F

The ice lobe, which was responsible for the development of the Trenary till plain, pushed through the low depression west of Munising, in Alger County. Its final extent and position are marked definitely by the location of the associated marginal morainal fragments which skirt the plain. The direction of the ice in the lobe was mainly south or west of south on the east side of Big Bay de Noc as evidenced by scattered glacial striae on the exposed rock pavement located by Leverett.

Topography and Relief

The Trenary till plain in Alger County (Plate IV, Fig. 1) stands at an elevation ranging from almost 1,100 feet in the vicinity of Dorsey in the north, to 835 feet in the area southeast of Trenary, and extends well above the highest water plane of Lake Algonquin. The surface slope is generally from northwest to southeast with most of the drainage channels thus controlled. The plain as a whole is generally quite smooth but locally assumes a somewhat wavy to undulating character. In places, where the drift is thin, the surface expression is influenced directly by the character of the underlying rock surface. Eskers are numerous and widely distributed throughout the extent of the plain. They are extremely variable in dimensions, ranging from merely a few hundred feet to several miles in length and from ten to fifty feet in height. They are generally narrow, although where several coalesce they may be expanded to form broken features a half mile or more wide.

A few drumlins in the vicinity of Eben Junction, in the northern part of the area, also give added irregularity to the otherwise uniform surface of the plain.

Character of the Drift

The drift in the Trenary till plain is fairly uniform in textural and other physical characters. Normally it possesses a fair association of clay, and constitutes a generally good agricultural soil. As a rule, the drift cover is thin, forming a thin veneer over the bed rock, and locally, especially in erosion channels, is lacking entirely.

In texture, the material of the drift is fairly heavy. The surface soil is loose and friable, and ranges from loamy sand to loam. The sub-soil is more firm and compact, usually quite heavy, and with a sandy clay character. Local patches of sand are distributed through the area but constitute a relatively small proportion of the surface. Ridges of sand and gravel, sorted, and in places well stratified, form a conspicuous feature in the relief. Drumlins, of the same material as the till plain, are found concentrated in the northern part.

The drift is commonly reddish in color and contains an abundance of large erratics. A large amount of locally derived limestone and dolomite

including material from the Hermansville, Black River and Trenton formations, is incorporated in the debris. Limestone is especially abundant in the southern part of the plain but decreases in amount northward, where the till becomes more silicious on approaching the belt of Cambrian sandstone. Near the Cambrian-Ozarkian contact, and for some distance southward, the till contains slabs of silicious dolomite carrying large amounts of the green mineral glauconite, described by Bergquist (10).

Much red sandstone, from the Lake Superior formation of Cambrian age, is intermixed with the drift in the northern part of the plain. It is probable that the red color in the soil throughout the plain is due to the incorporation of comminuted fragments of this highly ferruginous sandstone which was transported by the ice sheet in its southward advance.

The Eskers on the Trenary Till Plain

The numerous eskers, (Plate IV, Fig. 2) scattered over the surface of the plain, are composed of material ranging in texture from cobbles and coarse gravels to finer sands, rudely sorted and somewhat stratified. Blocks and slabs of local limestone are distributed through some of the ridges and occasionally form the bulk of the structure.

From the coarse nature of the included sediment it appears that many of the eskers, especially the shorter ones, were built up under conditions of rapidly moving waters in sub-glacial tunnels according to the theory as explained by Davis (11). The longer eskers were undoubtedly built up as a series of kames, by melt waters escaping into reentrants of the ice front, and became drawn out into long lines by the slow retreat of the edge of the ice while kame deposition was in progress, in accordance with the ideas advanced by Trowbridge (12).

The wide distribution of the eskers and their apparent lack of uniformity in trend and symmetry, together with the imbricated patterns developed, suggests stagnation of the Green Bay ice lobe to the north of the inner moraine, with consequent surface dessication. It is evident from the undisturbed condition of the stratified material contained in them, that the eskers were not formed in association with moving glaciers, but rather, under the influence of inactive ice. The conditions under which the Trenary till plain and its associated eskers were formed probably differ very little from those which Russell (13) describes in the development of eskers in the region of the Malaspina glacier in Alaska. Anderson (14) and Flint (15) have likewise emphasized the significance of eskers in the determination of stagnation areas in the waning stages of ice activity.

PLATE V

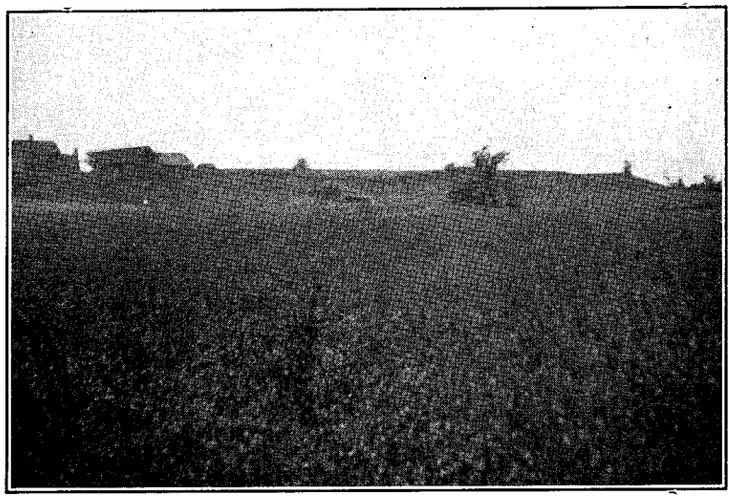

Figure 1.—Drumlin in Till Plain, one-half mile west of Eben, Alger County.

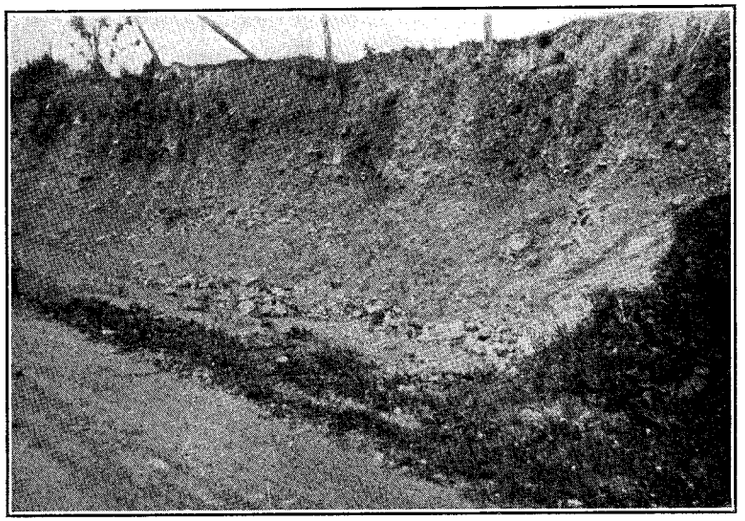

Figure 2.—Cross section of Drumlin showing heterogeneous arrangement of boulders and cobble in till.

Drumlins

A few drumlins are situated in the Trenary till plain in the vicinity of Eben Junction and Chatham (Plate V, Fig. 1). They are somewhat steep-sided and elongated, with a roughly north-south trend, parallel to the direction of ice movement. Compared with drumlins in Menominee County, the drumlins in this area are poorly developed. They average about twenty to forty feet in height and from less than a half to more than a mile in length. The few drumlins in this district are composed of a reddish colored, loose textured, boulderly till and contain an abundance of locally derived, flat blocks of limestone and dolomite. There is no definite arrangement of the material in these ridges, the coarser erratics and limestone slabs being set into the loose textured matrix in all positions and orientations. (Plate V, Fig. 2)

The presence of the drumlins in the northern part of the till plain demonstrates a renewed activity and readvance of the ice for a short distance over the previously deposited till plain, according to ideas advanced by Russell (16).

Conclusions

The conclusions which are drawn in regard to the origin of the Trenary till plain may be summed up as follows:

(1) The plain was formed in the axis of the Green Bay lobe following its final recessional halt as marked by the position of the innermost moraine in this area.

(2) The till comprising the plain, was deposited largely under an ice sheet which became stagnant and melted en masse through surface ablation.

(3) The eskers distributed over the surface of the area were formed largely in tunnels beneath the stagnant ice mass, also, in part, through the recession of kames built up in reentrants to the lee of the glacier, by melt waters issuing from the ice during its marginal retreat.

(4) After the stagnant ice mass had melted down there was a slight readvance of ice, probably from the Superior lobe which, in the northern part of the plain, modeled the surface into a series of poorly defined drumlin ridges.

The Cooks Moraine

Immediately west of Indian Lake, in Ts. 41 and 42 N., R. 17 W., Schoolcraft County, stands an isolated remnant of a moraine which is probably associated with the Green Bay lobe. It appears to represent the front of an ice sheet which moved in a southeasterly direction and is related to the same movement which affected the Garden Peninsula, farther south,

in Delta County. The reason for this interpretation is to be found in the bearing of the striae which is S. 15 E. near Cook's Mill.

The bulk of the moraine stands at an elevation between 750 and 800 feet and, except for the marginal borders, was above the level of the Algonquin waters (770 feet at Cook's Mill). The drift in this area is relatively thin and consists of a clayey to loamy till, with numerous limestone blocks and erratics. The glacial cover ranges from 0 to 25 feet in thickness and rests directly upon a floor of limestone. The topography varies from fairly smooth in the southern part of the area to undulating and irregular in the north. In much of the region, especially where the till is thin, the surface expression of the terrane is a direct reflection of bed rock control.

If the correlation of this morainic remnant is correct, then it is obvious that it represents the oldest and outermost position of the Green Bay lobe in the Lowland province of the Northern Peninsula. Consequently, it was deposited at an earlier date than the oldest outer moraine which is associated with the Superior lobe.

Outwash Plain Associated with the Cooks Moraine

A narrow belt of outwash fringes the southeast border of the moraine in the vicinity of Indian Lake, Schoolcraft County. The feature is relatively smooth and breaks gently into the level sandy lake plain on its outer margin. Near the edge of the moraine the plain stands at an altitude of slightly more than 750 feet and was undoubtedly washed by the waves of the Algonquin water as they beat against the shore cliff of the plateau. The highest part of the outwash plain rises to the level of the water plane of Lake Algonquin (770 feet) and was consequently slightly inundated. The plain is composed of cobbly, gravelly and sandy material, shallow in depth and rests on bed rock.

FEATURES DEVELOPED BY THE SUPERIOR LOBE

Moraines

THE NEWBERRY OR "OUTER" MORAINIC SYSTEM

The final withdrawal of the ice sheet from the basin of Lake Michigan and its northward recession into the Northern Peninsula, marked the closing phase of activity of the Michigan lobe. No deposits which can definitely be related to this ice tongue are in evidence in the Tahquamenon-Manistique drainage area. Shortly following the disappearance of the Michigan lobe, and in the waning stages of the Green Bay tongue, the ice mass of the eastern part of the Superior basin readvanced over the area as an independent glacier. The early activity of this lobe, in the

PLATE VI

Figure 1.—A portion of the Steuben section of the Newberry Morainic System. Fire Tower hill, near Steuben. T. 44 N., R. 17 W.

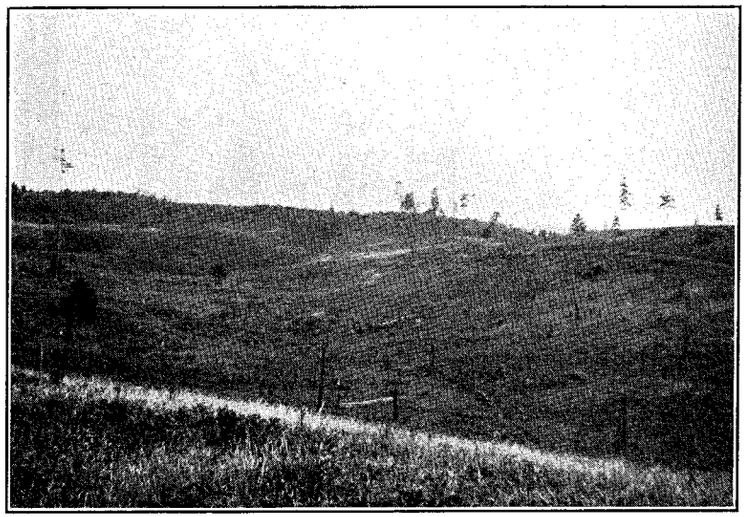

Figure 2.—A closer view showing undulating character of topography.

region east of the meridian of Munising, is associated with a well-defined but much broken morainic system, which for much of its course follows the southern edge of the Manistique-Tahquamenon swamp. It pertains to a lobe which covered the greater portion of the Manistique-Tahquamenon drainage basins in Schoolcraft and Luce counties. In view of the fact that this morainic system is so broken in trend, it will be necessary to consider it on the basis of its several units or segments.

The Steuben Segment—An Interlobate Feature

This feature has its western terminus in the east half of T. 44 N., R. 19 W. in Alger County. It is here characterized by low crested ridges and knolls which are separated by intervening areas of relatively flat, sandy outwash. In the extreme southeastern portion of the moraine, south of McComb Lake, the surface assumes a definite knob and basin type of topography. Numerous lakes are set within the basins between the knobs. Thence, it continues in a southeasterly direction and enters Schoolcraft County in T. 44 N., R. 18 W.

From the northeastern corner of Delta County, a well defined morainic limb extends southward along the east side of the Sturgeon River. This extension of the moraine into Delta County is unquestionably related to the Green Bay lobe and suggests an intermediate position of the ice front later than the Cook moraine, but before it receded to the Au Train-Whitefish lowland and previous to the shaping of the drumlins near Eben Junction by a readvance.

The position of the Steuben segment of the Newberry moraine, in the reentrant between the Green Bay and Superior lobes, definitely identifies its interlobate relationships, and accounts for the apparent strong relief of the feature. The eastern edge of the segment terminates in a sandy lake plain through which the Indian River has cut its channel. This river flows eastward through a lowland depression across the main mass on the moraine and has been responsible for much dissection on the morainal slopes. (Plate VI, Figs. 1 and 2)

This fragment of the outer moraine is generally sandy in character but carries local patches of clayey till and numerous erratics throughout. The topography, in the main, is moderately rolling to undulating. In relief, the crest of the moraine stands at an elevation between 750 and 900 feet. It rises above the plane of the Lake Algonquin waters and shows little or no effects of water modification except along the lower marginal borders which were washed by wave action.

The Hiawatha Segment

A second or middle fragment of the Newberry moraine finds expression as a low, water worked feature in T.s 42 and 43 N., R.s 15 and 16 W. It

PLATE VII

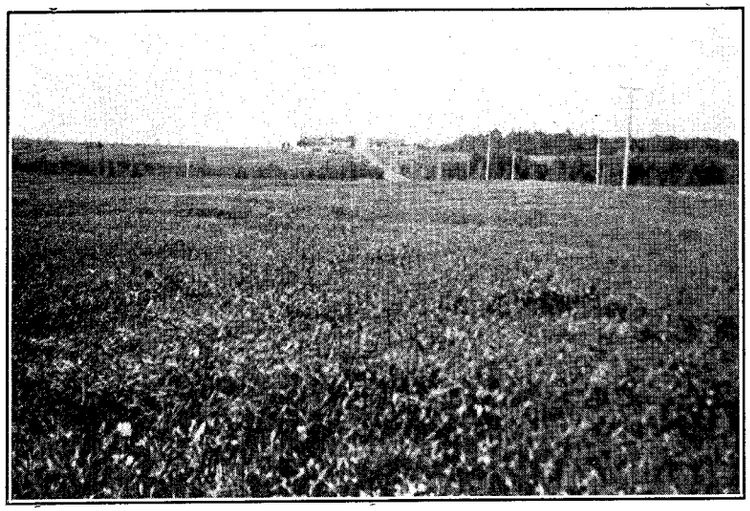

Figure 1.—Morainic topography in the vicinity of Blaney. A portion of the Newberry Morainic System shows characteristic level relief of water worked feature.

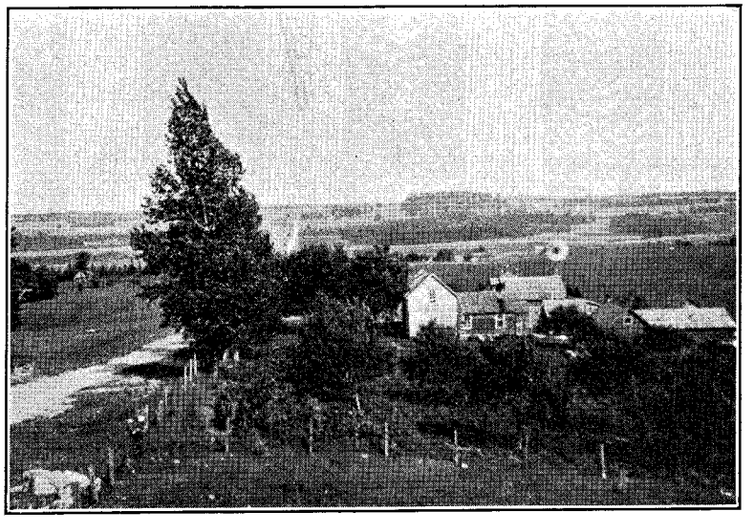

Figure 2.—Water worked morainic area of the Newberry System, in the Twin Lakes country. Sec. 10, T. 45 N., R. 10 W.

extends through the settlement of Hiawatha and is separated from its eastern and western components by broad stretches of intervening lowland swamp and lake plains. The soil in this section ranges in character from a gravelly to a sandy loam and contains little if any clayey material. Erratics and cobbles are strewn haphazardly over the surface and in some of the lower border tracts protrude through the thin overwash of sand, giving evidence of a much greater extension of the moraine in pre-Algonquin times.

The moraine near Hiawatha is relatively low crested and stands at an average elevation ranging between 730 and 740 feet. The surface character is subdued and level and portrays very definitely the effects of Lake Algonquin wave action. It stands 60 to 70 feet above the swamp southwest of it. The low lying margins of the moraine have been reduced to a level plain and the bordering outwash has been greatly modified by lacustrine activity. The demarcation between moraine and the overwash of Chamberlin (17), is not always distinct or definite due to the mergence of the two features at a more or less common level.

The Blaney Segment

A few miles east of Manistique, the main highway, US-2, ascends the Nipissing shore scarp to a sandy plain which stands at an elevation of 685 feet. This lake plain extends eastward for several miles beyond the scarp. Here it breaks off into a series of level disconnected morainal fragments which may be traced intermittently along the southeastern border of the Manistique swamp to the vicinity of Blaney. At this point, the ridge gains considerably in strength and assumes a fairly definite morainal character. (Plate VII, Fig. 1) It continues thus in a general northeasterly direction through McMillan and Newberry, to the southeastern corner of Luce County where it breaks off into a sandy lake plain.

This section of the moraine is confined essentially within the Manistique-Tahquamenon basin, north of the Niagara cuesta. It was molded by the ice sheet into a mass of rolling drift with fairly strong expression but possesses no definite ridge development. The outer edge of the moraine, for much of its extent, was built up to the level of the Niagaran escarpment and in places stands superimposed upon its crest with altitudes up to 1000 and more feet. The inner margin, on the other hand, borders the marshy lowland and descends to 720 feet in some of the lower areas.

The eastern end of the moraine, in the meridian of Blaney, is relatively wide, and averages twelve to fifteen miles across, from north to south, where it extends into Mackinac County. It narrows gradually to the east, and leaves the southeastern corner of Luce County in a series of dis-

membered fragments. The topography of the moraine is, for the most part, rough and irregular. It is characterized by a knob and basin type of development. The knobs are usually not very high and the basins are relatively shallow. The highest knobs, located immediately south of McMillan, rise to an altitude of over 1000 feet, and are well above the highest level of Lake Algonquin. The largest basin in the outer morainic system is occupied by Manistique Lake and covers an area of practically fifteen square miles in Luce and Mackinac counties. North Manistique Lake likewise fills one of the larger basins in the area.

The glacial drift which constitutes the moraine is largely sandy, with local admixtures of clayey material. The soil of the sandy areas is loose textured, porous and open, and allows good drainage. The heavier phases are more compact and firm and tend to retain a greater amount of water. The more important areas of clayey drift are found in the vicinity of the Manistique lakes and south of McMillan. Foreign boulders and limestone slabs of local origin are abundantly scattered through the glacial drift, especially in the more strongly developed inner portions of the moraine. In the weaker outer borders, the drift is sandy to gravelly in texture and erratics are generally quite scarce. These lower areas have been modified greatly by the waters of Lake Algonquin, which at one time covered most of the surface of the moraine. The true morainic character has here been masked by the accumulation of a thin veneer of fine sediment which was washed down from the higher inner slopes. Post-glacial streams have locally eroded their channels below the surface overwash to expose the underlying bouldery till.

An illustration of the variations which may occur is well displayed in the morainic area south of Newberry. The northern, or inner border of the moraine in this region is fairly strong in relief and carries a sandy, bouldery drift. Southward, down the back slope of the moraine, the topography becomes more gentle and subdued. Here the waters of the bordering glacial lake were active in modifying the older features. Surface boulders and erratics are very scarce, but a large amount of cobbly and gravelly material is enclosed in the drift. On the southern, or outer border, the relief is smoothed down to a low plain and the morainic character is almost completely lost. A thin outwash of several feet of fine gravel and sand seems to cover the original morainic topography, the till of which is exposed only where the surface mantle of sediment has been removed by erosion, especially in the valleys.

The drift of this morainic segment varies considerably in thickness, depending largely upon the disposition of the underlying bed rock surface. Where the rock floor is high and ridged, as along the crest of certain portions of the Niagaran cuesta, notably in the southeastern part of Luce County, the superimposed drift is very thin. The relief in such

areas is controlled directly by the underlying rock surface. In areas where the rock floor is deeply channeled, and particularly to the north of the escarpment, the drift has filled in the hollows and basins to a much greater depth. (Plate VII, Fig. 2).

Deep wells at the Asylum grounds in Newberry, on the inner margin of the moraine, enter rock at 320 feet. Wells which furnish the municipal supply of water for Newberry are in sand and gravel at a depth of 90 feet.

Two recesses occur in the northern border of the moraine: one between McMillan and Newberry, and the other, four to ten miles east of Newberry. In each of these areas there is a thick deposit of red clay of lacustrine origin. An artesian well recently drilled in the S. E. ¼ of the N. E. ¼ Sec. 8, T. 45 N., R. 10 W. penetrated 80 feet of red clay, above 50 feet of sand and 2 feet of gravel before entering bed rock. In the S. W. ¼ of the S. W. ¼ Sec. 13, T. 45 N., R. 8 W. artesian water was struck below 53 feet of red lake clay. Near Soo Junction in Sec. 35, T. 46 N, R. 8 W. a well penetrated 172 feet of red, gummy clay before reaching rock.

In conclusion, it may be stated that the Newberry morainic system represents the position of the ice front during the maximum extension of the independent Lake Superior lobe which readvanced shortly after the break up of the main Michigan ice tongue. The final withdrawal of the ice from the moraine marks the initial stage in the surface development of the extensive Manistique-Tahquamenon basins. The morainic system was originally laid down as a continuous feature and during the early history of the basin drainage played an important role in confining the waters of the lowlands behind it. The continuity of the morainic system was broken, first by the action of Lake Algonquin waters, and finally by erosion of through-flowing rivers which developed as uplift in the area progressed.

In terms of geologic time, the activities of the ice sheet which shaped the Newberry morainic system, may be correlated with the Sturgeon River moraine of the Green Bay lobe in Delta County. This would set the time, as following the complete disappearance of the Michigan lobe but antedating the formation of the eskers on the Trenary till plain. It seems probable that stagnation of the last remnant of the Green Bay lobe in the Northern Peninsula did not take place until the Lake Superior ice had withdrawn completely from the Newberry moraine and receded to a new front farther north.

THE MUNISING OR "INNER" MORAINIC SYSTEM.

A strong morainic system, formed by the Lake Superior lobe, and marking its second important halt in recession, may be traced from near

PLATE VIII

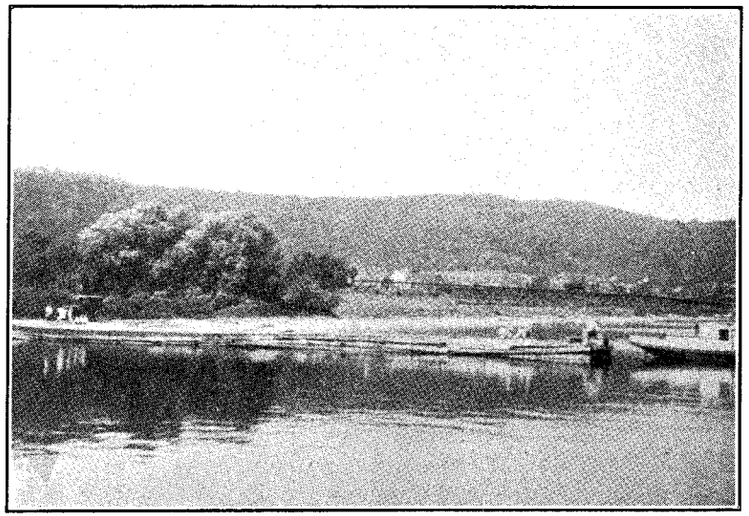

Figure 1.—High morainic bluff in the Munising System, near the city of Munising.

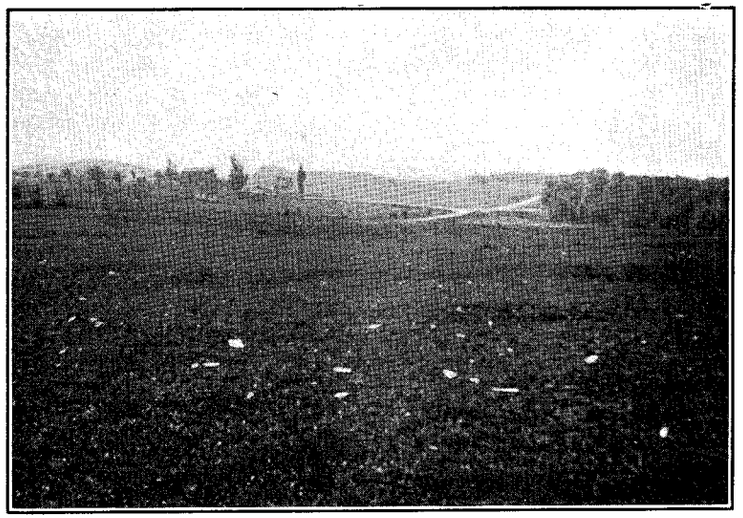

Figure 2.—Moraines of the Newberry System, near Laketon, S. E. ¼, Sec. 36, T. 46 N., R. 12 W.

the axis of the Green Bay lobe in the vicinity of Au Train Lake on the west side of Alger County, northeastward to the meridian of Grand Marais. Here it swings southeastward into the Tahquamenon swamp in the central portion of Luce County. For most of its distance in Alger County, the moraine parallels the shore of Lake Superior, although in places it lies some distance back.

The extreme western end of the system, where it swings southward into the Au Train-Whitefish depression, merges as an interlobate feature with the eastern limb of the inner moraine of the Green Bay lobe. In this section of the moraine the topography varies from rolling to gently undulating and in places flattens out to a fairly level surface. Erratics and boulders are prevalent and much sandstone and dolomite of local derivation are incorporated in the sandy gravelly clay till.

A narrow strip of moraine, not exceeding an eighth of a mile in width, borders the north edge of an extensive outwash apron from the west central portion of Sec. 31, T. 46 N., R. 19 W. for a distance of seven miles to the western edge of Sec. 19, T. 46 N., R. 18 W. It is separated from the main moraine to the north by a narrow bench of sandy lake plain which swings into the area from the southeast. This narrow belt of moraine appears to be an ice contact border and marks the position of the ice front during the interval when outwash material was being carried southward by melt waters. The morainal character of this contact belt is well preserved by the presence of the erratics and boulders incorporated, and by its relief.

The bench of sandy lake plain, which lies between the narrow contact belt and the main moraine to the north, evidently represents a fosse which was deepened sufficiently to allow the lake waters to remain after the main mass of the moraine had become uncovered.

In the vicinity of Munising the moraine shows considerable strength and is surmounted with high knobs which reach a maximum elevation of approximately 1010 feet. (Plate VIII, Fig. 1) Much of this area stood above the water of Lake Algonquin in its highest stage and was unaffected by its activities. The intercalation of lacustrine clay and sand with the glacial till on the morainal slopes is apparent to an altitude of 940 feet, or 340 feet above the datum plane of Lake Superior. Leverett (18) describes storm beaches on Scaffold Hill, in the vicinity of Wetmore, as high as 960 feet. He accounts for the water body being held up to this plane on the assumption that "the ice was still present in the great Manistique Swamp, to the east and southeast". Above 960 feet in this area, the slopes and crests are rugged. Below this level, however, the slopes are toned down and smoothed off considerably from the effects of water action along the Algonquin lake shores.

In the Munising-Wetmore portion of the moraine, the topography ranges from rolling and undulating in the higher positions, to gently wavy and somewhat flattened surfaces in the water-modified lower portions. The drift varies all the way from clayey till of ice deposition to local pockets of stratified sand and gravel of lacustrine origin in the modified areas. Erratics are abundant and, together with blocks of local sandstone and dolomite, constitute a considerable portion of the drift.

East of Munising, the moraine becomes quite bulky and reaches a maximum width of 14 miles in the meridian of Melstrand, where it breaks off into the marshy lowlands of the Cusino swamp. This section of the moraine is undulating in character and locally somewhat rugged in relief. It is quite generally creased by drainage channels with swampy borders which break up the continuity of the system on its eastern edge. The flattened crests and smooth surface slopes are significant of the activity of Lake Algonquin waters which completely covered the moraine.

From Melstrand, eastward for a distance of 17 miles, the moraine parallels the shore of Lake Superior as a tenuous belt, skirting the southern edge of the Beaver Lakes basin. The feature is extremely narrow for much of this distance, but is wider in places, ranging from less than one-fourth to several miles in width. The topography is irregular, beset with low hills on the inner border but flattens out at the outer or outwash margin. At the outwash border, the ridge has an average elevation of 800 feet but rises to almost 1000 feet in the more rugged portion directly south of Beaver Lake. Erratics and local boulders are numerous and the drift is sandy to loamy in character, with local admixtures of clayey till.

The general nature of this section of narrow moraine seems to indicate quite conclusively that it marks an ice-contact border. Here the margin of the glacier rested for a considerable period, during which it melted and spent its material in building up an outwash apron rather than a bulky moraine. That the ice front remained for some length of time in this position is evidenced by the vast extent of outwash gravel which was spread out south of the ridge. Leverett[1] confirms the writer's view that the ice must have formed a contact border in this area.

In the meridian of Au Sable Point in Alger County the Munising morainic system is offset to the south about three or four miles. Here it sets in again as a bulky mass of rolling drift and attains a maximum width of 10 miles where it extends southward into Schoolcraft County in R. 14 W. Near Grand Marais the inner border is almost two miles south of the lake shore. In this vicinity its continuity is broken by a low lying, swampy, outwash re-entrant, which extends into the Sucker Lake

[1]Leverett, F.,—Personal communication.

area in Schoolcraft County. This strip of poorly drained outwash may be traced northward into Alger County for a distance of seven miles through T. 40 N., R.s 13 and 14 W. Highway M-77 follows this lowland between the morainic segments for some distance, in the region from Seney to Grand Marais.

In the eastern end of Alger County the morainic segment exhibits an undulating to rolling relief. It ranges in altitude from 800 feet, along the borders of the outwash plain on the south, to over 1000 feet in the southwestern corner of Alger County. Much of its surface particularly below 950 feet was inundated by the waters of Lake Algonquin and presents definitely the results of wave activity in washed down slopes and subdued crests.

The drift in this area is composed predominantly of a grayish colored loamy sand, intercalated with lenses of reddish-gray silt and fine sand. Boulders of local sandstone and erratics are embedded in the loose till matrix.

In the region immediately west of Beaver, situated on M-77 about ten miles south of Grand Marais, the moraine loses strength. It was here modified to a considerable degree by the waters of Lake Algonquin. The surface has been eroded and reduced almost to the level of a flat topped plain. Small, scattered hills of low relief, together with erratics and the presence of numerous kettle basins, give support to its morainal origin. Along the Adams trail, west of Beaver, the outer margin of the moraine has been so completely subdued by lacustrine erosion and subsequently mantled with thin lake deposits of sand, that it is difficult indeed to discern its till character. However, in places, the till with its associated boulders, projects through the thin veneer of lacustrine sand and makes possible the true interpretation of the feature. The morainic expression becomes more pronounced towards the northern inner border.

Upon entering Luce County, the Munising morainic system takes a definite swing to the southeast and breaks off into the Tahquamenon swamp a few miles north of Dollarville. Like its counterpart south of the swamp, this moraine is not separable into distinct ridges, but stands as a mass of undulating drift.

On its inner border, the moraine here stands at an altitude of 750 to 800 feet and presents a strongly developed relief. The topography is generally quite undulating and in places broken by numerous basins which are hemmed in by knobs of varying heights. The drift is predominantly sandy and is locally interspersed with admixtures of gravel and clay. Erratics and occasional slabs of limestone are scattered through the section but not in such large quantity as in the moraine to the south. The limestone makes up a relatively small proportion of the drift but is conspicuous in the shore bluff which marks the north-

ern margin of the moraine, south of Cold Spring in Sec. 6, T. 47 N., R. 10 W. This shore feature marks the northern limit of limestone drift in Luce County and is undoubtedly quite near the Cambrian-Ozarkian contact.

The outer border of the moraine is relatively low and exceedingly weak. It descends into the Tahquamenon swamp at altitudes ranging from 700 to 720 feet. The drift here is largely sandy with gravel intermixtures and with but few erratics exposed. The surface is smooth and unbroken, except where it has been seamed with drainage creases which have cut down into the unmodified drift below.

This section of the morainic system was largely inundated by the waters of Lake Algonquin. A small area covering approximately ten square miles, in the southeastern part of T. 48 N., R. 12 W. and the northwestern corner of T. 47 N., R. 12 W. in Luce County, extends westward into the northeast corner of Schoolcraft and the southeast corner of Alger counties, where it rises to an altitude of 1000 feet. Here it was above the Algonquin level and stood as an island mass in the lake during the time of the greatest expansion of the lake. Six miles of marshy lowlands separate the eastern border of this segment of the morainic system from its eastern continuation in Luce County. This fragment of the moraine is completely enclosed by marshy lowland but may be traced as a conspicuous feature for a distance of eight miles to the depression of the Tahquamenon river, in T. 48 N., R. 8 W. East of the river the morainic system leaves the County in the vicinity of the Big Falls and enters Chippewa County twelve miles south of the Lake Superior shore. In Chippewa County it continues eastward, skirts the south shore of Whitefish Bay and finally merges with the Newberry moraine near Eckerman. From this point the combined systems follow through to Nadoway Point, the easternmost terminus of the moraine.

Significance of the Munising Morainic System

Although the present morainic system is broken into a number of units widely separated by rivers and marshes, it is nevertheless, obvious that it may have extended across the region with a continuous front shortly after the ice sheet had retired. It marks very definitely the border of the Superior lobe at the time when the Green Bay tongue was holding its final position in the peninsula. It is quite probable, that at this time the Green Bay ice sheet made the readvance that shaped the drumlins near Eben Junction and Chatham.

The position of the ice, as it stood upon the Munising moraine, was such as to block the present outlet of the Tahquamenon river in northeastern Luce County. Border drainage from the melting ice front was carried southward across a low plain which apparently had received

a very small contribution of drift from the retreating glacier. The discharge waters, flowing naturally toward the Lake Michigan basin, were for a time, undoubtedly impounded behind the as yet unbroken outer Newberry morainic system. Thus a more or less extensive interior lake developed between the outer and inner moraines, and persisted for some little time until the water succeeded in cutting channels across the barrier. At this stage, a number of rivers, extending from the outer margin of the Munising moraine and flowing into this interior lake, were formed upon the initial, slowly uplifting slopes of the intermorainic plain. The Tahquamenon drainage basin was as yet undifferentiated but in all probability received its due proportion of melt-water drainage from the waning ice.

THE CRISP POINT MORAINE

The final position of the Lake Superior lobe and of the Wisconsin ice sheet as a whole in Michigan, is marked by a narrow, transected morainal ridge of relatively weak expression, trending across the north edge of Luce County a few miles south of the Superior shore. It crosses the county in a series of broken fragments, which in some areas have been so completely dissected by wave erosion as to make it difficult to trace.

The westernmost fragment of this morainic ridge lies south and west of the Sucker River basin, in the western part of T. 49 N, R. 12 W., where it extends for a few miles west into Alger County. In this section the moraine has a fairly rugged development but does not stand sufficiently high to have extended above the waters of Lake Algonquin. Hence, it presents a water-washed and much modified surface. The expression is typically of the knob and basin type with many of the basins without lakes or swamps.

A second fragment continues eastward from the eastern end of the Sucker River basin through T. 49 N., R. 11 W. and thence into R. 10 W. The inner border of this section is quite definitely marked by a conspicuous, although somewhat broken, wave-cut shore which follows along at 715 feet elevation. The crest of the moraine, slightly south of the shore cliff, rises to an altitude of 730 to 750 feet but possesses a decidedly subdued relief. In the northwestern portion, however, its surface is deeply basined and the topography is rugged, due to the melting in place of detached blocks of ice which were left in the wake of the retreating glacier. The outer or southern border, on the other hand, is not so distinctly marked. It merges more or less indefinitely with the adjoining lake plain and becomes difficult to differentiate. The drift in this morainal segment is sandy, light, and loose textured. It contains scattered patches of gravel, cobble and occasional small amounts of clay. Boulders are relatively scarce although locally they may be quite evident.

In the northeastern corner of Luce County, extending east of the Two Hearted River into Chippewa County, near Crisp Point, is another fragment of the ridge. Here the moraine has developed a fairly strong expression and has a relief much higher than its western counterparts. The crest rises to an altitude of 800 feet but still stood below the highest Algonquin water plane. The surface is undulating and characterized by a swell and sag topography. The drift is sandy to clayey in texture and contains numerous boulders of fairly large dimension. The north edge of this morainal remnant is marked by a wave-cut shore cliff standing at a general elevation of 715 feet. Southward, the moraine loses its ruggedness and on its outer border merges indefinitely into the sandy lake plain and swamp of the Betsy Lake depression.

The general trend of the moraine, as evidenced by its various fragments from west to east across Luce County, suggests a north-northwest recession of the Wisconsin ice border from the southeastern end of the basin of Lake Superior. It is the youngest glacial feature in Michigan and marks the last definite position of the continental glacier in its retreat from the state. It is obvious from the weak expression of the moraine, that the ice which formed it did not hold its front in position for a very long period before finally melting.

The stagnant remains of the Green Bay lobe in the Trenary till plain region in Alger County, were no doubt, dissipated before the Superior ice sheet had reached the position of the Crisp Point ridge.

Outwash Plains

During the process of moraine construction, the ice borders remained somewhat stationary for long intervals, due to the established balance between advance and retreat. In the dissipation of the glacier front, a large amount of melt water was carried away much of the time, but more especially in the summer when melting was rapid and on a larger scale. Thus, water work accompanied ice work in all cases of melting and resulted in the modification of much of the material previously deposited by the glacier.

The glacier streams, which flowed from the melting ice across the moraines, carried considerable quantities of sediment out to positions in front of the borders. In the areas where the outflowing streams emerged upon more gentle slopes, velocities were reduced and the material carried was deposited in the form of alluvial fans. Fans from adjoining stream courses, building out in all directions, in places merged with each other to form broad alluvial plains of stratified gravel and sand. These plains were generally constructed in front of the moraines in the form of outwash and overwash aprons.

Outwash plains or aprons are, as a rule, composed of both coarse and fine material. The outflowing streams of melt water, transporting debris from the ice border were forced to drop the gravel and cobbles almost immediately upon reduction of velocity. The finer material, however, was distributed for considerable distances from the source of the sediment. Thus, the load carried was sorted out according to texture and rearranged by the water into stratified deposits, with the coarsest material spread out nearest the retreating ice front.

Features of this type are usually characterized by gentle to moderate relief, except where pits have been formed by the melting of detached ice blocks below the surface. The topography may then assume an irregular aspect but maintains, nevertheless, a generally even skyline. The material of outwash plains ranges from coarse silt to sand, gravel and cobble of varying textures but usually with a preponderance of the less coarse assortment. The structure is loose and porous, with the result that drainage is excellent. Erratic boulders may be present near the morainic margins of outwash plains, but are inconspicuous in other portions save where the mantle is so thin as to allow the shallow underlying till to protrude.

Outwash plains constitute a relatively small portion of the surface area in the Tahquamenon-Manistique drainage basins. They are confined largely to the outer borders of the Munising moraine and occur more or less as widely separated or isolated features. Like the moraines, the lower portions of the original outwash plain have, in part at least, been greatly modified by the activity of Lake Algonquin waters and, in certain areas, the feature has been completely removed by prolonged wave erosion.

OUTWASH PLAINS ASSOCIATED WITH THE MUNISING MORAINE

The Wetmore Plain

A conspicuous outwash apron extending from the Au Train-Whitefish depression in Alger County, eastward for a distance of ten to twelve miles into Schoolcraft County, occupies a position in the reentrant between the Green Bay and Superior lobes. It was built up in the course of ice recession, to a general level of close to 1000 feet near the ice contact, and except for its outer marginal borders stands well above the plane of Lake Algonquin. It is composed of loosely consolidated and porous gravel and sand. The surface slopes gently to the south-southeast, a condition largely controlled by its interlobate position. It is pitted with numerous basins, many of which hold shallow, irregular-shaped lakes. These were undoubtedly formed where detached masses

PLATE IX

Figure 1.—Burned over outwash plain, south of Kingston Lake. T. 48 N., R. 15 W.

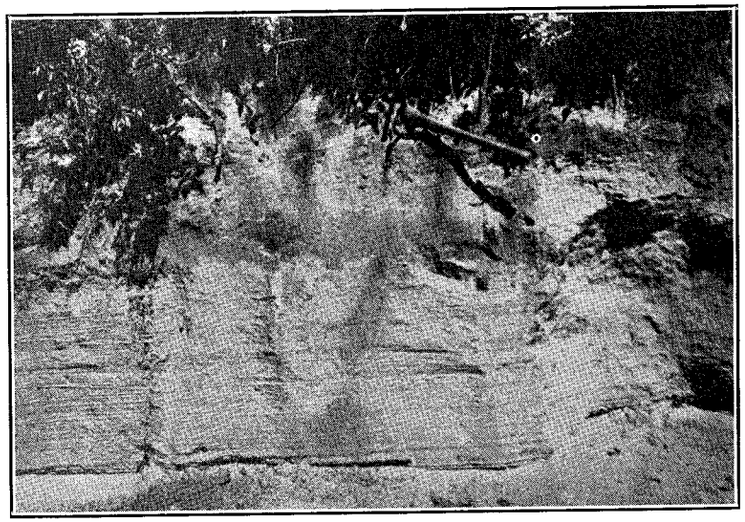

Figure 2.—Section of outwash plain showing stratification in the sandy material (Mattock 14" long). Sec. 4, T. 47 N., R. 13 W. Along M-77.

and blocks of ice remained after the active ice border had retreated beyond them.

The Wetmore plain has an average width of 5 to 7 miles through much of its course. It is flanked on its inner margin by a narrow fringe of moraine which appears to mark the position of an ice-contact border. The pitted nature of the surface, together with the unusual width of the plain, in contrast to the narrow associated moraine, seems to support Leverett's (19) views that the feature was built up in the course of ice recession.

From the meridian of Wetmore, eastward for a distance of twelve miles, to the vicinity of Melstrand there is little or no outwash fill along the outer border of the Munising moraine. Leverett (20) attributes the absence of outwash in this area to the ponded condition along that part of the ice border. He states also that "the parts where outwash plains occur were high enough to stand above Lake Algonquin or were very close to the upper level of the Algonquin waters." It seems probable, however, that the absence of outwash fill in this area may be accounted for by simple removal by wave action of material not built up sufficiently high to withstand the ravages of lacustrine erosion.

The Boot Lake Plain (An Outlier of the Wetmore Plain)

About five miles south of Shingleton, T. 45 N., R. 17 W., in Schoolcraft County, the main highway, M-94, rises to a gravelly, cobbly table land which stands at an altitude of 820 to 850 feet. This isolated patch of outwash, bordered on all sides by marshy lowland, covers an area of practically 10 square miles. It breaks abruptly, with steep escarpment slopes on all sides, to the surrounding marginal swamp. The plain is confined largely within the inter-stream area of two headwater branches of Stutts Creek, which apparently were responsible for its isolation and the development of its marginal cut-cliff character.

This small area of outwash plain is extensively pitted and carries a number of shallow, irregular basined lakes among which, Lilley, Boot, Sand, and Clear lakes are the most important. The elevation of the surface of this plain is lower than the east edge of the Wetmore plain, which is about six miles west, but lines up with it quite definitely when surface slopes are considered. The general altitude of this outwash fragment suggests that it is an outlier of the Wetmore Plain which was first isolated in part by wave action of Lake Algonquin waters and later by the erosional work of the post-glacial streams which now almost completely surround it.

This table-land, like its main western counterpart, stood slightly above the plane of Lake Algonquin and was not subjected to the modifying activity of the lake waters.

The Kingston Plain

A rather extensive outwash apron may be traced along the north edge of the Manistique-Tahquamenon swamp from the northwestern corner of T. 47 N., R. 16 W., in Schoolcraft to the west edge of Section 12, T. 46 N., R. 11 W., in Luce County. (Plate IX, Fig. 1) This plain covers an area of several hundred square miles and is by far the largest single outwash feature in the region. A tongue of the plain in Alger County, extends northward into the reentrant between two morainic segments in T. 48 N., R.s 13 and 14 W. M-77, the main trunk highway between Seney and Grand Marais, crosses this portion of the plain for a distance of about 8 miles. In this area, the plain is considerably broken by low-lying, poorly drained, swampy depressions, and is represented essentially as sandy, tree-covered ridges separating the undrained lowlands.

In Alger County, the plain is bordered on the north by a narrow belt of terminal moraine which undoubtedly represents another ice-contact border. It does not seem justifiable that such an extensive outwash apron as has here been developed could have formed from a moraine so narrow, unless the ice front remained stationary for long periods and during the continued wasting of its front, discharged much of its debris into the outflowing streams of melt water. Thus, when the ice sheet finally melted in retreat, there was very little debris remaining in the mass to be dumped, with the consequent result that a very narrow belt of moraine was left to mark the contact position of the ice.

With the possible exception of the area in Alger County immediately bordering Kingston Lake on the east and south for a distance of several miles from its margin, the plain is uniformly level and presents a relief which is characteristic of such features. The relatively even surface is etched in places with shallow lakes and depressions which give a pitted expression to the topography. These pits suggest that much of the outwash was formed in the path of the retreating ice margin.

East and south of Kingston Lake, however, the surface expression is irregular and broken, and gives the impression of a morainic relief. The topographic irregularity is due to deep pockets and basins which have been extended downward rather than to elevations developed above the general plain level. The sky-line is even and smooth over the area, despite the roughened surface character. This portion of the plain may owe its development to deposition of gravels and sand over a nearly continuous sheet of stagnant ice of irregular thickness, as suggested by Thwaites (21). Or it may have assumed its surface character through the melting of large detached blocks of buried ice which resulted in slumping of the surface.

Thwaites (22) regards the presence of pitted outwash in front of a moraine as "indubitable proof that the glacier extended beyond the moraine at a date not many years before its formation." Likewise, "a moraine behind a well developed pitted plain is the product of a comparatively rapid recession of the ice front and not of a readvance of any considerable magnitude." The conditions as found in this locality seem to justify these conclusions. The lack of erratics and glacial boulders in this area seem further to bear out the opinion that the feature is outwash rather than moraine. It also manifests a sufficiently thick overwash deposit of glacio-fluvial material to have completely buried any remnants of a moraine which may previously have been deposited.

The material of the outwash varies somewhat in the different areas. In the inner margin, near the morainal contact, the sandy-gravelly drift is intermixed with cobbles and coarser debris which would indicate transportation by rapidly flowing melt-water streams. Southward, extending into Schoolcraft County, the deposit assumes a more uniform texture ranging from sand to gravel, and is stratified in character. (Plate IX, Fig. 2)

Lakes and swamps are numerous and widely distributed throughout the extent of the plain, but on the whole the drainage is easy and follows southward down the natural surface slopes.

The eastern extension of the plain, continuing into Luce County, and especially that portion situated directly across the swamp from the village of McMillan, seems to have formed in the wake of a rapidly retreating ice-border. Near its inner edge, the plain is generally smooth and unbroken. It contains coarse cobbly and gravelly material interspersed with occasional boulders which protrude through from the underlying till. To the south, however, the surface of the apron is deeply trenched and pitted and presents a relief sufficiently rugged to be easily mistaken for a morainic feature. Superficial boulders are relatively rare in this area but may be encountered within a few feet of the surface as evidenced in the deeper skidding trails and along the floors of streams which have trenched their channels through the overwash.

It appears that this apron was formed upon a more rugged morainic topography, during a recession of the ice border which was marked by a succession of short halts. The outflowing melt-water streams did not carry out a sufficient amount of sediment to completely fill the depressions and smooth out the irregularities of the original surface. Leverett (23) suggests that the plain was here built up in a series of steps from south to north as the ice retreated from the area. He states further that "the ice contact at the north edge of each plain is marked by a low bluff-like rise, the northern edge of each plain being a little higher than the southern edge of the next one and being trenched in places by the passage of streams across it from the next later plain."

Chapter IV

LACUSTRINE GEOLOGY

GENERAL DISCUSSION

For a considerable time after the final disappearance of the Superior lobe from the position of Crisp Point Moraine in Luce County, and while the Wisconsin ice sheet still blocked the North Bay outlet in the northeast portion of the Superior Basin, there continued a widespread inundation of the Lowland province by the waters of Lake Algonquin. The greater portion of the peninsula from the meridian of Munising eastward was flooded, and remained so until the retreat of the ice fully uncovered the Ottawa drainage line. Only a few small isolated areas in this region rose above the level of the highest Algonquin waters and they were represented merely as islands.

Leverett (24) states that "in the southern part of the Peninsula near Gladstone, and on the Garden Peninsula east of Big Bay de Noc, the altitude of Lake Algonquin was about 120 feet above Lake Superior, but at Marquette it was 340 feet and just north of Sault Ste. Marie it was fully 400 feet, while at the southern end of Lake Huron at the head of the St. Clair outlet the altitude was only five feet above Lake Superior."

The glacial lake history of the Northern Peninsula is associated primarily with developments which took place in the Lake Superior basin and to a less extent with those in the Lake Michigan depression. According to Leverett (25), "the oldest and highest of the large glacial lakes in the Northern Peninsula was held in the basin of the Ontonagon River to the south of Copper Range. During the existence of this lake, the southern edge of the ice sheet appears to have rested on the Copper Range so that the waves were beating against an ice barrier on the north side of the lake." He places the altitude of this initial lake, Lake Ontonagon, at 1320 feet above sea level or more than 700 feet above Lake Superior and indicates that, during its short existence, the line of discharge led west from Lake Gogebic.

Lake Duluth, which followed Ontonagon, began as a small body of water in the extreme western end of the Superior basin, when the ice in that area had melted back for a short distance. This lake drained southward through the Brule River into the St. Croix and thence into the Mississippi. Leverett places the outlet through the Brule at 500 feet above Lake Superior in the beginning stages of the lake. During

its history, the outlet was cut down 50 feet and the water plane was lowered correspondingly.

The waters of Lakes Ontonagon and Duluth were confined, by the position of the ice barrier, entirely to the highland area in the western part of the peninsula. They had no direct influence upon developments within the Tahquamenon-Manistique basins inasmuch as the main mass of the Wisconsin ice sheet covered this area at that time.

As the ice in the Superior depression melted back eastward, a larger portion of the basin was uncovered. The lake waters expanded and at the same time the level was dropped to a plane below the Brule outlet. Thus there gradually came into existence a lake which eventually became confluent with the waters of the Huron and Michigan basins in the establishment of Lake Algonquin.

LAKE ALGONQUIN

Because of its widespread effects and influences upon the Tahquamenon-Manistique area, it will be necessary here to consider the problem of Lake Algonquin in some detail. In many respects, however, the details can never be complete because of the fragmentary evidence at hand in many of the areas. Shore line and strand features may be traced somewhat interruptedly for many miles and then again they may be entirely missing for equally long distances, with gaps between merely to be interpolated.

Field evidence available in Alger and Luce counties seem to indicate that the complete development of Lake Algonquin from the Duluth stage did not occur in one single change. Rather, the transition was gradual and during the process there were various incidents, as may be judged from the changes in the drainage lines of discharge.

One of the earliest connections of drainage between the Superior and Michigan basins, as correlated with Lake Algonquin, is associated with the Au Train-Whitefish depression, the head of which is situated in Au Train Lake, 9 miles west of Munising. During Algonquin times, when the border of the Wisconsin ice was standing in the vicinity of Munising and Grand Island, the water plane was raised to the level where it found an outlet through this passage into Little Bay de Noc. Although this channel has not been studied in complete detail in all of its course to Lake Michigan, sufficient evidence is at hand in the Alger County section to draw conclusions concerning its relations to drainage. Winchell (26) makes brief mention of a portion of this outlet in one of his early papers.

During the interval of discharge through this channel a large amount of water must have been carried with great velocity. The floors of both the Au Train and Whitefish rivers show evidence of considerable scour-

PLATE X

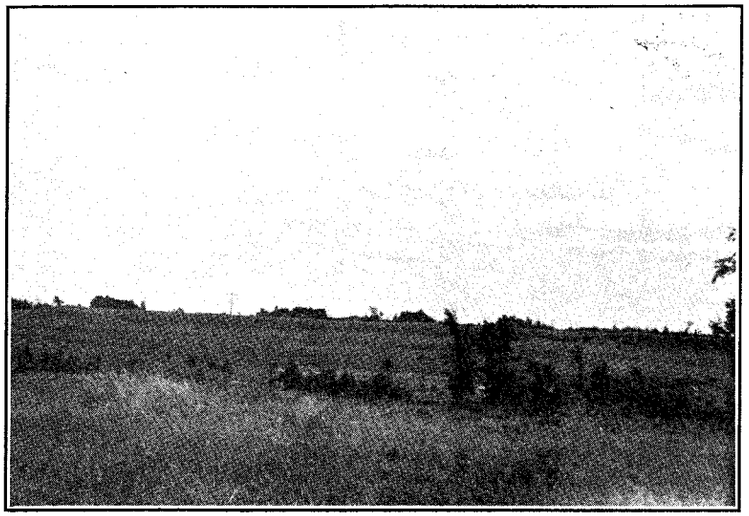

Figure 1.—Algonquin terrace and wave-cut cliff, one mile South of Chatham.

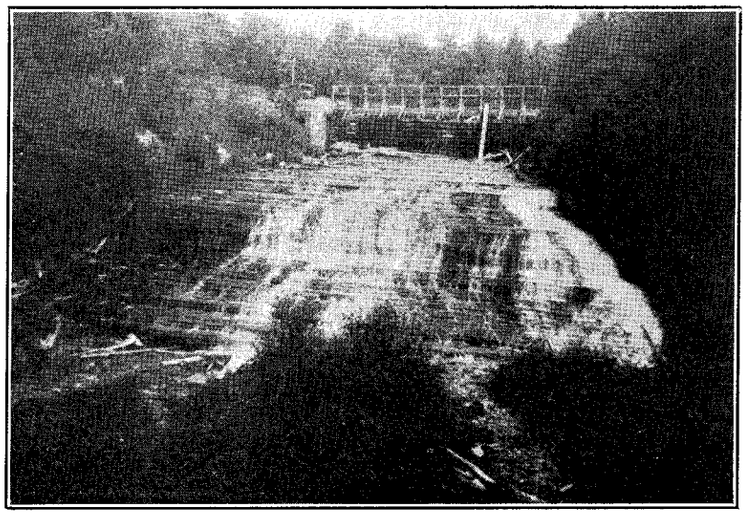

Figure 2.—Upper Falls on the Au Train River, near Forest Lake.

ing action. Bed rock, including the Hermansville dolomite in the north and Trenton limestone in the south, is exposed in extensive portions of the channels. Wherever drift occurs, it is generally so shallow that its base may be easily reached with a four-foot soil auger.

The drainage through this outlet was for a period sufficiently long to allow the formation of well defined wave-cut shore cliffs. These stand, in the region directly east of Limestone, at an altitude of 850 feet and may be traced northward out of the channel into the wide funnel opening a mile south of the village of Chatham. (Plate X, Fig. 1)

The present drainage basin carries two rivers: the Au Train flowing north into Lake Superior and the Whitefish which flows south into Lake Michigan, entering at Little Bay de Noc, near Rapid River. The divide between these two rivers stands a short distance south of Mud Lake in Section 30, T. 45 N., R. 20 W., at an altitude of 768 feet above sea level. Here the East Branch of Whitefish River gathers its head-waters for the Whitefish River farther south. The Au Train River draws its head-water supply from Mud Lake and a large number of feeder springs. In its northward course, near the village of Forest Lake, the river plunges almost 100 feet over a series of falls and cascades which have been carved out of the Hermansville formation, described by Bergquist (27). (Plate X, Fig. 2) It enters Au Train Lake at the Nipissing level and flows out across its sandy lake plain in a series of broad meanders, induced by low gradient, into Lake Superior.

In discussing the Algonquin beach in the Au Train-Whitefish lowland, Leverett (28) states as follows: "From a point near the Delta-Alger county line northward to Chatham there is a rise of 93 feet in a distance of 13.5 miles, or about 7 feet to the mile. In the southern 8 miles of this line the rise is 65.5 feet or slightly more than 8 feet to the mile, and in the northern 5.5 miles the rise is 27.5 feet, or 5 feet to the mile. This rapid rate of tilting is in a narrow passage only 1 to 1½ miles wide. Farther north, where the rate is lower, the waters had greater width."

Another passage which was opened up between the Superior and Michigan basins extends from Munising, southeastward through Anna River into the head of the Manistique swamp. This outlet was established at a time when the ice in the Superior basin had receded eastward beyond the meridian of Wetmore. The altitude of the passage is 838 feet, as determined by Leverett[1] by means of levels. The crest of this drainage way stands about 70 feet higher than the divide in the Au Train-Whitefish lowland. Hence, it probably functioned as an outlet for a short period during the early stages of outflow in the former channel, at a time when the ice barrier held the water plane to the higher level. The Anna River valley has been cut deeply through the Munising

[1]Leverett, Frank, Unpublished field notes.

morainic massif which in this region exceeds 1000 feet in altitude. The depression is narrow, however, and shows little evidence of excessive scour. It is obvious from these facts that the waterway functioned as a connecting passage for a comparatively short period.

Lacustrine activity, in the region of Munising and Wetmore, may be traced to an altitude of 950 feet. The slopes of the high moraines in this district show the effects of water action almost to the crests where lacustrine silts and clays are intercalated with the glacial till. Leverett (29), reports gravelly bars at 946 and 950 feet about a mile north of Wetmore and a storm beach at 960 feet on the north slope of Scaffold Hill south of the station.

These beaches are much too high to fit the highest Algonquin plane which should here have an altitude of 875 and 880 feet. It is probable then, as suggested by Leverett, that the higher beaches in the region are the product of local waters rather than the waters of Lake Algonquin. The high level of the water during this stage may be accounted for on the hypothesis that a large mass of stagnant ice still persisted in the Manistique swamp to the east and southeast and held the water up.

Still later, after the ice had retired from the land surface of the peninsula and the greater portion of the Superior basin was uncovered, a new passage was opened between the Superior and Michigan basins by way of the Tahquamenon-Manistique drainage depression. At this stage the glacier front blocked the North Bay outlet in Ontario. The drainage was affected through a narrow strait extending from the vicinity of Dollarville westward to 1½ miles beyond Danaher. At Dollarville the passage is about 3 miles wide and is bordered on both north and south by high moraines. Four miles westward, the channel widens out to 7 miles and includes a broad reentrant in the inner border of the Newberry moraine where a considerable formation of red lacustrine clay has been deposited. At McMillan the passage is 3½ miles wide, but narrows again to less than 2 miles in its narrowest portion, near Danaher. For the entire distance of 13 miles between Dollarville and Danaher the narrow channel is bordered on the south side by the massive Newberry morainic system whose bulk and altitude prevented undue widening in this area.

A mile and a half west of Danaher the passage opens up into the broad Manistique swamp which spreads out over the greater portion of the surface of Schoolcraft County. The headwaters of the Tahquamenon and the East Branch of Fox River, a tributary of the south-flowing Manistique, extend into the area and are separated by the low divide which stands in the swamp immediately north of Danaher in Section 27, T. 46 N., R. 12 W. The altitude at the divide is 720 feet above sea level

and represents the lowest possible connection between the Lake Superior basin and the Manistique drainage area.

The opening of the Trent outlet at Kirkfield, Ontario, caused the level of Lake Algonquin to become fixed. Taylor places the upper strand of the beach at Kirkfield at an altitude of 883 feet above sea level, or 276 feet above the Algonquin beach in the area of horizontality. During the Kirkfield stage of Lake Algonquin the entire area of the Tahquamenon-Manistique drainage ways was inundated, and it was during this interval that the various morainic systems of the Lowlands province were modified so effectively by wave action.

The Trent Valley functioned as an outlet for Lake Algonquin until the area was uplifted to such a height that the lake could no longer discharge through it. The overflow was then diverted to the Port Huron and Chicago outlets. In the transition from the Kirkfield to the Port Huron-Chicago stages of drainage development, there was an interval of short duration when the three-outlet phase was active, but as the uplifts continued to the north, the Kirkfield outlet was finally abandoned. The waters discharged through the Port Huron outlet were carried into the Erie basin and at Chicago they were drained through the Desplaines, Illinois, and Mississippi rivers to the Gulf of Mexico, as described by Alden (30). According to Taylor (31), "it was during this stage that the main part of the great northern uplift took place, raising the region north of Lake Huron, and Georgian Bay and most of that around Lake Superior by at least 600 or 700 feet."

It was at the time of this two-outlet phase that the water level of Lake Algonquin began to fall. Uplift movements to the north and the opening of lower outlets to the south and east resulted in a definite lowering of the water plane and the development of the lower Algonquin beaches commonly referred to by Leverett and Taylor as the Battlefield and Fort Brady shores.[1] The flood waters in the Tahquamenon-Manistique drainage basin probably separated in the vicinity of the divide near Danaher prior to the latest Algonquin (Fort Brady) episode. Part of the drainage was directed northward into the Superior basin and the remainder was diverted southward in the direction of the Michigan basin. The McMillan straits then ceased to function as a waterway connection.

[1] In U. S. G. S. Monograph 53—The Pleistocene of Indiana and Michigan, Leverett and Taylor apply the name Battlefield (pp. 435-436) to that well defined shore on Mackinac Island which stands at an altitude of 715 feet, and the name Fort Brady (pp. 436-38) to the series of lowest Algonquin beaches which stand at altitudes of 639, 653, 661 and 681 respectively.

From his studies of shore lines on Isle Royale and the Georgian Bay area, George Stanley is disposed to make the Battlefield and Fort Brady beaches in the vicinity of Grand Marais higher than mapped by Leverett and Taylor. He has found that the Fort Brady beach on Isle Royale rises rapidly to the eastward and so should be made much higher than previously indicated. At the time of this writing (August 1936) the issue as to the exact correlation of these beaches is still controversial.

PLATE XI

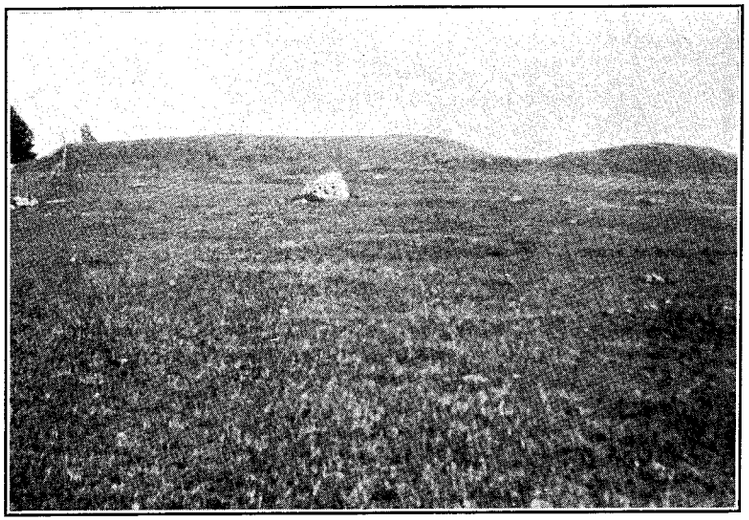

Figure 1.—Algonquin shore ridge, at 870 feet A. T., against the remnant of morainic ridge, Luce County. N. W. ¼, Sec. 10, T. 45 N., R. 10 W.

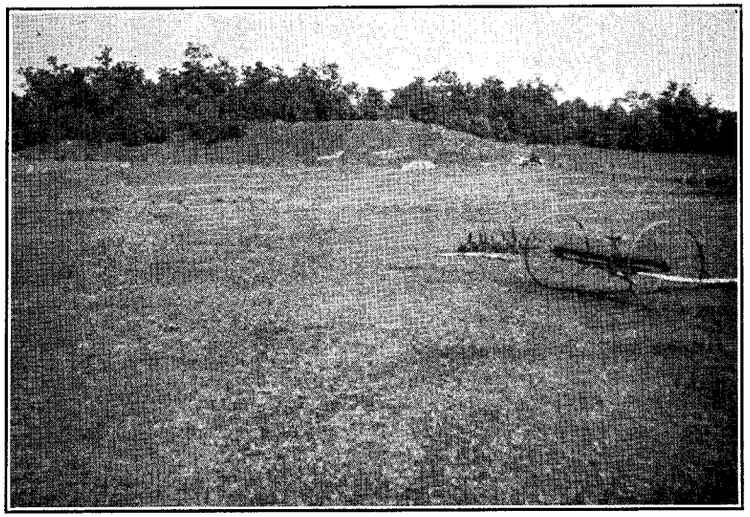

Figure 2.—Closer view of shore shown in Figure 1.

Further temporary halts in recession of the waters in Lake Algonquin are marked by a succession of beaches which in the region to the south of Grand Marais, in Alger County, may be correlated with the lower Algonquin stages. (Battlefield and Fort Brady)

When the ice sheet finally withdrew from the Mattawa and Ottawa valleys in Ontario, the North Bay outlet was opened. Thus, much of the overflow from Port Huron and Chicago was diverted to the north, with the result that the outlet was excavated to the rock sill at the North Bay col. The lowering of the outlet at the divide, together with the complete withdrawal of the ice from the basin, marked the close of the glacial Lake Algonquin and the inauguration of the non-glacial Lake Nipissing.

Shore Features Pertaining to Lake Algonquin

HIGHEST ALGONQUIN SHORE IN THE TAHQUAMENON REGION

The highest shore work recorded in the Tahquamenon area of Luce County is to be found in the high moraine immediately south of McMillan. The slopes of the moraine in this area show the effects of wave washing up to an altitude of 870 feet. This places the highest Algonquin level about 30 feet below the plain at Rexton, southeast, in Mackinac County, as determined by Leverett. The cause for this difference in shore levels is not determined but may have been due to the lodgment, in the McMillan straits, of a large block of stagnant ice which was massed up against the slopes of the moraine. The higher water, in the basin to the east, then must have had its shore pressed against the ice mass, and no records of wave action in this stage were preserved. However, when the water plane had been lowered to the level of 870 feet, the ice mass had either disappeared entirely or had left the slopes of the moraine to allow shore work to become effective there.

Two miles south of Dollarville, the main highway, M-28, ascends an abrupt shore slope to a level, water washed morainic plain which stands at an altitude of 870 feet above sea level. This plain fits the level of the highest shore work at McMillan, which means that the stagnant ice block must have filled completely the entire narrow passage from McMillan to Dollarville. Two small remnants of a higher moraine, one located in the southeast corner of Section 3, and the other just east of the main highway in the west-central part of Section 10, T. 45 N., R. 10 W., stand above the water-washed plain. These morainic fragments reach a maximum altitude of 910 feet and are faced with definite wave-cut cliffs 12 to 20 feet high. (Plate XI, Fig. 1 and 2)

A mile south of Newberry, in the vicinity of the Fire Tower hill, is a fragment of a shore feature at 875 feet. It may be traced as a well

defined shore cliff, from near the tower southeastward for a distance of slightly more than a mile, to the east-central part of Section 1, T. 45 N., R. 10 W. This shore, which surmounts the crest of the moraine, likewise fits the highest Algonquin plane at McMillan.

No other features of sufficient altitude to correlate with the highest Algonquin shore were located south of the Tahquamenon swamp in Luce County. This may be accounted for by the fact that no other areas in the Newberry morainic system reach an altitude sufficiently high to have risen above the water of the lake. Thus the greater portion of the moraine, except near McMillan was inundated and extensively washed by waters of Lake Algonquin when its plane reached the altitude of 900 feet, as recorded at Rexton.

LOWER ALGONQUIN SHORES IN THE TAHQUAMENON REGION

Further withdrawal of the ice sheet from the basin of Lake Superior, coupled with the effects of differential uplift and the opening of new lower outlets, forced a recession in the waters of Lake Algonquin. The records of this recession are preserved in a series of four wave-cut shore terraces which stand between the highest Algonquin and the much lower non-glacial Nipissing shores, in Luce County.

The outermost of these lower Algonquin shore lines stands at an elevation between 795 and 805 feet and marks the margin of the sandy lake plain along the inner edge of the Newberry moraine. It extends from the center of Section 10, T. 45 N., R. 12 W., just two and one-half miles south of Danaher, along the reentrant west margin of the moraine, to the bluff just north of Danaher. Thence it continues eastward along the inner slope of the moraine to McMillan. At this point it swings slightly south and forms the confining wall of the large embayment which continues to the vicinity of Newberry. From this point it continues southeastward for a distance of 6 miles into the northwestern corner of Section 15, T. 35 N., R 9 W., where it disappears into the swamp. Through much of its extent, the shore line is poorly defined and difficult to trace. The eastern end, south of Newberry, however, is marked by a strongly developed wave-cut terrace which is flanked by a forward strand of cobbly and gravelly material. The shore wash at the base of the cliff contains a large amount of local limestone and dolomite. The more shaly limestone slabs carry numerous fragments of trilobites of the genus *Ogygites,* which Ehlers (32) has ascribed to the Collingwood formation. It is quite probable that this formation lies very close to this locality although no exposures are known because of the complete covering of drift.

Another shore feature, with an altitude ranging between 795 and 810 feet, borders the north or inner slope of the Munising morainic system. It stands as a well marked wave-cut cliff and may be traced as a continuous feature from the northwest corner of Section 10, T. 48 N., R. 15 W., in Alger County for a distance of about 36 miles eastward into the southwest corner of Section 5, T. 47 N., R. 10 W., in Luce County. At this point it breaks into the great Tahquamenon swamp and loses its identity as a definite ridge. The relative position of the shore in the swamp may be traced roughly along a fairly continuous row of well developed sand dune ridges which trend southeastward for a distance of about 14 miles into the valley of the Tahquamenon River near its confluence with Gimlet Creek. These dunes have their steep lee slopes on the south and definitely mark the position of the strand at the time of their formation. They tie up very markedly with the base of the shore cliff immediately south of Cold Spring.

In the easternmost 5 miles of the shore cliff there is a great deal of Hermansville limestone incorporated as slabs in the shore material. This marks the northermost occurrence of calcareous rock in Luce County and may prove of geological significance in working out the contact of the Cambrian-Ozarkian formations, which throughout the area lie so completely concealed.

The cliff-like character of the shore seems to indicate that wave action continued for a relatively long interval while the waters of the receding Lake Algonquin lingered at this level. The sandy and gravelly bars, perched rather high upon the morainic slopes, were formed by storm waves and substantiate the view that deposition accompanied erosion in the shore processes.

The two shore features described above are too high to be correlated with the Lower Algonquin (Battlefield) beaches, which stand at an altitude of 720 feet at Mackinac and 760 to 790 feet at Grand Marais. They are undoubtedly the records of the lower members of the upper Algonquin group which stand slightly above the plane of the (Battlefield) beaches, and were formed during the stage when the Kirkfield outlet was discharging the drainage of the lake.

A further drop in the level of the Lake Algonquin waters or uplift in the basin is recorded by the shore, which follows along the inner edge of the Crisp Point moraine at an altitude of 715 feet. This feature may be traced from the juncture of the moraine with the Sucker basin, in Section 12, T. 49 N., R. 12 W., for a distance of ten miles eastward. Here the morainic segment terminates, and for the next ten miles the shore feature is obscure and may be followed only by level readings. It becomes definite again on the inner slope of the moraine in the northeast corner of Luce County where it can be followed to the vicinity of Crisp Point. This shore pertains to the stage in the Lake Algonquin

PLATE XII

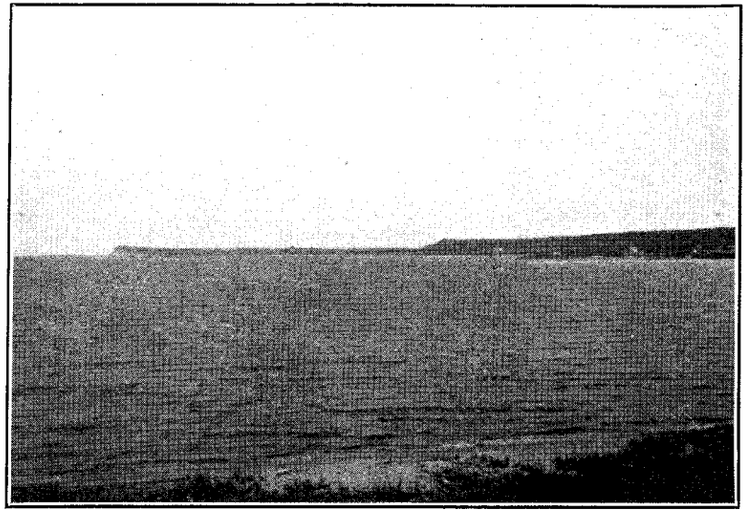

Figure 1.—Algonquin terrace and shore cliff. Nipissing scarp in extreme left. Near Grand Marais.

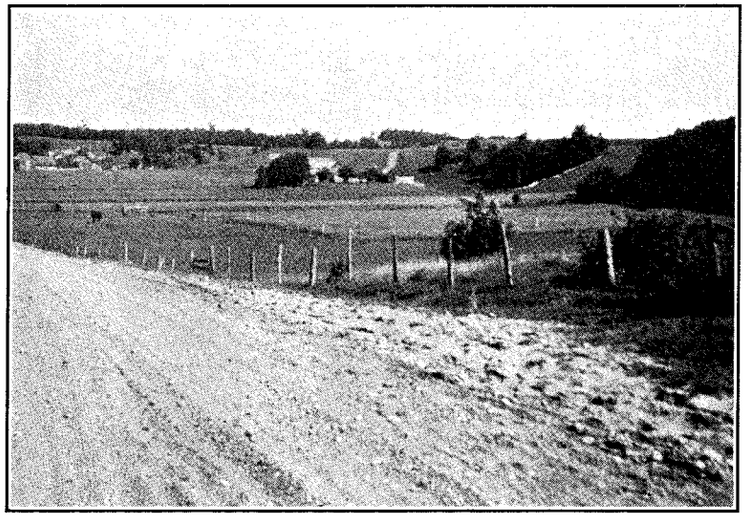

Figure 2.—Nipissing shore scarp and terrace. Near Grand Marais.

history when the Port Huron-Chicago outlet was functioning and may correlate with the beach at Grand Marais which stands at 725 feet and to which Leverett and Taylor have assigned the name Battlefield.

THE LOWEST ALGONQUIN SHORE

The innermost and lowest shore which may be definitely assigned to Lake Algonquin, in Luce County, parallels Lake Superior at a distance of from one to two miles south of its shore. It may be traced as a definite ridge from the west side of T. 49 N., R. 9 W., westward to the Sucker Basin. Here it swings to the south, follows the escarpment wall around the basin and terminates on the west side of the County. The plane of this shore stands at an altitude of 670 feet and correlates with the beach which has an altitude of 674 feet above sea level at Grand Marais.

During this stage of lake history the basin which now holds the Blind and Dead Sucker rivers was a deep embayment along the shore. This bay was filled with water until the advent of Lake Nipissing, when it was drained.

OLD SHORES IN THE GRAND MARAIS REGION

One of the most remarkable successions of abandoned lake shores to be found on the south Superior shore is located in the region of Grand Marais, in Alger County. In a distance of 2½ miles south of the lake, the terrain rises in the crest of the Munising morainic system, to an altitude of 900 feet above sea level. Here are preserved a series of 10 distinct beach fragments, ranging from the highest Algonquin at 895 feet to the Nipissing, at 625 feet above sea level, mentioned also by Leverett (33).

The highest Algonquin shore is built against the crest of the moraine and is succeeded down slope by several other Algonquin beaches, the lowest of which stands at 820 feet. (Plate XII, Fig. 1) Three beaches at levels of 785, 760 and 720 feet, respectively, representing the lower group of Algonquin shores, are fairly well marked and may be traced for several miles. A well defined shore at an altitude of 670 feet may be followed for some little distance through the area. It represents the lowest level of Lake Algonquin waters and is commonly referred to as the Fort Brady shore although this designation is questionable. With the exception of the three intermediate Algonquin shores, which are represented merely as depositional bars, the features are characterized by wave-cut cliffs which have been carved out of the moraine. Each of the various prominent shores carries a great deal of glacial till and large erratics. (Plate XII, Fig. 2)

PLATE XIII

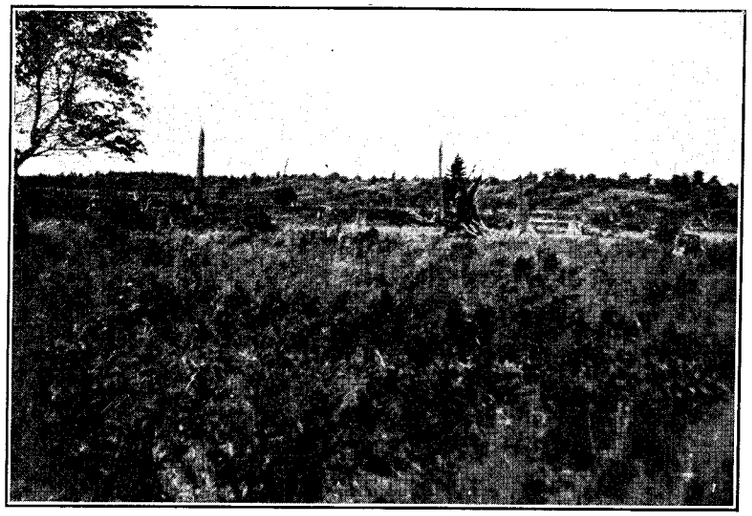

Figure 1.—Algonquin shore cliff. Near headwaters of Fox River. S. W. ¼, Sec. 2, T. 47 N., R. 15 W.

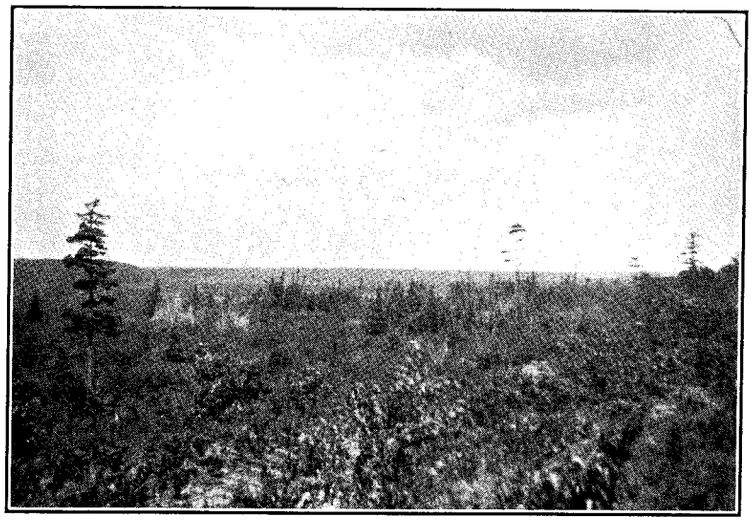

Figure 2.—Algonquin shore scarp at entry with Fox River Valley. 4½ miles north of Seney.

This series of lake shores presents a fairly good picture of the stages in lake succession as melting of the ice and differential uplifts progressively opened new and lower outlets.

ALGONQUIN SHORES IN THE MANISTIQUE BASIN

A prominent shore ridge related to Lake Algonquin activity, and marking a water plane at 870 feet, has been modeled out of the outwash plain in the headwater region of the Fox River, T. 47 N., Rs. 13 and 14 W., in Schoolcraft County. (Plate XIII, Fig. 1). The several headwater branches of the Fox have cut the shore line quite deeply back into the plain so that the scarp now borders the scalloped margin of the outwash in a series of irregular loops. This feature can be traced somewhat interruptedly along the south edge of the sandy plain, to the river escarpment of the East Branch of the Fox River, where it crosses highway M-77, 4½ miles north of Seney. (Plate XIII, Fig. 2)

The rock plateau west of Indian Lake, upon which Cook's moraine is situated, is bordered on all sides by relatively steep escarpment walls which represent the shore cliffs of Lake Algonquin. The elevation of the adjoining plain seems to indicate that erosional activity which carved the cliffs was performed during the highest stage when the Algonquin waters had attained a level of 770 feet. In this, the highest stage of Lake Algonquin, the entire plateau except the low marginal rim, was above the water and stood as an island in the surrounding lake.

In the morainic area east of the Manistique River in T. 42 N., R. 14 W., the glacial drift is very shallow and numerous rock ridges are exposed. This area appears to have been scoured very effectively by wave action of Lake Algonquin. Ribs of limestone and water carved cliffs are prominent in the higher areas. (Plate XIV, Figs. 1 and 2) The irregular surface was examined very thoroughly for evidences of former shores but no definitely connected features were in evidence. It was observed in several of the localities, notably on the eastern slope of the moraine, that the rock cliffs were notched at 700 feet. A gravel ridge in the S. E. ¼, Section 4, another in the center of the same section, are also at 700 feet altitude. (Plate XV, Figs. 1 and 2). Thus it seems probable that the Algonquin waters lingered at this level for a short period, but not long enough to produce very distinctive shore features. Another notch at 670 feet, along the eastern ridge in Section 3, may represent a still lower stage in the recession of the Algonquin waters.

The apparent absence of Algonquin shore lines in the Manistique Basin is due, in part, to the fact that there were very few features of sufficient elevation in the area to have recorded the higher stages. Subsequent scour and erosion by the waters of the Manistique River may

PLATE XIV

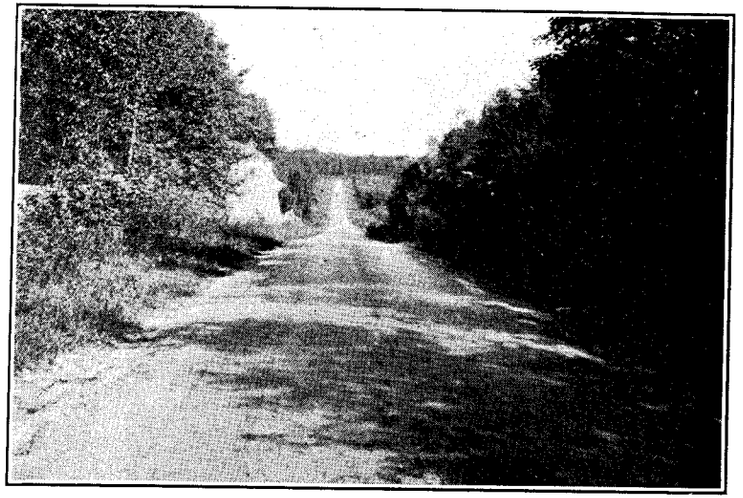

Figure 1. A view into Sturgeon Hole, a portion of the Manistique swamp, through the rock corridor in the S. ½, Sec. 14, T. 42 N., R. 16 W.

Figure 2.—Limestone block pavement on crest of a water washed moraine. Most of the till has been removed by water activity. N. E. ¼, N. W. ¼, Sec. 24, T. 42 N., R. 15 W.

PLATE XV

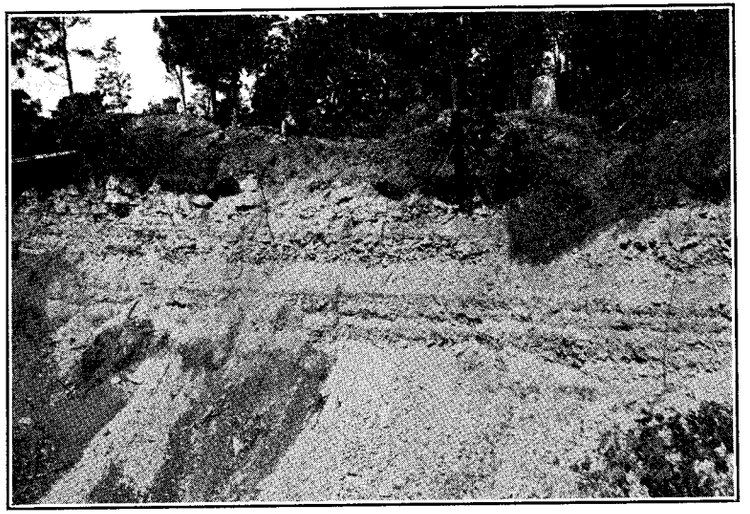

Figure 1.—Section through a cobbly, gravelly shore showing stratified layers. S. E. ¼, N. W. ¼, Sec. 4, T. 42 N., R. 14 W.

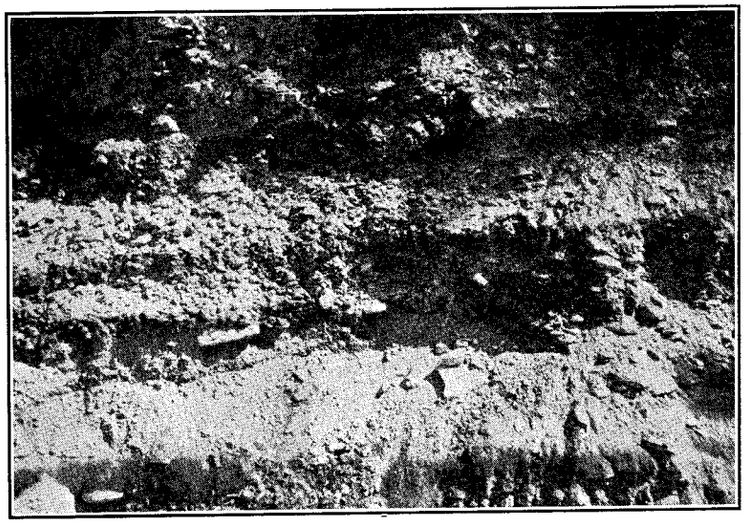

Figure 2.—A closer view of the feature showing the coarse assortment of material, mostly limestone.

have erased all evidences of shore action against the bordering moraine. Finally, it is probable that recession of the water in the lake was so rapid after the Port Huron outlet was opened, that the various stages in level could not be recorded along the shores.

THE NIPISSING GREAT LAKES

As has previously been mentioned, the Nipissing Great Lakes came into existence when the ice had withdrawn from the valley of the Mattawa-Ottawa rivers and allowed the opening of the outlet at North Bay. "During this stage, the discharge was through the Mattawa River to the Ottawa and thence to an arm of the sea in the St. Lawrence Valley."—Leverett (34). As a result of differential uplift which followed, the North Bay outlet was elevated sufficiently high to raise the water to the level of the St. Clair outlet at Port Huron. At the time when both outlets were in use there was a considerable amount of shore work in progress. The results of this wave activity are reflected in the prominent wave-cut cliffs and strong gravel bars which characterize the Nipissing beach throughout its extent.

The Nipissing Shore Features

LAKE SUPERIOR REGION

The shore of Lake Nipissing in Luce County follows rather closely the present shore, and stands at an altitude of 640 to 645 feet above sea level, or approximately 40 to 45 feet above the level of Lake Superior. The features of this shore are more strongly developed and much more continuous than are those of the Algonquin group. A sharp, well defined escarpment marks the shore for most of its extent in Luce County. Gravelly bars are present on the gentle slopes of the escarpment but wave-cut cliffs and terraces are prominent where the slopes are steeper.

In Alger County, the Nipissing shore forms a prominent escarpment in the village of Grand Marais. It may be traced from the northwest corner of the village, around the south side of West Bay to east-central Section 5, T. 49 N., R. 13 W. Here it swings southward in a rather broad embayment in Sections 4, 9, 10, and 11. In the south central part of Section 11, it turns northward again and leaves the County in the northeast corner of Section 12 at the point where the Sucker River turns westward into Alger County. For much of this distance of 7 miles, the shore is carved out of Cambrian sandstone which stands in vertical cliffs facing Lake Superior. The lower course of the Sucker River, where it swings through the Nipissing plain, was determined largely by the rock wall to its south.

PLATE XVI

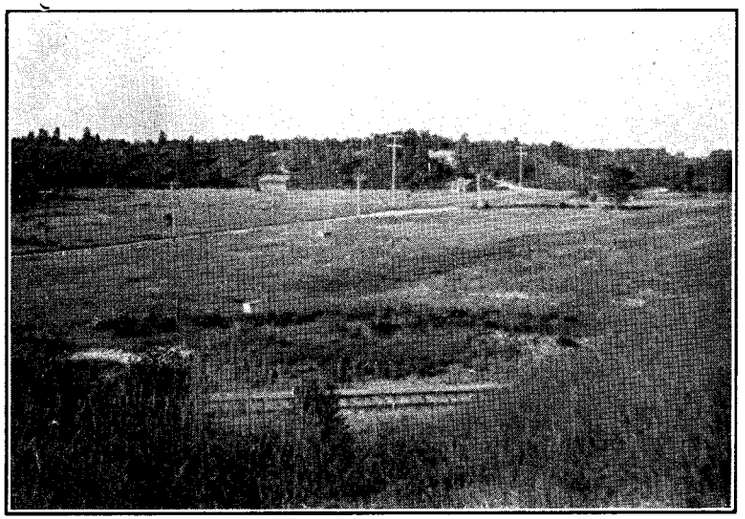

Figure 1.—Nipissing terrace with shore cliff in background. Two miles east of Manistique.

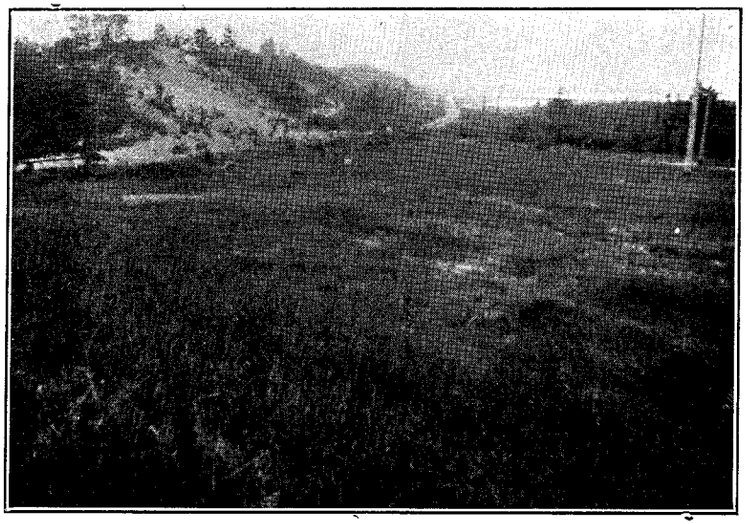

Figure 2.—Sand dunes on Nipissing plain. Ponded slough of Manistique River in background.

The city of Munising, has been built upon a Nipissing terrace at 640 feet in front of the high moraines whose slopes were washed by the waters of Lake Algonquin.

One of the most interesting and significant Nipissing plains is that in which is situated Lake Au Train. This lake is the remnant of a large Nipissing embayment which was cut off from the larger lake by the construction of a series of bars during the process of lowering of the Nipissing level. No less than sixty such bars, ranging from a few feet to a maximum of ten feet in elevation, are encountered in the mile and a half of road between the head of Au Train Lake and the junction of highway M-94, at the village of Au Train. These bars have been modified since their formation by aeolian activity. The wind, blowing over the sandy plain, has carried sand across the surface and deposited it upon the numerous bars. Secondary sand dune ridges have thus been established on the older dunes, with the resultant development of an irregular surface composed of small corrugations. This area is similar in surface structure to the corrugated feature, in the southeastern corner of Schoolcraft County, south of Milakokia River, which has been described in another section of the report. The corrugations in the Au Train plain are, however, of much lower relief.

The Nipissing Lake along the Superior shore had little or no influence upon the development of the Tahquamenon drainage area. Its waters were confined by heights of land which prevented influx to the marshy lowland tracts.

THE LAKE MICHIGAN REGION

The most prominent Nipissing shore on the Lake Michigan side of the Manistique basin may be observed in the area just two miles east of Manistique. At this point, the main highway, US-2, ascends the sharp shore cliff and emerges on a sandy lake bench 60 feet above the level of the Nipissing plain. The Nipissing shore scarp may be picked up as a definite feature in the southwestern corner of Section 32, T. 42 N., R. 15 W., a half mile east of the Manistique River. (Plate XVI, Fig. 1). From this entry, it follows southward to the Soo line track in Section 9. Here it swings due east and parallels the railroad, on the north side, for a distance of fully 2 miles. In the west-central part of Section 11, T. 41 N., R. 15 W., it turns to the northeast and terminates in Section 1, at the Marblehead Spur, a half mile north of the main line.

Throughout its entire extent, this shore is characterized by an abrupt escarpment built up against a higher sandy lake plain. Where highway US-2 intersects the shore cliff, the sandy fill has a thickness of approximately 100 feet. On the east end of the cliff, where it contacts a morainic

PLATE XVII

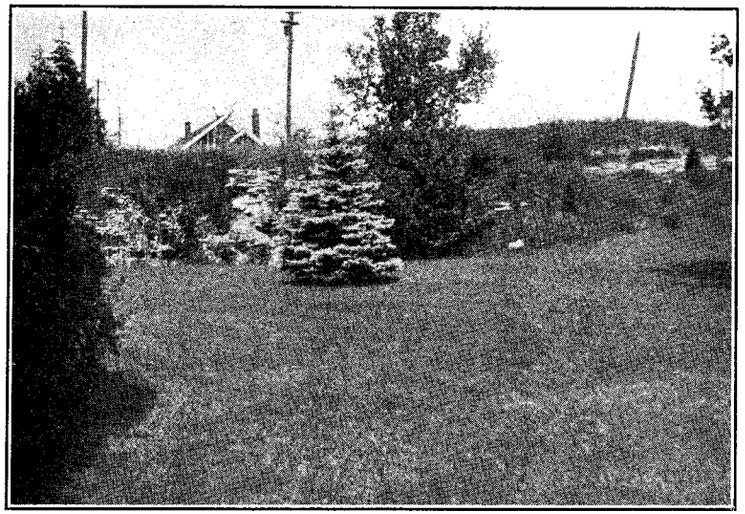

Figure 1.—Wave cut Nipissing rock cliff. City of Manistique.

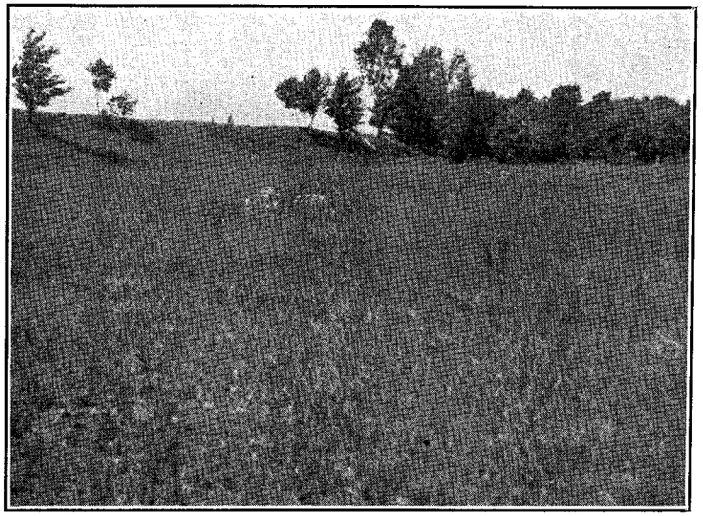

Figure 2.—Nipissing terrace and wave-cut shore cliff. Three-quarters mile south of Thompson. Sec. 6, T. 41 N., R. 16 W.

slope, the drift is less than 25 feet deep, according to well data obtained by Poindexter.

A spit upon which the city of Manistique stands, was built up from the southwest angle of the shore cliff. It stands at an altitude of 625 feet above sea level or 40 feet above Lake Michigan, which correlates with the Nipissing plane. This spit with its superposed Nipissing dunes has had a considerable influence on the lower course of the Manistique River, as has been mentioned elsewhere in the report. (Plate XVI, Fig. 2)

A wave-cut, rock cliff, marking the position of the Nipissing shore, finds expression within the limits of the city of Manistique. (Plate XVII, Fig. 1). Emerging from the lowland in the northeast corner of Section 8, on the north edge of the city, it trends southward around the west end of the abandoned quarry, to the intersection of Main and Lake Streets. Thence it breaks across to the corner of Terrace Avenue and Cherry Street, paralleling the latter to Steuben Street, where it swings north past the east edge of the cemetery, into the sand dune bluffs. The city of Manistique is located on a Nipissing terrace which slopes gently southward to the lake shore. Nipissing wave action was especially strong on this plain as is evidenced by the extreme thinness of the soil. Bed rock, where not exposed, may be encountered in almost any part of the plain within a depth of four feet.

A Nipissing cliff extends around the rocky headland of Point aux Barques in the southwest corner of Schoolcraft County. It may be followed as a fairly continuous feature northward to the village of Thompson, thence to the south end of the dune which skirts the southeastern corner of Indian Lake. This shore cliff is fronted by a complex of parallel, curving sand dune ridges, separated from each other by narrow, intervening, marshy lagoons. (Plate XVII, Fig. 2)

During the highest stage of Lake Nipissing, the water extended back into large embayments now represented by a number of lakes which evidently became cut off by bars thrown across the headlands at this time. Indian Lake, at 615 feet, Gulliver and McDonald Lakes at 616 feet above sea level are the remnants of the Nipissing embayments. Owing to the broken character of the upland areas, and the extensive marshy tracts surrounding these lakes, definite Nipissing shore features have not been preserved to any great extent, except just north of the station at Whitedale where they are difficult to trace out.

POST-NIPISSING SHORE FEATURES

Shore features, associated with a water plane standing between the Nipissing and present Lake Michigan levels, are prominent in certain areas along the shore in Schoolcraft County. The strongest of these shores

PLATE XVIII

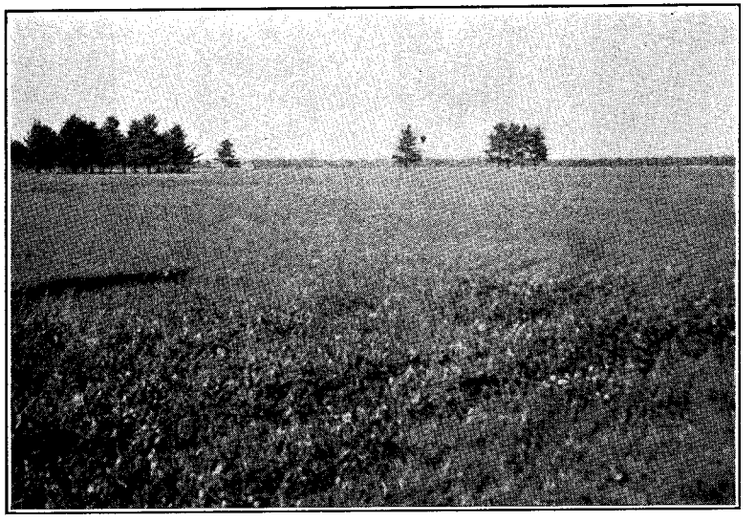

Figure 1.—Sandy lake plain on crest of the Nipissing escarpment, two miles east of Manistique. S. W. ¼ Sec. 3, T. 42 N., R. 16 W.

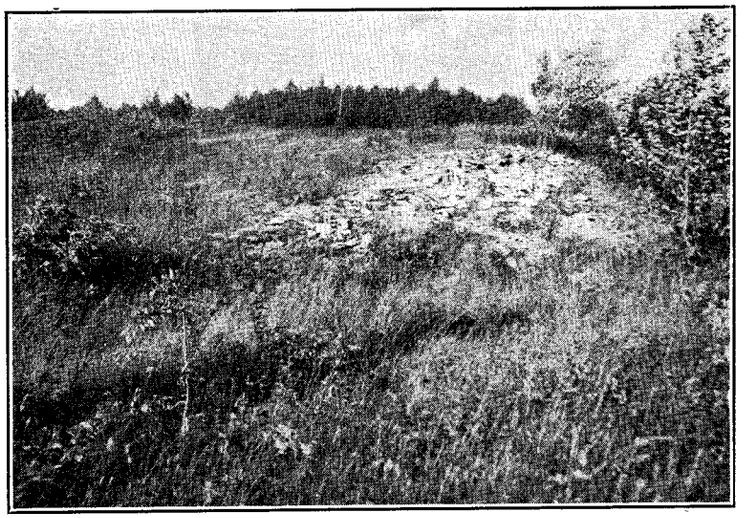

Figure 2.—Algoma shore ridge exposing rubble structure. Manistique.

is developed at an altitude of 600 feet above sea level, or at an elevation of 19 feet above Lake Michigan. Its components occur, in places, as wave-cut cliffs along the shore but more notably as rubble bars upon the Nipissing terraces. From information obtained by Hobbs (35), as a result of levelling on the Garden Peninsula, to the south, it is evident that the pronounced shores at 600 feet are correlated with the Algoma stage of lake history.

The Algoma Shore Features

The Algoma shore is not traceable as a continuous feature in Schoolcraft County, but occurs rather as more or less disconnected units sometimes widely separated, along the shore. In certain areas, the Algoma features are very definite but in the main they are either obscured by low dune developments, or missing entirely as a consequence of later wave activity.

Less than a half mile south of the village of Thompson, fronting the Nipissing cliff, is a small trace of the Algoma shore. It extends for a distance of about three-quarters of a mile as a wave-cut scarp, along the west side of Section 6. A series of fore-dune ridges have built up in front of the low cliff and extend outward to the present shore.

A group of three parallel rubble beaches, with more or less abrupt front slopes, was built up on the Nipissing plain in front of the shore-cliff, on the west side of the city of Manistique. The outermost of these bars stands at an altitude of 600 feet above sea level and has been ascribed to the Algoma shore by Miss Stevenson (36). (Plate XVIII, Fig. 1). The two higher beaches are transitional between the Nipissing and Algoma levels and were formed either during the lowering of the Nipissing waters or by storm waves during the Algoma stage. A great deal of rubble has been piled up on the Manistique headland in a series of parallel ridges at levels between the Algoma and the present beaches. Much of the rubble rests directly upon the limestone floor and is composed of material which has been broken from it by the waves. The ridges are low, but usually well developed. They may possibly represent storm wave deposits of the present lake.

Miss Stevenson (37) mentions a very definite cliff against the front slopes of the dunes on the Nipissing spit east of Manistique. She ascribes this cliff to the shore work of Lake Algoma on the basis of certain facts which are very obvious. She states further that, "the termination of the Nipissing sand dunes in the Algoma cliff represents the time when the down-cutting of the outlet, the uplift, or both, were halted and erosion by the waves became dominant in this area." This conclusion seems justified on the basis of the extensive stretches along the shore which have

PLATE XIX

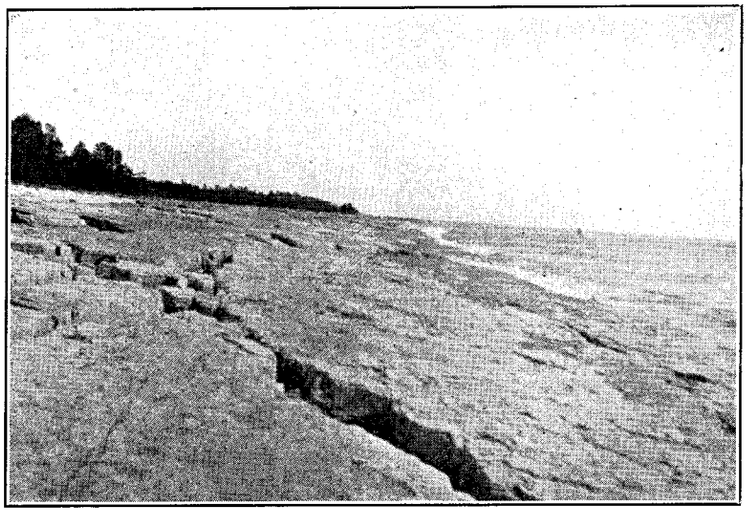

Figure 1.—Gently dipping limestone floor along shore of Lake Michigan. South of Seul Choix Point.

Figure 2.—Glacial erratics on limestone lake floor. Along shore of Lake Michigan just east of Manistique.

been scoured clean by the waves, to expose the limestone pavement. (Plate XIX, Fig. 1). The numerous glacial boulders and erratics distributed on the rock floor are merely the concentrated remains of till features which have been completely destroyed. (Plate XIX, Fig. 2). The fore dune ridges, gravelly bars, and sandy beaches which have been built up on the rocky platform between the Algoma cliff and the present lake, support her view that "since Algoma time deposition has been more important than erosion."

There are, no doubt, many other areas along the shore where Algoma features could be definitely worked out, but very detailed work such as carried on by Scott, Stevenson, and others will be necessary to accomplish such determinations.

Chapter V

AEOLIAN ACTIVITY

One of the most significant physiographic aspects of the Tahquamenon-Manistique drainage basins is related to the activity of the wind which was effective during glacial as well as post-glacial times. Wind-developed sand ridges and dunes comprise a relatively large proportion of the low lying marshy tracts of the region, and frequently are responsible for such complications as to make differentiation of the features very difficult, if not impossible.

The dunes of this area, may for the sake of convenience, be subdivided into three major groups, as follows:

(I) Shore Dunes along Lake Superior.
(II) Dunes of the poorly drained marshy, lowland plains of the main drainage ways.
(III) Shore dunes along Lake Michigan.

These will be discussed more or less in detail but special emphasis will be placed upon those of the second group.

I. Shore Dunes Along Lake Superior

Dunes of variable extent occur intermittently along the shore of Lake Superior in Alger and Luce counties and, in certain localities are of especial geologic significance.

A. ALGER COUNTY.

(Shore Dunes)

The sand dunes in Alger County are concentrated principally along the present shore of Lake Superior. Smaller dunes are distributed here and there on the shores of older lakes and occasionally on the margins of the larger swamps and marshes but are of little importance.

The most important, and by far the greatest development of sand dunes is found along the shore in the region of Grand Sable Lake in the vicinity of Grand Marais, in the northeastern part of the County. The Grand Sable dunes in this region represent, without question, the most imposing mass of wind deposited sand on the entire south shore of Lake Superior. They cover in total an area of approximately five square miles, and possess crests which attain a maximum altitude of 957 feet, or an elevation of 355 feet above the level of Lake Superior.

PLATE XX

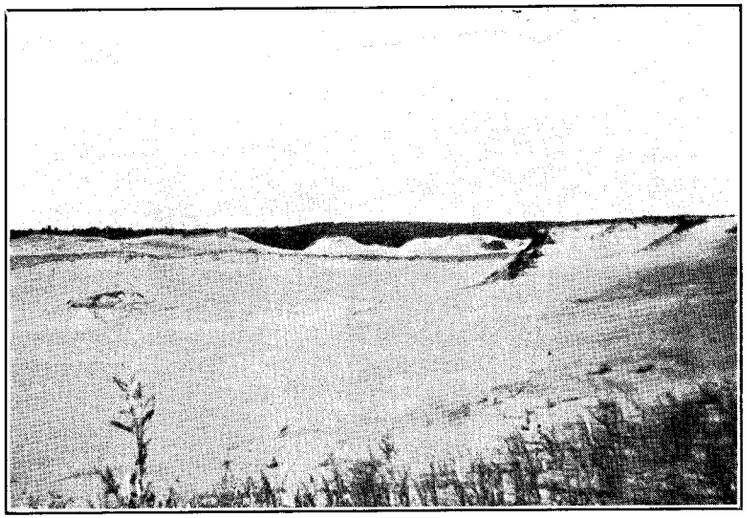

Figure 1.—Crest of Grand Sable dunes showing deflation hollows. Near Grand Marais.

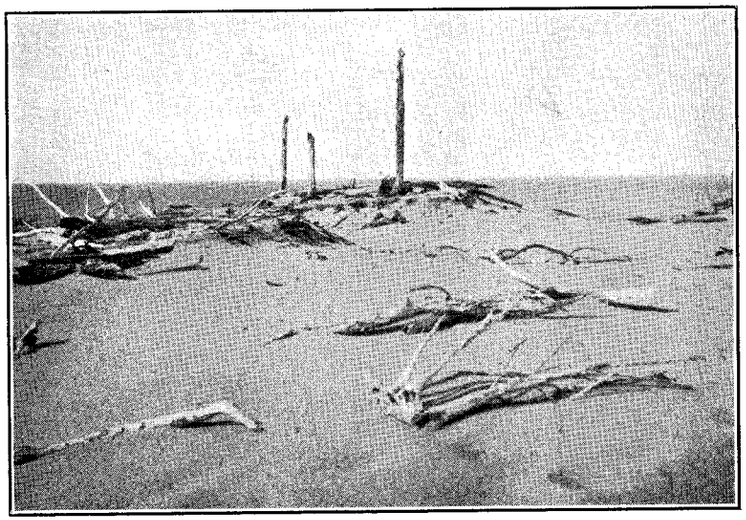

Figure 2.—Exhumed forest on crest of wind-swept sand dunes. Near Grand Marais. Lake Superior in background.

The topography of this dune area is especially rough and broken. Deep hollows and blowouts, extending at times to the original floor, have been scoured by wind deflation. (Plate XX, Fig. 1). The deeper bottoms of the blowouts in the area between Grand Sable Lake and Lake Superior are floored locally with small patches of coniferous growth suggesting a water table not far below. In the shallower bottoms, vegetation is scant and entirely lacking especially where the strong northwest on-shore winds sweep through. In places, along the more sheltered slopes, leguminous plants have been successful in gaining a foothold, and through their roots serve to bind the sand somewhat more firmly together. Exhumed forests on the wind swept crests of the dunes are evidence of post-dune wind activity. (Plate XX, Fig. 2)

On the exposed slopes, along the shore of Lake Superior, where a section may be obtained from the lake level to the crest of the dunes, many interesting features are revealed. The exposure portrays an aeolian character only near the surface. At the base of the shore cliff, boulder-clay of glacial origin extends upward 100 feet or more above the level of Lake Superior. The till is a mixture of sand, silt and clay, beset with numerous erratics of large dimension. Resting upon this glacial floor are a series of stratified beds consisting of an assortment of rounded cobbles, coarse gravels, sands and silts which continue upward to an elevation of approximately 280 feet above the lake level. The low sand dunes, along the shore, are perched upon this lacustrine formation at an altitude of 870 to 880 feet. (Plate XXI, Fig. 1)

From the juxtaposition of the stratified material in this section it would appear that the sand dunes, especially those along the shore, are situated on an older lake feature, possibly a bay-mouth bar, which had been thrown across the head of the embayment to form Grand Sable Lake, sometime during early Algonquin times. This suggestion is merely speculative and will require more detailed studies for conclusive proof.

The general absence of a vegetative cover in the Grand Sable section of the dunes has been responsible for a considerable amount of translocation by the wind. Immediately northeast of the lake, a forest is now in the process of being invaded by drifting sand. The sand has piled up to such a depth as to completely cover the smaller trees, and the larger ones are buried to half their total heights. The channel of Sable Creek, the outlet of Grand Sable Lake, is being continually shifted eastward by the rapidly invading sand. (Plate XXI, Fig. 2) Farther west, the sand is gradually encroaching upon the margin of Grand Sable Lake, and much material from the dune is being carried into its water.

In the deflation hollows or blowouts, the atmosphere is set into a turbulent motion as a consequence of the numerous cross currents and eddies which are developed by the lashing gales of Lake Superior. The

PLATE XXI

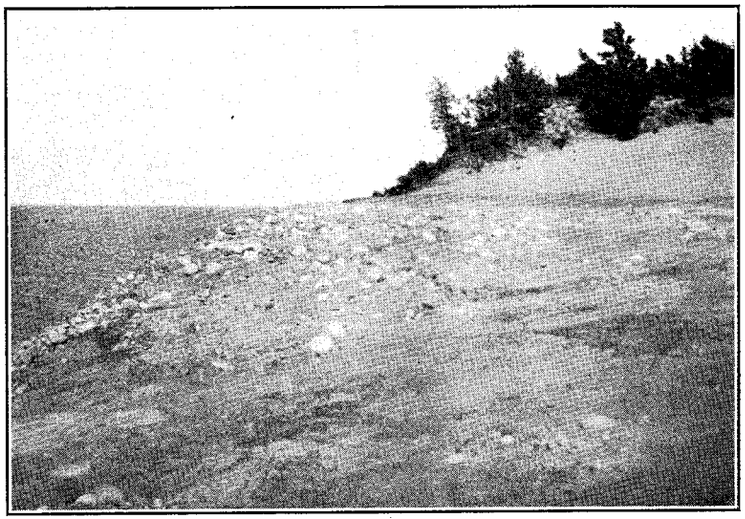

Figure 1.—Perched dunes resting on cobbly bar 280 feet above level of Lake Superior. Grand Sable area.

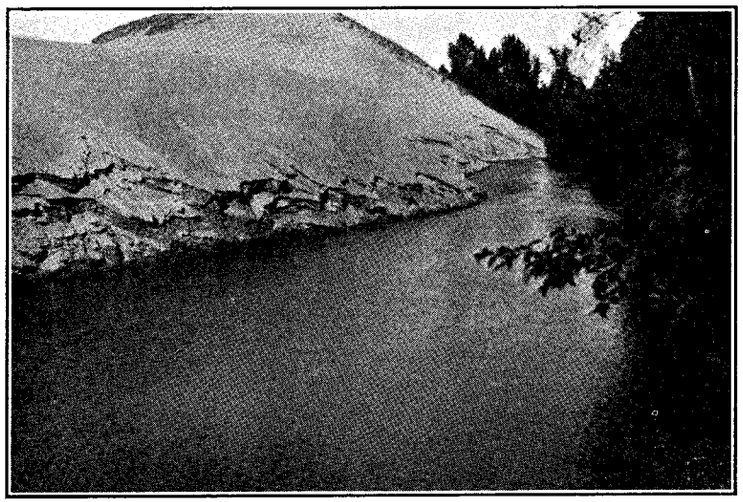

Figure 2.—Sand dunes encroaching upon channel of Sable Creek. Near Grand Marais.

PLATE XXII

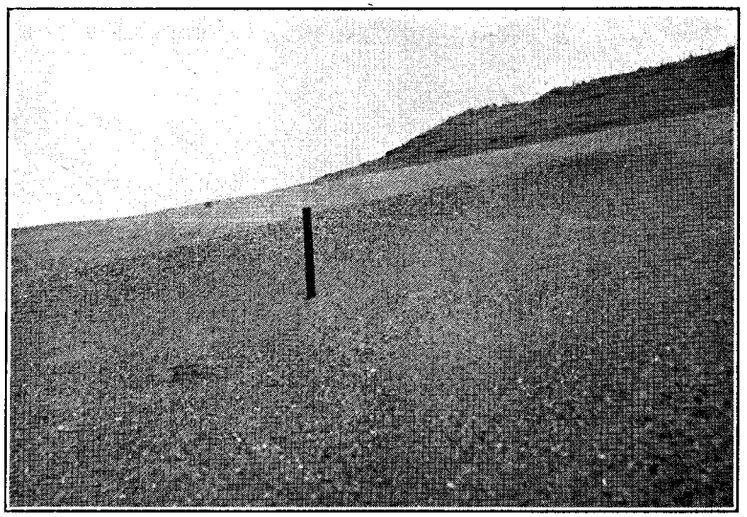

Figure 1.—A lag-gravel plain with perched sand dunes in background. Grand Sable dune area, near Grand Marais.

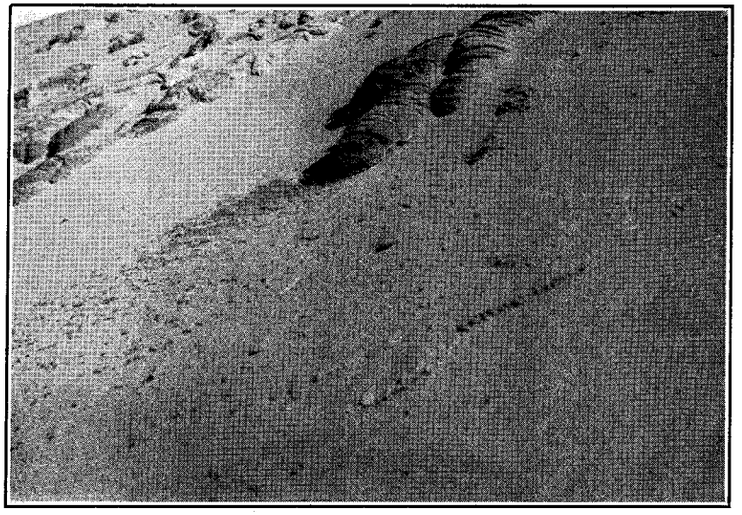

Figure 2.—Mud streams on north flank of Grand Sable dunes, near Grand Marais.

effect of this turbulence is largely that of sorting out and removing the finer particles and concentrating the coarser material to form a desert armor. Ripples are likewise produced and vary, according to texture of the material included and exposure to shifting wind currents, from minor rippled forms to giant waves, as mentioned by Bucher (38). One of the largest giant ripples observed after a severe wind, measured seven feet from crest to crest and had a height of 14 inches. This ripple contained faceted and polished rock fragments ranging from coarse gravel to angular pebbles of over an inch in diameter. In general, it may be stated that the ordinary ripples are for the most part veneered with a thin covering of coarse sand and fine gravel which acts in the capacity of preserving the constructional forms. It seems to follow also, that the size of the ripple is a function of assortment of particles and wind velocity, for the larger forms always contain the coarser material.

Along the Superior shore, where the perched dunes are relatively low and the sand mass is limited, the wind has successfully removed the bulk of the finer debris with the result that in local areas there has accumulated a concentration of coarse material on the residual floor to which Udden (39) applies the term, lag gravel. (Plate XXII, Fig. 1) Where complete removal of the dune sand has been accomplished, the cobbly material of the former beach is exposed.

On the less sheltered areas, where the finer particles have been removed, the long continued sand blasts have played upon the surface pebbles and cobbles to develop various types of wind-worn stones, to which Bryan (40) has collectively assigned the term "ventifacts". Many of these stones have been faceted by wind driven sand blasts to produce the characteristic Ein, und Drei-kanter of the German literature.

In the dune region west of Au Sable Lake, the forms attain their maximum development with crests reaching an altitude of 957 feet. This sand covered area is densely forested with a growth of hardwood which affords protection against deflation. Except in local areas, where the timber has been removed from the slopes, the sand is stable and very little shifting by wind has occurred.

In view of the geological evidence at hand, it seems reasonable to conclude that the Grand Sable dunes were formed from contributions of sand of a higher shore, rather than of sand from the present beach. In the first place, the dunes are perched upon a shore which stands at an elevation of 280 feet above Lake Superior. This shore is too high to correlate with the Nipissing and is undoubtedly related to one of the higher Algonquin lake levels. Secondly, the wave cut cliff which fronts Lake Superior is too high and steep walled to have allowed much movement from the present shore. Thirdly, the present beach, for most of its extent along the sand dune area is composed essentially of boulders,

cobble and gravel and scarcely any sand is now being reworked by the waves. Hence, little, if any, material of the present beach is fine enough in texture to be transported inland very far, even by the strongest winds blowing off Lake Superior.

The Grand Sable Bluffs

The Grand Sable dunes terminate in the central portion of Sec. 7, T. 49 N., R. 14 W. At this point and westward, for a distance of about a mile, the dunes give way to the steeply sloping Grand Sable banks. (Plate XXIII, Fig. 1) Aneroid measurements show these bluffs to rise to an altitude of 855 feet or 253 feet above the level of Lake Superior. The bluffs are composed essentially of water rounded quartz sand intercalated with lenses of gravel and pebbles of varying texture and composition. They slope down to Lake Superior with an average angle of repose of 35 degrees. Much sandstone, of local derivation, both rounded and in blocks, as well as numerous water-worn erratics, are included. Near the base of the bluff there is considerable silt, with the character of glacial till, which forms the matrix for the glacial boulders. The crest of the bluff is a wind-modified sandy lake plain over the surface of which small dunes have been developed. The sandy-gravelly bluffs terminate in Sec. 12, T. 49 N., R. 15 W., where the rocky headland of Cambrian sandstone sets in to skirt the shore around Au Sable Point.

Another prominent area of dune development lies in the region east of East Bay, near Grand Marais. This region of dunes continues along the Superior shore and extends for a considerable distance eastward into Luce County. The dunes in this section are definitely aligned in more or less paralled ridges, separated by intervening longitudinal depressions. They are not perched, but rather have their bases at the shore level of Lake Superior. Thus, their summits are lower than those of the Grand Sable section and range from 40 to 60 feet above the level of the lake. These dunes are heavily forested, or otherwise blanketed with vegetation, and the sand in them is fixed, except near the immediate shore where small fore-dune ridges are in process of formation.

A limited area of dune features has been developed along the north side of the Sucker River in the south eastern part of T. 49 N., R. 13 W., and the north eastern part of T. 48 N., R. 13 W. These dunes have a general trend from northwest to southeast and extend more or less parallel to the Algonquin shore. They are arranged in definite ridges but have a relief rarely exceeding 30 to 40 feet. (Plate XXIII, Fig. 2)

In the region north of the Beaver Lakes, low piles of sand have been heaped up by the wind. They are more or less barren of vegetation, and subject to much movement by drifting. The windward slopes of these dunes lie some distance back from Lake Superior but the back slopes

PLATE XXIII

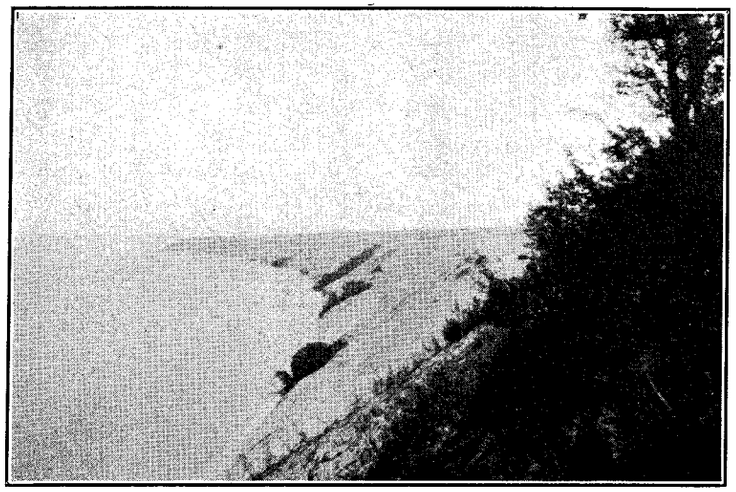

Figure 1.—Sand bluffs near Au Sable Point.

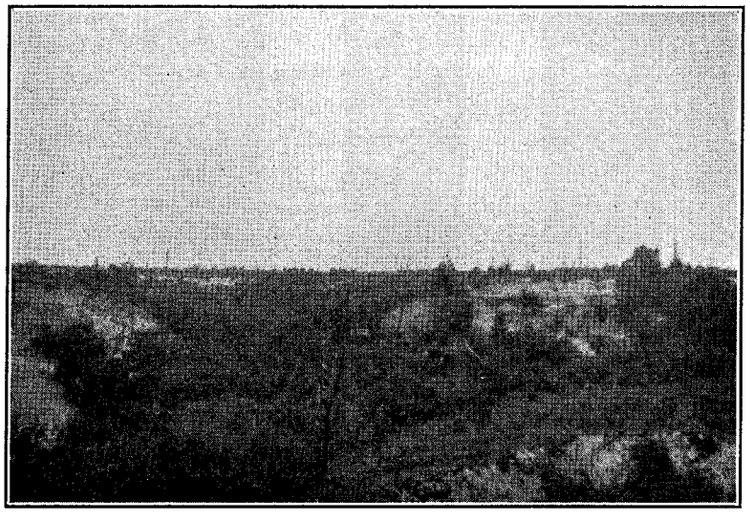

Figure 2.—Sand dunes in the Sucker River basin.
Sec. 26, T. 49 N., R. 13 W.

have been carried leeward to the north shore of the Beaver Lakes, to form marginal features. This dune section varies in width from less than an eighth of a mile on the southwest end of Little Beaver Lake, to slightly more than half a mile on the west side of the Beaver Lake outlet.

A broken line of narrow dunes extends along the Superior shore, around the Grand Portal headland from Chapel Beach, for a distance of seven miles to the westward. These dunes are relatively low and lie directly behind a rocky shore. They were formed at a higher stage of lake level when a sandy beach was being developed along the margin. Except in the coves and reentrants, practically no sand is being contributed to these dunes by the present beaches.

A series of low, but rather well formed dunes have developed along the mouth of Au Train River just to the north of the village of Au Train. This sandy tract extends for a mile along the shore of Lake Superior and has an average width of about six or seven hundred feet. Much of the material in these dunes has been brought in by the sluggish Au Train River, which in its course from Lake Au Train, meanders broadly across the low-lying sandy Nipissing plain. Lake Superior is likewise contributing new material to the growth of these dunes which in most of their extent are barren of vegetation and subject to much movement by the wind.

B. LUCE COUNTY

(Shore Dunes)

There are three definite areas of dune development along the shore of Lake Superior, in Luce County. The most westerly dune lies north of the Sucker Basin in Twps. 49 and 50 N., R. 12 W. and is a continuation of the sandy ridges which may be traced eastward from East Bay in Alger County. Unlike their counterparts on the west side of the Sucker basin, these dunes are relatively high and attain crests which rise to 100 feet above Lake Superior. They are clothed with vegetation, and except for the fore-dune ridges along the shore, are quite definitely fixed. The position of these dunes, situated against the wave cut Nipissing bluff, would suggest a post-Nipissing origin.

An area of dunes along the lake shore in R. 9 W. has been built up into a series of low tenuous ridges on a post-Nipissing plain, from material of the present beach. They are well clothed with vegetation and thus lie protected from serious translocation by the wind. The bulk of the aeolian sand in this area lies north of the Two Hearted river and appears to terminate near its mouth. Fragmentary patches of drifting sand mostly in the form of fore-dune ridges on the present beach, may be picked up here and there, eastward to Temple Lake.

The most easterly dunes in Luce County are situated along the shore of

Lake Superior in Twp. 8 N., where they may be traced to Crisp Point on the county line. They stand upon the Nipissing terrace and, in all probability, were blown up by wind from the Nipissing strand.

II. Dunes of the Poorly Drained, Marshy, Lowland Plains of the Main Drainage Ways

The most extensive single physiographic feature of the area included in this report is the marshy lowland tract associated with the drainage basins of the Tahquamenon-Manistique rivers in Luce and Schoolcraft counties. This lowland, marshy plain represents the floor or bed of glacial Lake Algonquin, the predecessor of Lake Superior. The plain, as a whole, is poorly drained and, since its occupation by the Algonquin waters, has received a vast accumulation of organic matter which is embodied in a shallow mantle of muck and peat resting upon the lacustrine sand beneath. (Plate XXV, Fig. 1)

The level monotony of this extensive drainage area is broken by innumerable ridges and knolls of sand, which Scott agrees, are deposits of aeolian activity and may definitely be classified as dunes. Thousands of these dunes are distributed through the lowland tract and range in size from merely a few feet to 60 and more feet in height, and from a few hundred feet to several miles in linear extent. In a broad way, they follow the mainly developed drainage channels of the region, but are also aligned as east-west ridges along the successive shores related to the retreatal fronts of Lake Algonquin. Scott has suggested that these continuous rows of dunes mark the position of former shores and represent definite shore features.[1] The dunes of this area were formed before the organic deposits were developed at a time when the dessicated sand in the broad, shallow, river flats and along the lake shores was fully exposed to winds, and moved by them. Because of the poorly developed drainage facilities of the area, the water table has always stood rather high and its position has limited definitely the depth to which translocation, as described by Free (41) could develop.

The building up of dune successions, especially along the borders of the receding lake, was responsible for considerable derangement in the drainage lines. Sand ridges, thrown as barriers against the streams, which were then developing in the wake of the lowering Lake Algonquin, caused a damming of the youthful drainage and a consequent impounding of the water. Thus the streams were forced to overflow their shallow channels and spread out to form the marshy interfluves.

Many of the dunes, particularly those which follow the drainage courses, are irregular in shape but relatively symmetrical in profile.

[1]Scott, I. D., Personal communication in the field.

Those forms, however, which are associated with former beaches and possess a trend from east to west are usually characterized by gentle windward and steeper leeward slopes.

The divide between the waters of the Tahquamenon and Manistique rivers roughly defines the line along which the Algonquin waters split when recession was in progress. North of the divide, in the Tahquamenon basin, the shore dunes carry their steep leeward slopes, facing southward; but south of the divide in the Manistique basin, dunes have their steep slopes facing northward. This condition of opposed dune slopes in the two basins is significant in that it throws much light on the problem of recessional activity of the waters of Lake Algonquin.

It seems logical to assume that the dunes in this area were formed in much the same manner as post-glacial dunes have formed and are still forming. It is obvious then that the winds which sculptured the aeolian ridges must have been on-shore winds in order to have moved beach material landward. The opposable slopes of the dune ridges thus bear out the conclusion that the Algonquin waters parted in the region of the Danaher divide with the result that two basins ultimately formed. The water in these basins continued to recede, being drained out, in part to the north and in part to the south.

That the lowering of Lake Algonquin was the result of gradual and not rapid recession is manifested by the numerous parallel rows of dunes which lie between the main divide and the present basins of Lake Superior and Michigan. In many of the areas, ridges of sand 50 to 60 feet in height have been piled up along the older shores and present evidence of relatively long intervals of temporary halts in lake recession, during which accumulation of sand was in progress.

In many parts of the Manistique drainage basin, the features are so complex as to make complete differentiation impossible. Ridge after ridge of sand, separated by intervening marshy lanes, and interspersed with small tracts of sandy lake plain, stretch for miles across the lowland region and in places cover entire townships. So complicated is some of this country that the individual features are not revealed, nor can they be separated in the areal mosaics constructed from photographs on a scale of 4 inches to the mile. Such areas have been designated *complexes*.

Two distinctly different lowland complexes may be distinguished in the Manistique river area. One of these has been given the name of Seney complex, from its type development in the vicinity of the town bearing this name. The other has been termed the Manistique complex because of its distribution along the shore of Lake Michigan near the city of Manistique.

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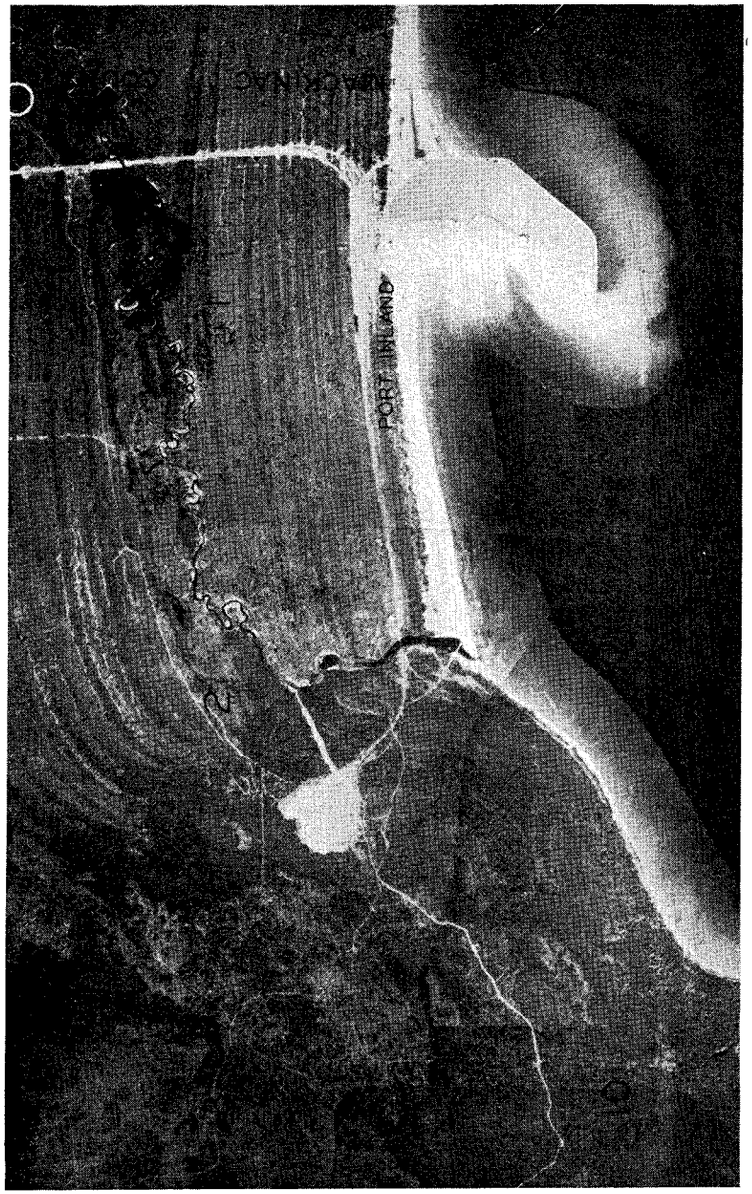

Michigan
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Air photo of fore-dune ridges, near Seul Choix Point, Schoolcraft County.

THE SENEY COMPLEX

This feature is essentially of an interior character and consists of wind blown sand in the form of ridges and knolls, interspersed with open marshy areas and muskeg. The dunes may be present as isolated forms scattered through broad tracts of lowlands, or they may be connected as more or less continuous and closely spaced ridges separated by intervening marshes, and poorly drained swamps. The sandy uplands make up from 25 to 75 per cent of the complex area and are usually covered with Norway, white and jack pines. The marshy lowlands constitute the remainder of the region and are grown over to grasses, sedges, cassandra and occasional timber size forest trees.

The dunes in the Seney Complex are extremely variable in size and extent. They range from mere waves, a few feet high covering a sandy lake floor, to extensive dunes, 50 to 60 and more feet in height. Some of the knolls are of distinctly local character and occur as individual small patches. The ridges, on the other hand, may continue across country for miles without interruption. Extensive areas of sandy lake floor break into the complex, but are generally much modified and show very definitely the effects of translocation and deposition by the wind.

THE MANISTIQUE COMPLEX

The Manistique complex is concentrated largely along Lake Michigan and consists of a succession of narrow, parallel ridges which follow closely the trace of the present shore. The ridges are separated by narrow swales, seldom exceeding 2 chains in width. They are timbered with Norway, white, and jack pine whereas the associated swales have a cover of spruce, cedar, and tamarack, with cassandra or grass in the open areas.

The dune ridges in the Manistique complex generally follow closely along the present shore, often in the form of fore-dune features. Progressing landward, the ridges become successively higher and higher until finally they merge in the hinter dune area and lose their individuality in the massifs.

The swales are quite uniformly interspaced with the ridges and give to the relief a character which is typically undulating. Because of its structural character, the writer here proposes to describe the relief as "corrugated." A beautiful example of corrugated surface may be viewed in the southeast corner of Schoolcraft County, north of Lake Michigan in the vicinity of the Inland Steel Company harbor. (Plate XXIV)

In the distance of a little more than a mile between the lake shore and Milakokia river, in this area, there are a series of 36 low, parallel sand dune ridges ranging from 5 to 15 feet in height. They are separated from each other by narrow marshy lanes. Starting as low fore-dune

ridges along the shore they become successively higher and more completely developed as the distance from the shore increases. North of the Milakokia river, the ridges give way to a massif of dunes which reaches a maximum elevation of 125 feet above the level of Lake Michigan and terminates completely at the swamp which borders the shores of Shoepack lake.

In the area, between the well defined inner fore dune ridges and the main massif, is a transitional belt of deformed ridges. These ridges are roughly *en-echelon* in arrangement and present their scalloped hollows windward. It appears entirely probable, as Scott has suggested, that the waves on the prograding shore may have initiated the hollows in the deformed dune areas, which later were subjected to wind modification.

The fore-dune ridges, built up in succession along the receding shore are moderately symmetrical in shape. They do not possess the characteristic leeward-windward slopes, and for the most part the profile is quite uniform. There seems good reason to believe that the parallel ridges may possibly correspond to off-shore lacustrine bars which have more recently been modified by aeolian activity.

Opportunity for study of a small isolated dune section, associated with the marshy tract, is afforded in the vicinity of the fire tower located a short distance south and east of the village of Seney. The tower is situated on the crest of one of the highest dunes in the region and overlooks a vast expanse of open muskeg and timbered swamp on all sides. The dunes here are well developed and possess the characteristic leeward and windward slopes. They rise to a maximum altitude of 800 feet or to an elevation of 60 feet above the surrounding marshy plain. The dunes are here massed together and rather closely crowded into a compact area of only a few square miles. (Plate XXV, Fig. 2)

The features are somewhat complicated in structure and present a variety of forms. Piles of sand without trend break off into definite ridges which, with their associated intervening sand-floored basins may be traced uninterruptedly for some distance eastward. Deflation hollows and blowouts are associated with certain portions of the district and occasional forms having the appearance of barchans may be viewed from the tower.

Close investigation of the area, especially in the valleys and the basins, reveals the presence of glacial till and boulders which form the foundation for the dunes. It is very probable that during the interval of dune development a small isolated mass of moraine standing along the margin of Lake Algonquin in its southward retreat from this area, intercepted the sand which was whipped up from the adjacent shore and was in large

PLATE XXV

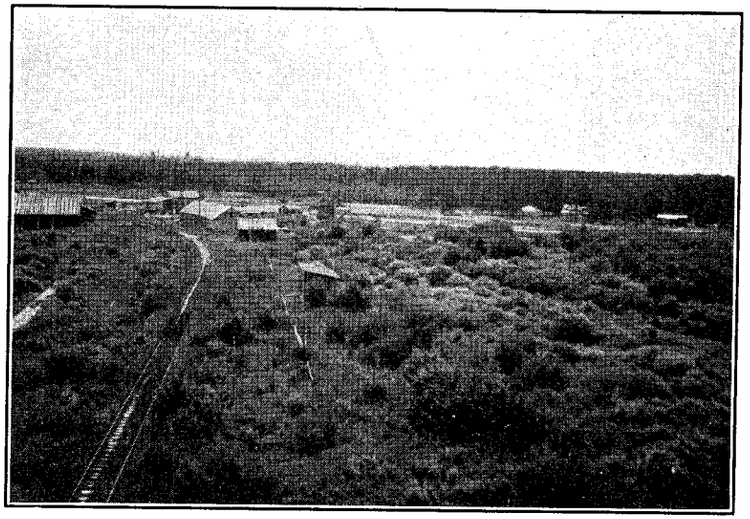

Figure 1.—A portion of the Manistique swamp. Near Walsh.

Figure 2.—Sand dune topography near Seney as viewed from the Fire Tower—looking northwest.

PLATE XXVI

Figure 1.—Dune blown up against the slope of a moraine in the Manistique swamp. N. E. ¼, Sec. 21, T. 42 N., R. 15 W.

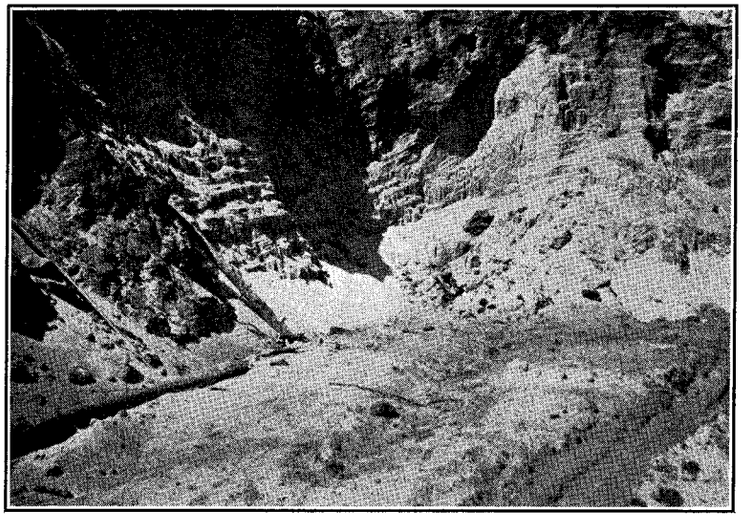

Figure 2.—Section of dune showing cross-bedding in the unconsolidated sand. Tahquamenon swamp, two miles north of McMillan. Sec. 21, T. 46 N., R. 11 W.

measure responsible for the aeolic accumulation. Similar features prevail in other areas where morainic ridges border the swampy lowland. (Plate XXVI, Fig. 1)

INLAND DUNES

From detailed studies made of the features in the marshy complex of the Manistique swamp, it is apparent that the majority of the dunes were shaped by the wind along prograding shores of Lake Algonquin. This is especially true of those ridges which have an east-west trend across the lowlands.

On the other hand, however, there are a multitude of aeolian features which appear in no way to have had any association with retreating shores. Dunes of this type are distributed along some of the major drainage ways and follow, in general, the trend of the stream courses. To a large extent, they are most strongly developed on the west banks of the southeastward flowing rivers, a fact which would demand prevailing wind activity from the northeast.

In connection with these dunes, the question arises as to whether they should be classed as shore dunes or strictly as inland types, following the classification of Solger (42), Högbom (43), and others. The writer is inclined to consider them as inland features and suggests an origin which is correlated indirectly with stream activity.

In describing the general physiographic character of the Manistique swamp on pages 59-61, mention was made of the almost universal distribution of shallow bodies of muck and peat over the lake laid sandy floor. Close studies of a large number of dune areas along the rivers failed to reveal a single major dune form which has been developed upon a base of muck or peat. So far as could be determined, sandy plains provide the foundation for the structures. Hence, it follows that the dunes were formed upon flood plain areas in the lowland tracts. As the rivers in their early history eroded their channels into the lake plain, a large amount of sandy material was released. Much of the finer sand was washed up on the flood plains and flats along the river borders during each flood. Exposed during periods of low water, the sand became desiccated and in such a condition was easily moved by the prevailing winds and then piled up into definite ridges along the lee banks.

Again, these dunes may have been developed by transportation and deposition of older deposits of aeolian sand which had previously been laid down along the lake shores. Thus modified, should they still be classed as inland types or would they better fit into the category of shore dunes?

The storm winds in the region are at present from the northwest off Lake Superior, whereas the position of the dunes in the stream areas

call for a prevailing northeast wind. This discrepancy in wind direction need not be an obstacle to the solution of the problem inasmuch as a large mass of ice still persisted to the north and east of the Superior basin. Anticyclonic storms generated over the ice area, may have been responsible for the directional change during Algonquin times, following the theory advanced by Hobbs. (44)

III. Shore Dunes Along Lake Michigan

Sand dunes occur intermittently along the entire shore of Lake Michigan, from Point aux Barques to the Inland Steel Plant, in Schoolcraft County. Throughout most of this distance they border the lake and constitute a complex of ridges which are aligned more or less parallel to the shore. The ridges are separated from each other by interspaced lanes of peat-filled marshes and occasional sandy, lake plain flats.

The dunes in this area are variable in dimension. They range from low, narrow fore-dune ridges now in process of being piled up on the present shore, to rather bulky massifs which rise to 125 feet and more above the level of Lake Michigan, in the southeastern corner of Schoolcraft County. According to studies made by Scott and Miss Stevenson of the Manistique area, there have been three stages of dune activity. These are ascribed to Nipissing, Algoma and present shores. The largest and most deformed dunes of the region have been traced back and correlated with the Nipissing beach which here stands at an altitude of 625 feet, or 40 feet above the level of Lake Michigan. The Algoma dunes can be definitely tied up with a beach at 600 feet. Dunes of this stage are low and under-nourished and in no way comparable in bulk to the Nipissing features. The recent forms, as has already been mentioned, are mainly low, tenuous fore-dune ridges seldom exceeding ten feet in height. They are being constructed from material of the present beach and are evident wherever a supply of sand is available. The slopes of these young ridges are more or less uniform and symmetrical and, although not representing the angle of repose of the included sand, appear to be slightly steeper on the leeward sides.

Dunes are somewhat lacking along the shore in those areas where the floor of the lake is composed of bed rock. These dune-barren localities are situated primarily in the headland portions of Point Aux Barques and Seul Choix Point. Another extensive tract of rocky shore lies between the city of Manistique and the Nipissing shore scarp a few miles to the east. It is significant to note, in the areas where the limestone beds form the lake shelf, that an abundance of large erratics are scattered over the surface. These boulders are the concentrates of former till deposits, the finer material of which has been completely removed by subsequent wave action. It is quite possible that they represent the remnants of glacial features which may have correlated with the final stages of activity in the Lake Michigan lobe. This view, however, cannot be conclusively proved because of the lack of sufficient evidence.

The dunes of the Lake Michigan shore have played an important role in the history of the Tahquamenon-Manistique drainage basins. They were responsible, to a considerable degree, for the damming of the newly formed rivers in Nipissing times. This damming of the drainage in the lower reaches caused flooding in the interior lowlands and resulted in the swampy, poorly drained condition which characterizes the region.

From the fact that the shore dunes of the interior lowland tract are associated with the activities of Lake Algonquin, it seems logical to conclude that drainage was free and open during most of this time. This view is based on the consideration that the sandy lake flats had as yet not been encroached upon by vegetation which was responsible for the accumulation of the vast expanses of shallow muck and peat. Thus, a continuous supply of sand was originally available for wind translocation.

With the close of the Algonquin stage, the waters were lowered to the Nipissing level and remained in this position for a considerable time as is evidenced by the prominent wave-cut cliffs which mark the shore near Manistique. The building of dunes on the newly formed lake terrace, eventually blocked the outlet of the Manistique River, and at the same time likewise affected its tributaries in the hinter plain. It was during this period of flooding, that organic activity became prominent and peat was laid down upon the sandy floor as a protective buffer against further ablation.

When the Manistique River finally opened a new outlet into Lake Michigan the flooded waters were carried out. The tributary streams, with headwater areas uplifted by the differential movements which had been in progress through much of Algonquin times, became actively engaged in cutting channels into the sandy lake floor. This renewed fluvial activity in the tributary streams provided a new source of sand which, blown up from the flats and flood plains, became piled up into dunes along the river courses.

It is thus possible to trace out two major episodes of dune formation in the Tahquamenon-Manistique drainage basin. The earlier of these episodes may be correlated with wind activity along the retreating shores of Lake Algonquin. The dunes of this stage are definitely of the shore type. The later dune developments are tied up with the Nipissing activities along the Lake Michigan shore and the consequent formation

of inland features along the stream courses. An interval of flooding and peat accumulation separates the two successions.

SUMMARY AND CONCLUSIONS

The Tahquamenon-Manistique Drainage Area, representing the most extensive tract of marshy lowland in the state, seems to hold a key position in the final interpretation of the Pleistocene problems of the Belted Lowlands province of the Northern Peninsula. The activities which prepared and ultimately shaped the surface expression of the area are associated with the waning stages of the Labrador ice sheet in late Wisconsin time. Three distinct episodes are represented in the development of the surface features; these are related to glacial, lacustrine and aeolian processes.

Glacial Activity

In the first episode, that of glaciation, it is significant that the region was affected largely by a readvance of the ice from the Superior basin. The movement of this ice mass, as recorded by striae on bed rock, was largely south-southwestward, in contrast to the generally westward direction of an earlier invasion. It is quite evident that the Green Bay ice block which still persisted to the west was responsible to a large degree for the newly directed movement.

Glaciation has left its stamp on the character of the region in the form of two strongly developed morainic systems, which I have named the Newberry and the Munising moraines, respectively. The development of these morainic systems is contemporaneous with the final activities of the Green Bay lobe in the region of Trenary till plain. It seems plausible, from the related positions of the moraines of the Green Bay and Superior lobes, to assume that the ice in the Green Bay lobe had become stagnant before the glacier completely retired from the west end of the Munising moraine.

Throughout the area, no features can definitely be ascribed as having been formed by the Michigan lobe before its final disappearance. There is a possibility, however, that the bouldery concentrates, including large erratics, which fringe the rocky shore of segments of Lake Michigan in Schoolcraft County, are the remains of the final till deposits of the Michigan lobe. Owing to the completely modified character of the surface and the fragmentary bits of evidence at hand, it is possible only to make conjectures concerning such a relationship. Nevertheless, it seems wholly within the province of good judgment to believe that the final position of the Lake Michigan lobe was somewhere between the present lake shore and the front of the Newberry moraine. Possibly the

Michigan lobe retired much in the same way as did the Green Bay lobe, as a stagnant body of ice, and may have been overridden to some extent by the readvancing sheet of ice from the Superior basin.

Although the moraines which were left by the Superior ice lobe are fragmentary and disconnected because of subsequent erosional activity, they were undoubtedly continuous in their trend for some time after the ice retired from them. Hence through the interval when lacustrine activity was paramount, they served as barriers, at least temporarily, against rapid outflow and were thus responsible for much of the ponding of water which occurred in the early development of the basin.

With the exception of a few localized areas where it has been completely fragmented, the Newberry morainic system forms the outer margin of both the Tahquamenon and Manistique drainage basins. This moraine served as a control in basin development for the area and likewise determined definitely the course of the Manistique River and to some extent the course of the lower reaches of the Tahquamenon. If this moraine had not been deposited in the position which it now holds, it is barely possible that neither of the two large river systems could have been initiated. Under such a set of circumstances there would have developed upon the tilted lake plain a series of parallel independent drainage lines such as are now represented by the numerous branches of the Manistique River. Carrying the speculation of such a condition a step further, it seems reasonable to venture that the marshy lowlands would have assumed much more extensive proportions to the east of the present major drainage lines.

Lacustrine Activity

The second episode, related to lacustrine activity, did not begin until the body of the Superior ice sheet had disappeared largely from the surface of Michigan and the Superior basin was freed of ice at least to the meridian of Wetmore. At this stage, the Anna River at Munising carried discharge water of the partially formed Lake Algonquin across the high moraines south of Munising, into the head of the Manistique swamp. The contribution of water through this passage was relatively small and the outlet was short lived as is manifested by the small amount of scour and the narrowness of the valley. The occupation of the valley by the Algonquin waters is evidenced, however by the presence on the slopes of the moraine within the valley, of intercalated lacustrine silts, clays and sands to an altitude of 838 feet above sea level. These deposits are thinly laminated and can no doubt be classed as varves, according to descriptions by Antevs, (45) Reeds (46) and others.

A further retreat of the ice northeastward in the Superior basin, and

the attendant differential uplift in the region, resulted in widespread inundations. The water from Lake Algonquin found its way across the lowland areas of Luce County and spread out in sheets over the interior sandy plains. During the highest stage in lake level, the greater portion of the relief was under water, merely a few highland tracts standing high enough to remain above. In this stage of lake development wave action was effective on the crests and slopes of the higher moraines, especially those that were either slightly above, or submerged in, shallow water. Thus, much of the relief was modified, with the result that slopes were washed down and smoothed out and the original irregular surfaces became flattened to a considerable degree.

An important passage for the waters from the Superior to the Michigan basins was affected through the Tahquamenon depression across the narrow straits at McMillan, into the Manistique lowlands. The divide, near Danaher, stands at an altitude of 720 feet and represents the lowest passage established between the two areas.

The continued uplift of the Superior basin resulted in the diversion of more drainage waters through the Port Huron outlet and caused the plane of Lake Algonquin to be lowered. When the waters were too shallow to cross the divide in the McMillan Straits, they split. Part of the water drained out northward through the Tahquamenon depression, and the remainder found its way southward into the Manistique drainage basin. This parting of the water into two separate water sheds is evidenced by the opposing slopes of the dunes on either side of the divide. The northern dunes have their steep lee slopes facing southward whereas the southern dunes have the steep slopes facing northward.

The Tahquamenon and Manistique rivers did not come into existence as definite water courses until the Lake Algonquin level had been lowered sufficiently to allow channels to be etched into the sandy lake floor. They increased their length, not alone by headward erosion, but largely through extension of the lower reaches as the water in the retreating lake subsided. Throughout the process of river development, uplifts were effectively in progress. The Lake Superior basin, being farther removed from the hinge line, naturally suffered a greater amount of movement than did the Lake Michigan basin. The result of the differential uplift activity was to raise the rock sill of the Tahquamenon River at the Upper Falls to a point where the drainage could no longer overflow. The ponded waters spread out into the low lying flats and a large shallow lake was formed in the basin.

The differential uplift, on the other hand, raised the headwater area of the Manistique River to a much greater degree than its outlet. This caused the river to be rejuvenated, with the result that it was able to deepen its channel materially.

Aeolian Activity

The third episode involved in the Pleistocene history of the Tahquamenon-Manistique drainage area is concerned mainly with aeolian activity. Wind work, on a large scale, was initiated at the time when the waters of Lake Algonquin began to subside in the interior basin and continued well into and through Nipissing times. The majority of dunes within the drainage basins were formed during the retreatal stages of Lake Algonquin. They were blown up into ridge rows from the successive beaches on the prograding shores and represent the various positions of the strand as the water level receded.

Although shore dunes constitute the larger proportion of aeolian features in the region, it is nevertheless significant that extensive areas along the major river courses are beset with dunes. These have been developed on the flood plains and river flats out of material which was translocated by running water. They seem to bear no relationship whatever to the receding shores of the older lakes, but rather parallel the major valleys. Hence, they are not shore dunes in the true sense of the word and because of their inland origin may well be classed as interior dunes.

The development of thousands of dunes scattered broadcast over the lowland area, has been responsible for a great deal of derangement in surface drainage. The dunes which formed along the older shores impounded much water during lake retreat and prevented its complete removal. Lagoons, formed behind the numerous shore ridges, became sites for organic accumulation which is reflected in the almost universal distribution of muck and peat over the sandy lake floor. Broad interstream acreas of marsh and muskeg give further testimony to the ponded condition of surface drainage, subsequent to dune formation.

In much of the drainage basins the dune ridges are so numerous and widespread in distribution that it is impossible to map them as separate features. Together with the intervening marshes and sandy lake flats, they constitute a complicated and undifferentiated relief.

The final chapter in the geologic history of the drainage basins has not yet been written. Numerous changes will, no doubt, be made throughout the years to come. The existing rivers will from time to time shift their courses and new streams will develop in the region. The drainage for the most part is still in a youthful condition but as the stage of maturity is approached and more tributaries are superposed upon the watershed slopes there is no question but that much of the peat and muck which now cover the surface will be removed. Extensive sandy flats will thus become exposed to renewed activity by the

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Air photo showing oxbow lakes and cut-offs in the lower reaches of the Manistique River.

wind and in time, the interstream areas will be covered with sand in place of the present muck and peat.

The low gradient in the lower reaches of the Manistique River has resulted in the development of broad meanders and cut-offs. (Plate XXVII) The sluggish character of this portion of the river was induced, in part at least, by damming of the older outlet by dunes formed along the Nipissing shore. Further changes in the outlet may have the effect of ponding tremendous volumes of water in the lower more or less unconfined valley ways.

In conclusion, it should be stated that the work which has so far been done in the area is inadequate to solve all of the problems which naturally present themselves in so complicated a region. The present paper is merely the first step in an attempt to unravel the events of the past. More exact data worked out on the basis of precise levelling are needed to correlate the various water planes accurately and to tie up definitely all of the steps involved in the lacustrine history. It is hoped, however, that the features which have been mapped will serve as a basis for more detailed studies of the local problems in the region.