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.

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 on 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 Round 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 preglacial 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.

In the journey up the outlet which flows over bare rock in places, it is interesting to note that the channel has been deepened

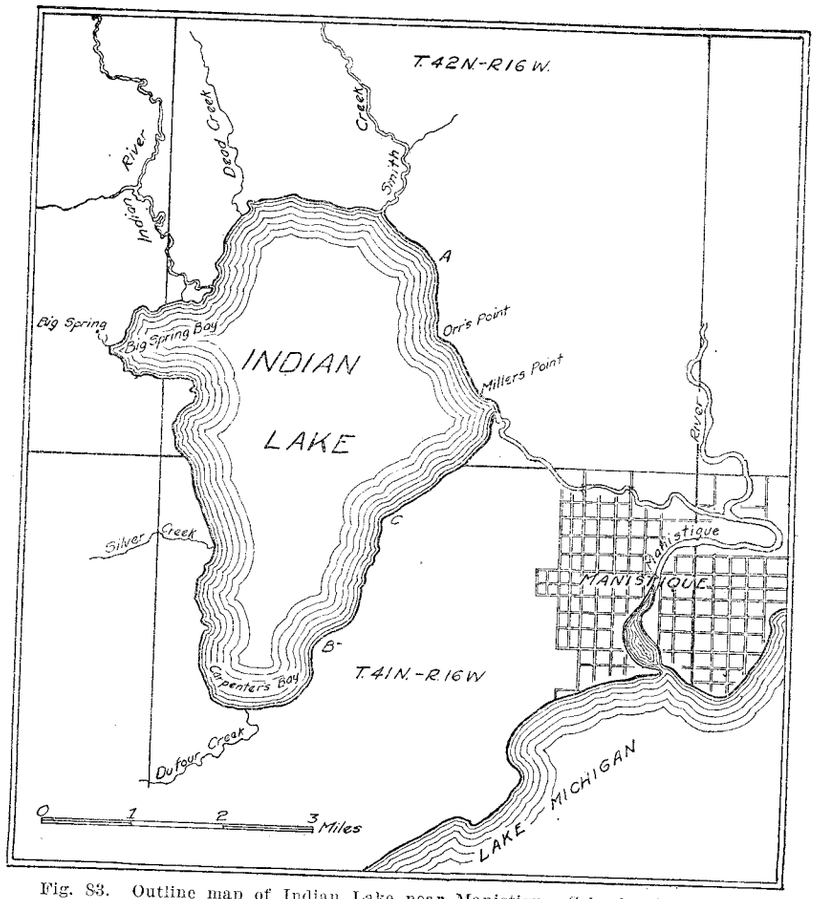
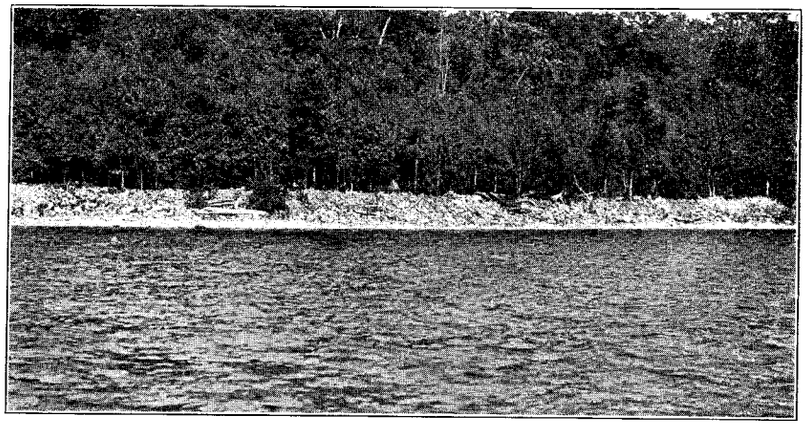
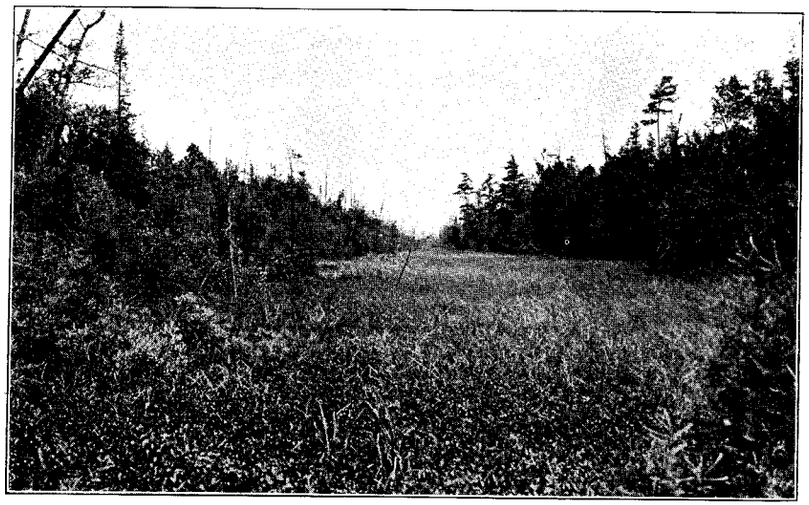


Fig. 83. Outline map of Indian Lake near Manistique, Schoolcraft County.

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



A. ICE RAMPART, INDIAN LAKE.



B. VEGETATION, LAGOON AND BAR, NEAR INDIAN LAKE, SCHOOLCRAFT COUNTY.

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.

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, there-

fore, 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 1800 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 Rush 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 due 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

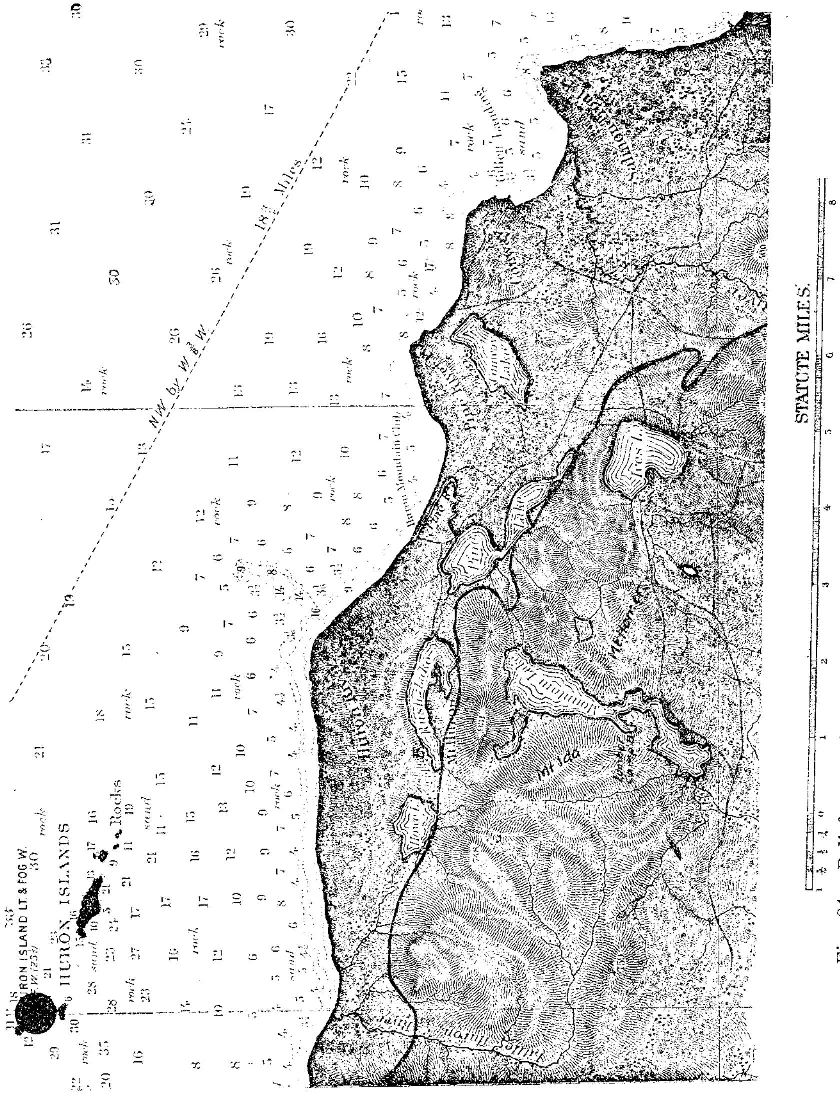
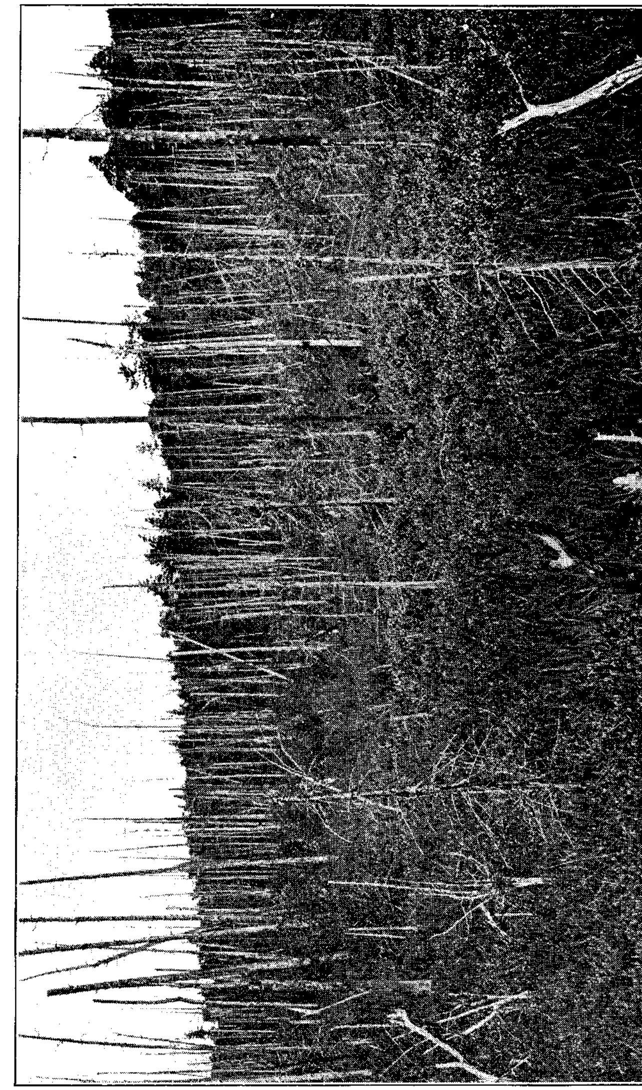


Fig. 84. Relief map of the Huron Mts. (From U. S. Survey chart with additions)

the sandstone. This is further strengthened by the fact that the sandstone north of Howe and Rush lakes rises well above the level of these lakes. It seems probable, then, that in pre-glacial times a stream flowed northward to the Lake Superior basin, cross-

Michigan Geological and Biological Survey

Publication 30, Geological Series 25, Plate XVIII.



EXTINCTION BY VEGETATION, ARM OF PINE LAKE, HURON MOUNTAINS.

ing 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.

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 dam 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.

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 transi-

tional 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 defined 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 montonnces* (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 comes 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

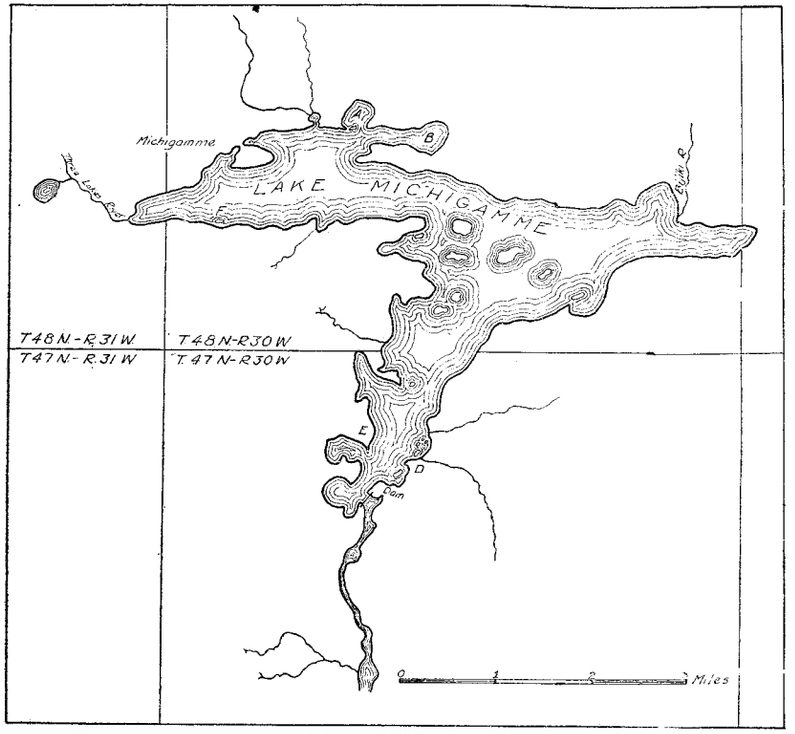


Fig. 85. Outline map of Lake Michigamme, Marquette County.

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.

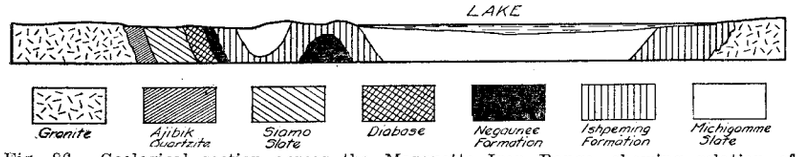


Fig. 86. Geological section across the Marquette Iron Range, showing relation of Lake Michigamme to the formations. (After Van Hise and Bayley)

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.

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 rolling 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.

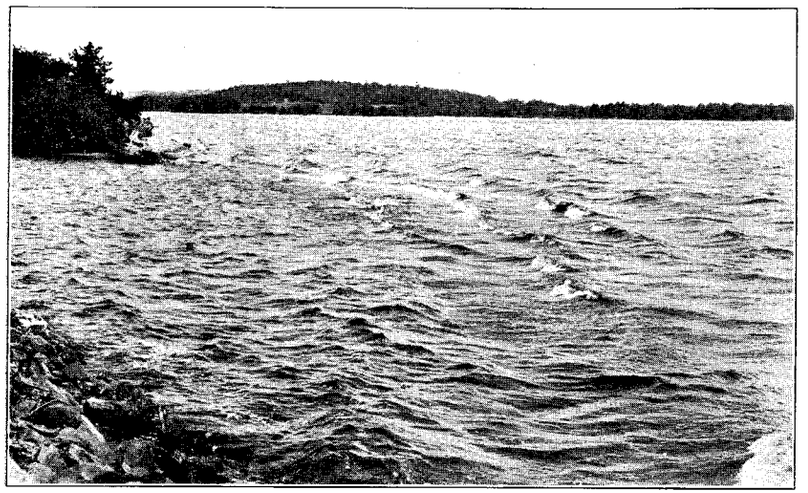
The boulder beach continues around the peninsula east of the town of Michigamme where it is interrupted by a railroad fill. North of the railroad tracks in this vicinity precipitous rock cliffs form the south side of a ridge running parallel to the lake shore. The base is generally of uniform elevation 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.

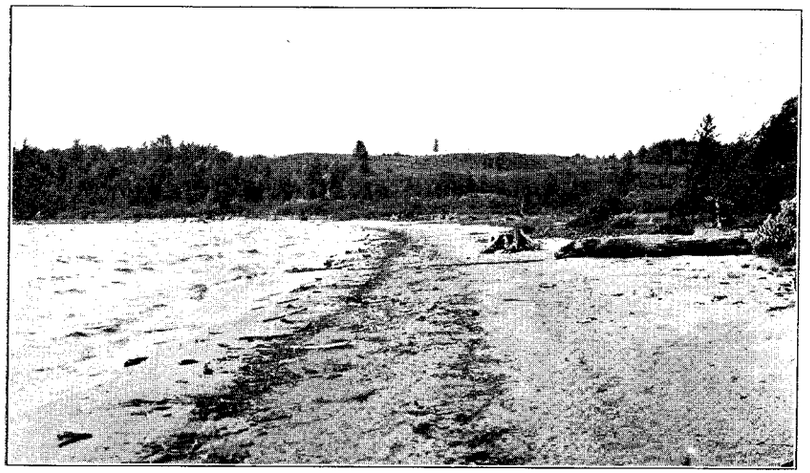
Beyond the cliffs the tracks leave the shore and turn northeast across a bay that is half filled with floating bog. Between this bay and the indentation, designated as A on the map, the shore is of sandy drift which has been cut back recently into low cliffs. The recent cutting is due to a renewal of 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.

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

The eastern side of the entrance shows much less 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 in 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 accumu-



A. WAVES BREAKING OVER SUBMERGED BAR, LAKE MICHIGAMME.



B. STORM BEACH, EAST END OF LAKE MICHIGAMME.

lated 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,

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

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.

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.

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

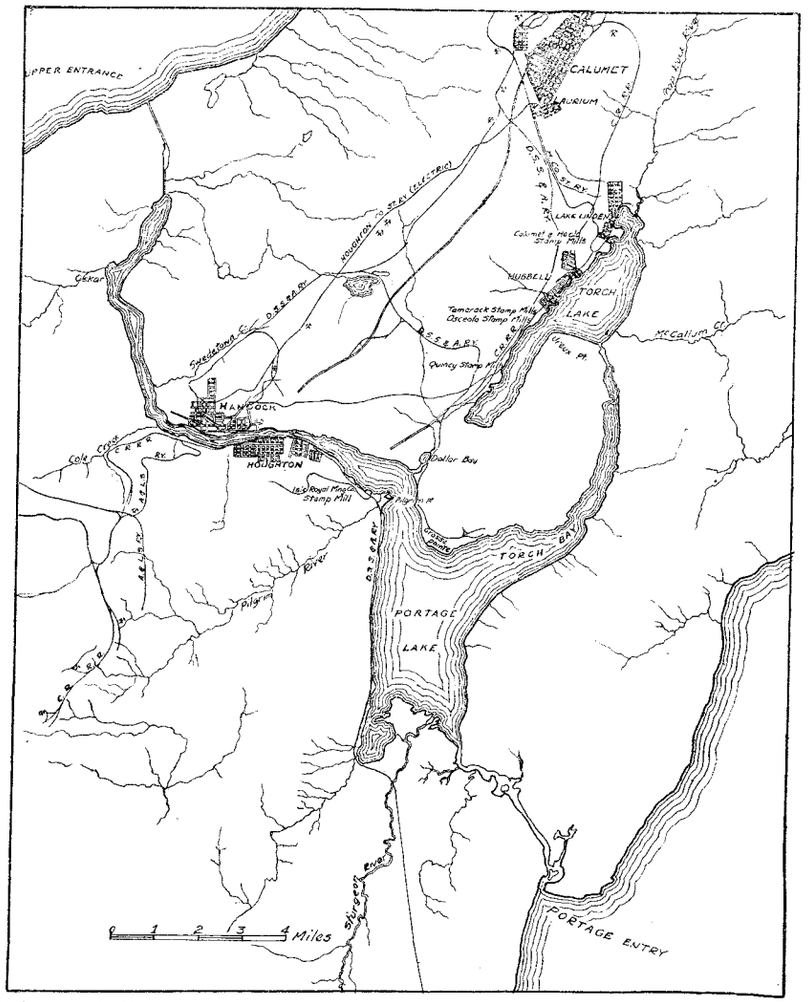


Fig. 89. Outline map of Portage and Torch Lakes and vicinity, Houghton County. (From U. S. Lake Survey chart.)

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 streams 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.

Applying this sequence of events to the region under consideration, the resistent rocks of the Copper Range were folded and, at the close 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 northeastward 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 deltas 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 up-stream, 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 southwestward 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 cur-

rent 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

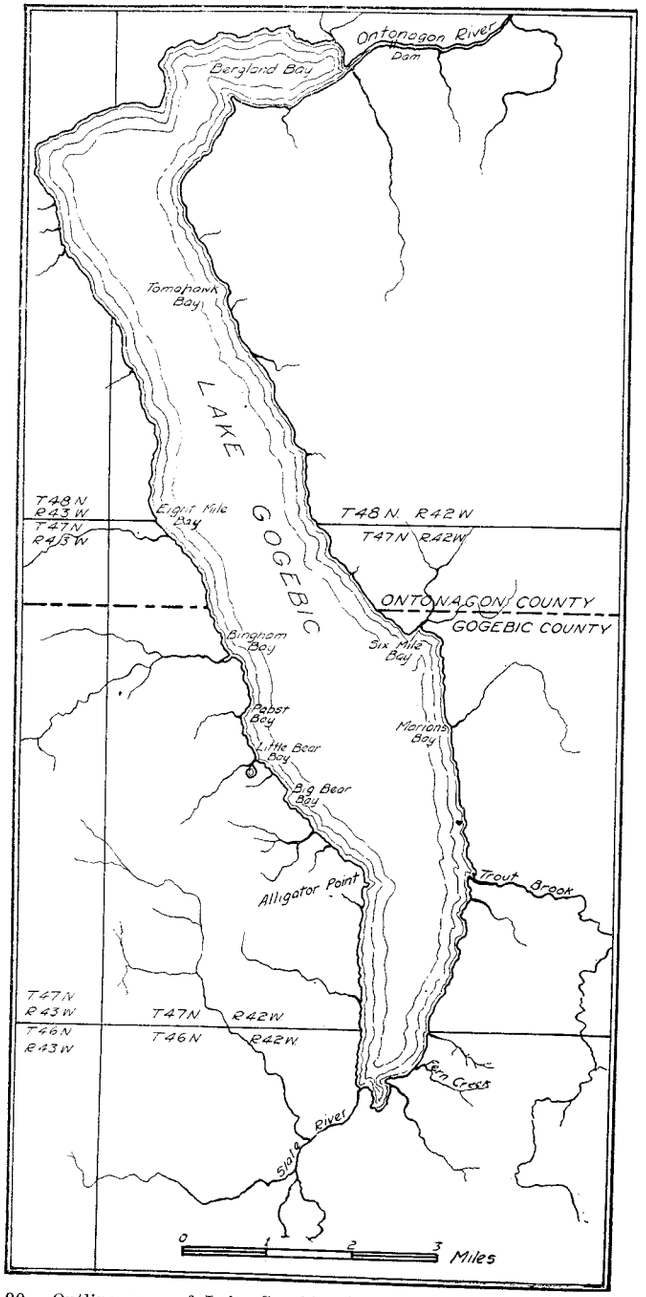


Fig. 90. Outline map of Lake Gogebic, Ontonagon and Gogebic Counties.

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

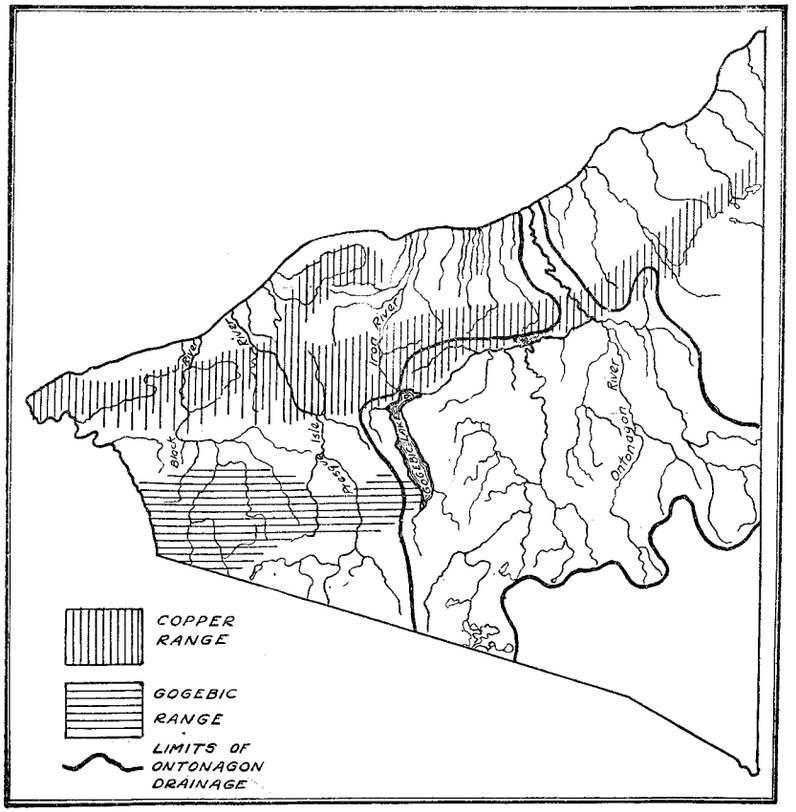
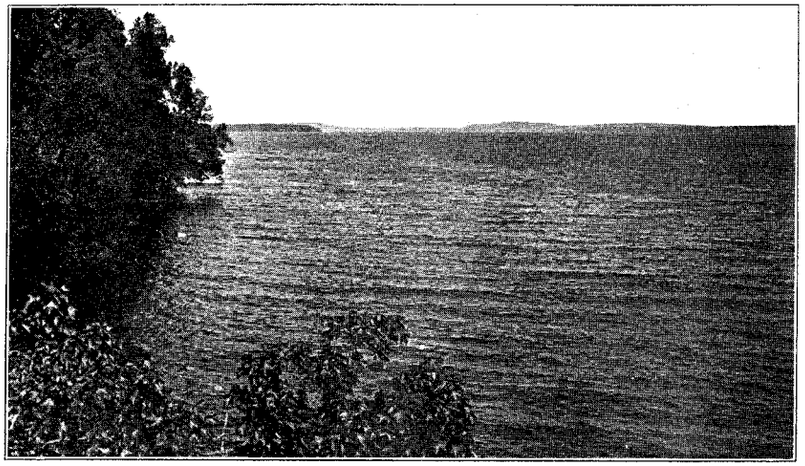


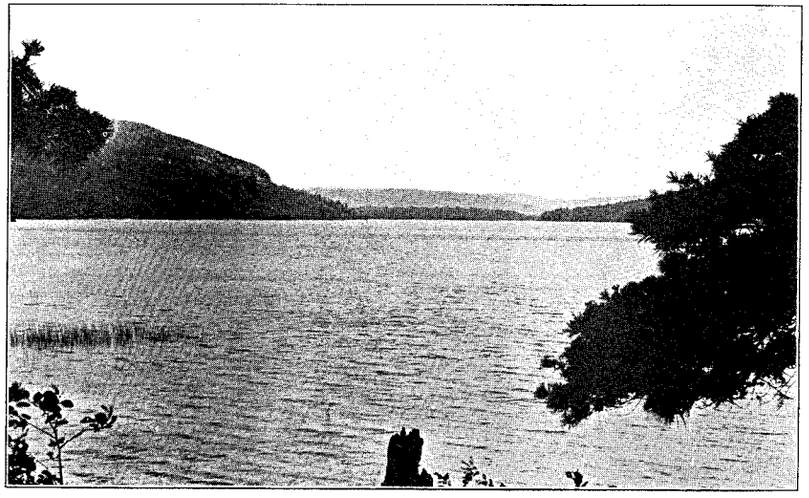
Fig. 91. Map of western part of the Northern Peninsula showing the general distribution of the Copper and Gogebic Ranges and also the basin of the Ontonagon River.

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



A. LOOKING NORTH ON LAKE GOGEBIC.



B. MOUNTAIN LAKE, HURON MOUNTAINS.

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.

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.

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.

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 part 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

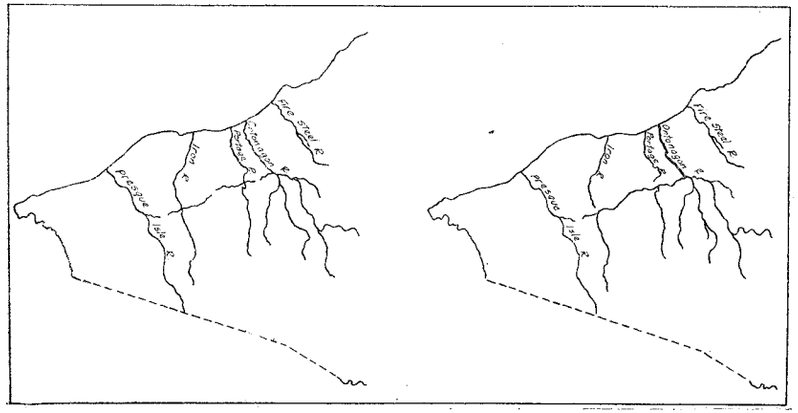


Fig. 92. Map to show the change in drainage which has taken place within the present basin of the Ontonagon River. Map to the left illustrates probable drainage in former times, and map to the right shows the series of stream captures and present drainage system.

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.

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.

Ice 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 occurrrnce. 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

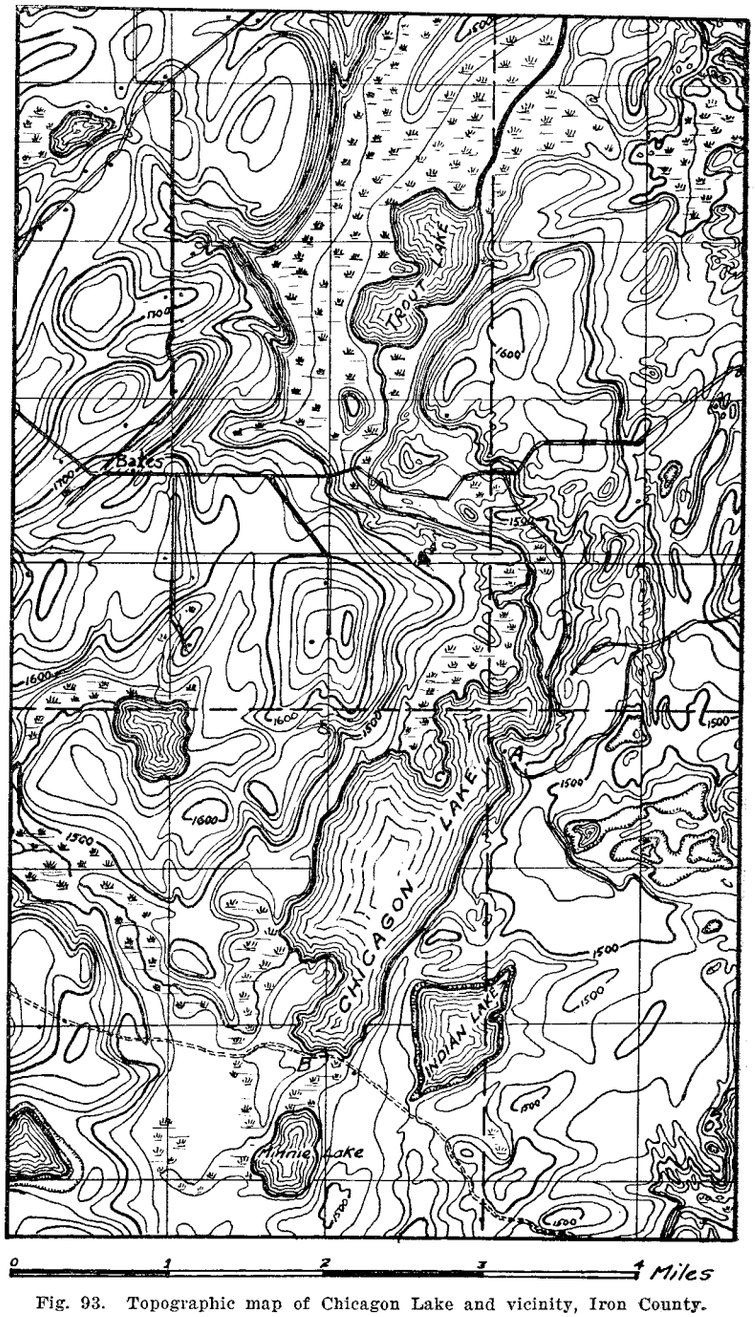


Fig. 93. Topographic map of Chicagon Lake and vicinity, Iron County.

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 rise to stories to the effect that Indians had paved these shores in times 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, thus 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.

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.

CHAPTER IX

LAKES OF THE KALAMAZOO MORAINIC AND OUTWASH SYSTEM.

As stated in the Introduction, the work, the results of which are given in this chapter, was undertaken in order to include a much wider representation of the lakes in the various parts of the State but has been confined to the Southern Peninsula. It is possible that the distribution of these lakes would have been emphasized more had a county unit been used as a basis for their grouping. Such a unit, however, is not only artificial but difficult to adhere to and it was decided to group them according to their relation to the various positions of the border of the glacier during its retreat. Following this system the lakes may be referred to the three morainic systems shown in Fig. 3 with a fourth class of lakes bordering the Michigan-Huron shores.

The order of discussion is chronological in that the groups are taken up in the order in which they were uncovered by the ice but no attempt has been made to arrange the individual lakes in each group in the succession of their appearance. This grouping is used largely as a matter of convenience and emphasis should not be placed on the sequence for which no claim of accuracy is made.

GROUP I

In this group are included the lakes which lie in that portion of the State not covered by the ice at the time of formation of the Kalamazoo morainic system, see 2, Fig. 3, and also those within the moraine itself. They occur in Lenawee, Washtenaw, Jackson, Hillsdale, Branch, Cass, Kalamazoo, Calhoun, and Barry Counties, those of St. Joseph County having already been described. During this stage the reentrant between the Erie and Saginaw lobes of the glacier was located in northwestern Washtenaw County. The strong relief of the surface at the angle of the V formed by the junction of the two moraines presents a strong contrast to the greatly pitted outwash plain that spreads out like a fan to the southwest into Jackson County. Numerous lakes are found both in the morainic basins and in the pits in the outwash.

The greater number of morainic lakes is found within Washtenaw County and of these Sugar Loaf was selected as typical.

SUGAR LOAF LAKE

Sugar Loaf Lake is located somewhat more than five miles north of west of Chelsea and can be reached by conveyance from that city. The basin is larger and more irregular than the outline of the lake suggests and consists of several connected basins. A more flooded condition formerly existed and there is a probability that a much greater territory was covered by this lake at that time. The former shore line is well shown just east of the inlet at the north side. At this higher stage some of the smaller indentations were cut off by bars, a good example of which may be found a short distance east of the inlet mentioned. The material for the bars was carved from the bold cliffs which line this shore of the lake, but was limited in amount for bars were not thrown across the larger indentations and the exposed terrace is narrow. At the present level the slight development of the shores is consistent with the small expanse of the lake which is not conducive to strong wave action and vegetation is getting started at the shore. This lake is not so popular as some in the vicinity but cottages were in the course of construction at the time of the writer's visit.

CAVANAUGH LAKE

This small lake lies four miles west of Chelsea and a mile and one-half north of the Sylvan Road stop on the interurban line. It is one of the most popular lakes in this section of the State. The many excellent locations for cottages have been used, especially on the south and east sides, and a number of excellent summer homes have been built. The lake lies in one of the numerous basins formed in this locality. Many are morainic basins but that of Cavanaugh is a fosse. Several of the lakes in this vicinity are separated by low sags which served as connections during a former flooded condition of drainage. Thus Doyle Lake to the east was once connected with Cavanaugh but a bar developed across the opening and may have separated the lakes during the later stages of the high water. This bar which swings around the southeast part of the lake may serve as a starting point for a study of the shores. Other features of the higher level are an exposed terrace at the foot of a cliff which rises locally to considerable height.

CROOKED LAKE

Crooked Lake is located a short distance northwest of Cavanaugh and, although longer, is much narrower and more irregular in outline. The east shore of the lake for most of its extent is faced by steep cliffs consisting of the sand of the outwash plain west of Cavanaugh Lake. On the west, however, the land rises with more gentle slope to the moraine on the west. Such a trough-like depression between an outwash plain and a moraine has been termed a fosse and it seems logical, therefore, to call a lake situated in such a depression a fosse lake. The lake, however, is more true to type along the northern part than near the south end. The east side of the lake is used to some extent for resort purposes and affords good locations. This lake has also stood at a higher level but the shore features are not as pronounced as on Cavanaugh.

In the extreme southeastern part of the outwash, and also of Jackson County, are located two interesting lakes, Wamplers and Vineyard.

WAMPLERS LAKE

Wamplers Lake lies on the line of Jackson and Lenawee counties. It is not on a railroad but near the Chicago Pike and is reached by automobile over good roads. This pleasing body of water extends nearly two miles in an east-west direction but is less than one mile in width. The lake is much visited during the summer months and has a well appointed hotel in addition to numerous cottages. The greater number of buildings are located on the northeast shore and in particular on a split bar of a former level which stands several feet above the present level. This bar developed westward from the high cliff at the east end of the lake, splitting into two separate bars in the vicinity of The Farm. Soon after leaving the cliff it crosses a swale which formerly served as a connection with a small lake basin to the east. An exposed terrace may also be made out in places but this is rapidly being worn away by a revival of wave cutting due to damming of the outlet. A complete study of the drainage and shore conditions of this lake should prove interesting. The basin lies at the junction of the moraine to the south and outwash on the north but has the characteristics of a pit rather than those of a fosse.

VINEYARD LAKE

Vineyard Lake lies a mile or more west and north of Wamplers Lake and may be reached most conveniently from Brooklyn about

three miles distant on the Ypsilanti, Hillsdale Branch of the New York Central Lines. The lake occupies a large, irregular pit in the outwash which has a length of more than two miles and a width in excess of one half mile. The principal irregularities are two long bays which extend to the north and to the northwestward. The lake is not as attractive as many in the vicinity because of the shallow water near the shore which is covered with a heavy growth of rushes and weeds. This condition is due to the partial exposure of a well-developed terrace, which was formed at a higher level. Steep and prominent cliffs face a large part of the shores, indicating strong wave action at the higher level, but most of the quarried material seems to have been carried out by the undertow to form the terrace, inasmuch as no bars were seen in the course of the rapid study made of this lake.

CLARK LAKE

Clark Lake, situated ten miles south of Jackson on the Cincinnati Northern R. R. which maintains a station stop at the west end of the lake, is another popular summer resort in southeastern Jackson County. This narrow basin—the lake measures less than one-half mile in width but more than two miles in length—appears to be part of an east-west drainage line which extends eastward from the lake to the Raisin River north of Brooklyn. In the immediate vicinity of the lake the channel is flanked on both sides by patches of moraine which rise above the till plain but to the east runs through outwash. The writer's information as to the depth of the lake is unsatisfactory but indicates relatively shallow water. It is evident, however, that the basin is not true to any one type. Inasmuch as it clearly is not a pit and also is not characteristic of morainic basins, a process of elimination leads to its classification tentatively as a sag in a till plain.

The long stretches of high ground along the sides due to the presence of moraine furnish excellent locations for summer cottages and the lake is well populated during the summer months.

The east-west orientation of the lake allows the stronger storm winds full sweep of the lake and consequently considerable adjustment of the shores has taken place. This adjustment occurred during a level between two and three feet above the present and the shore features stand a short distance back from the water. These features include forms resulting from the action of waves, currents and ice, the latter two frequently combining in the formation of a single form. In particular, the rampart-bar at Pleasant View may be mentioned. Well-developed bars encircle the ends of

the lake, that at the east end proving useful in damming the outlet. Among the more interesting features are the cuspate foreland and completely enclosed lagoon in the vicinity of Eagle Point.

DEVILS AND ROUND LAKES

The moraine which flanks the outwash just discussed on the east and south is of exceptionally high relief and includes the well known Irish Hills which lie south of Wamplers Lake. From one locality in these hills as many as seven lakes may be seen. These lakes are for the most part too small to be used extensively as summer resorts and were not studied. Many of the basins, however, are separated by very low land and, furthermore, show some alignment, suggesting the problem of former drainage conditions, the solution of which could not be undertaken at this time.

Among the larger lakes of this district are Devils and Round. These lakes are very popular with summer visitors as may be surmised from the extensive resort at Manitou Beach at the southwestern end of Devils Lake. Round Lake is less than a mile in diameter and is well named. Devils Lake is considerably larger than its neighbor, having a maximum length of more than two miles, but is much more irregular in shape, the outstanding feature being a narrow arm which extends nearly a mile and one-half to the northward. The lakes may be reached via the Cincinnati Northern R. R. but the greater number of visitors come in automobiles.

As regards origin these basins may be classed as morainic. That of Devils Lake appears large for basins of this type. Soundings may show, however, that the lake floods several basins. This was the case formerly with this lake and Round. The merging of the two lakes occurred when the water level stood about four feet higher than at present and the important adjustments of the shores took place at this stage. The most consistent feature is the partially exposed terrace which stands at the foot of the numerous cliffs. Currents also were active and deposited their loads at the indentations. A striking example of this may be seen at the narrow neck of land which now separates the two lakes. Currents in both lakes aided in building a strong bar which extended nearly across the opening and, with the lowering of the water level, divided the continuous sheet of water into the present Devils and Round Lakes. This locality serves as an excellent starting point for a physiographic study of these lakes.

BAWBEESE, COLDWATER AND MARBLE LAKES

The lakes visited in Hillsdale and Branch counties are discussed as a group because of the similarity of the origin of the basins. They all lie in channels through which the waters of the melting ice escaped to the south and southwestward. Within these channels tongues of ice of uneven thickness become stagnant and were covered by the deposits of the streams, forming narrow strips of outwash of even surface below the general elevation of the surrounding country. The subsequent melting of the ice caused a settling or pitting of the surface which took the form of channels at a still lower elevation through which the present drainage flows. Due to uneven thickness of the ice tongues these lower channels are ungraded, the deeper parts being filled by the present lakes.

One of these channels runs in a southeasterly direction through Hillsdale and forms the setting for a string of five lakes the largest of which is Bawbeese on the outskirts of the town. This lake, named after an Indian chief, is very popular locally, the south shore being lined with cottages. For a lake of this size, one and one-half miles in length by less than one-half mile in width, the adjustments of the shore are strong. These adjustments all took place at a level five feet above the present level and may be accounted for by the sandy character of the material of the outwash which is easily worked. Cliffs are neither frequent nor prominent but, nevertheless, strong bars were built across indentations along the sides, the most prominent standing a short distance back from the present shore along the south side and that connecting Wolff Point on the north shore to the mainland. The outlet of the lake is now dammed and the rejuvenation may best be observed in the rapid cutting at Wolff Point.

About three miles west of Hillsdale a similar channel almost parallels that just discussed. Within this channel are numerous small lakes whose shores show little development but whose basins were formed in the same manner. A third channel runs nearly north-south about one mile east of the line between Hillsdale and Branch counties. Likewise in this channel are numerous lakes, the largest of which are Hamlin and Long, which are too small to show decided adjustments of the shores. The fourth and last of these channels lies in southeastern Branch County and is much wider and less defined as a channel than those just mentioned. The pits are correspondingly larger and less elongated in form but are arranged along the course of the channel. Our interest lies in the larger lakes at either end of the string, Marble and Coldwater,

the intermediate ones, Long, Mud, Bartholemew and Middle being too small for special consideration.

COLDWATER LAKE

Coldwater Lake is the southern member and also the largest of the chain, having a length of three and a maximum width of one and one-half miles. The lake is triangular in shape and contains a large island in the southeastern part. A road skirts the east shore for most of its extent and forms an approach for the large number of cottages which have been built on this part of the lake. It is the only lake of the chain whose extensive marl deposits have not been tapped for the manufacture of cement and is therefore the most popular, although an eight mile drive from Coldwater is necessary to reach the lake. This lake probably stood at a higher level formerly but, if so, the drop in level has been not more than two feet, an amount so small that the present high water stage in the spring might well be confused with a definite higher level. The shore features are relatively simple. Waves have been very active in forming the steep cliffs. Most of the material carved from the cliffs seems to have been distributed by the undertow rather than by long-shore currents, inasmuch as a well defined submerged terrace lines most of the shore and little evidence of the closing of indentations by bars was found.

MARBLE LAKE

Marble Lake extends three miles south from the edge of the town of Quincy on the Hillsdale-Adrian branch of the Michigan Central R. R. and is therefore easily accessible by rail. This lake, although of practically the same length as Coldwater Lake covers less area on account of its nearly uniform width of slightly more than one-half mile. It is essentially rectangular in shape except for the large embayments at either end. The lake has been of considerable economic importance in that its extensive marl deposits have been utilized in the manufacture of Portland cement at the Quincy mill. These deposits are now virtually exhausted in this lake but are being worked in the lakes to the south. The removal of the marl with steam shovels has caused an abrupt drop into deep water, a condition which makes the lake dangerous from the viewpoint of the resorter and has worked to the detriment of the lake. The workable deposits of marl appear to occur off the west shore mainly and consequently the east side of the lake has not suffered from artificial destruction of the shore. In addition, the east shore

from Cedar Point southward is favored with one of the best locations for summer cottages the writer has seen, consisting of a flat well above the water and covered with a grove of beautiful oaks. This location has, of course, been "discovered" and numerous cottages line the shore. Here also is found the key to the shore adjustments of the lake. A well defined submerged terrace extends off-shore and slopes outward so gently that a zone of considerable width is exposed during low water. Great quantities of small shells which have contributed to the formation of the marl may be found on the beach, thrown there by the waves. An almost continuous cliff lines the shore but breaks at an elevation of five feet above the present level. This cliff with the occurrence of complete bars at the same elevation crossing the occasional indentations is sufficient to establish a former higher level of the lake. The action of currents is best shown at Cedar Point which extended out into the lake as a spit at the higher level.

GOGUAC LAKE

Goguac Lake is located just outside the southwestern limits of Battle Creek. The street car system of the city has extended its service to the lake which has become a recreational center. On this account and also the fact that a considerable part of the shore is utilized for a public amusement resort, Willard Park and a golf course and Country Club, the number of private cottages are not as numerous as might be expected.

This small lake lies in a pit which in outline is roughly like an hour glass and is nearly twenty-five feet below the general level of the outwash. The shore is faced by steep cliffs of sandy material broken occasionally by minor indentations. The adjustments of the shores, therefore, were largely confined to the attack of waves and the accompanying undertow which formed bold cliffs and a well defined submerged terrace. In places a part of the terrace is exposed at the foot of the cliff, indicating a former level between two and three feet above the present. This is further shown by the exposed bars and spits at the indentations and at the cuspate foreland at Willard Park. In addition to the shore features of the lake, an interesting example of the extinction of a lake by vegetation may be seen on the Willard farm just east of the road leading to Willard Park.

GULL LAKE

Gull Lake is one of the best in the southern part of Michigan. It is nearly five miles in length and more than one mile in width for

most of its extent. It is located about equidistant from Kalamazoo and Battle Creek but some three miles north of the main road between these cities. The popular means of transportation to the lake is by automobile but interurban service is maintained by the Michigan R. R. Co., connecting Grand Rapids as well as the cities mentioned. However, it must not be inferred that the appeal of this lake is limited to the locality for many of its visitors come from far without the State. Cottages are numerous, especially along the east shore, but, in addition, there are a number of imposing estates. The popularity of the lake, however, is not due entirely to its fortunate location and large size. Another reason is the excellence of the shores, due in large part to the physiographic developments that have taken place.

This basin is sunk below the surface of the extensive outwash plain which developed in the wide angle between the Michigan and Saginaw lobes when the ice border stood a few miles from the lake. The lake is large for a typical pit but may be included in this class until more detailed studies are made.

One of the first observations to be made at Yorkville which is situated on the outlet is that the lake has been dammed, causing what appears to be a serious flooding of the lake. The flooding of the outlet is clearly in excess of eight feet and it is, therefore, surprising to find the shores of the lake uniformly dry. The explanation is soon found in unmistakable evidence of an abandoned level more than six feet above the present lake at which stage the major adjustments of the shores took place.

The lake furnishes a wealth of material for physiographic study which could not be attempted at the time this work was done and, therefore a brief description of conditions near Midland Park is given as a key to other adjustments. At this locality the broad flat upon which the cottages are built is the exposed terrace of the higher level. It ends abruptly at the foot of a steep cliff, twenty or more feet in height, which marks the former shore line. On the terrace may be found two distinct sand bars which swing northward towards Bryant Point. The bar nearer the lake stands at the lower elevation, indicating a halt in the lowering of the lake level.

At present the adjustments are not important. Ice action is perhaps the most effective but prominent ramparts are not found on account of the sandy character of the material on the shore.

CROOKED LAKE, BARRY COUNTY

Of the numerous small lakes which lie in the outwash that developed in the reentrant angle between the Michigan and Saginaw lobes of the glacier only Crooked and Wall lakes were visited by the writer. Crooked Lake is located in southwestern Barry County and is reached most conveniently by automobile, although the Chicago, Kalamazoo and Saginaw R. R. passes the resort on the northeastern shore.

The lake lies near the apex of the elbow shaped outwash plain and occupies either a single pit of very irregular outline or a number of connected pits which have a striking northeast-southwest orientation. It has a length of more than four miles but consists of narrow parallel channels and bays separated by islands and peninsulas so that its area is relatively small. Lower Crooked is, in fact, an oblong channel which surrounds a large island and is not only narrow but shallow. Little adjustment of the shores has taken place and they are consequently muddy. The chief interest in this part of the lake lies in the heavy growth of vegetation which will eventually convert Lower Crooked into a marsh.

At the northeastern end, Upper Crooked, the lake expands to more than a mile in dimensions and some adjustment of the shores may be seen at a level nearly five feet above the present beach. One of the best localities to observe this higher level is at Stony Point which is a spur of the nearby moraine covered with a thin veneer of outwash material. The end of the point is a steep wave-cut cliff from which the material to form the spits on either side was carved. This locality indicates the adjustments that may be expected on other parts of the shore of Upper Crooked. In addition to the development of the shores considerable filling by vegetation has been accomplished and is especially evident on the numerous shoals or "blind islands".

WALL LAKE

Wall Lake is located two miles northeast of Crooked in the very apex of the outwash plain which developed in the reentrant between the Michigan and Saginaw lobes. The north shore is bounded for the most of its extent by moraine but from the opposite side outwash stretches southward for miles. The basin was caused by the melting of buried ice and is, therefore, classed as a pit.

This small lake has a length of less than one and one-half miles and a width of somewhat more than one-half mile but is interesting nevertheless. In contrast to Crooked Lake its shores are broken by a

single long peninsula and it is deep, so that the waves have an unobstructed sweep. Many adjustments of the shores, therefore, may be observed and those on the north shore are selected as typical.

The most striking adjustments in this locality are the steep cliffs at the headlands, the perfect bar which rises fully five feet above the present water level and is responsible for the name of the lake, and the decided off-shore terrace. In addition, strong ice ramparts were noted along the west side. This almost perfect adjustment means excellent shore conditions for resort purposes and the lake is deservedly popular during the summer months.

AUSTIN GROUP

AUSTIN, LONG, WEST (PIKE) AND GOURD NECK LAKES

This group of lakes lies some seven miles directly south of Kalamazoo on the Grand Rapids and Indiana R. R., trains of which stop at Austin Lake. The lakes are discussed as a group because they all occupy pits in the outwash plain first mentioned in the account of Gull Lake. Furthermore they all drain southward through the Portage River into the St. Joseph and were once connected, with the possible exception of Gourd Neck, during a former swollen condition of the drainage which appears to have been general in the State.

Austin Lake is the central member of the group and has a length of two and one-half miles and a maximum width of slightly more than one mile. It is very shallow a fact which evidently has effectively hindered wave action for there are few shore adjustments to be found. The lake has been artificially lowered and as a result a broad sand flat is exposed along the shore. The flat is covered with reeds which with other water plants are encroaching on the shallow lake. The lake is popular as a fishing ground but the cottages are built on the neighboring lakes which have more attractive shores.

West, or Pike Lake, lies a few rods directly west of Austin and is nearly circular in form, the largest diameter being somewhat more than one mile. The sudden darkening in color of the water off shore gives the impression of a deep lake and a decided submerged terrace. Such is not the case, the effect being produced by the change from sand to mud which marks, nevertheless, the limit of effective wave action. The shallowness of the water has not interfered with the wave action as on Austin and decided adjustments of the shore are to be found. An excellent and convenient starting point for the study of these features is the resort at

the east end where the land between this lake and Austin rises but slightly above lake level. The most decided feature is the strong sand bar at an elevation of about four feet above the lake which crosses the flat between the lakes and shows that the lakes were connected during a higher stage and that later West Lake became an independent basin. This part of the lake is the most popular and the bar, although obscured somewhat by cottages, is, nevertheless, easily recognized. Similar adjustments are to be expected on other parts of the shore but probably are not as well developed inasmuch as the east shore is exposed to the strongest winds.

LONG LAKE

Long Lake is situated a short distance to the northeast of Austin into which it drains across a flat so low that it must have been flooded at the earlier stage indicated on West Lake. In this case no bar crossed the flat and the separation of the lakes must have been caused by the lowering of the water level. Elsewhere along the shore no evidence of current action was found but sharp cliffs indicate work by waves. This, however, was not great inasmuch as both bars and submerged terrace are lacking. The lack of these features has not proved a deterrent influence on its use as a summer resort as shown by the resorts on the south and southwest shores.

DIAMOND LAKE

The last lake in Group I to be considered is Diamond Lake. It is located just east of the limits of Cassopolis which is the junction point of the Grand Trunk and Air Line Division of the Michigan Central so that no difficulty need be encountered in reaching the lake. The lake is attractive and of good size for this section of the State, its dimensions being two and one-half miles in length and more than a mile in width. Many cottages and costly summer homes have been built along the shores near Cassopolis and on the island.

From the physiographic viewpoint the lake is of little interest except as to the type of basin which is one of the numerous pits which break the surface of the outwash plain. The level of the lake is high due to the obstruction of the outlet by a dam at Brownsville and, although the shores are not badly flooded, the waves are gradually wearing back the banks and undermining trees.

CHAPTER X

LAKES OF THE VALPARAISO-CHARLOTTE MORAINIC AND OUTWASH SYSTEM

In Group II are included the lakes which lie in the area between the Kalamazoo morainic system, 2, Fig. 3, and the Valparaiso-Charlotte morainic system of Southern Michigan, 3, Fig. 3. It will be noted from the figure that both the eastern and western interlobate areas became greatly accentuated as the ice shrank back to the position indicated by the Valparaiso-Charlotte moraine during which stage they existed as narrow valleys with ice walls. The western interlobate was much more pronounced, extending from the vicinity of Grand Rapids northward beyond Cadillac, a distance of nearly one hundred miles, as compared with less than half that distance for its eastern counterpart. Both, however, are made up of a patch-work of deposits which is characteristic of such locations. Between the two interlobates the formations are much more regular and have an east-west trend.

WALLED LAKE, OAKLAND COUNTY

This lake is roughly triangular in shape and has a length of one and one-half miles and a maximum width of somewhat more than one mile. Its shores are regular in outline with the exception of one long point on the northwest shore, thus the sweep of the waves is unobstructed. The lake lies for the most part in a morainic depression but at the south end overflows on the till plain which spreads southward from the lake. A road circles the lake and follows the shore on all but a part of the west side so that the shores are readily accessible. As to train service, the Jackson Branch of the Grand Trunk runs within one-half mile of the north end and the Detroit-Saginaw Line of the Pere Marquette has a stop at Wixom, three miles west of the lake.

For physiographic study the west shore is the best, although sharp cliffs and an exposed terrace are present on the east side. The sharp point on the west side is a spit which may be followed without difficulty southward for nearly a half mile. Soon after leaving the point one notes that the bar takes on the characteristics of an ice rampart or wall which is so distinctive as to give the lake

its name. The absence of bars at other points on the shore where they might be expected leads to the conclusion that ice push has been the dominant force active on the shores. The lake is very popular as a summer resort and nearly all the available frontage on the west, east and southeast has been built upon.

WHITMORE LAKE

Whitmore is another of the popular lakes of this group. It is located ten miles north of Ann Arbor on the boundary between Washtenaw and Livingston counties. Trains of the Ann Arbor R. R. stop at the south end, but with the improvement of the roads the automobile is the more popular means of reaching the lake.

The lake lies in a region of complicated glacial deposits and many interesting features of this type as well as shore features may be seen. The high hills at the north end are kames. On the east a strip of outwash borders the lake but gives way to ground moraine which extends to the south end of the lake. The south side consists of a flat outwash plain, on the west of which lies a narrow stretch of ground moraine followed by a moraine of low relief along the greater part of the west side. The lake has neither outlet nor inlets and for most of its extent the shore is bounded by banks which are of moderate height but steep for unconsolidated material. The basin appears to be a pit formed by a rather large block of ice of irregular thickness buried by outwash which developed from the southward. The outwash is a broad channel which carried the water escaping from the ice when the front of the glacier stood a short distance northwest of Ann Arbor.

As to the shore features, the chief interest lies in a higher level of the lake during which the water discharged through an outlet at the southeastern part. After leaving the lake the former outlet turns abruptly to the north and extends to the Huron valley. The development of the shores at the higher level was exceptional for a lake of this size and resulted not only from the activity of waves and currents but of ice as well. The best locality for study is along the northwestern shore where excellent examples of cliffs, spits, bars and ice ramparts may be found. At present the encroachment of vegetation is beginning in parts of the basin and is progressing rapidly on the spit-like form extending out from the south shore of the lake.

HURON RIVER GROUP

PORTAGE, BASE LINE, STRAWBERRY, ZUKEY, ETC.

The lakes included in this group are located in the valley of the Huron River southwest of Lakeland, situated at the junction of the Ann Arbor R. R. and the Jackson Branch of the Grand Trunk R. R. They all occupy parts of an elongated pit that extends in a northeast-southwest direction from Lakeland to Portage Lake. This pit was formed by the burial of an ice mass of very irregular outline and thickness in a former drainage channel through which the water from the glacier escaped in a northwesterly direction beyond Pinckney and thence to the southwest towards Jackson. The subsequent melting of the ice left a depression below the level of the outwash, which conformed in general outline to the ice mass and also contained a number of deeper basins which contain the present lakes.

The several lakes of the group are not discussed independently because the adjustment of the present shores is insignificant and also because a higher level was found at an elevation sufficient to have merged all into one large lake having numerous bays, peninsulas and islands. The principal indication of this stage is the gently sloping flat which extends from the lake shores back to the sharp cliffs and is interpreted as an exposed terrace. In addition, bars which swing out from steep cliffs were found. Thus, the study of the former shore will give the best results. Some of the most interesting localities are the sand point on the east side of Portage Lake north of the cottages, the north shore of Base Lake near the outlet, and the great bar which swings southwestward from the cliff on the southeast side of Bass Lake.

These lakes are used extensively as summer resorts, the most popular being the pairs, Portage-Base and Zukey-Strawberry, located at the ends of the chain.

DUCK LAKE

Duck Lake is located in northeast Calhoun County almost equidistant from Albion, Charlotte and Eaton Rapids, from which cities it draws many summer visitors. The nearest railroad stop is Springport on the Hillsdale-Lansing Branch of the New York Central, but good roads have made the automobile the principal means of reaching the lake. This small lake of one and one-half miles in length and somewhat more than one-half mile in width lies for the

most of its extent on a till plain, the land rising to the moraine at the south end. The basin is, in general, shallow and has, furthermore, numerous shoals. Thus, it may be considered as one of the larger sags in the till plain modified by minor sags and swells.

The material of the shores is compact till except for the sandy morainic material on the south end; and consequently the attack of the waves has been slight. The adjustments have taken place at a level four feet above the present stage and are found at either end and the east side. At the south end clean sand beaches indicate an assorting of the material by the waves; and a fairly well defined submerged terrace is the result of the accompanying undertow.

At Charlotte Resort a strong bar crosses the mouth of a former bay and at the north end there is the possibility of a similar form, obscured by the road. Waves and currents have had little force on the west shore as shown by the presence of marl beds. The ramparts on this shore, however, show a powerful shove by ice. A heavy growth of rushes on the offshore terrace indicates the beginning, at least, of the extinction process by vegetation.

CHIPPEWA LAKE

A number of small lakes are situated in the large morainic tract of north-central Mecosta County, and Chippewa Lake, which lies twelve miles east and north of Big Rapids, was selected as representative of these lakes. There are no rail connections but a good road from Big Rapids insures a comfortable trip by automobile or other conveyance.

Except for a narrow strip of outwash at the north end, the lake lies in a very sandy moraine of strong relief. The knobs and basins of the surrounding land have counterparts in the shoals and deep holes of the lake bottom so that the lake is typical of those which flood several adjacent morainic basins.

The slopes to the lake are a series of cliffs and flats, thus furnishing numerous possibilities for adjustments which were readily carried on in the sandy material but at a level nearly five feet above the present lake. In addition to the steep, wave-cut cliffs, the work of currents at the entrances to bays is noticeable. Many of the smaller indentations of the original lake were completely cut off by bars which have been remodeled into ice ramparts in some cases. However, at the larger bays spits are found. An interesting example of this was noted along the southwest end of the lake where the road follows the spits which developed from each side of the large bay, now nearly dry. Along the outwash at the north

end the terrace of the higher level is well exposed and is from two hundred to three hundred feet wide. Another of the many interesting features is the land-tied island of the former level on the east shore. This lake has exceptionally interesting physiographic features which, together with the sinking of the water level, account for the present rather regular outline of the lake. It is becoming a very popular summer resort, the more favored locations being the village of Chippewa Lake, the north shore, and the land-tied island with connecting bar.

HESS LAKE

Hess Lake lies about two miles southwest of Newaygo, located on the Grand Rapids-Petoskey Branch of the Pere Marquette R. R. This lake has a length of nearly one and one-half miles and a rather consistent width of about three-fourths of a mile. The shores are regular in outline on all but the south side, which is broken by a number of bays and promontories. The lake is shallow —it probably does not exceed thirty-five feet in depth—and is surrounded by outwash except at the southwestern shore. It is, therefore, classed as a pit.

From the study of this lake it is apparent that the northerly and easterly winds have not been effective in the adjustment of the shores. The irregular south shore consists of headlands, which show few effects of wave action, and mucky bays, sparsely grown up to lily pads. The power of the westerly winds, however, is well shown on the north shore. As usual the adjustments were found between three or four feet above the present level and bars first appear near the middle of the north shore. The bars increase in strength towards the east end where former bays have been completely cut off. Ice action is also powerful and ramparts of sand, bound by the roots of trees, were noticed. The north shore of the lake is a popular summer resort and, due to the favorable shore conditions and its accessibility, is almost completely lined with cottages. The south shore is reached by a roundabout route over sand roads, and but one location, a camping ground, was found.

REED LAKE

The location of Reed Lake within the city limits of East Grand Rapids accounts for the great popularity of this small lake of but slightly more than a mile in length and less than a half mile in width. It lies in a morainic basin that is irregular both as to depth and outline. The shore is generally well drained except

about the muddy bay at the east end. As a recreational center the lake is interesting but as an illustration of physiographic developments little can be said. The shore agents working in hard till accomplish little on a lake of this size and the adjustments of the shore are few and simple. Waves have succeeded in steepening the banks and forming a moderate off-shore terrace, a part of which is now exposed due to a drop of at least three feet in the water level. Bars are found only at the smaller indentations and stand back of the present shore. One example of a bar completely enclosing a small bay was found in the vicinity of Pierce's Landing. A heavy growth of vegetation both in the lake and on the shore indicates the initiation of the extinction process.

MINER LAKE

Miner Lake is a small lake one and one-half miles in length and less than a mile in width but is, nevertheless, one of the larger lakes of Allegan County. It is located about three miles northeast of Allegan and lies in an irregular depression of a till plain near its junction with the moraine. As is usually the case for small lakes whose banks are till, the adjustments of the shore are not far advanced. Inasmuch as there has been a lowering of the level of the lake, the adjustments are now beyond the reach of the waves and have virtually ceased to develop.

Furthermore, vegetation has taken hold and extinction appears to be the next step. Aside from wave cut cliffs and a partially exposed offshore terrace little of interest was noted. The lake is not popular as a summer resort but is frequented mainly by fishermen.

PAW PAW LAKE

Paw Paw Lake lies within two miles of the northern border of Berrien County, within a mile of the towns of Coloma and Watervliet and six miles west of Hartford. These towns are all located on the Chicago-Grand Rapids Branch of the Pere Marquette. The lake may also be reached directly by interurban from Benton Harbor. In addition, the main roads are excellent.

The total length of the lake is two and one-half miles but its width is but slightly more than a half mile, the elongation being nearly east-west. The chief irregularities are bays at the southwest and northeast ends, the latter being set off from the main lake by two distinct peninsulas. The peninsula on the east side and the east shore of the lake near the outlet are the favored locations for

summer homes which line the shore even though the shore conditions are not uniformly good.

The lake lies on a till plain but is not typical of such lakes in that it is reported to be one hundred feet deep. The banks slope gently to the shore on the north side but on the south rise more abruptly from the lake, due possibly to a general rise in the till plain towards the moraine whose border stands about one mile to the south.

The lack of the adjustments of the shores is very noticeable considering the size of the lake and may be accounted for in part by the fineness and compactness of the till of which the shores are composed. The features found were all at a higher level and consisted mainly of sharp cliffs and an exposed terrace fronting the elevations. One small spit was noticed at the west end but none were seen at the other favorable localities, such as the peninsula at the east end which was an island at the higher level.

In recent times wave action has been renewed and is actively cutting back the shores wherever the vegetation has been removed. Such a condition suggests an obstruction in the outlet, in this case a dam four miles down the outlet.

This lake is a good example of the service of a lake as a reservoir for during the spring floods the Paw Paw River backs into the lake, causing exceptionally high water and the flooding of some of the low ground upon which cottages unwisely have been built.

CORA LAKE

That part of the surface of the outwash plain extending southwestward through Paw Paw in Van Buren County and drained by Dowagiac Creek which was not covered by glacial Lake Dowagiac is dotted with numerous small pits. A number of these pits hold water and are very typical of this kind of basin, having in many cases no outlets and insignificant inlets.

A group of lakes of this type is located some six miles southwest of Paw Paw and of these Cora, Three Mile, Little and Big Reynolds and Eagle lakes were visited. Conditions are so similar in these lakes that the brief description of Lake Cora will serve as a key to the many interesting examples of shore adjustments that may be found on all of them.

This lake may be reached via the Kalamazoo, Lake Shore and Chicago R. R. which stops at the summer resort on the north side, although the automobile is proving a more popular means of reaching Cora Lake on account of the excellent roads. The resort, consisting of a commodious hotel and a number of cottages, is an in-

dication of the popularity this small lake has enjoyed. The basin of the lake consists of a main pit surrounded by numerous smaller connecting pits, making a rather irregular depression. Yet the shores are of exceptionally even contour, the greatest break being Paradise Point, and the disparity may be accounted for by the shore adjustments that have taken place. This lake which has no outlet has varied in level within recent times and now stands low. It has stood between three or four feet higher and at this level the adjustment of the shore occurred. The change in color off-shore indicates a well defined terrace, the upper part of which is now exposed as a sand flat. At the higher ground steep and prominent cliffs rise from the terrace, and at the indentations completed bars are found in virtually all cases. Paradise Point is of sufficient interest to warrant special mention for short bars have tied a former island to the mainland. As stated earlier, similar conditions hold for the other lakes of this group and their study should prove interesting.

SISTER LAKES

Another group of pit lakes in the outwash drained by Dowagiac Creek, including the Sister Lakes (Round and Crooked), Dewey and Magician lakes, was visited by the writer. They are located five to six miles northwest of Dowagiac on the northern boundary of Cass County and have no direct railroad connections. These lakes, which are classed as pits, stand near the edge of the moraine to the west and are sunk well below the surface of the thin veneer of outwash, so that till is frequently exposed on the shores. Furthermore, the pits are so numerous that the outwash in places has a hill and depression topography very similar to the morainic knobs and basins. Since the moraine is very sandy, these two types of topography are best differentiated from the hill tops which rise to approximately the same elevation within the outwash but are of variable height in the moraine.

Considerable variation is found as to shore features on the different lakes of the group. Crooked, Round and Dewey are similar in development but Magician presents a decided contrast.

The latter is very irregular in form, having many bays and points and some islands. Strong wave action is possible only on the headlands and islands, and currents have little chance to develop on the irregular shores. Consequently the adjustments are limited to wave cutting in favorable localities and consist of sharp cliffs and an off-shore terrace. The outer edge of the terrace now

appears as a flat at the foot of the cliffs, due to a lowering of the water level.

The lake is very attractive from the scenic viewpoint and numerous cottages line the shore.

The remaining lakes of the group, Crooked, Round and Dewey, are very similar, except in form, and present a contrast to Magician in that the adjustment of the shores by both waves and currents is very decided. They have all stood at a level four to five feet higher than at present and are, therefore, fringed by a broad sand flat. Improved roads lead to almost all parts of the lakes and they are, consequently, developing as summer resorts.

Among the more interesting features are the very noticeable cliffs fronting the high ground. Considerable recession of the cliffs has taken place, and a sharp off-shore terrace is of general occurrence. In addition, strong currents built bars across the mouths of indentations and spits at some of the points. Thus, on Crooked Lake a completely enclosed lagoon was found at the east end of the lake. Also the first point on the south side has been increased in length by a spit, and at the west end a bar may be made out, although very much obscured by the road, which indicates a probable connection between Round and Crooked lakes.

On Dewey Lake the most interesting developments have occurred at the east end which leads into a marsh nearly as large as the lake. This marsh was formerly a shallow arm of the lake connected by a narrow but deep channel. Spits started at the higher level on each side of the channel and succeeded in closing about one-half of the gap. The marsh is a good example of almost complete extinction by vegetation which obtained an early start in this shallow part of the lake.

INDIAN LAKE

Indian Lake is located in the northwestern part of Cass County just off the western boundary line. It lies nearly six miles west of Dowagiac and the roads leading to it are improved. From the geological standpoint it is located on an outwash plain within a short distance of a moraine which skirts the west side of the lake. It is, thus, a pit but a large one for the lake is nearly two miles in length by almost a mile in width and is regular in outline. The regularity of the shore is due in large part to the adjustments of the shore which are numerous and interesting. They were accomplished at a level some three feet higher than the present and on the sides of the lake show a close correspondence to the strength and frequency of the winds.

On the east side the waves have formed bold cliffs and sand beaches, and currents have thrown complete bars across the embayments. On the opposite side, however, the cliffs are less steep, the beaches muddy and the bars with a single exception conspicuous by their absence. This is a spit which developed southward across the entrance to a large huckleberry swamp and probably did not rise above the former level for much of its extent. This contrast, which is emphasized by the encroachment of vegetation at the more protected places on the west side, shows clearly the greater effectiveness of the westerly winds.

At the ends of the lake the topography of the shores is very dissimilar, and the more pronounced effects have been produced at the north end under the drive of southerly winds, although the spit noted on the west side indicated stronger northerly winds. Thus, the land at the north end is low with the exception of the island-like hills at Highland from which complete bars swing in either direction around the head of the lake and cut off a broad swamp. At the south end, however, the land is higher and cliffs predominate.

With these general considerations the specific features may be left to those interested to work out. As a final consideration attention may be called to the geographic relationship between the physiographic development of the shores and the settlement of all but the west shore of this very popular lake.

CHAPTER XI

LAKES OF THE PORT HURON MORAINIC AND OUTWASH SYSTEM

The lakes included in this group are located within the Port Huron morainic system, 4, Fig. 3, and in the area between this system and the Valparaiso-Charlotte moraine, 3, Fig. 3. In general, the glacial deposits of this area are irregular in distribution with the exception of two areas: The lake plains of the southeastern part of the State and the regular series of formations which mark the retirement of the Saginaw lobe. In the latter of these areas the lakes are few in number and relatively unimportant and in the Erie plains they are almost entirely absent. The one lake of the Erie lowland (Ottawa) seen by the writer is little more than a mud hole, a large part of which dries up during the summer, and is interesting only as an example of a lake located in a sink. There are also no lakes of importance in this section of the eastern interlobate area, which extends well into the "Thumb" region. Therefore, the lakes in this group are located in the north central and western parts of the Southern Peninsula but do not include the lagoons along the west coast which are discussed in the following chapter.

CRYSTAL LAKE, MONTCALM COUNTY

Crystal Lake lies seven miles south of west of Stanton in eastern Montcalm County and may be reached by a drive of about ten miles over roads that were found in excellent condition. It is one of the few popular lakes which are located in the regular series of deposits of the Saginaw lobe.

The glacial formations have a north-south trend in this locality and the lake lies in an irregular morainic depression that originally consisted of several basins. This depression is situated on the edge of a sandy moraine which gives way to a till plain just east of the lake. The easily eroded material, the irregular outline of the lake, and the succession of hills and swales at the shore made favorable conditions for the numerous adjustments found on all the shores except the north, in which locality the lakeward slopes are uniformly gentle. At the uplands sharp cliffs show cutting by the waves, at the swales bars, usually complete, indicate the

activity of currents, and on the gentle slopes ramparts signify shove by the ice.

In addition, the shore adjustments enable one to decipher an interesting series of events in the physiographic history of this lake. The most favorable locality for this study is along the southwest shore where a former bay has been cut off by a series of bars and rampart-bars. The highest is a large sand bar which stands fully six feet above the present level of the lake. Between this bar and the lake are two distinct rampart bars at intermediate elevations which mark halts in the lowering of the lake to its present level. This locality requires careful study but, once solved, will simplify further study of the shores.

The most significant adjustment was the closing of the mouths of embayments by bars which, with the lowering of the water level, reduced the original area of the lake by at least one-half. In this connection the spit which developed along the northeast shore on the flat between Crystal and Mud lakes may be mentioned.

COLDWATER LAKE, ISABELLA COUNTY

Coldwater Lake is ten miles northwest of Mt. Pleasant in west central Isabella County; but a drive of fourteen miles from this city is necessary to reach the lake. The lake rests in a pit in a narrow strip of outwash, which fronts a moraine to the eastward and was formed by border drainage, that is drainage running parallel to the ice front. The pit is located so close to the moraine that the southeastern shore is composed of the till of this formation. The relief along this shore, therefore, is great and presents a decided contrast to the surface of the outwash which rises barely more than ten feet above the level of the lake.

The adjustments are slight indeed along the shores bounded by outwash although many lakes similar in size—the length is approximately one mile and the width one-half mile—have decided shore features. The cliffs on the east shore show some wave action, but the southeastern shore, where the uneven morainic topography furnished more favorable conditions for adjustments, is the most interesting. In particular, may be mentioned the large amphitheatre which opens into the lake. Two well developed spits, which stand at elevations of three and five feet above the present level, swing out into the opening in parallel courses from the south shore and show that this indentation would have been cut off eventually, if their development had not been stopped by a lowering of the water level.

It is evident from the spits just mentioned that the lake has stood at two higher levels but the presence of an old dam on the outlet a few rods from the lake makes uncertain the relationship between at least one of the spits and a natural level of the lake. The level of the lake when the dam was operative and the length of time that this level was maintained was not learned, and it is possible, then, merely to make the suggestion that the lower and weaker spit was formed at this artificial stage.

Aside from the shore features at the southeast end, the lake furnishes an example of the partial filling by marl, formed in part of the minute shells that are abundant on the beach.

MISSAUKEE LAKE

Missaukee Lake is the largest of a group of ten or more lakes which are located in west central Missaukee County. It may be reached via the Lake City Branch of the Grand Rapids and Indiana R. R. which stops at Lake City on the east shore of the lake.

All of these lakes lie in pits in an outwash plain and of these the Missaukee Lake depression is by far the largest; it is nearly circular with a diameter of somewhat less than two and one-half miles. The lakes either have no outlets or drain eventually into Missaukee, the southeastern member of this group. Inasmuch as the drainage of the region in general is to the southeast, Missaukee Lake occupies the key position and it has no natural outlet, the artificial channel operating only at infrequent periods of exceptionally high water. The Missaukee Lake depression, although it contains the deep holes characteristic of pits, is nevertheless, very shallow. The writer's information is that the general depth of water is approximately fifteen feet, and, inasmuch as the surface of the lake stands about ten feet below the surface of the outwash, the total depth is twenty-five feet. The shallowness of the water must hinder the development of the larger waves but, nevertheless adjustments of the shore have taken place, due probably to the ease with which the outwash material is worked.

The adjustments are found above the present surface of the lake and indicate the usual higher level in past time. Along the south and east shores the depression has regular walls, and an almost unbroken, wave-steepened cliff faces the lake. At the foot of the cliffs there is now exposed a broad sand flat which continues beneath the water to a decided "drop-off" wherever the water is deep, as at the east end. The effects of current action are best seen along the very irregular north shore and are too numerous for specific mention in this brief report. Before leaving Lake City a

well developed bar may be seen, and along the north shore examples of exposed spits, bars enclosing lagoons, and land-tied islands are numerous. The north shore bars are distinct but stand at a lower elevation than that at Lake City which is interpreted as an indication that these forms were in process of formation when the lake level subsided.

The extinction of former embayments by draining and vegetal accumulation is another interesting phase of a physiographic study of this lake, the details of which should prove to be well worth while.

The lake has not kept pace with many others as a summer resort but has qualifications which are superior to some of the more popular, including good fishing and favorable shore conditions on the south side.

MANISTEE LAKE

Manistee Lake is in northeastern Kalkaska County and may be reached from the town of Kalkaska on the Grand Rapids and Indiana and the Pere Marquette railroads. A drive of ten miles is necessary but the writer found the road good with the exception of the last mile.

This lake is located on the southwestern extension of the interlobate area between the Michigan and Huron lobes which joined at approximately right angles in the vicinity of Gaylord. The formations involved are a moraine, the Port Huron, and a rather broad strip of outwash lying to the southeast. The lake lies on the outwash at the junction of these two formations. It is the largest lake in the region, having a length of two miles and a width that averages nearly a mile. The basin is regular in contour but varies most on the west side, due possibly to the influence of the moraine whose border runs not far from this shore. The basin forms a part of a broad drainage channel which is followed by the Manistee River to the southwest. Either the outwash is excessively pitted near the lake or the basin is not a pit, for the slopes quite generally rise gently from the lake. Whatever the origin of the basin may be, a small amount of material was furnished by wave action but this was distributed to such advantage that pronounced changes were effected. Thus, at a higher level the waves cut a broad terrace on the east shore and the material was worked southward into a strong sand bar which crosses the lowland at the south end as far as the outlet. On the opposite side of the outlet the material derived from the short stretch of low shore was carried in both directions and deposited in small spits near the outlet and on the

south side of the entrance to an embayment to the northwest. Other adjustments were found on the west shore including well defined ice ramparts where conditions are favorable for their formation. The lake is not popular as a summer resort so far, as there are no cottages but it is visited by fishermen and campers who can get boats at the south end.

BIG STAR LAKE

Big Star Lake is located in the southwestern part of Lake County and has an area of about two square miles. Its length is more than two and one-half miles but its outline is so irregular that the width varies from less than one-fourth mile to more than one mile. It is not so popular as similar lakes nearer Lake Michigan but, nevertheless, is an attractive lake which should develop as a summer resort in the future. The nearest railroad stop is Baldwin on two lines of the Pere Marquette system, eight miles distant by road. The writer found the road from Baldwin to the lake in good condition and advises this route for those unfamiliar with the winding sand roads of the jack pine and grub oak plains.

The nature of the Star Lake depression is very easily recognized for one may almost fall from the edge of a most monotonous sand plain to the lake shore, so sharp are the bluffs which surround the lake. It is clearly a pit but is large and much more irregular than the present crooked outline of the lake. This disparity between the outline of the pit and the lake is due to the adjustments of the shores at a higher level, the greatest changes having been caused by the deposition of bars across the mouths of bays. Such adjustments are best defined on the south side and are well illustrated along the southwest shore where a bar completely closes a narrow lagoon. Similar forms, but not complete at the larger embayments, may be found on the south shore. The source of the material of these bars is the numerous sand cliffs which rise nearly twenty feet above the lake. Apparently a small amount of recession of the cliffs was sufficient to supply the material inasmuch as the off-shore terrace, although well defined, is narrow, and the strip exposed by the recession of the water has been removed from the foot of the cliffs.

The north shore consists of broad bays and headlands, and currents have developed along the shores of the bays rather than across the entrances, eventually dissipating in the lake off the ends of the points. Thus the changes in the outline on this shore are less striking than on the south side.

FREMONT LAKE

Fremont Lake is situated on the southern edge of Fremont in southwestern Newaygo County, the city limits extending to include a park on the north shore of the lake. The town is located on the Muskegon-Big Rapids Line of the Pere Marquette R. R., and the lake is not an unreasonably long walk from the station.

The basin lies at the border between outwash and till plain and is rather difficult to classify as to type. The till plain borders the north and east sides of the lake, the remainder of the shores consisting of the sands of the outwash. Also the eastern part of the basin is shallow, a characteristic of lakes in the sags of till plains, but the western part is deep. Thus, it appears that we have here a pit which is open to the east and that the water is sufficient in amount to fill not only this pit but also flood an adjoining depression of the till plain to the east.

The basin is very regular in outline and consequently very few adjustments by shore currents are to be found. The two bars noted stand at an elevation which denotes a former level of the lake about three feet above the present surface. One, a very indistinct spit, runs northwestward on the low flat at the southwestern part of the lake, and the second, also a spit but much better developed, extends from the bluff on the west side of the outlet to the stream channel. A much greater adjustment resulted from the action of waves and undertow and consists of numerous cliffs but more especially a decided submerged terrace. The terrace is uniformly present but varies in width, being greater along the shores bordered by outwash. The outer part of this terrace is exposed by the sinking of the water level, forming a sand flat which has a width of more than one hundred feet in places on the south shore. Ice shove is also effective as shown by the decided ramparts in the vicinity of the outlet. In some places as many as four ramparts were found, giving the impression of an ice-shove terrace although it is probable that such is not the case.

Another interesting feature is the delta which is the site of the park on the north shore. This delta consists of the silt deposited by the stream which enters at this point and was built at the higher level. The stream now carries a different type of load, consisting of the refuse of the canning factory and tannery which makes a very unpleasant condition of the shore.

BIG BLUE LAKE

Big Blue Lake is in the northeast corner of Muskegon County and may be best reached from Whitehall on the Pere Marquette R. R. One may go in from Twin Lakes or Holton, but, in any case, the roads are not good for automobile traffic at the present time. They are sand roads which offer difficulties even to those who are familiar with their peculiarities. A favorite description of such roads is parallel snake tracks through second growth woods, which means constant attention to the steering of the machine in order to avoid getting out of the tracks and striking trees or stumps. Also the sand becomes loose in dry weather and the traction is very heavy making it almost impossible for heavy machines to "plow through." Frequently, the familiar north-south, east-west system of roads is sadly lacking, and numerous branch roads offer opportunities to stray, none too pleasant an experience for most people in such thinly settled areas. The writer suggests the road from Whitehall.

It is obvious from the foregoing statements that Big Blue Lake, although within ten miles of a railroad, is not readily accessible at the present time. Yet it is a very attractive lake and is frequented by those who desire a complete change from the formalities of city life. The visitors come almost entirely from the vicinity of Chicago and have built a number of cottages which are grouped at the east end and at two localities on the north shore.

The lake measures nearly two miles in length by about three quarters of a mile in greatest width and lies in a deep pit in an outwash plain. In addition to the main depression, small pits are so numerous that the lake shores have a rolling topography, and the varied shore conditions made possible numerous adjustments which have been readily accomplished in the loose sand. These changes occurred at a level five feet above the present and are so numerous that mention of each feature would entail a description of almost the entire shore of the lake. The bluffs have been steepened by wave action and drop to a narrow exposed terrace which frequently continues under water to a "drop-off". At the embayments the bars, which rise well above the present level, are so well developed that it is possible to follow the shore around the lake dry shod except at the small brook which drains the lake. In addition to the work of waves and currents evidence of strong ice push may be found. This is the only noticeable adjustment which is taking place under present conditions.

TWIN LAKES

Under this heading are four small lakes which are located about ten miles northeast of Muskegon on the Muskegon-Big Rapids Line of the Pere Marquette R. R. They are now known as East, Middle, North and West lakes. All of these lakes lie in shallow pits in the same outwash plain as Big Blue Lake, six miles to the north. None of the lakes has an area of one-half square mile but, inasmuch as they are connected, the group may be considered as one.

The water level now stands about ten feet only below the outwash surface. The lakes have no surface outlet and consequently the water level varies over periods of years, the highest level as recorded by the shore features having been three feet above the present or about seven feet below the plain. Thus, at that time the waves were able to accomplish much without the removal of an excessive amount of material and as a result there is present an off-shore terrace that appears out of proportion for a lake of this size. A part of the material quarried by the waves was distributed along the shores also and formed a number of distinct bars. One of the best localities to observe these is on the north shore at the connection between East and Middle lakes. The bars on Middle Lake are stronger than those on East, one in particular nearly crossing the lowland connecting the two lakes. Also in the same vicinity an island was tied to the mainland of Middle Lake. Two spits extend out from the south end of this island and show clearly the difference in activity of the currents in the two lakes at this point. The larger spit developed in Middle Lake, due to the greater power of the westerly winds. Another interesting example of the development of a spit occurs at the east end of North Lake where a broad arm of this lake was nearly isolated and has since become a marsh. Other similar features may be found on the shores of these lakes, and their discovery may be left to those interested.

The lakes are connected with Muskegon by an improved road in addition to the railroad and are popular summer resorts. A camping ground and boat livery are located at the east end of East Lake but the majority of the summer inhabitants own cottages many of which are much more pretentious than the usual summer resort cottage.

WOLF LAKE

Wolf Lake is six miles east of the city limits of Muskegon and within one-fourth mile of the main road between Muskegon and Grand Rapids. Auto bus service to the lake is maintained in summer so that no difficulty need be experienced in reaching it. The ride, however, is most monotonous for one travels over a sand plain so flat that even a slight variation in the surface claims the attention, and the variations are few indeed. Once there, the lake comes into view abruptly and is recognized at once as a pit for the sand plain near the lake is outwash and steep bluffs rise consistently from the water to a height of about twenty-five feet on all sides.

The regular outline of the lake as shown on the map is misleading as far as the original basin is concerned for there are small embayments on all but the south side. This change in outline is due to the natural development of shores which occurred when the lake stood nearly five feet higher than at present. The lowering of the water exposed the former shore and, thus, facilitated the study of its features. Inasmuch as the lake has no outlet, the drop in level is an indication of a climatic change, the significance of which is not as yet clear.

On a lake the size of Wolf,—less than one square mile in area and with a greatest diameter of less than a mile,—the waves and currents are comparatively feeble, but the high bluffs of loose sand were easily eroded, thus furnishing abundant material without seriously reducing the power of waves or currents. Consequently, the bluffs, although steepened, have not receded to any great extent and there is no decided off-shore terrace. The work of the shore currents, however, is much more noticeable in that a relatively small amount of material was deposited in such a way as to cause very decided changes in the outline of the lake. The reference here is to the bars which developed across the necks of embayments. These bars do not completely close the openings in all cases but are consistent in that their development shows a direct relationship to the prevailing winds. Thus, along the east shore which is exposed to the strongest winds one may follow the shore irrespective of cliff or swale because the bars are complete, but on the north and west shores only spits are found.

The lake has insignificant inlets and is fed mainly by springs, which accounts for the exceptionally clear water. This in combination with clean beaches, excellent locations for cottages along the bluffs, and good fishing has made this lake a favorite with the residents of the vicinity.

CHAPTER XII

BORDER LAKES AND LAKES OF DIVERSE ORIGIN OUTSIDE THE PORT HURON MORAINIC SYSTEM

The lakes described in this chapter constitute our fourth group and include those which lie outside the limits of the Port Huron Morainic system, 4, Fig. 3, as well as the border lakes which are within the area of the third group. The border lakes are so numerous that the fourth group may be conveniently subdivided into border lakes and those of diverse origin.

BORDER LAKES

The border lakes are all former coastal embayments which have been cut off by the development of great sand bars across the openings and are, therefore, lagoons. The bars developed during higher stages of Lake Michigan—Algonquin or Nipissing—and were left well above the water level when the waters of these lakes subsided. Then there followed a period of eastward movement of the finely assorted sand of the bars caused by westerly winds and deposition of the sand in great rows of dunes which are unsurpassed, at least as regards size, so far as is known. Later the dunes became covered with vegetation which so effectually stopped their movement, always to the east, that they have remained fixed in position to the present time, except for occasional blow outs.

A blow out is merely the renewal of the movement of a fixed dune but apparently originates in a limited area and works up the front slope in a narrow zone to the very crest. This results in a great trough on the front slope, the transformation of the crest into a saddle, and a fresh deposit of sand on the back slope which is very steep. Often the blow outs encroach on the lagoon, causing a projection of the shore, and in this way contribute to the filling of the basin. It is recognized that the dunes are but indirectly related to the study of lakes, but they are most attractive and furnish such excellent locations for summer homes that this brief sketch of their history seems warranted.

Even though the manner in which these embayments were isolated be known, there still remains the problem of the type of embayment, of which there are several. Some are easily recognized

but others, for example Pine, Walloon, Torchlight, etc., which are described in an earlier chapter, present difficulties. Among the types of basins easily recognized are the numerous drowned mouths of streams. The causes of the drowning, or partial submergence, of the mouths of the streams entering the southern part of Lake Michigan is due to the uplift of the land in the northeastern part of North America following the retirement of the glacier. It is not necessary to go into the details of this complicated subject to realize that, if the lower part of Lake Michigan were not affected by the uplift while the northern part was being elevated, the water would pile up in the southern part of the lake and, thus, rise with reference to the land. Such was the case and in the tributaries of Lake Michigan as far north as the Betsie River at Frankfort the water backed into the mouths of the stream valleys.

The outline of such lakes is very irregular and, in a typical case, consists first of a main channel which may, or may not, be winding. Farther inland the main channel ramifies and each ramification may in turn divide so that the pattern resembles that of a deciduous tree. In all cases in Michigan the lakes branch to the east and, inasmuch as the strongest winds are from the west, the force of the waves is so largely dissipated in the diverging channels that the effects are insignificant. Conditions were unfavorable for adjustments by shore currents and the occurrence of features due to these agents are very exceptional. Waves and undertow were effective in forming cliffs and terraces which are found with monotonous regularity at levels above the present, in particular the level of Lake Nipissing which stood about fifteen feet above the present lake along this part of the shore. One other common characteristic of these lakes is the tendency for the heads of bays which have entering streams to be silted up, forming a delta-like flat which has pushed a singularly even front into the lake.

This degression, which possibly over-emphasizes the characteristics of the drowned-river lagoon, was made purposely in order to avoid the dull repetition which became very apparent when the attempt was made to discuss individually each lake of this type. Nine of these lakes were visited by the writer, as follows: Kalamazoo near Saugatuck, Black near Holland, Spring near Grand Haven, Muskegon, White near Whitehall, Pentwater, Pere Marquette near Ludington, Manistee, and Betsie at Frankfort. A number of these are well known ports which need no discussion here except that they are thereby made more accessible. Their use as summer resorts, however, is of interest. The exposed terrace of the higher level serves as an excellent site for cottages and their location just

east of Lake Michigan assures at least a tempering of the summer heat. It is not surprising, therefore, to find some of them almost lined with summer homes many of which are costly estates. Of these mentioned Black, Spring and White are the most popular.

The lagoons of diverse origin, obviously, cannot be discussed as a group as were the drowned streams nor can the probability of shore adjustments be postulated in advance. Consequently they are discussed individually, although this method may give undue prominence to some of these lakes.

BASS LAKE

Bass Lake is located about five miles north of Pentwater and twice this distance south of Ludington, both on branches of the Pere Marquette R. R. Ludington is also accessible by boat, but in either case a drive is necessary to reach Bass Lake, which is situated near the excellent West Michigan Pike.

The most distinctive feature of this lake is that it parallels the Michigan shore instead of extending inland. The west shore consists of an exposed sand bar which is not wholly obscured by dunes and on the opposite side the land slopes gently upward to a sharp rise at the same elevation as the bar, this elevation being that of Lake Nipissing. Furthermore, the lake gradually increases in depth towards the west side and at most hardly exceeds twenty-five feet. The basin, therefore, is the deeper part of a shallow embayment which existed during Lake Nipissing and is masked by sand so that the surface indications are of little aid in the determination of its origin. It appears to be part of a narrow crescentic lagoon which was isolated during Nipissing time, the position of the bar having been determined by the then prominent headland a few miles north. This type of lake is rare in Michigan, the only other example seen by the writer being Devil's Lake near Alpena, an unattractive lagoon rapidly filling with vegetation.

The shore features of Bass Lake are very similar to the lagoons already discussed. The Nipissing shores are best developed and stand about fifteen feet above the lake. They consist of a broad terrace and cliff on the east side, and of a sand bar and flat on the west. Below the Nipissing terrace a lower exposed terrace is evident on the east shore but no deposits by shore currents were found. Aside from the terraces the most interesting physiographic development is the large delta formed by a stream entering the east side of the lake. This delta is triangular in shape but is exceptional in that it extends into the lake as an apex rather

than one of the sides of the triangle, due to the fact that the stream did not form distributaries.

The lake is developing as a summer resort and cottages have been built on both sides. The west shore in the dune area is by far the better location and is also the more popular.

PORTAGE LAKE, MANISTEE COUNTY

Portage Lake is located eight miles north of Manistee and may be reached by the boats of the Michigan Transit Co., the Manistee and Northeastern R. R. from Manistee, and by automobile over excellent roads. The lake is three and one-fourth miles in length. Two broad points, one each on the north and south shores, break the otherwise regular shores but are offset in position so that they give the effect of a sinuous channel of about one mile in width. This is misleading, as may be determined from the very excellent Lake Survey Chart No. 777 which shows that the lake consists of two basins separated by a narrow submerged ridge over which the water is but sixteen feet in depth. The greatest depth of the basins is sixty feet in each case but the eastern basin is much the larger in extent. The lake is separated from Lake Michigan by a narrow row of high dunes which is continuous except for two gaps, one across which the present channel has been dredged and another one mile north which was the natural outlet of the lake.

The basin resembles an elongated amphitheatre, the walls of which are moraine of high relief, the floor is till plain and the stage the dunes. Such a distribution of glacial formations is evidence that the depression was in existence at the time of the last advance of the glacier and that a small lobe flowed into the depression, the front of the ice halting for a time sufficient for the formation of the moraine. The bar which closed the open end was formed during Nipissing time and the dunes were formed subsequent to the subsidence of that lake.

The shore features of Portage Lake are very simple and require little more than brief mention. The specific features are all found at the Nipissing level and consist almost exclusively of a cliff, below which a broad terrace slopes to the lake. The only example of a bar seen on other than the west shore was at Onekama where a small stream is turned westward by it. Another physiographic form is the broad flat at the east end of the lake which is interpreted as a delta built during Nipissing time. The northern half of the submerged ridge which crosses the lake off North Point, as shown on the Lake Survey Chart, is at least, suggestive. The material is

sand, and the form and location are characteristic of the beginnings of a shore current deposit.

This lake shares the popularity of the lagoons of the Lake Michigan coast but has not developed as a summer resort to the same extent as some of those farther south. Numerous cottages are scattered along the shores but the favorite location is on the dunes at the west end. Here is a large colony which includes a well appointed hotel, a recreation pavilion and a large number of private cottages. A water supply system is maintained so that a very comfortable vacation may be spent on this lake.

PLATTE LAKES

The Platte Lakes, Big and Little, are situated in western Benzie County on a triangular-shaped flat bounded on the east and south by moraine and on the west by Lake Michigan. The nearest railroad stop is Honor on the Manistee and Northeastern, but railroad connections from the south are not convenient. A drive of less than three miles brings one to the narrow strip of land which separates the two lakes. Another route is to drive from Frankfort which is the northern terminus of the Ann Arbor R. R. and also a stop for the boats of the Michigan Transit Co. The latter route involves a ten mile drive the last half of which was found to be over heavy sand road. The more comfortable trip for automobiles is through Honor.

The writer attempts no explanation of the origin of the lake basins in this flat because the area was covered by one of the predecessors of Lake Michigan and is, therefore, masked by sand. Whatever the type of basin, it is known that this area was once flooded, with the exception of a group of high morainic hills on the north shore of Big Platte, and furthermore was connected with Crystal Lake through the Round Lake depression which is followed by the road. The narrow connection between the two lakes was closed by a bar along the Crystal Lake shore and the main depression at least partially separated from the main lake in a similar manner.

The shore of Lake Algonquin in this vicinity washed steep cliffs that stand well back of the present lake shores and furnish the chief source of interest in the study of the Platte Lakes, for the adjustment of the present shores is negligible. A complete study of this former lake involves an area of more than twenty square miles and a similar number of miles of shoreline. Time was not available for such a study but a hint of the possibilities was gleaned from the bars noted near the outlet of Big Platte. Near the lake the bars follow the outline of the shore and, therefore, are evi-

dence that this lake was isolated from Lake Algonquin and that this level was maintained for some time. A study of these lakes might well begin in this locality and should by all means include the area along the outlet to Lake Michigan. Another locality that should prove interesting is that to the northwest of Little Platte.

The Platte Lakes are extensively fished but in other respects are not so well adapted to general summer resort purposes as many of our lakes. There are a number of excellent locations for cottages on Big Platte but a large part of the shore is low and not desirable as a building site.

GLEN LAKE

Glen Lake and surroundings form one of the most attractive bits of scenery of its kind the writer has had the pleasure of seeing. We may pass over the details of its location in western Leelenau County and the routes to the lake very briefly. The trip by the Michigan Transit Company's boat is pleasant but the sailings are infrequent. The trip in from Empire, seven miles distant, must be tedious on account of poor railroad connections. The trip from Traverse City by automobile is long, although the roads are not bad. The inference that the lake is somewhat difficult to reach is correct, but the effort is well worth while.

The Glen Lake depression may be likened to a great oval race track in the center of which is a large island, the present Glen Lake filling the entire eastern and the southwestern part of the oval course. The stands which surround all but the north side of the depression show an evolution, the originals consisting of a loop of high hills on the east and south. Later developments erected a west stand, the sands of the great Sleeping Bear. The best seats are located in the south and east stands for from here one may see below the cobalt blue water of the circular main basin of the lake with its fringe of maize, and off to the west is the narrow arm of the lake which bows to the Sleeping Bear.

The depression was very probably in existence previous to the final invasion by the glacier which slightly overran the depression and persisted in its position. During this time earthy material was constantly beng brought forward and dropped as the ice melted. This material was piled higher and higher in hugh hummocks so that when the ice finally disappeared a high moraine or wall was left, which constitutes the south and east limits of the basin. But this explanation does not account for the high land (island) in the central part of the basin and, therefore, is qualified.

This high land was once certainly an island for the waters of Lake Algonquin entered the basin through channels on the north and on the west sides isolating it. For a time the waves and currents of Algonquin coursed the track but eventually the western entrance was closed by a sand bar. Then followed a subsidence of the lake to the level called Nipissing and the west stand (the Sleeping Bear Point) was erected, the material being the sand of the bar and the builder the wind. The great Sleeping Bear is now a blow out, or better a moving dune. The colors of the lake are significant. The blue is due to a modification of the sun's rays as they pass through the water and the depth of color varies with the thickness, therefore the lake is deep. Similarly, the narrow but sharply defined fringe is the yellow of the sands seen through a thin layer of shallow water, signifying a submerged terrace. A final step was necessary for the complete isolation of the lake, namely the closing of the north entrance during Nipissing time by a series of bars which still retain the water at an elevation of seventeen feet above Lake Michigan.

Our interest in the lagoons lies primarily in deciphering their geologic history but Glen Lake also furnishes many examples of shore features so generally lacking on lakes of this type farther south. These features, formed to a large extent when one or both of the entrances were open, are naturally on a large scale. Thus, the cliffs are high and steep, the bars complete and large, and the off-shore terrace wide and distinct. A final episode is due to the interference of man and is unfortunate. Reference is made to the damming of the outlet which has not seriously flooded the lake but has renewed the activity of the waves. The consequent recession of the cliffs is serious and will result in the destruction of portions of the newly graded boulevard, for effective preventive measures are too costly to be feasible.

This lake is beautiful, its physiography is most interesting, and the shore conditions are excellent, but, nevertheless, cottages are not numerous. It appears to lag on account of its isolation but must develop rapidly as a summer resort once its qualifications are appreciated.

GRAND LAKE, PRESQUE ISLE COUNTY

A number of lakes that would naturally be discussed here, Elk, Torchlight, Pine, etc., have already been described in detail, so we must pass on to the Huron shore to complete this part of the group. Grand Lake is situated in western Presque Isle County within three miles of Lake Huron and a somewhat greater distance

directly north of its neighbor Long Lake, which is described in detail in an earlier chapter. A long ride is necessary to reach the lake from Alpena, the most convenient railroad stop, but the road is excellent for most of the drive. Reference is made to Long Lake because of the great similarity of the two lakes in form, size, orientation, shore conditions and type of basin. With slight variations a single general description could be made to serve for both. Grand Lake varies in two respects: It has numerous islands and is a lagoon or at least an arm of the predecessor of Lake Huron.

The basin probably does not exceed thirty feet in depth and on the average is considered shallow. Its total length is more than eight miles and the maximum width not greater than two. A conclusion as to the origin of this elongated depression is a matter of considerable difficulty, inasmuch as a number of factors which cannot be accurately determined must be considered.

The lake is located in a region in which the bed rock is thinly covered with glacial deposits and in places outcrops at the surface. A logical inference, therefore, is that the basin is not due primarily to glacial action insofar as deposition is involved. However, the course of the lake is parallel to the movement of the glacier and the possibility of glacial scour suggests itself at once. In following this suggestion, the distribution of the underlying rocks is an important aid. They are all tilted sediments and, if not covered, would appear at the surface in belts which correspond quite closely with the orientation of the lake and the movement of the ice as well. The geological map of the region shows us that the lake stands on a narrow belt of shale on either side of which is limestone and also that the lake shores along the sides coincide fairly well with the boundaries of these formations. Inasmuch as shale is much more easily eroded than limestone, it is logical to conclude that a trough was eroded in the shale. The presence of the numerous islands, however, is evidence that this was accomplished to a greater extent by running water than by ice for ice would have swept the basin clean. The final isolation of the basin was accomplished by shore currents of Lake Nipissing which closed the ends of the trough. This conclusion, however, is too definitely drawn. The glacial cover is more complete on the east side than on the west, and the position of the boundaries of geological formations, where not actually exposed, are relative at best. Therefore, the manner of formation of this basin as given should be considered as a basis for future work which will furnish the facts necessary to the solution of the problem.

The study of the shore of this lake was a disappointment. The effects of ice shove were noted in several localities but aside from this little was found. The beaches are almost uniformly of coarse material and show little assortment, the one exception being the sand beach near Birch Hill. Such a condition is, however, not surprising if certain features of the lake are kept in mind. The shallow water and numerous islands greatly hinder the normal development of the waves, and the moderate waves that are formed are further reduced in crossing the off-shore shoals. Finally when they strike the beach they encounter a compact till, which is heavily laden with large rock slabs, and can accomplish little. Also the currents are of a like order with the additional deterrent factor of an irregular shoreline which, obviously, does not furnish any extended stretch of shore along which the currents may develop. The most conspicuous feature about the lake is the sheer rock cliff which follows the west side. The cliff stands above and back from the lake and is probably the shore of Lake Nipissing the waves of which were capable of a powerful attack.

The lake is especially attractive on account of the numerous bays, headlands and islands and is extensively visited during the summer months. Numerous cottages occur in groups at the more favorable locations on the east side and future development is to be looked for.

VAN ETTEN LAKE

Van Etten Lake is located within a mile of Lake Huron about two miles north of the village of Oscoda on the Detroit and Mackinaw R. R. The lake has a length of nearly four miles and a width of less than one. This narrow basin extends from Lake Huron in a northwesterly direction to an extensive swamp and apparently continues as the valley of the Pine River. It drops below the surface of a sand flat in bold cliffs and is exceptionally regular in outline. The sand flat is a long strip which lies between the Algonquin and Nipissing beaches and is, thus, the off-shore terrace of Lake Algonquin. Upon this eastward sloping terrace Nipissing bars developed hemming in several shallow lakes such as Tawas, which is little more than a marsh, and Cedar. Van Etten Lake is also located between the two shores, the Algonquin passing just west of the upper end of the lake and a Nipissing bar serving as a retaining wall at the lower end. The basin is much deeper than those of the other lakes on this plain and is clearly of different origin. Just what the origin may be is difficult to determine and one can do little more than conjecture until detailed studies are made. As a

working hypothesis the writer suggests that, when the configuration of the basin is known, it may be apparent that the basin is a broad channel cut through the sand flat by the Pine River after the recession of the lake to the Nipissing level.

The shore features of Van Etten lake are relatively simple. Cliffs predominate and step down to the shore showing a former level about four feet above that at present, probably the Nipissing. Although the west shore is less regular than the east there are no decided embayments other than the valleys of entering streams, and bars are not found. Nevertheless, currents were active and left the shore at the points, forming poorly developed cuspate forelands, all at the higher level. The most decided physiographic feature, however, is the partially isolated basin at the upper end which is an excellent example of filling by vegetation.

The excellent East Michigan Pike parallels the west shore a few rods back from the lake and possibly accounts for the growing popularity of this side of the lake. This shore is rapidly being built up but the east side is apparently being deserted, although skirted by a good road.

LAKES OF DIVERSE ORIGIN

The lakes described in this chapter, Group IV, which are not lagoons are located with one exception between the limits of Lake Algonquin and the Port Huron Moraine, 4, Fig. 3. The lakes visited occur in two groups with the exception of Carp Lake near Mackinaw City and Bear Lake on the west side of the State. One group is located along the boundary between Iosco and Ogemaw counties and the other a few miles southwest of Traverse City.

The lakes of the first group lie on a strip of moraine of very irregular shape and of great relief. The sharp slopes and sandy material of the moraine are not conducive to good roads, and a trip through this region by automobile is not an unalloyed pleasure. Ellake at the west end of Long Lake is a station stop on the Rose City Branch of the Detroit and Mackinaw R. R. but a visit to Sage Lake necessitates a drive.

LONG LAKE, IOSCO COUNTY

Long Lake appears more like a channel than a lake for its width barely exceeds one-fourth mile but its length is more than two and one-half miles, if its sinuous course is measured. The eastern part of the basin is a very irregular morainic depression which continues westward onto a till plain. Many of the irregularities of the basin do not appear on the map because their depths are not sufficient to bring them below the present level of the lake. In the past, however, a higher level was maintained which, although it stood only four feet higher than that at the present time, flooded several large embayments on the north side. From the study of the shores it is apparent that these indentations were abandoned because of the sinking of the water level rather than by their isolation by bars. A number of small bays were cut off by bars and some of the points lengthened by spits but, in general, the adjustments were still in an early stage of development when interrupted.

Among the specific localities where adjustments may be seen may be mentioned the sharp point on the southeastern shore. The greater part of this point is not a current deposit, but the distal end is clearly a spit which continues as a submerged bar across the narrow channel between it and the north shore. Another interesting locality is at Kokosen Resort. Currents were especially active on the west side of the point and, in addition to a straightening of this shore, have built a small hook which curves to the southeast from the tip of the point. East of the point several small indentations are completely isolated by bars and, at the large bay that runs north to a small circular lake, a long spit extends eastward part way across the depression. These forms are all at the higher level and may be readily observed.

The lake has a large group of excellent buildings at Kokosen Resort which apparently has declined in popularity in recent years.

SAGE LAKE, OGEMAW COUNTY

Sage Lake is not easily reached and a long drive is necessary whatever route is taken. The roads were not in good condition at the time of the writer's visit to the lake and the route taken was so roundabout that no directions as to roads are suggested.

The lake is more than two and one-half miles in length and has a maximum width of one mile. Perhaps the homely comparison of a meal bag tied near each end will serve to describe the shape of the lake. The main part of this lake lies in a depression consisting apparently of a number of morainic sags so placed as to form a large basin which completely trenches a strip of very sandy moraine, and the narrow ends are the extension of the basin onto the till plains which flank the moraine. The basin was not studied in sufficient detail, however, to venture a conclusion as to the cause of this peculiar grouping of the sags.

The moraine is one of very strong relief in this locality and the road which skirts the northeast shore is a succession of hills and swales. The swales are large and the shore, therefore, consists of an alternation of broad bays and prominent headlands. The southwest shore, however, is much more regular and is fronted by a cliff that is almost continuous. The adjustments of the shores of this lake all stand at an elevation between three or four feet above the present level and indicate an even earlier stage of development than those found on the shores of its neighbor, Long Lake. The headlands and high banks have been carved into steep cliffs but the off-shore terrace, where present, is poorly developed. Conditions are favorable along the northeast shore for deposition by currents but little had been accomplished when the sinking of the water level interrupted the work. No case of a complete bar was found but several spits were noted on the northeast shore. In all cases the spits are attached to the east sides of the headlands, indicating prevailing currents from the west. The best example is located just west of the Lake View House and is a hook about one hundred feet in length.

Sage Lake has not been developed as a summer resort but a beginning has been made. The writer is inclined to believe that this is due very largely to the difficulty encountered in reaching it. When the roads are improved this lake will be better known and should attract an enthusiastic summer colony.

CARP LAKE

Carp Lake is located on the boundary of Emmet and Cheboygan counties about seven miles south of Mackinaw City. The Dixie Highway and the Grand Rapids and Indiana R. R. both pass the west end of the lake. The lake is more than three miles in length and one and one-half miles in greatest width but is shallow. The basin lies within the limits of Lake Algonquin which flooded the region with the exception of a small patch of moraine which borders the northwestern shore of Carp Lake. The original characteristics of the basin are, thus, concealed by the sand which was distributed over this area by the waves and currents of Lake Algonquin. However, the presence of a moraine suggests the possibilities that the depression may be a large morainic basin which was partially filled by sand or a sag in a till plain with a small amount of filling.

The shores of the lake are rather uniform, and, therefore, no great changes in outline have resulted from the adjustment of the shores. Yet interesting shore features are to be found and among them a

series of bars and ramparts along the shore at Carp Lake Village. These bars are spaced on the gentle slope which extends from the lake shore back to a low cliff and mark former levels of the lake. Two well defined sand bars skirt this shore but in places as many as four rampart-bars were seen. Inasmuch as the writer could not determine the elevation of these bars in this work, the relation of the lake levels represented by them to Lake Algonquin cannot be given. However, the very strong bar of cobbles which cuts off the marsh along the northeast shore must be an Algonquin beach because currents of sufficient power to move rock fragments of cobble size do not develop on lakes of the dimensions of Carp Lake. Another Algonquin bar swings part way around the east end of the lake and is located about two hundred and fifty paces back from the shore. The action on the present shores is limited very largely to ice shove and the main interest in the study of the lake lies in its relation to Lake Algonquin, a more extended study than could be made for this work.

The north shore of the lake is well adapted to summer resort purposes and is very easily reached from the main highway. As a result several groups of cottages have been built and future development may be expected.

GRAND TRAVERSE LAKES

DUCK, GREEN, LONG AND SILVER

Another group consisting of more than a dozen lakes, large and small, is located a few miles southwest of Traverse City and of these lakes Long, Silver, Duck and Green were visited. These lakes all occupy pits in an outwash plain and those seen by the writer have a north-south trend. Some of the lakes show similarities in other respects, which are well brought out from a study of Green and Duck lakes.

GREEN AND DUCK LAKES

These two lakes, which are separated by a strip of outwash of hardly more than one-fourth mile in width, might well have been named Twin Lakes. In addition to a like orientation and origin, their area and form are very similar. Furthermore each has a projection on the east side, that on Duck being the more prominent. Also the adjustments of the shores are alike in character, in both cases being in a very early stage. In fact, very little adjustment

has taken place, although the lakes are approximately three miles in length and one mile in width, and they are not especially interesting from this viewpoint. The most prominent features are the steep cliffs, but apparently little recession has taken place. Currents have accomplished almost nothing except to remove the material from the cliffs, and depositional forms are rare. At the end of the peninsula on Green Lake, for instance, one might expect a large deposit but finds instead a relatively small submerged bar. Likewise on Duck Lake but one or two bars were found and they crossed very minor indentations.

The problem in connection with the study of these lakes is to account for the lack of adjustment of the shores. We may immediately eliminate the size and time elements in this consideration, for nearby lakes which are smaller and have been existent for a similar length of time show a much greater development of the shores, but farther than that the problem is as yet unsolved.

Long stretches of the shores are suitable for resort purposes and the fishing is considered good, so that the lakes are popular. Green Lake, however, appears to be the choice for those who build summer cottages but for the itinerant recreationist with camping outfit the State Park between the two lakes furnishes an excellent location on either. This park of eighty acres is almost unique for it is one of the few remaining tracts of Michigan's once famous pine forests. A trip to this region is well worth while and is easily made from Interlocken, the junction point of the Manistee and Northeastern and Pere Marquette R. R.

LONG LAKE, GRAND TRAVERSE COUNTY

Long Lake which is located some six miles southwest of Traverse City is one of the most attractive lakes in the vicinity. It is more than four miles long and nearly two miles in greatest width but is so irregular that its size is not appreciated on first sight. The view is also obstructed by several islands which add to the picture. One must drive to the lake but will surely encounter difficulties with sand roads to the south if the attempt to circle the lake is made by motor. Such a trip, however, will emphasize the sandy character of the outwash in which this lake lies for the basin is a pit, but a most irregular one. This irregularity in addition to the islands, which interfere with the full development of waves, may give rise to expectations of poorly adjusted shores; however adjustments have taken place.

At the north end one is in doubt as to whether the swamp was

cut off from the main lake or not, for the bar, if such it be, is faint, but evidence may be found of a former level of the lake about three feet above the present level, at which stage the swamp was surely connected. Also the off-shore terrace is well developed here, and in places the part exposed by the sinking of the water is still intact. To the southward the bars increase in development and completely close the narrow openings of the embayments. One of these closed embayments on the shore extends some distance inland and is occupied by Mickey Lake.

It is not our purpose to cite all of the individual examples of adjustments. As a working basis, however, it may be assumed that the smaller embayments are cut off. The larger bays are open to the lake as would be expected from the exceptionally tortuous shoreline along which continuous currents could not develop, even though no islands obstructed the reach of the waves. The headlands have furnished the material for the deposits and have retreated somewhat under the attack of the waves. But the progress of the adjustment of the shores was interrupted at an early stage by subsidence of the water and little has been done since that time.

As a summer resort Long Lake has lagged in comparison to many others that are less attractive. This is due in part to its location near the beautiful Grand Traverse Bay but also to some extent to its inaccessability. Roads are being improved and people are using lakes more and more for recreation, so that this lake will surely share in summer resort development.

SILVER LAKE, GRAND TRAVERSE COUNTY

Another lake of the group under consideration is Silver, located about two miles east of Long Lake. It also lies in a pit in the same outwash plain but very near the margin of the moraine, so near in fact that the narrow basin continues northward from the north end of the lake as a stream valley in the moraine. The lake averages less than one-half mile in width but is more than five times this figure in length. It actually appears much narrower on account of the numerous islands which obstruct the view across the lake. Furthermore, the lake is very deep and the black water comes close to the shore. This makes the lake very dangerous and is detrimental to its development as a summer resort.

It is, however, most interesting as a physiographic study. It has no outlet and varies greatly in level over a period of years. At present it stands nearly five feet below the highest water mark

which has determined the elevation of the features formed by the adjustment of the shores. This higher level may be reached during exceptionally wet periods, but the higher levels which are almost universally found on other lakes make it more probable that this is a permanently abandoned higher level.

It is difficult to select a starting point for the discussion of the numerous shore features of Silver Lake unless one describes them all in detail. Waves have been very active but there has been little cliff recession. Of the material derived from the cliffs some has undoubtedly been carried out by the undertow but it was not sufficient in quantity to build a wide off-shore terrace, which would require an excessive amount of material in this deep lake. The material which was worked along the shore by currents, however, although possibly not greater in amount, has produced more noticeable effects. All of the indentations except two are small and have been cut off by bars. And of the two larger embayments one only, the large bay on the southeast side, is open. The other is at the north end and is completely bridged by a strong bar which separates the small Mud Lake from the main basin. In this connection the islands are interesting. The original islands were nine in number most of which are distributed off the east shore opposite Silver Lake Resort, but this number is now reduced by at least three by the development of bars which either tied islands to each other or the mainland. The details of these bars were not worked out and should prove an interesting part of the study of the numerous physiographic features on the shore of Silver Lake which offers such a decided contrast to the nearby Duck and Green lakes.

BEAR LAKE

Bear Lake is located in northwestern Manistee County about midway between Manistee and Beulah, eighteen to twenty miles distant. Such distances seem rather long but the road in each case is the West Michigan Pike which was found to be in excellent condition. An automobile ride of this distance is preferable to the trip of seven miles from Norwalk which has a one-train-a-day service on the Manistee and Northeastern R. R.

The lake is an open expanse of water of very regular outline and has dimensions of two and one-fourth by one and one-fourth miles, the longer axis having an east-west direction. The western part of the basin hardly exceeds fifteen feet in depth but depths of fifty to sixty feet are reported for the eastern part. The glacial formations may be readily made out as one approaches the lake on the

Pike from the south. At first the route is through a rugged moraine from the crest of which a broad outwash plain may be seen below in the distance, extending northward to another moraine some six miles away. Beyond the crest the moraine slopes sharply to the north and the entire lake appears in view, extending from the foot of the slope onto the outwash. The basin is limited on the east side by upland but stretches eastward as a low, heavily-wooded swamp to Bear Creek, several miles away. Briefly stated the lake basin is part of a depression in the outwash at its junction with the moraine. This depression has some of the characteristics of a fosse but is in part a pit, as shown by the deep basin which forms the eastern part of the lake.

The shore features of Bear Lake are very simple because the shore conditions are singularly uniform. The shore is lined by wave-cut cliffs except at the east end. Where the depression continues eastward conditions were favorable for deposition by currents, and, in spite of the presence of a road around this shore, a well defined bar may be traced across the flat to the higher ground on the north side. Also a similar form developed eastward in front of the swamp at the northeastern part of the lake but was never completed. These forms stand well above the present level and mark a higher stage of the lake. At present the shore agents are rejuvenated and the recession of the cliffs is very evident. The reason for this revival of activity is high water but the cause of the high water is uncertain. The natural conditions of the outlet which flows from the east end have been altered by the building of a road, and, in particular, the position of the outlet has been shifted south of its normal position. This may account for the filling of the artificial outlet which functions only at high water and has no definite channel for some distance east of the bar.

The lake has not yet developed as a summer resort, although it is well suited for such use. This seems to be due to the fact that it was formerly isolated, for, since the construction of the West Michigan Pike and the thereby more convenient access to the lake, it is becoming popular.

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