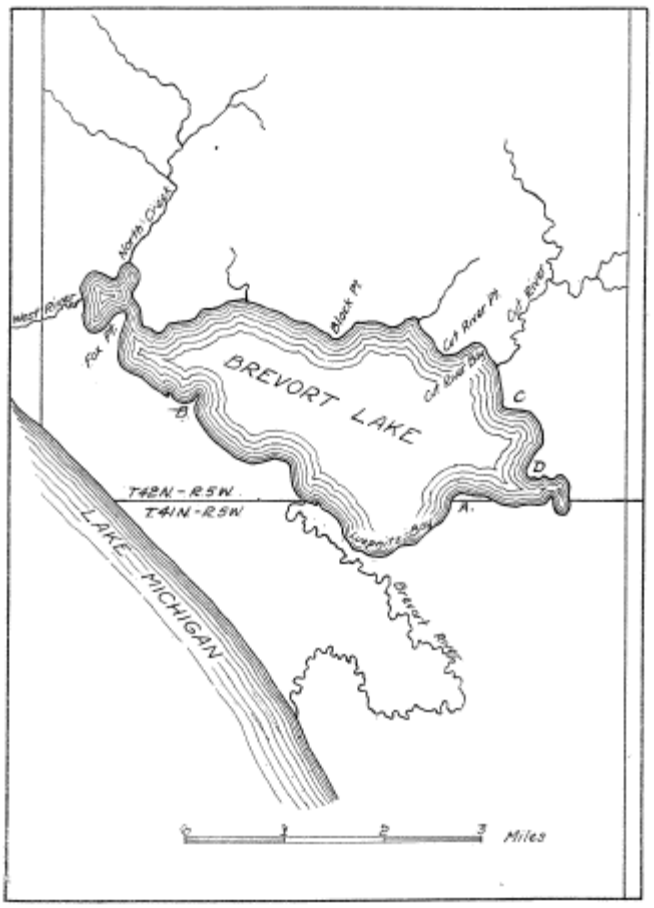

Figure 81. Outline map of Brevort Lake, Mackinac County.

The relatively smooth east-west shore on the south side of the east end is caused by one of the low rock knolls covered with a veneer of drift. Along the shore the

waves have removed the finer drift and exposed blocks of limestone which have been forced into the low cliff by ice. Some expansion of the ice takes place in winter but ice jams are the more powerful, according to the statements of the inhabitants of the region. Along this shore as far west as the point A on map, which is caused by the southward turn of the shore into Luepnitz Bay, is a wide submerged terrace which drops into deep water at six feet. The west edge of this terrace is in line with the extension of the shore of Luepnitz Bay. On the west side of the point a distinct boulder-lined strand stands above the sand beach of the present level. This strand probably represents a natural level of the lake, which is low at the present time, due to the blowing out of a log jam at the outlet. The blowing out of the dam accomplished more than its purpose and deepened the outlet.

Along the east shore of Luepnitz Bay two small swamps drop below the general level. No current action was noted at the swamp nearer point A but the more westerly swamp is completely cut off by two parallel bars. The bar farther inland is the stronger and indicates a stage during which the lake stood nearly six feet above the present level. This stage will be referred to as the Higher Level. The second bar was formed during the Upper Level which preceded the deepening of the outlet. West of this swamp a smooth sand beach runs to the southwest shore of the lake. The shore of Luepnitz Bay is exposed to strong westerly and northerly winds which have caused a well-defined submerged terrace extending approximately one hundred yards off shore. Also much material is carried eastward along this shore and deposited on the terrace off point A, forming a broad, submerged hook.

The entire south shore is lined with sand dunes whose back slopes rise steeply from the lake. At present, the dunes are fixed but formerly they encroached on the lake from the west, causing a projection of the shore at each dune. Such projections were more exposed to wave action, than the intervening shore and were cut back rapidly on account of the easily eroded sand. In this way a relatively smooth shoreline developed, but below the water level a triangular terrace extended off shore from each dune. The recession of the cliffs and the formation of the triangular terraces probably took place during the Higher Level of the lake. With the recession of the water to the Upper Level, conditions were reversed and currents began to deposit along the edges of the triangular terraces. Thus, at the present time these terraces are deeper in the center and resemble V-bars. From the vicinity of the outlet to the west end of the lake, westward moving currents are the more powerful and the triangular terraces have been remodelled in form as well as surface. They, therefore, are extended in a northwesterly direction. The best example of this is point B which extends northwest two hundred yards beneath the water.

The outlet bends abruptly to the southeast soon after leaving the lake and flows in a direction parallel to the southwest shore of Brevort Lake for nearly three miles before turning towards Lake Michigan. It then doubles back on its course for more than a mile and finally enters Lake Michigan on a reverse curve, that is, swings back to the southeast. The turning of the upper part of its course is due in part to the growth in a southeasterly direction of the original bar which separated Brevort from Lake Michigan and also to the general trend of the topography where not covered by dunes. The outlet was not followed by the writer to Lake Michigan but the final turn to the southeast is probably due to the drift along the shore in this direction.

The sags between the dunes vary in elevation above Brevort Lake and in many places are low enough to cause swamp conditions along the shore. At such places the exposed terraces of the higher levels are wider than usual and have no distinct line of separation, giving the effect of a single terrace of exceptional width. No definite bars cross the mouths of these indentations which were relatively broad, but occasionally an ice rampart is found, for example, west of point B. These ramparts may be remodeled bars but this is uncertain.

A well-defined submerged terrace fringes this shore and drops consistently at six feet; except off the projecting dunes. As has been intimated, the outline of its outer edge is much more irregular than the present lake shore. Fox Point is a blunt sand spit which developed mainly at the Upper Level and nearly closed the channel into the west arm of the lake. At present the growth is very slow but; nevertheless, may complete the spit. The west arm is shallow and very muddy, and there is a possibility that the rapidly encroaching vegetation may fill the basin before it is isolated by the spit at Fox Point.

The entire north shore of the lake is bordered by a broad exposed terrace which terminates at a low cliff approximately one mile north of the lake. This terrace correlates with the great bar along the south shore which isolated Brevort Lake and was formed during the late Nipissing stage of the Great Lakes. For the greater part of its extent the terrace drops to the shore of Brevort Lake in a low cliff at the foot of which rests a line of boulders, indicative of ice action. The points are caused by excessive accumulations of boulders which, obviously, retard the action of the waves. On the other hand, minor indentations were present along this shore but were virtually all cut off by bars during the Higher Level. In front of the bars the beach is of clear sand and has been pushed into a rampart in many places. Just east of Black Point a small terrace, standing below the elevation of the bars, is evidence of the Upper Level. The evidence of the latter, although sufficient to establish this stage, is meager and the obvious conclusion is that it was of short duration.

A submerged terrace of variable width and slope follows this shore. In general, the depth at the drop off increases from two feet near the west end to six feet at the east end. This variation cannot be entirely accounted for but may be ascribed in part to the increased effectiveness of the storm winds from the west

as the reach becomes greater. It was noted that the lesser depths at the dropoff were in many cases due to a low ridge near the edge of the terrace and may be accounted for to some extent by ice action. Powerful ice jams occur on the north shore and reads heights of ten to twelve feet at times. The interesting fact is that they not only drive on the shore but are also piled on the edge of the terrace where the low ridges are located. The effects are more pronounced in the shallower water, that is, nearer the west end, and the stronger ridge is formed at the edge of the terrace in this part of the lake. It seems reasonable, then, that the large variation in depth at the drop off is due in part to ice action. The effect of these jams on the shore is best seen west of Black Point where an excellent rampart has been formed.

In the vicinity of Cut River Point currents have produced some decided effects. The point itself is a V-bar which is better developed on the west side, indicating stronger current action from this direction. It stands well above the present lake and was formed during the Higher Level. But the most striking effect is the formation of the Cut River reef which is a submerged bar extending far out into the lake in accordance with the curvature of the west side of the point. It has been somewhat modified on the east side, but the abrupt drop into deep water indicates that the activity of waves and currents is slight on this side. Cut River Bay has a sand beach of even curvature back of which is a low ice rampart. The possibility of a bar, remodelled by ice action, naturally suggests itself but is difficult of proof. The river is forced to the east before entering the lake, showing the prevalence of currents from the opposite direction. A large quantity of silt has been deposited by the stream and has been distributed on the east side of the bay, forming a broad, submerged terrace.

At C currents of about equal intensity left the shore from both directions and built a symmetrical V-bar of greater dimensions than that noted at Cut River Point. This also was formed at the Higher Level but the enclosed lagoon is still a good-sized pond. In addition to the exposed V-bar, a submerged bar similar to the Cut River Reef extends well out into the lake. The balance of the currents on either side of this point is due to the protection afforded the shore north of the point by the Cut River reef. Thus, only local currents are set up on the north side and by winds of short reach, but on the south side the currents are formed along a greater stretch of shore and by winds of longer reach, although of less power. However, part of the material derived from the shore between C and D was carried southward and deposited at D in a spit. The greater part of this deposit is submerged and, together with the submerged terrace on the opposite side of the lake, leaves only a narrow channel of deeper water leading into the east bay. The north and east shores of this bay are low and the only shore-feature of importance is a well-defined ice rampart. The effect of vegetation as an aid in the formation of ramparts where the material is sand is here well shown, for the rampart is not present across the clearings. During the higher levels a distinct submerged terrace was formed which now supports a heavy growth of rushes. The edge of the terrace is the off-shore limit of rushes and may thus be readily traced during the growing season.

Brevort Lake was originally an arm of Lake Michigan but was completely shut off from the main body of water by a bar of large-dimensions which has since been heaped into dunes. During the Nipissing stage the broad, exposed terrace bordering the north side of the lake was formed. Later the water subsided and halted for a relatively long time at a level six feet above the present stage. At this level the greatest adjustment of the shores took place but the permanent effects were accomplished by currents. Undoubtedly waves were active and aided materially in the formation of a submerged terrace, but this has been subsequently remodelled. Numerous spits began their development at this time and in some cases became bars, but no very striking changes in outline resulted. The strongest action took place on the north side, as shown by the cut off indentations and the V-bars at Cut River Point and locality C. It is possible that the reef at Cut River Point and the projections to the east were at least started during this stage.

A second subsidence halted at an intermediate level whose features are poorly preserved and was probably of short duration. Nevertheless, many of the forms of the preceding stage were remodelled and in some cases added to. The spits were either planed down to the water level or greatly extended. The terrace of the Higher Level was generally cut down to conform to the lower water level, and, on the south shore, parts of the remodelled terrace have become areas of deposition. The present stage was initiated by human interference and minor shore adjustments are progressing slowly. The work to be done consists in remodelling the forms of the previous levels by waves and the extension of the previous deposits by currents. The most prominent change will result from a continuation of Fox Point across the entrance to the west arm.

Ice jams have been and still are very active on the lake with marked results where conditions are at all favorable. Some headway has been made towards the extinction of the lake but this is of local importance. Vegetation is well established at the ends of the lake and considerable filling has been accomplished. This is especially true of the west arm where the process is aided by the silt of North Creek. Another locality where sedimentation is important is at the mouth of Cut River, but, in general, it may be stated that the process of extinction is in an incipient stage.

THE MANISTIQUE LAKES

The moraine which extends across southern Luce and western Mackinac counties has already been mentioned in the discussion of the Lowlands of the Northern Peninsula in Chapter I. Within this belt the local relief is low, and the topography consists of irregularly placed

knobs of gentle slope and shallow basins which are larger than is usual in moraines of strong relief. Subsequent to its formation, the moraine was covered by Lake Algonquin and, inasmuch as the depth was moderate in this locality, received a veneer of sand over its surface. Numerous lakes stand in the basins, and attention is called in particular to the Manistique lakes which are situated near the western borders of Luce and Mackinac counties. These three lakes are named North Monistique, Monistique, and South Monistique on the Land Survey maps but are now called Round, Manistique, and Whitefish respectively, the o in Monistique having been changed to a.

These lakes lie in the peculiar drainage system of the Manistique River, a brief description of which follows. The main stream has a general southwesterly direction and, in its upper course, seems to follow the border between the moraine on the east and the swampy plain on the west which rises very gradually in elevation to the northwestward and extends to within a few miles of Lake Superior in the vicinity of Munising. The greater part of the water of this drainage system flows southeastward in numerous parallel tributaries which join the trunk stream at approximately right angles. On the other hand, the tributaries from the east are not only smaller but less numerous and, moreover, have the hap-hazard pattern typical of the drainage of a morainic country. Round and Whitefish lakes drain into Manistique Lake and thence to the Manistique River, forming the largest tributary entering the main stream from the east.

The two larger lakes, Manistique and Whitefish, were examined by the writer. They may be reached by conveyance either from Gould on the Soo Line or from McMillan on the Duluth, South Shore and Atlantic R. R. A railroad spur runs from Seney to Curtis which is located between the two lakes, but the train schedule was uncertain at the time when this study was made.

MANISTIQUE LAKE

Manistique is the larger of the two lakes, its area being 15.8 square miles as compared with 6.4 square miles for Whitefish. It probably floods several contiguous morainic basins and has, therefore, a very irregular shore-line. A few knobs rise above the surface of the lake, forming small islands. The lake is very shallow, the reported maximum depth being twenty-five feet. Random soundings were made in the course of this work, but no depths greater than twelve feet were obtained. But, assuming the larger value to be correct, it is to be expected that the larger waves agitate the water to the bottom of the lake and their development, therefore, is greatly impeded. That this is actually the case is shown by the excessive turbidity of the water after storms. In general, then, adjustments of the shores are on a small scale, even though the topography is favorable to the development of forms by both waves and currents.

Along the entire north shore the most consistent adjustment is the submerged terrace which, however, is not sharply defined. It is merely a zone of sand whose outer edge is marked by a change in material rather than by a steeper slope. In many places the position of the outer edge may be approximated from the reeds of circular cross-section which seldom grow beyond the terrace and often form a fringe at the edge. On account of the gentle off-shore slope, a small, amount of material has sufficed to form this terrace, and the effects of waves and currents at the shore are not pronounced. At the higher land clay bluffs line the shore, as at A and along the south shore, see map, Fig. 82, but along the flatter slopes the activity of the waves and currents seems to have been limited to the formation of beaches, the material of which is well assorted.

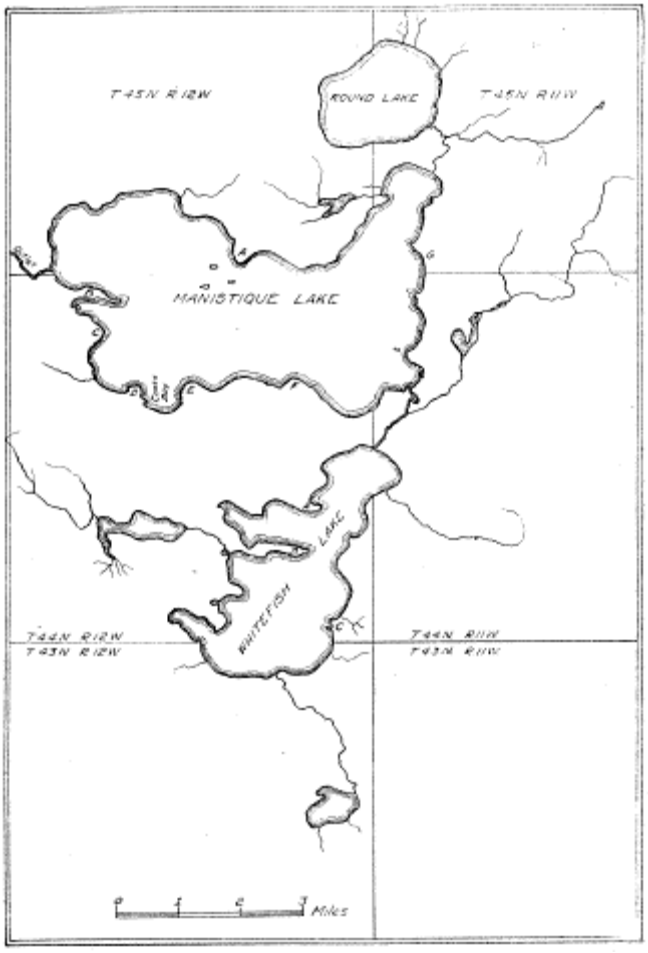

Figure 82. Outline map of the Manistique Lakes, Luce and Mackinac Counties.

On the west shore in the vicinity of the outlet, the off-shore slope is so flat that it is doubtful if even the largest waves strike the beach with any considerable force. The key to the activity in this locality is the long, narrow point, B on map, at the end of which currents from either direction must run directly out into the lake. A small bar has been built outward from the end but is submerged for most of its extent. Thus, some current action is indicated, but wave action is not sufficient to pound the material above the water level. The greater width of the

submerged terrace on the north side of the point is evidence that the currents on this side (possibly return currents from the northwest shore) are the better developed. This is due not only to the greater reach of the waves affecting the north side of the point but also to the smoother shoreline which allows stronger currents to develop, other conditions being equal.

The blunt projection C stands well above lake level, rising like an island above the lake on the east and the swamp on the west. This elevation is composed of till which furnishes coarse beach material, consisting of gravel and boulders. The presence of a faint terrace ten to twelve feet above the present level on the lakeward slopes of this point is an indication of a higher stage of the lake. This in itself is not sufficient to establish this stage but, inasmuch as another fragmentary terrace at the same elevation was found at the opposite end of the lake, it seems reasonably certain that the lake formerly stood at this level. This point, therefore, must have been a low island at that time. South of this former island the vegetation of the swampy lowland is encroaching ob the lake and there is no definite beach.

The land bordering the south shore of the lake stands higher in general than that along the shores already described, and cliffs of moderate height are more frequent. Thus, from the low shore south of C to F an almost continuous bluff faces the lake at varying distances from the present shore. The bluff does not follow point D but extends directly across to the head of Cooks Bay where it rises twenty feet above the lake. This point is a low swamp and is apparently the terrace of a level of the lake which was intermediate between the highest and present stages. From the head of Cooks Bay the bluffs make a large loop eastward and return to the shore about one-half mile east of point E. A small spit on the west side of this point is the only definite current deposit noted on this shore of the lake. The adjustments have been slight, and the fact that the spit is composed of cobbles, ranging in size from three to six inches in diameter, suggests ice as an aid at least in the formation of this feature.

Beyond E the topography is undulating and causes a series of broad headlands and wide embayments. Invariably the beaches at the headlands are of coarse material and in the embayments they are of sand. At the apex of the broad outward curve between E and F the ice has pushed up a distinct ridge of boulders off shore. This was, probably formed by ice jams, since the lake is somewhat large for expansion. At F a bluff and beach of the intermediate level, mentioned in connection with point D, are readily detected. The alternation of headland and embayment continues along the east shore and offers little of additional interest except at G. Here a patch-of the terrace of the highest level was found.

In conclusion, it seems unnecessary to add to the statement concerning the shore adjustments made in the introductory part of this description. Yet from the study it seems probable that the lake has stood at two higher stages in the past, one at ten to twelve feet above the present level and another at three to four feet. Obviously, the highest level must have covered a .much greater area than the present lake and possibly included Bound and Whitefish. As regards extinction, vegetation appears to be the most important factor. A heavy growth of rushes forms an almost complete fringe about the lake, but the accumulation of their dead parts is not important as yet. The entering streams apparently bring in little sediment for, if such were the case, deltas would be formed at their mouths.

WHITEFISH LAKE

Whitefish Lake lies within a half mile of Manistique and extends four and one-half miles to the southwest. The east shore winds about in broad curves, but the opposite side is very irregular, consisting of long points and narrow intervening bays. The longest of the points almost crosses the lake near the middle, point B in Fig. 82. The lake is deeper than Manistique and, although less than one-half the size (6.4 sq. mi.), shows considerably greater adjustments of the shores. Yet, as compared with those found on the shores of many of the lakes of the Southern Peninsula, the adjustments are on a small scale.

At the narrows between this lake and Manistique, the low shore is lined by a sand beach which soon gives way to the westward to bluffs which rise to a maximum height of thirty feet. Along the west side the shores are poorly adjusted and little of interest was found north of locality A. The sand spit at this point has been built by currents moving eastward along the south side with but slight additions from the north. The total amount of material deposited here is relatively small, a fact confirmed by the lack of adjustment of the shore to the west. In fact, the shore of the entire bay to the south has suffered little change and is being encroached upon by vegetation. The lack of adjustment must be due to the shallow water, which interferes with the development of the waves, and to the short reach of the strongest winds. Point B is the index to the activity of the shore agents in this part of the lake and the essential feature is a small sand bar which extends northeastward from the end of the point. Unquestionably here, as at A, the currents along the south side of the point have accomplished most but apparently are not powerful. No great amount of cutting has taken place but much of the finer material has been removed, leaving a beach of coarse material interspersed with numerous boulders.

No adjustments worthy of description were noted between point B and the south end of the lake, although the irregular shore offers many opportunities for adjustment. Minor indentations at the heads of the first two bays south of the point would .surely have been cut off if currents had been active along these shores. Obviously, with no currents developed in the bays, spits would not be formed at the headlands.

At the south end, the beach becomes sandy and has a more even curvature, which is suggestive of better adjustment. Weak currents are driven eastward along this shore and swing out into the lake at C on the east side. A small spit is growing here but has not reached the islands which stand off shore. Inasmuch as the spit is located south of the main bend in the shore line, currents from the north have not contributed to its formation. Aside from this spit the shore features on the east side of the lake are of little interest. The alternation of sand and boulder beaches at the embayments and headlands respectively persists to the outlet. As mentioned previously, the boulder clay is covered with a veneer of sand. At the embayments the sand is not removed but merely adjusted along the beach. At the headlands wave action is sufficient to remove the sand and enough of the finer material of the till to concentrate the boulders on the beach.

In general, wave action is the predominant force in the adjustment of the shores of this lake. In the more exposed locations rather prominent cliffs have been cut. The quarried material, however, was very largely distributed on the off-shore slopes, forming a zone of sand which corresponds to a distinct submerged terrace. Rushes have established themselves on the terrace quite generally but are frequently limited to a thin fringe at the outer edge, giving a ready means of determining its location. No evidence of the higher levels noted on Manistique Lake was found, although the highest level of Manistique must surely have flooded this lake.

INDIAN LAKE

Indian Lake lies in the drainage of the Manistique river, forming a catch basin for the Indian River, whose head waters lie more than twenty-five miles to the northwest. It empties into the Manistique about two miles above the mouth through a short outlet which is navigable for small craft in its upper part. Thus the lake may be reached by boat from the outskirts of the city of Manistique.

Indian Lake is five and three-fourths miles in length and has an area of thirteen square miles. Thus, the average width is two and one-fourth miles but the maximum width, measured from the outlet to the head of Big Spring Bay, see Fig. 83, reaches nearly double this figure. From one viewpoint this lake may be considered a lagoon, for it was isolated from the Lake Michigan basin by a short sand bar which bridged the rather narrow connecting channel. On the other hand, the lake basin lies directly transverse to a pre-glacial ridge of rock which is thinly covered with glacial material. Limestone outcrops in Manistique, at Millers Point on the east side of the lake, and on the west side between Silver Creek and the south end. From this it seems probable that the Nipissing bar, which cut off this lake, extended between rock buttresses.

The rocks in this region are stratified and dip towards the center of the Southern Peninsula, that is, slope down to Lake Michigan. The trend of the layers at the surface is, therefore, approximately parallel to the Lake Michigan shore. Previous to glacial times, harder rock layers came to the surface in this vicinity and formed a somewhat elevated ridge, or cuesta (see Chapter I), while on either side broad troughs were formed by the more rapid erosion of the weaker layers. In the vicinity of Indian Lake a stream flowing in a southeastward direction crossed the cuesta through a narrow gap. It so happened that the movement of the glacier was also towards the southeast, that is, along the course of the stream which flowed through the gap, and the valley may have been enlarged in this way. The enlargement of the valley by the glacier was more pronounced in the softer rocks north of the gap than at the gap, and a broad basin with a relatively narrow outlet to the south was formed. After the melting of the glacier, the basin was partially filled by the sand plain which lies north of the lake and the southern end was closed by a bar.

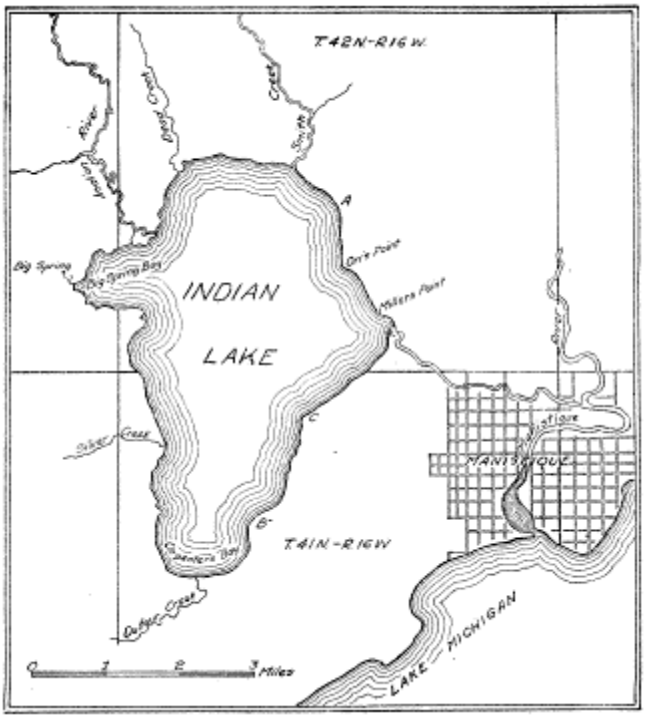

Figure 83. Outline map of Indian Lake near Manistique, Schoolcraft County.

In the journey up the outlet which flows over bare rock in places, it is interesting to note that the channel has been deepened approximately three feet. This arouses expectations of a higher level of the lake which is not apparent along the shore from the outlet to Millers Point. This stretch of shore is faced by a low cliff of limestone rubble. The rock is a thinly bedded, highly fractured limestone and has been greatly disturbed by the push of ice on the face of the cliff. Around Millers Point, however, the cliff recedes and between it and the shore stands a well-defined terrace which corresponds in elevation with the outlet before it was deepened. At the point of departure of the cliffs from the present shore a strong rampart of five to six feet in height has been pushed up by ice. Northward the rampart splits into two distinct ridges, one of which follows the present shore.

The other swings back from the shore and extends to Orrs Point as a ridge on the terrace. Near the northern end the material of this ridge becomes clear sand and the front slope flattens, or in other words, the rampart merges into a bar.

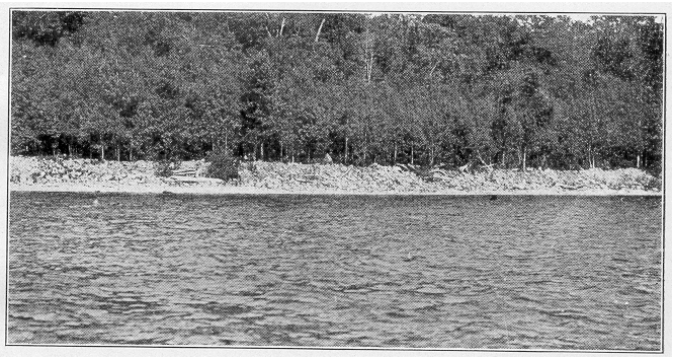

Plate XVII, A. Ice rampart, Indian Lake.

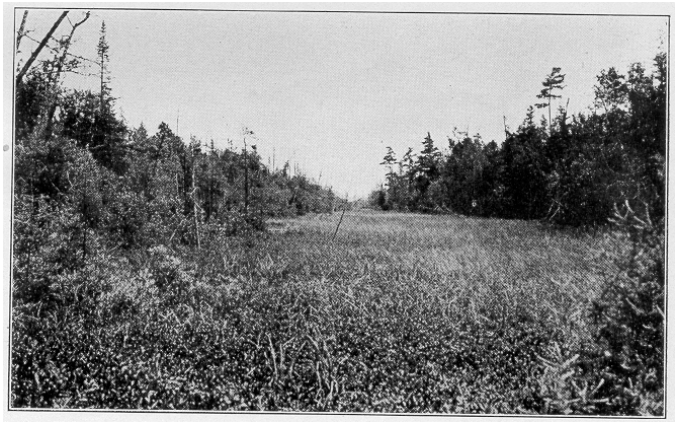

Plate XVII, B. Vegetation, lagoon and bar, near Indian Lake, Schoolcraft County.

Back of the cliffs of the .higher level mentioned above, the land slopes so gently towards the lake that it appears flat. A few higher spots rise above this flat and in each case the foot of the normally gentle slope has been carved into a low cliff. This is interpreted as a terrace and shore of a still higher level of the lake, which stood higher than the Nipissing stage of the Great Lakes, but below the Algonquin. Thus, evidence is at hand to establish two higher stages of the lake, the Upper and the Intermediate. The activity during the Upper stage was largely that of waves in this vicinity and resulted in the formation of low cliffs and a well-defined terrace. During the early stages of the Intermediate Level, wave action likewise predominated and similar forms developed. Later, however, conditions changed, due possibly to a slight lowering of the level, and currents, aided by ice, built a rampart-bar along the terrace, which served as a breakwater for the cliffs to the rear. At the present level, waves and currents are engaged in removing the finer material from the beach, leaving the coarser to be pushed into a rampart by the ice.

At Orrs Point rock again outcrops and the shore is lined with angular fragments of limestone. North of this point this coarse material is piled into one of the best ramparts found on our lakes. See Plate XVII, A. The rampart rises fully six feet above the lake and is a sharp ridge with steep front and rear slopes.

At the point of deflection of the shore to the northwest, A on map, the cliffs turn to the northeast and the high land drops to a wet, grass-covered plain which rises barely above the present lake level. This swamp borders the entire north end of the lake as far as the south shore of Big Spring Bay and extends for miles to the north, rising with imperceptible slope. Obviously, the lake covered a considerable part of this lowland during the higher levels but no attempt was made to determine its limits. Sand ridges, which may be either spits or off-shore bars, were noted crossing the lowland, but the only one traced was the spit which extends from the cliffs at A to Smith Creek. The present shore is mucky and has no definite beach.

Indian River enters the lake just north of Big Spring Bay and, in fact, has been instrumental in forming the north shore of this bay. Great quantities of silt have been brought to the lake by this stream and deposited in a typical delta across which runs a number of distributaries. The shore line has been built out in this way and the delta is encroaching on Big Spring Bay from the north. In addition to the exposed part of the delta, a broad submerged platform extends fully a mile off shore. Little sediment is brought in at low water stage under present conditions but there is a possibility of large additions to the submerged portion of the delta at least during times of flood.

Big Spring Bay takes its name from a large spring nearby. This spring has no effect on the lake shore but as the "wonder point" of the vicinity deserves mention. It is a large pool about 200 feet by 100 feet in surface extent and nearly fifty feet deep. The water issues with considerable force through a fracture in the bottom and is so transparent that the cloudlike effects of the sand fountain at the bottom may be clearly seen.

The west side of the lake from Big Spring Bay to the south end is bordered by high ground, and the prominent shore features are the cliff and terrace of the Intermediate Level. The limestone outcrop, mentioned in the introductory remarks on this lake, occurs at the small point about one mile north of the south end of the lake.

Carpenters Bay is lined with an adjusted sand beach which has been thrown up into a storm beach in places. A lagoon of about fifty feet in width stands to the rear and in turn gives way to the beach of the Intermediate Level. These beaches run to the dunes on the east side of the bay. The dunes are composed of the sands of the Upper Level bar which cut off the Indian Lake basin and are situated farther inland than the original bar. From this locality south to Lake Michigan, the material is all beach sand and is distributed in a succession of topographic forms similar to those found on the Nipissing bar at Brevort Lake. Thus the gentle slope between the dunes at the east side of Carpenters Bay and Lake

Michigan consists of a series of nearly parallel bars and narrow lagoons. The swamp condition of the lagoons is interrupted by the bars, and the two forms may be readily differentiated by the vegetation which consists of lanes of swamp grass between lines of evergreen trees, the latter marking the bars and the former the lagoon. The contrast between the two types of vegetation may be appreciated from Plate XVII, B. The number of these bars was not determined but, judging from the plate, must be large. It is probable that those nearer Lake Michigan run approximately parallel to the Michigan shore, but in the vicinity of Indian Lake there is a tendency for them to swing to the shore south of C from both directions, that is, to come together and form a V. Those from the northeast are the stronger and are truncated in some instances at the present shore, forming slight projections of the shore line and increasing the height of the cliffs. From the vicinity of C to the outlet, the bars follow the direction of the present shore. The growth of these bars in a northeasterly direction has forced the outlet to the north side of the depression through which it flows and accounts for the southward bend of the stream after leaving the lake. Obviously, these bars were formed after the isolation of the Indian Lake basin. The tendency of the exposed bars along this part of the lake to come to the shore south of C is puzzling. The shore is exposed to winds having a westerly component and, on the average, the stronger currents flowed to the northeast. The material carried by the currents must have been derived from the south, inasmuch as the outlet would have prevented acquisitions from the opposite direction. Some source of supply of material near point C seems essential and the large off-shore shoal in this locality is at least suggestive.

Summing up, it may be stated that two higher levels may be recognized from a study of the shores of Indian lake. Also the outlet is dammed at present and the water is somewhat higher than formerly. The flooded condition, however, is not serious and has resulted in but a slight increase in the activity of the shore agents. During the highest level, the lake was much larger than at present, the principal extension being to the north and northeast. During this stage, the lake was separated from the main lake, and its northern border very probably adjusted by the development of bars across the sand plains. The latter was not determined by the writer, but the presence of sand bars in proximity to the present shore substantiates the inference. The subsidence to the Intermediate stage caused a large reduction in size and brought the shores near their present position, except at the north end. However, in this locality important adjustments were made by current action, so that there was little change in the outline of the lake after the final subsidence. The activity of ice on the shores of the Intermediate and present levels at least is clearly shown and the ramparts thus formed are among the best found by the writer. This lake, especially on the northeast shore, is well beyond the maximum limit of size for ice expansion, and ice jams, therefore, have exerted the shove. It is evident that sedimentation by streams from the north has greatly reduced the extent of this lake in the past but is of less importance at the present time. The lake is of sufficient size to act as an efficient settling basin, so that there is little probability of rapid deepening of the outlet, ignoring the presence of the dams. A slight revival of activity has resulted from the obstruction of the outlet and modification due to this may be anticipated in the future.

HURON MOUNTAIN LAKES

In general, the surface of Michigan stands at a relatively low elevation. In the Northern Peninsula the western part, or Highlands, rises considerably above the eastern Lowlands and includes the highest elevations in the State. Two areas only, the Porcupines and Hurons, rise above 1300 feet and have been dignified by the term mountains. The appropriateness of this appellation depends largely on the viewpoint. Speaking more particularly of the Huron Mountains, the summits certainly do not tower above the land to the south, but from the north they rise sharply a thousand feet and more above the level of Lake Superior. Such elevations may seem insignificant to one accustomed to the lofty, snow-capped peaks of our western mountains but to the plains-dweller or navigator might appear formidable. The writer is unaware of the history of the naming of the Huron Mountains but suggests that, perhaps to the explorer whose paths are guided largely by the water ways, the name mountains may not have seemed inappropriate, much less ridiculous.

The so-called Huron Mountains consist of a number of hard rock knobs, bare or sparsely covered with vegetation, which form the western terminus of a narrow belt of ancient crystalline rocks extending from the vicinity of Marquette to the Huron River. This belt outcrops along the shore of Lake Superior for about ten miles above Marquette and then extends slightly more to the west than the lake shore, leaving a narrow coastal strip which is underlain by the brown Lake Superior sandstone. The mountains rise above the coastal strip, which is considered a part of the Lowlands of the eastern half of the Peninsula, and were never reduced to the level of the ancient peneplain which was formed in this region. The last great episode in the geological history of this region was its erosion by glaciers. The entire surface of the land was covered by the ice and the most important work in the Huron Mountain area was degradational. By this the soil was removed and the rock surfaces were smoothed and rounded. Thus, the elevations were fashioned into knobs and the valleys into broad depressions with gently undulating floors. Deposition by the ice occurred largely south of the mountains and was slight within the mountains and on the lowland belt. On the coastal belt thin deposits of till and sands of Lakes Algonquin and Nipissing are present, but in the mountains the veneer of disintegrated material, where present, seems barely sufficient to support the heavy forest growth.

The region has suffered from forest fires and but little virgin forest still remains. The country is as much a wilderness as may be found in the State and furnishes ideal conditions for the get-back-to-nature recreationists who desire a complete change. Quite naturally, this locality has been selected by the Huron Mountain Shooting and Fishing Club for its private grounds. The fascination of this region need not be analyzed but it may be ventured that not the least important factor is the numerous small lakes. Ten of these are named on the map issued by the club and none exceeds two square miles in area. They may be divided into two groups: Those lying in basins within the mountains and those on the piedmont or on the lowland belt. Mountain and Ives lakes are described here as illustrations of the former type, and Conway, Pine, and Bush of the latter group.

Mountain and Ives lakes, see Fig. 84, stand more than a hundred feet above those lying on the lowland, and their outlets cascade steeply to the lower level, exposing the underlying rock for part of their courses. They appear to stand in rock basins which were gouged out by the ice and later partially covered with drift or lake deposits of Algonquin age. The elongated form of Mountain Lake is clue to the fact that it rests in a valley which crosses the range and extends into the thick glacial deposits to the south. The character of this valley will be better understood when the geology of the broad embayment between Huron River and Pine River points is known. Cliffs of brown sandstone face the Lake Superior shore along these points and for some distance within the bay. They then recede from the shore and converge towards Pine Lake and the mouth of the valley in which Mountain Lake lies. Along the Superior shore the cliffs give way to a great sand deposit which forms the head of the bay. This sand formation holds back Pine Lake and is, in reality, a great sand bar, the north slope of which consists of no less than twenty-five small bars, conforming in direction with the Lake Superior shore. From this it seems clear that this embayment formerly extended back to the Mountain Lake valley and was cut off by current action during a higher stage of Lake Superior, probably the Nipissing. Moreover, the elongated form and alignment of Howe, Rush and Pine lakes approximately parallel to the border of the crystalline rocks is suggestive of a cross-channel at or near the contact of the crystalline rocks and the sandstone. This is further strengthened by the fact that the sandstone north of Howe and Bush lakes rises well above the level of these lakes. It seems probable, then, till at in pre-glacial times a stream flowed northward to the Lake Superior basin, crossing the crystaline rocks of the Huron Mountain range and the brown sandstone. The latter was much more easily eroded and not only a wider but deeper valley was cut, causing the steep slope between Mountain and Pine lakes. Also tributaries developed near the contact of the different formations and entered the main stream from both sides in the vicinity of the western expansion of Pine Lake.

Conway Lake lies in a separate depression which was likewise cut off from Superior during Nipissing time by a bar which developed between Pine River and Conway Points.

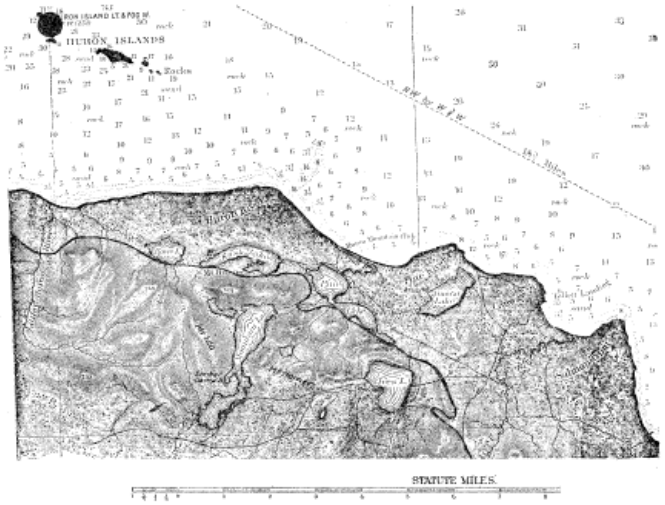

Figure 84. Relief map of the Huron Mts. (From U. S. Survey chart with additions)

PINE LAKE

The Club House and Cabins of the Huron Mountain Club are located on the Superior shore in the vicinity of Pine River. A short walk from the Club House across the sand beaches brings one to Pine Lake near the outlet. The presence of a darn prepares one for the fringe of dead timber and large quantity of driftwood. West of the outlet the waves are moderately effective and a beach of even contour extends to the west end of the lake. Near the outlet the beach material is rubble and is taken as an indication of the sorting action of the waves. Farther west, the waves wash the clear sands of the retaining bar and have formed a beach of even curvature, faced by a sand cliff of varying height up to ten feet. The variation in height of the cliff is due to the fact that the shore does not run parallel to the bar. There is also a well defined submerged terrace in this vicinity. The projection at the west end of the lake is caused by a knoll of till. This material is in itself more resistant than the unconsolidated sand but, in addition, contains numerous boulders which accumulate on the beach, due to the selective action of the waves and possibly to ice push, and effectually hold up wave action. South of this projection the trough which connects Pine Lake with Rush is encountered. Near the inlet a low flat, scarcely above the lake level, extends for a short distance northeastward. The flat surface, black soil, swamp shrubs, and dead tamaracks are adequate evidence that this was formerly an arm of the lake but has been entirely filled by vegetation. See Plate XVIII.

South of the inlet till borders the shore and little adjustment has taken place. The beach is uneven and of coarse material, and no submerged terrace is present. To the southeast the slopes are flatter and the material is sandy. Currents have carried considerable material to the southeast and deposited it in a spit which runs out on the lowland surrounding the inlet from Mountain Lake.

On this bar are two ridges which are probably storm beaches. The projection at the mouth of the inlet appears to be a delta but is badly flooded on account of the dam. Continued growth of this delta would surely close the entrance to the middle arm of the lake, Second Pine. This, however, is not probable because the waters of Mountain Lake carry little sediment and the course of the outlet is too short for much to be acquired after leaving the lake. The present delta probably consists of the material eroded from the channel of the outlet in the early stages of the existence of this stream.

Plate XVIII. Extinction by vegetation, Arm of Pine Lake, Huron Mountains.

Within Second Pine the till soon gives way to the smooth, side slopes of a prominent rock knob upon which the waves have made no impression. The abrupt projection beyond the rock shore is caused by a till knoll. The shore has the usual breakwater of boulders and is but slightly affected by the waves. Nearer the entrance to Third Pine abundant snags form a still more effective breakwater and the shore shows still less adjustment. Third Pine is a narrow embayment upon which small waves only are possible and, consequently, little adjustment is to be expected. In addition, the hard crystalline rock is exposed on most of the south shore and shows no effects of wave action. Along the north shores of Third and Second Pine the material is sandy drift, and the beach is of sand or fine rubble. Nevertheless, there has been little adjustment, otherwise bars would have been thrown across the restricted entrance to these basins.

As regards shore adjustments, then, this lake has little to offer. This is due largely to its small size, but other factors are hard rock exposures and, at present, the large quantity of driftwood. The extinct embayment at the northwestern end, however, is a perfect example of complete extinction by vegetation.

CONWAY LAKE

Conway Lake lies about a mile northeast of the upper end of Pine Lake and is easily reached by trail. This lake is also a lagoon of Lake Nipissing, which was not drained by the sinking of the water level. The narrow retaining bar may readily be recognized. This lake, although of good size, has no outlet and is probably drained by seepage through the bar to Lake Superior or across the swamp which extends from the northeast end of the lake to the Salmon Trout River. The lake is evidently very shallow because small waves disturb the lake to the bottom, making the water very turbid, and this is to be expected from the swampy lowland upon which the lake stands. The only evidence of shore adjustment by waves and currents found was at the southwest end where a small indentation has been completely isolated by a sand bar. The interesting thing here is that the lagoon is dry, although its bed is apparently below the level of the lake. The absence of effective waves and currents, however, has proved favorable to the preservation of the ramparts formed by the expansion of the ice, even though the sandy material is not especially conducive to their formation. An almost continuous rampart surrounds the lake but never exceeds two feet in height. In places it is so small that even a slight cutting by the waves would destroy it. Vegetation in the form of rushes and lily pads has taken hold and one may predict a relatively rapid extinction of the lake from this cause.

RUSH LAKE

The adjustment of the shores of Rush Lake seems all out of proportion to the size of the lake, after a visit to Pine and Conway. The lake is irregular in shape and not greatly different in size from the foregoing. It, nevertheless, exhibits shore features which are indicative of intense activity in spite of the fact that the eroded material is to a large extent the Lake Superior sandstone.

In the vicinity of the depression through which the outlet flows the beach is of sand and of even curvature. To the south the beach curves around a blunt projection, the cause of which is not apparent at the shore. A short distance back, however, stands a well-defined cliff cut in brown sandstone, which was formed at a level approximately four feet higher than the present. Inasmuch as Rush Lake stands more than sixty feet above Lake Superior, this must have been a transitional stage between Algonquin and Nipissing. The projection, therefore, was more prominent during the early stage of this higher level and was cut back by wave action. Below this point along the south shore is a beach, smooth except for one small point, caused by an accumulation of boulders. The beach material increases in size from sand to rubble and where coarse has been pushed up into a low ice rampart which extends practically uninterruptedly beyond the boat house. Fringing the entire south shore of this bay is a well-defined submerged terrace of varying width up to fifty feet, which drops into deep water at about four feet. This terrace is evidence of strong wave action along this shore which, furthermore, may be corroborated on the slope to the south. Proceeding back from the shore, one encounters first the cliff of the four-foot level which in places is undercut in the brown sandstone. Still higher, thirty feet above the lake, may be found fragments of a shore line formed during another of the transitional

stages between Lakes Algonquin and Nipissing. An especially good example of an undercut cliff may be seen at this level above the south side of the narrows of the bay. Above the thirty-foot level there appears to be a broad terrace with cliff which may be the Algonquin shore. This, however, is not distinct and the interpretation is uncertain.

The trough in which this bay lies rises gently to the west and extends through to the south shore of the lake. During the four-foot level the shore stood about one hundred paces to the west and at the thirty-foot stage completely flooded the narrow channel, making an island of the present peninsula which forms the north shore of the bay. The peninsula is composed of brown sandstone which has been carved into an almost continuous cliff at the four-foot level along the south side, being undercut in places as much as fifteen feet. The amount of recession of the shore during this period is shown by the width of the exposed terrace which reaches a maximum of twenty feet. For a body of water so small as this lake must have been, the wave activity appears excessive, especially so since its effects are negligible at the present level. Since there was little difference in the size of the lake during the four-foot level and at present, the excessive cutting of the former stage must be attributed largely to a longer period of time during which the waves were acting.

Wave cutting is also the predominant factor in the development of the north shore of the peninsula. The greatest effects are found at the four-foot level and in the brown sandstone, as on the south side. An eastward drifting current along the south shore of the main part of this lake is formed during northwest "blows" but is dissipated in the bay near the end of the peninsula. Thus, no deposit is found at the tip and none will be formed until the bay is closed. A small sand deposit on the west side of the entrance to the bay is taking the form of a spit but its growth is apparently very slow. Farther west the activity of the waves is especially noticeable, inasmuch as the shore of the thirty-foot level was entirely removed by the recession of the cliff of the four-foot stage, which is exceptionally high.

Near the west end of the lake the heavily timbered slopes rise steeply to Mount Huron, in places making a 40° angle with the horizontal, and show little erosion by the shore agents at the higher levels, although hard rock was not encountered. The shore of the thirty-foot level is not distinguishable and that of the four-foot is relatively faint. The lack of strong shore features along this part of the lake is due, to some extent, to the short reach of the effective winds, but the possibility of their partial obliteration by the slumping of material down the steep slopes is suggested by the peculiar submerged projections along this shore, which may be material brought down in landslides.

At the west end of the lake a sand beach skirts the trough which continues westward towards Howe Lake. This trough rises above the thirty-foot level, so that the Rush and Howe lake basins were not connected during that stage. Along the north shore near the west end, the material is a sandy till but soon gives way to the brown sandstone. The four-foot level is marked by a continuous cliff as far as point B on map, but the thirty-foot shore is fragmentary, appearing infrequently as a notch in the cliffs. Along this stretch of the shore the submerged terrace is narrow, varying from five to twenty feet in width, but east of point B it widens to more than one hundred feet, the depth at the outer edge remaining at four to five feet. North of this shore stands a flat topped ridge of sandstone thinly covered with glacial material, beyond which is a dry trough extending parallel to that in which Rush Lake lies. The ridge continues to the boat house at the northeast corner of the lake, rising well above the lake level. Along this naturally smooth shore there was little opportunity for current deposits so that the features consist almost solely of cliffs, notched at the four and thirty-foot levels. However, some activity by currents from the west is shown by the gradation of the material on. the present beach, the size diminishing toward the east end where the beach is of fine sand. The coarser material has been pushed into local ramparts by ice, but the action is evidently of but moderate intensity.

Concluding, it may be emphasized that wave cutting has been the most important factor in the adjustment of the shores of Rush lake at the various levels. Furthermore, it may be stated that the results accomplished by the waves on this small lake, which probably never exceeded one-half mile in average width and two and one-half miles in length, were exceptionally great and surprisingly so after a study of the nearby lakes of like size.

IVES AND MOUNTAIN LAKES

Of the two lakes within the Huron Mountains, Ives is by far the simpler. This nearly circular basin was covered by the waters of Lake Algonquin, but this fact is disclosed by the elevation rather than by distinctive shore features. At this time its shores were open to the buffeting of the waves of the main lake and, if these shore features are indistinct, the adjustment at the present level must be slight indeed. As a matter of fact, where the hard rock is exposed the waves have made no impression. The best denned shore feature on the lake occurs on the northeast shore south of the outlet where the sandy material has been washed into a shallow submerged terrace of approximately thirty feet in width.

Mountain Lake, on the other hand, is long and irregular in outline, and presents numerous opportunities for adjustments by all of the shore agents. The shore materials are the hard rocks of the Huron Mountain mass and glacial material, including both till and sand. Obviously, the adjustments are more pronounced in the glacial material.

In the vicinity of the outlet the material is sandy, and an excellent beach and submerged terrace are prsent. The

latter is more than one hundred feet in width and drops into deeper water from a depth of thirty inches. At the north end the sand has been cut into low cliffs but towards the outlet these drop to a sand beach upon which stands a low ice rampart. The outlet cuts through these forms and, within one-quarter mile of the lake, begins to cascade over the granite rock.

South of the outlet the material changes to till and the beach contains many boulders. The shore as far as Mt. Homer is irregular due to a succession of minor projections and small bays. The shores consist uniformly of boulder strands at the projections and sand beaches in the bays. This would indicate wave action on the points and a gradual filling process by currents in the bays. In addition to the effects of waves and currents may be seen some excellent ramparts, formed by the expansion of the ice during the winter. In fact, the rampart is almost continuous but is much better developed at the projections because of the coarser material. At such locations these ridges contain boulders up to three feet in diameter and rise steeply to heights of several feet, the largest standing seven feet above the lake.

At the foot of Mt. Homer the crystalline rock comes to the shore and very little adjustment is noticeable. Where the rock slopes-gently to the lake, the surfaces appear as smooth as when uncovered by the glacier, but on the steeper slopes a slight roughening of the rock at the water level was noted. This roughening is due to the breaking off of small angular blocks of the rock along fissures. It seems probable that frost action has been more effective than the waves in this process, inasmuch as the water deepens rapidly at such locations and the fragments sink below the reach of the waves, thus depriving them of the tools which are necessary for abrasion. South of the narrows the east shore is more irregular than to the north and, in addition to the projections of till, has two rock promontories off which lie small rock islands. The glacial material is till and the beaches along such stretches of shore are lined with boulders. On the rock promontories the rock exposed, on the north side is roughened as described above but that on the southern exposure shows little change. The greater effectiveness, of the northerly winds is clearly shown here and this may be attributed to their long reach as well as their high velocities. The small islands off the rock points are likewise of solid rock but are not outliers which have become detached from the points by wave action. They are formed by ice scour and their smooth convex surfaces appear so like the backs of sheep that such forms are known as *roches montonnees* (sheep backs).

At the south end a forked bay extends to the southeastward. The depression which causes the north fork leads to the small but interesting Canyon Lake which was discussed in Chapter I under lake basins due to faulting. The Cliff River enters through a depression at the southwestern end of the lake, and this sluggish stream is depositing its sediment in a delta which, as yet, has caused no great projection of the shore. This is not necessarily an indication that the delta is small for the valley of the lower course of the stream is a low swamp and possibly was an arm of the, lake which has been filled by the deposits of the stream. A similar form lies at the mouth of a small stream entering the lake one-fourth mile north. In both cases the front slope of the deltas drops steeply into deep water from depths of not more than fifteen inches, indicating active growth of the delta and moderate wave activity.

The west shore is very similar to that on the east side but, in general, the slopes are flatter. Thus, the shores of the bays are inclined to be swampy and are fringed with alders. The beaches are bouldery except in the bay which lies south of Lumber Camp Bay and is connected with it by a swampy trough. The trough is sand-filled and the beach of the bay in the south arm is due to the working over of this material rather than to current action. Northward the shores are cut in till as far as Lumber Camp Bay and the beach contains many boulders. Within this bay, the beach material gradually reduces in size to sand at the head. This is due largely to a variation in the glacial material but may result in part from transportation of the finer material southward along the beach by waves and currents.

Northward along the west side, conditions are similar to those on the opposite side but the outline of the shore is more regular. At the foot of Mt. Ida the rock outcrops on the shore but does not form a projection. The rock shore gives way to a boulder beach and this in turn is interrupted by the only current deposit on the lake which can be recognized with certainty. Currents from both directions, but particularly from the south, have turned from the shore and built an embankment nearly two hundred feet out into the lake. The exposed part is similar to a V-bar but lacks the central depression. The submerged portion drops steeply into deep water from a depth of thirty inches.

Within the bay at the northern end the boulder beach presents little of interest. This bay is a part of the same depression in which Portage Lake lies. At the north end of the lake the hard rock of Mt. Huron conies to the shore and shows a very slight amount of abrasion. This gives way to the sand cliff described at the beginning of this discussion.

In general, it may be stated that the lake is too small to show the effects of intense wave action. The presence of a submerged terrace which drops at about thirty inches is 'an indication of waves which may reach a length of eight feet and a height of less than one foot. Such waves have had no effect on this hard rock in the many years they have been active. The glacial deposits, however, show wear consistent with the size of the lake. The greater effectiveness of the winds having northerly and westerly components is a natural consequence of the form of the lake and the prevalence of storm winds from these directions. This is seen in the tendency towards stronger wave action on the east shore and current action on the west. The effects are also greater

in the northern arm than in the southern, due to its greater size and regularity in outline. The lake is in a youthful stage and a discussion of the possibilities of extinction seems futile.

LAKE MICHIGAMME

On the extreme western border of Marquette County lies the "Big Lake," Michigamme. With an area of seven square miles, it seems insignificant compared to the Great Lakes, which were well known to the Indians who frequented this country, but locally, its importance probably justified its Indian name. For miles about it is the largest inland lake, but its claim to our interest is not based on size alone. Unique in form, picturesque in location, studded with numerous islands and broken by bays, this lake possesses a charm equalled by few, if any, of the lakes of the State, and in addition offers abundant material for physiographic study.

In shape, it resembles a large Y, spreading its arms to the west and southwest a distance of about six miles from its eastern end, see Fig. 85. The first view of the lake is usually obtained from the railroad whose tracks follow the north shore. The part seen is the island-studded north arm set among the bald hills of the Marquette Range, which project above the tree tops.

Although the glacier covered this region and the rounded and smooth rock knobs present striking evidence of its action, it is necessary to go to the rock formations and structures in order to understand the origin of this peculiar basin. The ridge-and-valley topography of this section is due to the varying resistance of the rock formations of the Marquette Range which have a general east-west trend. In this region the range is a great trough or syncline which is deformed by a minor fold on the north side just east of the lake, as shown in Fig. 86.

The upturned edges run along the north side of the lake in a narrow belt, but the range spreads out to the southwest, and from this expansion two small troughs extend to the south and southeast, the latter reaching to Republic. The different rock formations vary greatly in their resistance to erosion and of these the Michigamme, which underlies the greater part of the lake, is the least resistant. However, this formation is variable in hardness and is very resistant where changed by metamorphic processes. This is illustrated on the islands and along the southwest side of the lake, where the rocks stand in bold hills. These rocks were greatly eroded by running water previous to the invasion of the ice, and a general system of east-west valleys and ridges was formed. This trend is consistent along the north side of the lake, but on the opposite side swings towards Republic in a broad curve to the south and southeast. The valleys followed the least resistant rocks and, in particular, the Michigamme formation which in itself appears to be softer in proximity to adjacent formations. Thus, in addition to the east-west valley in which the northern part of the lake lies, a branch extended towards Republic and is now occupied by the south arm. and the outlet of the lake.

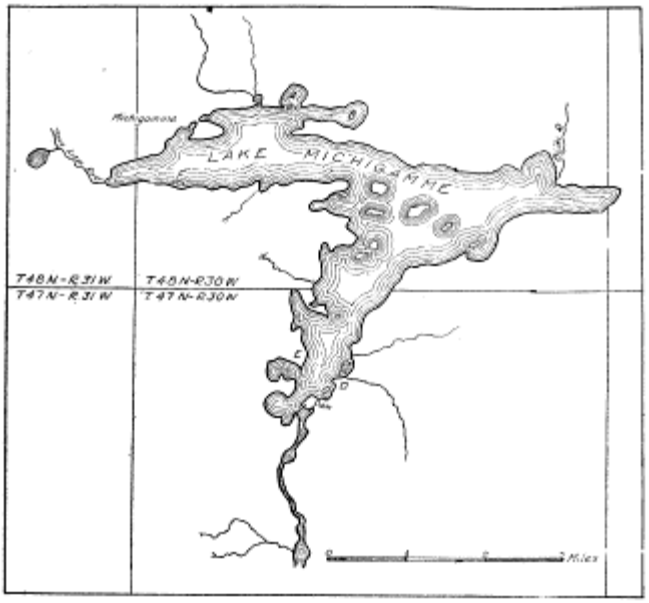

Figure 85. Outline map of Lake Michigamme, Marquette County.

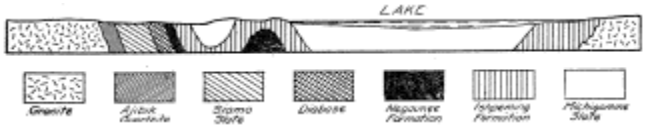

Figure 86. Geological section across the Marquette Iron Range, showing relation of Lake Michigamme to the formations. (After Van Hise and Bayley)

Such probably was the topography in its main aspects when the ice advanced from the northeast. The presence of islands indicates that the scouring action of the ice was able only to modify the existing surface by rounding off the hills and deepening the basin. The passage of the ice was across the main trend of the ridges and, while its general movement was independent of the topography, that of the ice border must have been greatly influenced by the relief features over which it passed. Thus, it is probable that the ice poured through the gaps in the ridges on the north side of the lake and spread laterally into the valley, deepening it locally into a basin. As the glacier was disappearing a remnant of ice filled this basin and deposited great quantities of sand at the east and west ends and along the outlet. In this way the Michigamme basin, due largely to pre-glacial conditions, was modified and isolated by glacial action.

In a lake as irregular as Michigamme frequent adjustments to wave and current action are to be expected, and the observer is not disappointed in this case. Hard rock outcrops in places on the shores but the greater part of the material within reach of the shore agents is of glacial origin. The drift is sandy as a rule and is, therefore, easily attacked. Along the sides it is thin or absent but reaches considerable thickness at the ends, especially the west. The adjustments may best be described in the order of a traverse around the lake,

beginning at the west end, a trip easily made by boat but offering difficulties on foot.

At the west end, the Three Lakes River enters the constricted arm of the lake from a narrow sand-plain which extends to the northwest beyond Nestoria. About a mile to the west the land rises to elevations of a hundred feet above the lake and has a roiling surface composed of heavy sand interspersed with large boulders. A well record in this locality gave twenty feet of heavy sand underlain by ninety feet of quicksand which, therefore, extends below the level of the lake. This sand plain, although not typical outwash, is broken by several pits in which small lakes and swamps lie. Bass Lake in T. 48 N., R 31 W. is an excellent example and is rapidly being filled with vegetation which completely encircles the lake and is in the floating bog stage. Just before entering the lake the Three Lakes River has deposited the sands brought from its upper stretches and nearly filled a former bay of the lake through which it now flows in a broad serpentine course. In addition to the sedimentation, vegetation is now rapidly completing the filling of the bay. The bay was caused by a projection of till from the north shore along which the road runs to a bridge across the narrows. The lakeward side of the projection has been straightened by shore action under the influence of easterly winds, which here have a long sweep, and a short but complete bar cuts off a narrow swamp now grown up to vegetation. Along the north side as far as the town of Michigamme, the strand is of large boulders swept clear of smaller material. Wave action is slight at present, but soundings indicate a terrace of about one hundred feet in width which drops into deeper water from a depth of seventeen feet. A rock bottom was encountered out to depths of eight feet, but beyond this firm gravel was encountered to the south side of the lake. A terrace extending to a depth of seventeen feet indicates an intensity of wave action far too great for a lake of this size. The writer is, therefore, inclined to believe that there is present here only a cut-terrace, represented by the rock-paved bottom, and that the gravels are due to a strong return current at this end of the lake rather than to local undertow.

The boulder beach continues around the peninsula east of the town of Michigamme where it is interrupted by a railroad fill. North of the railroad tracks in this vicinity precipitous rock cliffs form the south side of a ridge running parallel to the lake shore. The base is generally of uniform elevation several feet above the present level of the lake but is obscured by a talus of large rocks. Below the cliffs is a flat upon which the South Shore tracks are built. The formation bears a striking resemblance to a wave-cut cliff and terrace but the writer was unable to find further evidence of a former level of the lake at this height.

Figure 87. Sketch showing plan of the spits on the north shore of Lake Michigamme.

Beyond the cliffs the tracks leave the shore and turn northeast across a bay that is half filled with floating bog. Between this bay and the indentation, designated as A on the map, the shore is of sandy drift which has been cut back recently into low cliffs. The recent cutting is due to a renewal of activity caused by the artificially raised water level. The material of this shore has been carried in both directions and deposited in bars at the turnings of the shore. The bar at the eastern extremity of this beach is submerged but its presence is indicated by the breaking of waves over it during storms, see Plate XIX, A. On the west side, however, the bar stands above water but is being cut away rather than added to at the present time, and has been bisected as shown in sketch, Fig. 87. The eastern side of the entrance shows much leas action, indicating less powerful waves from the east winds of restricted reach. The north shore of the arm to the east, B on map, is likewise composed of sandy drift and is cut into fresh cliffs ten to fifteen feet high. In this case the material is transported to the east end of the bay where, augmented by the sediment of an entering stream, it is deposited an a sand bar which cuts off the swamp to the rear. The undertow has been active in carrying the sand out at the head of this bay and an excellent submerged terrace has developed, the surface of which was covered with well developed ripple marks when seen by the writer. The point forming the south side of the bay is caused by a ridge of hard rock veneered with drift and shows little wave action on the bay side. The main shore of the lake along this point shows active cutting, the beach varying from fine sand to boulders, depending on the character of the drift. This material is broken up by the waves and transported eastward by the prevailing westerly winds. Otherwise we should expect some deposition at the tip of the point. Along this shore, especially well shown at point C, was found a wave-cut notch in solid rock about two feet above the present level. The cliffs vary from two to ten feet in height and are bordered by a terrace ten to fifteen feet wide at its foot. At the present level the strand is lined with boulders accumulated from the drift which covers the hard rock on its lower slopes. This upper level, as indicated by the notch, does not correspond in elevation with the base of the high cliffs farther to the west and probably marks the higher water level of the lake.

About a mile from the east end of the lake the Bijiki River brings down, for the most part in the spring, great quantities of sand which is carried out into the lake in a great bar extending almost to the south shore. This bar has a pronounced effect on the waves, in that they are suddenly shortened in length and increased in height, making a rather treacherous bit of water during storms. The river is able to keep its channel open on the average but during a strong west wind at the time the writer visited this locality a sand bar was being formed across the channel. East of the Bijiki River rock hills again stand near the shore. An interesting bar was noted just

to the east of a rock projection where the railroad embankment begins. The bar which resembles a cuspate foreland, extends onward in line with the shore to the west for some distance and then turns abruptly back to the shore, as shown in the accompanying sketch, Fig. 88. The enclosed lagoon is compound, the different parts being separated by sand bars, and shows a development in steps similar to the formation of a hook. This is further emphasized by the heavy growth of vegetation in the older part to the west. During the writer's visit a storm beach was being piled up on the front of the bar and enclosed a narrow lagoon. This probably was not permanent but illustrates the importance of storms in the building of such features. One exceptionally heavy storm may do more work than a long period of moderate winds. As may be inferred from its shape, the bar has been built mainly under the influence of westerly winds but It is probable that easterly and southerly winds have played some part in forming the portion which extends from the point to the shore on the east side.

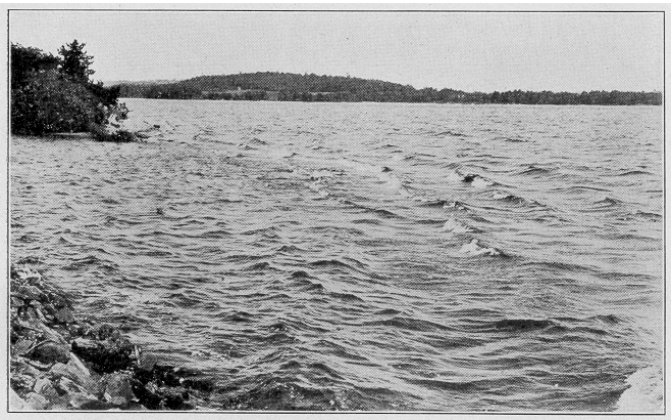

Plate XIX, A. Waves breaking over submerged bar, Lake Michigamme.

Plate XIX, B. Storm beach, east end of Lake Michigamme.

Beyond the bar a railroad embankment of stone borders the lake nearly to the eastern end. At this end of the lake the beach receives the full force of the waves thrown up by the westerly winds, which regain their form, after crossing the .sand bar of the Bijiki River, and is a perfect curve except where littered with drift wood. The slope is flat and a broad beach of fine sand is exposed. The force with which the waves strike this shore is indicated by the presence of two storm beaches which are too low to appear in the photograph, Plate XIX, B, but are denoted by the lines of drift wood resting in the shallow trenches to the landward of each beach. The upper or landward storm beach was formed during higher water, probably in the spring, while that next the shore was in process of formation when the picture was taken. The broad submerged terrace which extends off this shore indicates an exceptionally strong undertow.

Figure 88. Cuspate foreland on the north shore of Lake Michigamme. (Sketch from photograph)

Along the southeast shore, bouldery drift is abundant and the shore is lined with large rocks which hold up wave action. This continues to the point north of the dam, D on map, where deposition has increased 'the length of the point. In addition to the exposed part, this point extends for some distance under water, as shown by the growth of rushes. At present, however, it is being cut away rather than added to. In the bays on the west side of the south arm little wave action takes place, but the promontories are being attacked. At point E the material is sandy and the cutting has been rapid. However, the currents lose their force in crossing the mouth of the bay and a spit runs south from this point, continuing under water nearly to the opposite shore. North of this point the headlands are due to hard rock which outcrops on the shore in places. The cutting by the waves in such places is a matter of a few inches only at the present level, due in part to the resistance of the rocks but chiefly to the fact that they extend steeply below the surface and the fragments quarried by the waves drop into deep water and do not serve as tools. In many places a higher water level which agrees with that found on the north shore was noted.

Along the south shore of the west arm hard rock comes to the shores locally but much of the beach is of boulders. Opposite the town of Michigamme and lying close to the shore is Sundstrom's Island, F on map, a small island of till which is slowly being tied to the mainland at the southwestern corner. The bar runs to the southeast and is submerged at the present time but may have been dry during low water before the dam was put in. From this point to the west end of the lake the shore is composed of large, in some cases huge, boulders.

The islands of the lake form one of its most picturesque features. With the exception of some of the smaller off-shore islands, they are composed of the more resistant

rock. The larger ones in the main lake are surrounded by low rock cliffs or a boulder strand but show little off-shore deposition. They have been rounded off by the glacier and, in the south arm, are elongated in the direction of the ice movement. The latter may be considered as *roches moutonnees* (sheep backs) partly submerged.

PORTAGE AND TORCH LAKES

The Portage and Torch Lakes under discussion are situated in Houghton County and together form a very irregular shaped basin which is most interesting with regard to its origin. In a general way, it may be considered as consisting of two troughs which intersect at an angle of about 50°. See Fig. 89. The broader, or main trough, runs approximately parallel to the west shore of Keweenaw Bay and also to the trend of the rocks which form the Keweenaw Peninsula. The narrower trough winds across the peninsula in a general northwest-southeast course but has been closed at the north end by current activity during an, earlier stage of Lake Superior. Dredging operations readily converted this trough into a ship canal which affords this important copper region direct shipping facilities both to the east and west. The expansion at the intersection of the trough Is occupied by the main body of, Portage Lake. Closer examination, however, shows that the main trough is consistant only from Dollar Bay on Portage Lake northeastward, and is occupied by Torch Lake and the Trap Rock River; also that the continuation of this trough across Torch Lake is followed by the Pilgrim River and is a much less conspicuous topographic feature. The depression in which the main body of Portage Lake lies runs slightly west of south, joining the Torch Lake trough at an angle of about 35°. It is followed by the Sturgeon River which in its lower course meanders across a valley flat formed by the deposition of its heavy load of silt. Briefly stated, then, the depressions in which these lakes lie consist of three troughs: One running parallel to the Copper Range, a second which crosses the range, and a third extending almost due south from the intersection of these two.

In order to make clear the manner of formation of these troughs, the more important episodes in the physiographic history of this region will be briefly sketched. The first great event of interest in this connection was the complex folding of the ancient rocks of the Lake Superior region. The axes of the folds are parallel to Lake Superior, and, as a result of this, the rock layers dip beneath the lake and extend in an approximately east-west direction. A notable exception to the latter is the copper-bearing rocks of the Keweenaw Peninsula which have a northeast-southwest trend. After the folding, these rocks were subjected to prolonged erosion during which the surface was peneplaned. However, considerable relief existed on the peneplaned surface, due to the differences in the resistance of the rocks; also the complexities of the folding caused varied topographic features among which the ridge-and-valley type was prominent. The period of erosion was followed by a sinking of the land below the level of the sea, during which sediments of great thickness were deposited. These filled the valleys and covered the ridges in the vicinity of Lake Superior so that, when an uplift occurred, the streams flowed directly to the Lake Superior depression over the surface of these nearly flat-lying rocks. Then followed the removal of the greater part of the sediments by erosion, exposing the former topographic features. The ridges were encountered first but the trunk stream's were -able to maintain their courses across them. The tributaries, however, developed. along the former valleys in many cases". In this way a system of transverse drainage was imposed upon the former topography. Finally, the region was invested by glaciers which modified its surface both by abrasion and deposition.

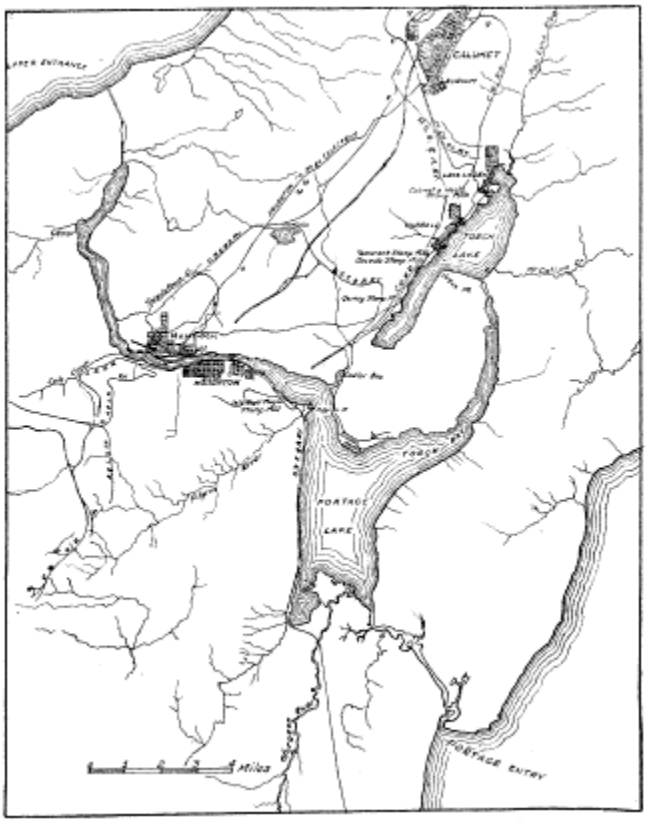

Figure 89. Outline map of Portage and Torch Lakes and vicinity, Houghton County. (From U. S. Lake Survey chart.)

Applying this sequence of events to the region under consideration, the resistent rocks of the Copper Range were folded and, at the dose of the first period of erosion, formed a prominent ridge. This ridge was buried later by sediments which also filled the depression between it and the Huron Mountains. When the land was again lifted above the sea, the drainage flowed in a northwesterly direction from the Huron Mountains across the buried Copper Range. During the period of erosion which followed, the range was uncovered but the trunk streams succeeded in maintaining their courses across it for a time, forming numerous gaps. In addition, tributaries developed along

the southeastern edge of the ridge. Later, streams developed from the northeastward in the less resistant sediments of the Keweenaw Bay depression and diverted the head waters of the trunk streams, forcing them to abandon their courses across the range. Within the Keweenaw Peninsula proper but one of the gaps has been worn down to the level of Lake Superior and this is occupied by Portage Lake. The reason for the persistence of this particular gap is uncertain but it seems probable that it follows a fault plane along which erosion was more easily accomplished.

If the existence in former times of a trunk stream flowing north-eastward through this gap is conceded, the troughs occupied on the one hand by Torch Lake and the Trap Rock River, and on the other by the Pilgrim River may be easily accounted for as tributary valleys on the upper side of the ridge. In addition, it is known that the rocks on the east side of the entire range have dropped along a great fault and it is believed that this has had some influence in the location of the courses of these tributary streams.

The meager information at hand does not warrant a definite conclusion as to the origin of the Sturgeon River depression. The occurrence of hard rock outcrops between it and Keweenaw Bay seems to be an argument for a pre-glacial valley. If such is the case, it must have been a tributary to the trunk stream which crossed the peninsula through the Portage Lake gap, and its size seems disproportionately large. Enlargement of this valley by glacial scour is not probable for the movement of the ice which affected the east side of the peninsula was almost directly across this valley. On the other hand, the lobe of ice which ran into the Keweenaw Bay lowland deposited moraines in a festoon which conforms more or less closely to the outline of the bay, and the possibility that the valley stands between morainic ridges cannot be dismissed without further study.

As in the case of a number of the inland lakes of Michigan, the Portage and Torch Lake basins were flooded by the predecessors of Lake Superior—Lakes Algonquin and Nipissing. The beaches of Lake Algonquin stand more than four hundred feet above Lake Superior and take one far afield. During Algonquin time the greater part of the peninsula was submerged and only the tops of the higher hills stood above the water, forming a chain of islands which were aligned in conformity to the trend of the peninsula and, for the most, elongated in the same direction. The Nipissing shore, however, stands but thirty-four feet above the present lakes, and may be easily recognized a short distance back from the shore for most of its extent. It is, however, usually beyond the reach of the waves of the present level and is well preserved. The greatest departure from the present outline of the lakes during this stage occurred along the course of the Sturgeon River, whose lower course was flooded for a distance of twelve miles. The present connections with the main lake existed but were necessarily somewhat greater in width. The Upper Entrance (north) was closed by a sand bar in Nipissing time, but the Portage Entry remained open. The closure of the Upper Entrance was due not only to its lesser width and more favorable shore conditions, but also to its position on the west shore of the peninsula which is exposed to the full force of waves driven by the strongest winds.

The narrow north arm of Portage Lake, see Fig. 89, nowhere reaches a half mile in width and, furthermore, is protected from strong winds by the high flanking hills, so that the shore features are not noteworthy. The most pronounced features are the delta-like accumulations of sand. In some cases these occur at the mouths of streams and appear to be natural, but others are the stamp sands from the copper mills. The accumulation of the latter was rapidly obstructing the channel and it became necessary to establish harbor limits for this part of the lake. At Pilgrim Point the deposit is a delta of the Pilgrim River which has shifted its course on the flat at least once. The submerged part of this delta shows clearly a northerly drifting current along the shore south of the point. The broad submerged terrace which extends eastward from the point may be, in part, the deposits of such currents previous to the present extension of the delta of the Pilgrim, but the deposition of a large quantity of stamp sand from the Isle Royal mill makes this interpretation uncertain.

The records of the weather bureau station at Houghton show that the prevailing storm winds in this locality are from the west, northwest and north. Thus, the entire west shores of both Portage and Torch Lakes lie in protected positions and should, therefore, show less pronounced effects of the shore agencies. This is well shown along the shore which extends almost due south from Pilgrim Point to Pike Bay at the south end of the lake. Not only the features of the Nipissing shore but those of the present level as well are meagerly developed. Cutting has been the predominant process but, as a rule, has been slight in amount, as shown by the low cliffs and narrow submerged terrace. A number of minor projections, which need not be specifically mentioned, occur along this shore and are due to one of several causes, among which may be mentioned delta's of streams! entering Lake Nipissing, similar forms at the present level, old docks, and vegetation. The latter protects the shores and, where removed, allows a recession of the shore line by wave cutting, see Fig. 40, Mullet Lake. Obviously, the projections occur where the vegetation is intact. The abundant .growth of rushes and, in places, lily pads is an indication that this shore is nearing complete adjustment to the present conditions.

The extension of the lake far to the southward during Nipissing time has already been mentioned and also a hint as to the activity of the Sturgeon River been given. A better appreciation of the work of Sturgeon River may be gained from a study of its lower course. At its mouth stands a large delta which causes the irregular projection of the south shore of the lake. The stream does not split into distributaries but has shifted its course

a number of times in the past, causing the ragged growth of the delta. An abandoned channel at the northwestern point indicates the position of the stream when the growth of the delta threatened the complete isolation of Pike Bay. Other abandoned channels exist southeast of the present mouth of the Sturgeon. Deposition at the mouth of the Sturgeon in its present position will in time tend to obstruct the outlet which has a feeble current. The small channel leading into Pike Bay is artificial, having been cut for logging purposes. In the vicinity of this cut a sudden rise in the surface of the delta occurs on both sides of the Sturgeon River. This rise, although slight, is interesting because it indicates two stages in the growth of the delta. The higher, or upstream, part developed during the Nipissing stage and is evidence of the great quantity of silt carried by the Sturgeon during that time. Some idea of the amount of material deposited may be gained from the submerged portion of this delta alone, which fills a valley twelve miles long and more than two miles in width to a depth of at least twenty feet and possibly double this figure, a volume estimated at twenty million cubic yards. In addition, the exposed part of the delta, the extent of which is undetermined, must be considered. The lower stage of the delta has grown since the drop to the present level and is relatively insignificant compared with the Nipissing delta. Including both the exposed and submerged parts in the estimate, it probably has an extent less than one-tenth the submerged part of that of the Nipissing stage.

The channel through which the Portage River flows is of considerable width and carries on its side slopes the well-defined cliff and terrace of the Nipissing level. The undisturbed frontal slope of the terrace drops to a low swamp across which the stream winds in broad curves which closely resemble meanders. At the Portage Entry the river has been turned to the right before entering the lake by a sand bar which grew from the bluffs to the east and has nearly closed the entrance.

Along the east side of Portage Lake the slopes are uniform and gentle. Consequently, the shores are unbroken by large indentations but still have minor irregularities which indicate a lack of perfect adjustment to waves and currents. Wave cutting predominates, as on the west side, and low cliffs line the shore for most of its extent. The activity on this shore is somewhat greater than on the west side but the effects are hardly more noticeable. At present the accumulation of drift wood affords considerable protection to the shore.

The irregularities of the shore-line are greater in the narrow Torch Bay than on the shores of the main lake and consist of projections rather than of embayments. A number are due to artificial structures but the numerous natural points in this protected arm lead one to suggest that perhaps more emphasis should be placed on the adjustment of the shores of the main lake.

Within Torch Lake the east shore is exceptionally smooth for about one mile, a fact which may be attributed to current action. The blunt projection northeast of McCallum Creek is clearly a hook but formed at a level higher than the present. From this locality to the north end of the lake, the shore features are similar to those on the main shore of Portage Lake. Around the depression at the north end of the lake the contour of the shore has been modified somewhat by the silt of the Trap Rock River, but no definite delta has been formed. As at the south end of Portage Lake, Lake Nipissing flooded the lower part of the depression through which the Trap Rock River now flows but extended hardly more than two miles from the present shore.

The Nipissing terrace is well defined along the west shore of Torch Lake and upon it are located rail and wagon roads, as well as numerous stamp mills and smelters. To the sands of the former, e. g., the Calumet, Hecla, Osceola and Quincy stamp sands, are due the large projections of the shore line. So prominent are the projections that the natural shore agents on this protected shore are of little effect. But on the opposite shore in the narrow part of the lake below Ureux Point, the waves and currents are much more effective. Cliffs line the shore from the point to within a half mile of the southwestern end of the lake, and for a considerable part of the distance are cut in red sandstone. The material quarried from these cliffs has been transported southeastward and deposited in a spit at the end of the lake. The Torch Lake depression continues through to Dollar Bay on Portage Lake but nowhere rises above the Nipissing level. It therefore formed a second connection between the two lakes at that time.

Before leaving the discussion of these lakes, the shore of Portage Lake from Dollar Bay to Grossepoint demands consideration. The Nipissing shore features, although distinct, are on a small scale, and the activity is not great at the present level. Thus, the small projection opposite Pilgrim Point, a delta of Nipissing time, has neither been reduced nor added to. Yet off Grossepoint there exists a submerged hook, the Middle Ground, which in extent far surpasses any similar feature to be found on the lake. Clearly this hook is much too large to have been formed by wave and current action on the short stretch of shore northward to Dollar Bay. This discrepancy may be readily accounted for by considering that the hook is an incipient form built during the Nipissing stage, when the currents had full sweep of the shore northward to Ureux Point on Torch Lake.

GOGEBIC LAKE

For the origin of the euphonious name of Gogebic Lake, we must go back to the Indians. Its derivation, however, is uncertain, some authorities suggesting that it is a contracting of *agojebic* meaning "rocky" or "rocky shore," and others that it comes from *gogebing*, "dividing lake." The former seems the more appropriate on account of the rock outcrops in the vicinity of the lake, notably the Alligator Head which occupies a commanding position about the southwestern shore of the lake.

Gogebic Lake, see map, Fig. 90, has a total length of fourteen miles, if the eastward extension at the north end is included, and covers an area of somewhat more than twenty square miles. It is remarkably consistent in width and is relatively free from prominent projections and deep embayments. In fact, where widest it does not exceed two and one-half miles and nowhere narrows to less than three-fourths of a mile except at the ends. It extends in a general direction which is somewhat east of south and departs from this only at each end. The direction of the south end is almost due north-south while at the north end an abrupt bend to the east occurs. These changes in direction of the lake will be better understood after a discussion of the origin of this basin.

Obviously, much of the surface of a region over which continental glaciers have passed is covered with a variable thickness of drift which obscures the underlying rocks and increases the difficulty of interpreting the preglacial conditions. If, however, the relief of the land over which the ice passed was great, as was the case in this region, the depressions were quite consistently covered by the glacial deposits, while the uplands received a thin veneer of drift or were left bare. Nevertheless, the deposits are usually not of sufficient thickness to conceal the former topography, and the general features of the pre-glacial landscape may be deciphered.

The prominent topographic features of this region are two rock ranges which stood well above the surrounding lowlands in preglacial times and still form the commanding elevations. The more northerly is the Copper Range which forms the backbone of the Keweenaw Peninsula and extends southwestward into Wisconsin, following the trend of the Lake Superior shore. Near the western boundary of the State it comes in contact on the south with the Gogebic Range which is the eastward extension of the Penokee Range of Wisconsin. This range has a nearly east-west trend in Michigan but ends abruptly at the west shore of the south end of Gogebic Lake. These two ranges thus form a westward-pointing V, the southern limb of which is relatively short. See Fig. 91. The pre-glacial drainage developed in a manner described for the region to the northeast (see Portage and Torch Lakes), and the streams flowed across the ranges into the Lake Superior basin. Thus, numerous gaps were formed, some of which are still occupied by streams. Many, however, have been abandoned and are now wind gaps.

In order to attain our immediate purpose, that is, the origin of the Gogebic Lake basin, it is necessary to consider the Copper Range only, inasmuch as the basin apparently does not cross the Gogebic Range. See Fig. 91. From the map it will be seen that Gogebic Lake occupies a narrow depression which skirts the east end of the Gogebic Range, extends northward to the Copper Range, and then turns abruptly to the east along the edge of the Copper Range. The Ontonagon River which drains the lake likewise follows the south side of the range and extends fully twenty miles to the east before breaking through. Directly north of Gogebic Lake is a low wind gap through the range, see Plate XX, A, in which are located the headwaters of the Iron River. From the gap this river flows almost due north to Lake Superior. Furthermore, Gogebic Lake is relatively shallow, and it therefore seems reasonably certain that the two depressions—the Iron River valley and the basin of Gogebic Lake—were formerly continuous. If such were the case, the cause of the abandonment of the gap offers a problem.

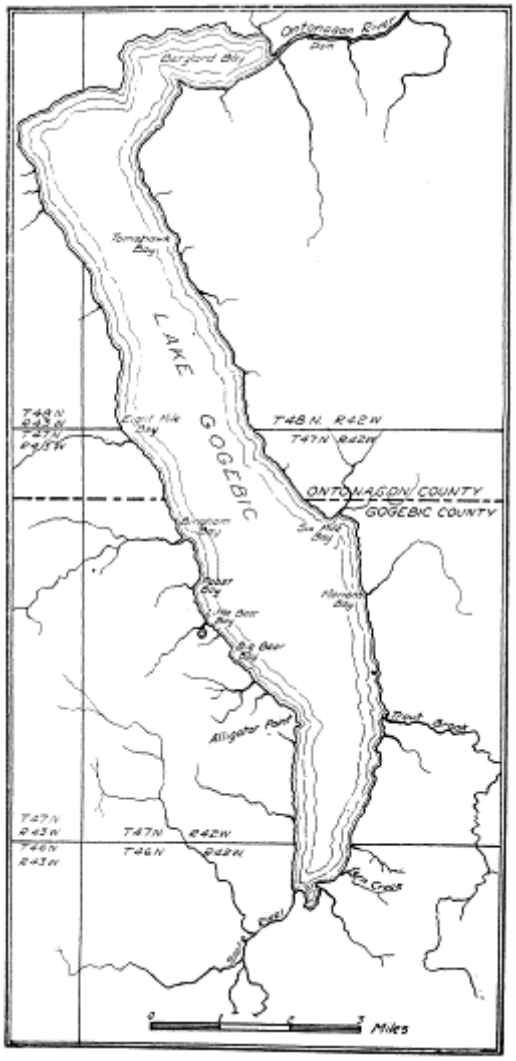

Figure 90. Outline map of Lake Gogebic, Ontonagon and Gogebic Counties.

The solution of this problem is difficult on account of the glacial deposits, in particular the morainic material in the bottom of the gap, and will remain uncertain until further work has been done. In fact, the problem of the drainage of the entire Copper Range is one that the writer desires to study further. As it is, two ways by which the gap may have been abandoned suggest themselves. The simpler way is to account for this by glacial action. The ice passed over this region in an almost southerly direction, as may be seen from the striations on Pilot Rock at the south end of Gogebic Lake. It seems certain that the ice must have passed directly up the pre-glacial valley whose course is now

marked by Iron River and Gogebic Lake. Some abrasion was, of course, accomplished but, inasmuch as Gogebic Lake is relatively shallow, it is felt that the basin was not greatly enlarged in this way. Soundings taken off Six Mile Bay show a gradual increase in depth to fifteen feet in more than one-third the distance across the lake. These soundings, although very incomplete, seem to indicate a flooded channel rather than a definite basin.

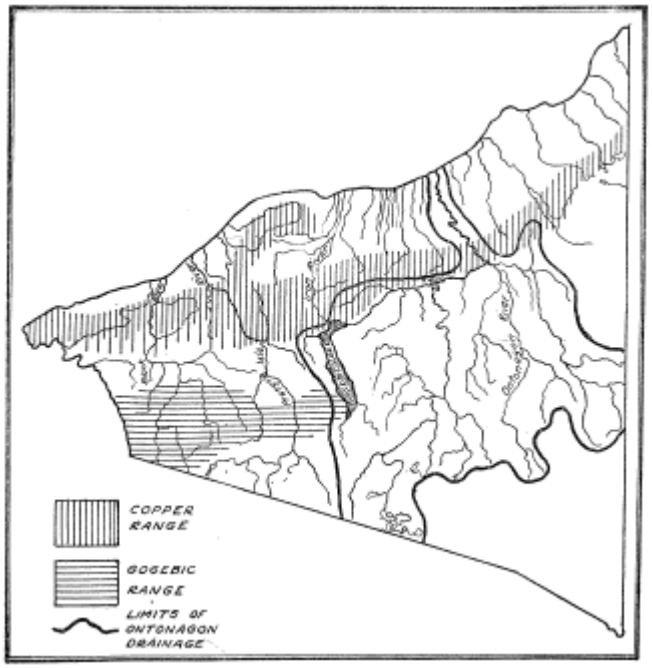

Figure 91. Map of western part of the Northern Peninsula showing the general distribution of the Copper and Gogebic Ranges and also the basin of the Ontonagon River.

During the recession of the ice, the border halted along the heights of the Copper Range. At this time the waters to the south were impounded and formed a large lake, Ontonagon, which spread eastward into Houghton County but discharged through an outlet to the west. Further recession of the ice, the details of which we may omit, uncovered the gaps and that of the Ontonagon River proved to be the lowest in the range between the Fire Steel and Presque Isle rivers. This gap then served to drain the ponded waters south of the Copper Range and still continues to drain not only the area occupied by this lake but also a large area to the south which extends to the Wisconsin line south of Gogebic Lake. During the halt of the ice, however, morainic material was deposited along the range but in greater amount in the gap north of Gogebic Lake than in that occupied by the Ontonagon River. Thus, the portion of the stream flowing in the Gogebic Lake-Iron River valley south of the range was diverted eastward to the Ontonagon. The lowest course open to this water lay just south of the Copper Range, due probably to preglacial tributaries which followed the south side of the range and flowed into the Ontonagon on the one hand and to the Gogebic drainage on the other. Obviously, the divide between these two streams originally stood higher than the gap of the Gogebic drainage. Thus, when the water was forced to flow across this divide by the plugging of the gap north of Gogebic Lake, the lower portion of the diverted part of the stream was flooded, forming Gogebic Lake.

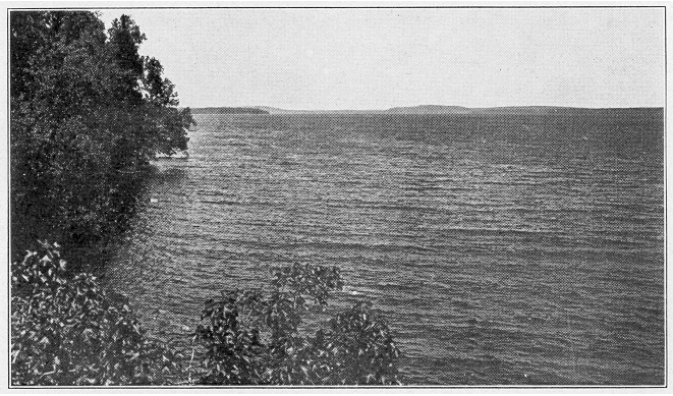

Plate XX, A. Looking North on Lake Gogebic.

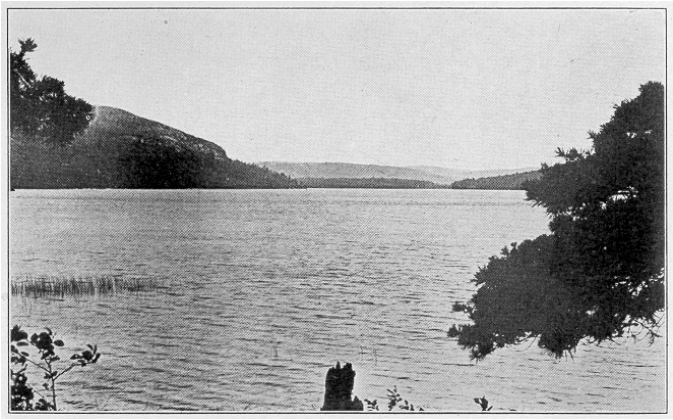

Plate XX, B. Mountain Lake, Huron Mountains.

Another conception of the origin of the basin of Gogebic Lake is based on the action of pre-glacial streams. As stated previously, it is believed that this region was once completely covered with sediments. After an elevation of the land which lifted the region above the level of the sea, stream courses developed on the surface of the sediments, flowing northwestward into the Lake Superior basin. This drainage system was maintained for the most pare as the streams cut through the sediments and encountered the buried rocks below. In this way there was imposed on the folded rocks below a system of drainage, the trunk streams of which ran across, or transverse, to the rock ridges. Less is known of the tributaries inasmuch as the valleys are masked with drift, but, drawing an analogy from well known regions where this type of drainage prevails, it may be stated with some confidence that many of them developed along the upper sides of the ridges. The headward extension of such tributaries of adjacent streams brought about conflicts for territory which eventually resulted in the formation of secondary divides. The trunk streams, however, varied in their ability to deepen their channels, mainly on account of differences in volume, and the larger streams cut the deeper gaps. This, in turn, gave an advantage to the tributaries of such streams which were able to lengthen their courses at the expense of the weaker streams on the opposite sides of the divides. In

this way the divides shifted from the larger streams towards the smaller and at the same time became lower in elevation. In some cases this process continued until the upper courses of the weaker streams were captured by the tributaries of the stronger and the water gaps abandoned.

According to this conception, the Ontonagon River, the largest stream in Michigan which crosses the Copper Range at the present time, was of like magnitude in pre-glacial times. Tributaries developed along the south side of the Copper Range, but that working eastward was much the smaller on account of a conflict with the drainage of the Keweenaw Bay depression. On the west side, moreover, the tributary had a decided advantage over the tributaries of the adjacent streams and steadily worked headward until it captured the upper course of the stream flowing in the Gogebic Lake-Iron River valley. See Fig. 92. Between this depression and the Ontonagon gap other cases of capture by the same stream are, of course, possible. Following the capture, continued down-cutting by the Ontonagon resulted in a deepening of the upper part of the Gogebic Lake-Iron River valley.

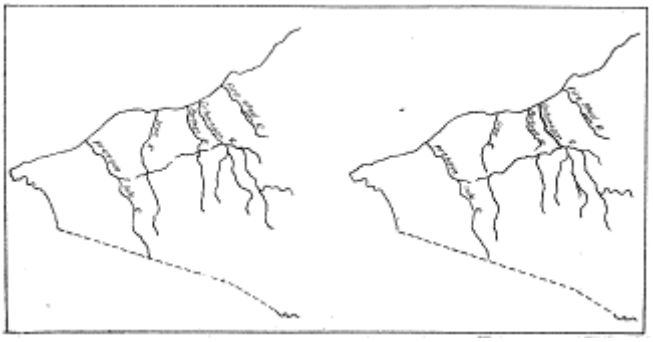

Figure 92. Map to show the change in drainage which has taken place within the present basin of the Ontonagon River. Map to the left illustrates probable drainage in former times, and map to the right shows the series of stream captures and present drainage system.

The flooding of the valley to form Gogebic Lake is still to be accounted for, and consideration of this phase of the problem brings to our attention the abrupt eastward turn of the north end of the lake. This arm is consistent in size with the remainder of the lake and may be interpreted as a portion of the pre-glacial valley which continued to the eastward, thus corroborating the idea of stream capture. If this be the case, the flooding must be due to glacial deposition in the course of the stream below Gogebic Lake, although some deepening by glacial scour is possible.

With this discussion of the two ways in which Gogebic Lake may have originated, we leave the subject for future work to settle and pass on to a description of the shores of the lake. The study of the lake, aside from the origin of the basin, was less interesting than was to be expected, for two reasons. The absence of prominent headlands and deep embayments gives little opportunity for the distribution of wave-cut material in forms that produce striking results. In addition, the lake has been dammed for power purposes and at the time of the writer's visit stood nearly three feet above its normal level, obscuring to a large extent the natural shore features.

The popular Gogebic Resort at the south end of the lake may be reached by a five mile drive from Gogebic Station on the Chicago & Northwestern R. R. At the opposite end, however, the Duluth, South Shore & Atlantic skirts the north shore, stopping both at Bergland and Lake Gogebic. The latter route is perhaps the most convenient for a physiographic study because the flooded condition of the lake and the reason therefor are at once apparent.

In general, the slopes rise more steeply from the lake on the east side than on the west. The relief of the lake, however, is considerably more on the west side than on the opposite side, and this is due to the existence of the heights of the Gogebic Range at the south end and of a low swamp which leads westward from the northwestern shore. The swamp borders the lake from Eight Mile Bay to the north end, a stretch of more than four miles.

In Bergland Bay and, in fact, along most of the north shore, the flooding of this lake is very apparent. Where the shores are high, wave action is particularly effective, but along the low shores and for an undetermined distance inland, the forest trees stood in water when seen by the writer. The normal shore features were so obscured that little could be made out except at the sharp point on the south side of Bergland Bay. This appeared as a submerged sand bar upon which stood dying trees and is interpreted as a sand spit in process of disintegration. It is claimed by the interests who maintain the dam that the summer of 1913 was the only time since the dam was built (1906) that the water remained consistently high. This, however, does not mean that the effects of the revival of the shore agents will not be felt, for the water stands abnormally high in the spring which is a time of frequent and powerful storms. The material along the east shore as exposed by the waves is a sandy till, and the topography of the land may be described as gently rolling. Thus, there are minor points and bays but not of sufficient prominence, as a rule, to turn currents from the shore. Waves, then, are the prevailing agent of erosion and cliffs of variable height the prominent physiographic feature. At the slight projections, boulders are concentrated on the beach but in the embayments the material is smaller in size. The indications of current action are slight indeed and are, thus, the more noticeable. Those found were opposite Eight Mile Bay a short distance north of the township line and consisted of two short stretches of gravel beach and a small indentation which was cut off by a bar. The material of the bar was coarser towards the north end and shows that the effective currents are driven southward along the shore.

The abrupt turn of the shore into Six Mile Bay appears favorable for current deposition, but none was found. East of the stream which enters this bay, a well defined spit separates the low swamp along the stream course

from the lake, but joins the cliffs a short distance south. South of the bay a boulder ridge below the cliff indicates strong ice shove which is not generally evident along this shore. Once discovered, however, the numerous boulders lined on the beach become significant. Cliffs prevail to the south end of the lake but are interrupted at the mouths of the streams. Evidence of ice push is found in places, but the most noticeable feature along this stretch of the shore is the spit on the south side of the mouth of Trout Brook. As was the case at Six Mile Bay, northward moving currents left the shore and built a small spit which has turned the mouth of the stream in the same direction.

A reversal in direction of the effective currents takes place between Trout Brook and the south end of the lake, for the shore east of Ice House Bay is lined by a smooth sand beach which continues into the bay as a spit. Under normal conditions this spit would in time close the entrance to the bay but at present is being removed. The promontory between Ice House Bay and the Slate-River is a hard rock knob upon which the glacier recorded the direction of its movement by striations. These show the movement to have been parallel to this part of the basin.

The high banks on the east side are wooded to the beach and show but moderate activity of the waves as compared with the-opposite shore. Just south of Alligator Point a most unexpected V-bar was found. This, of course, is a deposit built by currents from both directions, but no reason for the currents leaving the shore is ventured at present. Above Alligator Point a large rock outcrop of suggestive shape peers through the woods and has been descriptively dubbed the "Alligator Head."

North of Alligator Point the shore swings to the northwest and is somewhat more irregular. Nevertheless, wave action predominates and but one current deposit was noted, a V-bar between Pabst and Bingham bays. Along the low shore from Eight Mile Bay northward, ice ramparts are the striking feature. The singular number might almost be used in referring to them, for the ridge is nearly continuous and reaches a height of fully five feet in some places.

In conclusion it may be stated that the most striking fact brought out by the study of the shores of Gogebic Lake is the revival of the activity of the shore agents. This is of very recent date and the most pronounced effects are those produced by waves. The cliffs are universally freshened unless protected by vegetation, and shore currents are ineffectual. Examples of active deposition under the present conditions are few indeed, and in some cases the forms built under former conditions are being removed. In general, greater activity is displayed on the east shore than on the west and this is to be expected on account of its position on the lee of the prevailing storm winds.

lee shove is apparently very strong but shore conditions are usually unfavorable for the formation of ramparts. On the northwestern shore they are very well developed but elsewhere the lining of boulders on the beach is the usual occurrence. The way in which the ice works on this lake is not known to the writer but, judging from the width of the lake, both jams and expansion may be effective.

CHICAGON LAKE

This small lake is situated a short distance north of the Wisconsin-Michigan boundary line in Iron County. It lies for the most part in a northeast corner of T. 42 N., R. 34 W., but small portions spread out into the adjoining townships, from which it flows northeast to the Paint River. It is most readily reached from Iron River over the excellent Iron River-Crystal Falls road, which crosses the outlet about a mile from the lake.

Its shape is elongated, as would be expected, for it lies in a valley between the drumlinoidal hills which are characteristic of this region. As may be seen from the map, Fig. 93, the valley is blocked by morainic knobs across which the Crystal Falls road runs and which separate this basin from the one to the north occupied by Trout Lake. The lake, then, may be assigned to the class formed by morainic dams to which type Fortune Lakes, situated about two miles to the west, also belong.

The shores along the sides are generally high and dry and afford many excellent locations for cottages which have as yet not been taken advantage of to any great extent. Both ends of the lake are swampy and this is especially true of the north end. The lake at this end is shallow and supports a growth of rushes. Shrubs grow to the water's edge and hold up any slight wave action that may occur in this restricted part of the lake. The encroachment of vegetation is marked in this locality and has reached the advanced stage of quaking bogs which appear as flat, grass-covered areas.

The east shore is comparatively straight with the exception of a projection near the north end and is flanked by smooth, rounded slopes which are steep in places. On a lake of this size wave action is not intense and shore forms are not to be expected on a large scale. Along the northeast shore as far as Park's farm the shores are lined with a pavement of boulders which extends a short distance above the present water level. This gives way in places to a small but definite boulder ridge, elevated about three feet above the lake and a smaller amount above the narrow strip -to the landward side. The regularity of the boulders on the shore has given to stories to the effect that Indians had paved these shores in past but this may readily be accounted for on physiographic grounds. The material of the banks is a sandy till and the wave action weak, so that only the sand is carried away. The boulders, concentrated, are then .shoved to the shore by ice expansion which is sufficient to form definite ridges locally. The elevation of the boulders indicates a higher level for the lake and this is well supported by the frequent occurrence of an

elevated shoreline about three feet above the present level.

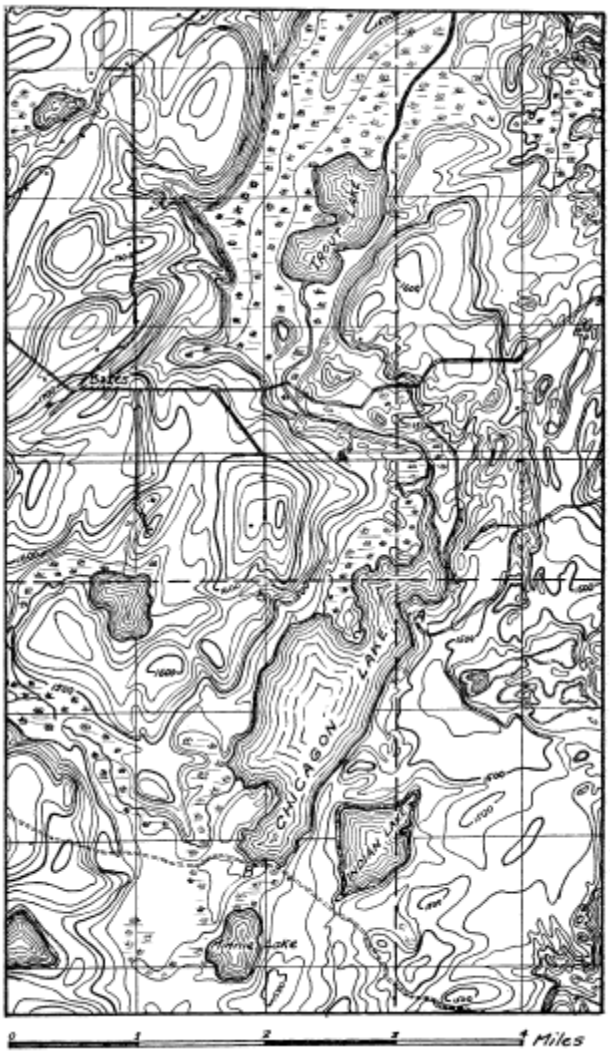

Figure 93. Topographic map of Chicagon Lake and vicinity, Iron County.

This higher level marks the original position of the shores but may also mark a temporary high level. Forty years ago an extensive beaver dam is known to have been maintained on the outlet of the lake and has since been destroyed. The water may have stood at the upper level during the existence of the dam but it hardly seems probable that this would have been maintained long enough to allow the cutting off of indentations, as is the case just below Park's farm where a bar completely closed an opening at the higher level. The lowering in level seems to be better accounted for by the cutting down of the outlet.

At Point A, see map, an interesting change has taken place. This point is incorrectly shown on the map for the tip of the point is in reality a rather elongated knob with a low, flat tract between it and the main shore. On the slopes of the knob and also the main shore, the strand of the upper level may be seen above the flat. This indicates clearly that the knob once existed as an island, separated from the mainland by shallow water. From this point to the south end, the shores are high and are nipped by the beach of the upper level. The extreme south end of the lake is bordered by a good sand beach which gives way to an ice rampart along point B, where the land is higher. The west shore of the lake presents little of interest until the point C is reached, at which wave action seems to be most effective. On the very tip of the point the beginnings of a spit of coarse cobbles pointing to the south was noted. The effective winds, therefore, come from the north and northeast. Beyond this point the shores merge into the swamp at the north end of the lake.

From the description, it is clear that wave action is slight on this lake. It seems to be limited to the transportation of sand, except in one case, point C. The effects as to cliff formation are almost negligible because of the presence of numerous boulders which rapidly become concentrated on the beach and hold up the wave action. The absence of a cut-and-built terrace is in keeping with the slight amount of wave action and the lack of adjustment by current deposition. Ice action is relatively prominent and is of the expansion type, for the probability of any extensive ice jams on so small a lake is slight.