OCCASIONAL PAPERS

ON THE

GEOLOGY OF MICHIGAN

STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
P. J. Hoffmaster, Director

GEOLOGICAL SURVEY DIVISION
R. A. Smith, State Geologist

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GEOLOGY OF MICHIGAN

PREPARED UNDER THE DIRECTION OF

R. A. SMITH, State Geologist

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LETTER OF TRANSMITTAL

To the Honorable, the Director and the Board of Commissioners of the Department of Conservation of the State of Michigan:

Hon. P. J. Hoffmaster, Director
Hon. William H. Loutit, Chairman
Hon. Philip Schumacher
Hon. Harry H. Whiteley
Hon. M. J. Fox
Hon. Philip K. Fletcher
Hon. Joseph P. Rahilly
Hon. William J. Pearson
Hon. Wayland Osgood, Secretary

Gentlemen: In compliance with Act No. 65 of 1869 as amended by Act No. 179 of 1871 of the Public Acts of Michigan under which the Geological Survey Division of the Department of Conservation operates, I have the honor to present herewith three reports on the geology of Michigan, by Prof. R. C. Hussey of the University of Michigan, Prof. W. A. Kelly and Prof. S. G. Bergquist of the Michigan State College, and recommend that they be published as Publication 40, Geological Series 34, of the Geological Survey Division, Department of Conservation, as part of the Annual Report for 1936.

Prof. Bergquist's report on the surface geology and development of the Tahquamenon-Manistique drainage system was prepared as a part of the Land Economic Survey of the eastern part of the Northern Peninsula and is a study and description of the surface conditions in the drainage basins of the two main river systems of Luce, Alger, and Schoolcraft counties, and the origin of scenic features in the State Forests of these counties. A foreword has been added, briefly outlining the glacial history of the State and the development of the Great Lakes and containing definitions of glacial features. The report with its accompanying maps and illustrations should be of interest and value not only to the student of glacial geology, soil, and forest conditions, but to tourists as well.

The report on the Trenton and Black River rocks of Michigan by Dr. R. C. Hussey was prepared as a part of the routine study of the rock exposures of the State under the plan of Geological Survey activities. The report is of very timely interest at present, not only because of its scientific value but also because of its economic application in the development of the petroleum interests in the State. The Trenton and Black River rocks are almost the lowest rocks in the State in which one may look for oil accumulations. These rocks rise to the surface in the Northern Peninsula and slope southward under the basin in the central part of the State. Little descriptive matter has been published about them; thus the report of Dr. Hussey is a valuable contribution to the literature of the formation which may in the future solve the petroleum problems of the State. At present the Trenton has been explored only around the edges of the State, but as upper oil "sands" are depleted deeper drilling will become the practice, in search for new supplies. A report such as this will be of value to the companies engaged in the deeper explorations.

The report on the Pennsylvanian system of Michigan was prepared by Dr. W. A. Kelly of Michigan State College (like the report on the Trenton by Dr. Hussey), as a part of the plan of the Survey to continue a comprehensive study of each of the geological formations of the State. The Pennsylvanian is the youngest system of rocks of the State and contains the coal beds, some gas "sands", water zones, and, where the rock comes to the surface, some building stone is obtained. In addition the Pennsylvanian assumes an economic value in the petroleum development of the State. A common practice in oil exploration is the drilling of shallow test wells to some "marker" bed. Because the Pennsylvanian rocks are the upper rocks of the central part of the State and are relatively shallow, they assume great importance in shallow test drilling and a comprehensive description of them is of value to the oil industry as well as to general geology.

The three reports are outstanding contributions of both scientific and economic value and should aid in the development and utilization of the eastern part of the Northern Peninsula as well as aid in the development of the mineral industry of the State and be a marked contribution to the geologic literature of Michigan.

Respectfully submitted,
R. A. SMITH,
State Geologist.

September, 1936

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STANARD G. BERGQUIST, PhD.
Michigan State College

THE PLEISTOCENE HISTORY OF THE TAHQUAMENON AND MANISTIQUE DRAINAGE REGION OF THE NORTHERN PENINSULA OF MICHIGAN.

By
STANARD G. BERGQUIST

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

JUNE, 1933

Published as a part of the Annual Report of the Michigan Geological Survey Division, Department of Conservation, for 1936

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THE GLACIAL HISTORY OF MICHIGAN

Centers of Ice Accumulation

During hundreds of millions of years great seas invaded much of the continent of North America and vast accumulations of gravel, sand, mud, and lime were deposited in these basins to form the foundational rocks out of which Michigan was developed. But the actual sculpturing of the present surface, the development of the hills and valleys, or relief, and the delineation of the State into the definite physical unit we know today was not accomplished until yesterday in geological time, rather late in the Pleistocene or glacial epoch.

During this rather recent event, vast sheets of ice in the form of glaciers gathered in the snowfields of Canada and slowly spread over the surface of the northern half of the North American continent, covering its surface with a blanket of ice that was probably a mile or more in thickness. There were four major and several minor centers of refrigeration and ice accumulation in North America during this time. (Fig. 1). One center which was on the plateau east of James Bay is named the Labradorean. The greatest ice movement was southwestward from this plateau. The ice advanced 1,600 miles almost to the present Ohio River, whose course was more or less definitely established along the border of the glacier. Locally the ice advanced slightly into southern Illinois. It was this mass of ice that spread over Michigan in several invasions and shaped the hills, valleys, and plains and placed the rivers and lakes almost as we know them today. And it was the melting water from this ice which collected in basins to form the Great Lakes.

Another glacier, the Keewatin, developed on the low, flat lying plains west of Hudson Bay. It was the largest of the three ice fields and in its greatest movement spread southward nearly 1,500 miles, to the position of the Missouri River, whose course was unquestionably defined along its margin.

The third center, the Cordilleran, occupied the basin-like plateau between the Selkirk Mountains and the Cascade Range. Its activity was confined largely to the lofty mountains of western North America with little or no movement into the surrounding lower regions.

Greenland was also a center of accumulation. Here the ice spilled over the borders of the continent into the surrounding seas but did not join the main ice mass of the North American Mainland.

During the greatest ice activity in the Pleistocene epoch the continental glaciers covered approximately 4,000,000 square miles of surface in North America, 2,000,000 square miles in Europe, another 2,000,000 square miles in Asia, 5,000,000 square miles in Antarctica, and 800,000 square miles in Greenland.

Today, the ice sheets have largely melted from North America, Europe and Asia, but still remain in Antarctica and Greenland covering practically all the south polar area and all but the marginal tracts of Greenland.

Figure 1.—Map of North America showing the area covered by ice during the Ice Age. After W. C. Alden.

Ice Invasions

In spite of varied controversies regarding certain details of activity, glacialists are generally agreed that the ice blankets melted away and

then reaccumulated several times causing renewed invasions of the ice sheets during the Pleistocene epoch. These invasions were separated from each other by long intervals of time during which the glaciers melted back into the accumulation centers.

For convenient reference each ice invasion has been given a specific name and each interval of time between invasions—interglacial stage—has also been named, referring to those places where the glacier left important records which glacial geologists have learned to read.

These records consist of:

1. Long lines and festoons of hills—The Moraines. The rock debris which the ice had scooped off the land in its steady push out from the various centers and which was left behind when the ice melted comprise the *moraines*. If the rate of backward melting was equal to that of the forward push, the front of the ice remained stationary for relatively long intervals and the load of glacial drift was dumped along its front in ridges of rounded hills interspersed with valleys and basins—the *marginal moraine*. Each moraine in the state has been given a name, usually the name of a town or river which is an important geographic location on the moraine.

2. Ground Moraines—formed when rapid recession of the ice, due to excessive melting, caused the rock waste to be spread out over the surface from which the ice had just retreated. The moraines are constructed of all types of debris that the ice was able to collect, including boulders, cobbles, gravel, sand and clay, intermixed and without assortment. The ground moraines, on the other hand, are constructed largely of unassorted clay and sand with scattered boulders. They are usually fairly level and smooth in relief and are known also as *till plains*.

3. Outwash or Overwash Plains—formed by rivers flowing out from the edge of the melting glaciers washing the gravel, sand and clay from the ice and spreading them out in front of the moraines. In the sorting process the coarse material such as cobble and gravel was deposited close to the ice margin, and the finer material such as sand and clay was carried farther out for deposition. Each time the progress of ice retreat was halted, moraines and outwash plains were built up. Whenever the ice melted back rapidly with no long stops in recession, *ground moraines* were developed. When river channels in the ice became choked with sand and gravel, *eskers* were left.

4. Eskers—long narrow ridges commonly referred to as hogs backs and Indian trails. Rivers existed in the ancient glaciers as they do in the glaciers of Switzerland and Alaska today. The river channels became filled with the sand and gravel in the ice, which, when it melted, allowed the channel shaped masses of assorted sediment to settle gently to the underlying surface of bed rock or till plain.

All the glacial deposits taken together are known as *drift,* and by means of the drift the great glacier wrote its own story for future students to read just as the glaciers of today are leaving similar but less extensive records for modern study.

Nebraskan Invasion

The earliest of the glacier invasions is commonly referred to as the Nebraskan; it started approximately a million years ago or about the time that the Ape-man of Java (Pithecanthropus erectus), came upon the earth. This glaciation was undoubtedly the most extensive as well as the longest of the several stages.

The Nebraskan invasion was followed by the Aftonian interglacial stage during which the glaciers melted back to near the centers of accumulation.

Kansan Invasion

The second invasion of the ice sheets was the Kansan which, according to Leverett, dates back some 450,000 to 600,000 years ago. During this stage the ice reached southward as far as the northeastern part of Kansas and covered all but the outer edges of the Nebraskan glacial deposits, the so-called gumbo-tils in the region to the west of the Mississippi River. The ice of this invasion advanced from the Keewatin center and passed over Manitoba, Minnesota, Iowa and Missouri and encroached broadly on the Dakotas, Nebraska and Kansas.

Then followed another interval of melting, the Yarmouth interglacial, and the Kansan drift surface was exposed to pronounced weathering. Deposits of peat, and forest beds 15 feet thick lying above the Kansan drift give evidence of a relatively long interval of ice removal. It is probable that the pre-historic Heidelberg man appeared in Europe during the time of the Yarmouth interglacial stage.

Illinoian Invasion

The third invasion, the Illinoian, occurred between 150,000 to 200,000 years ago, and was marked by a decided readvance of the ice from the Labradorean center. This time, the ice spread across the district of the Great Lakes, westward as far as the Mississippi and southward approximately to the line of the Ohio River. The Illinoian drift is exposed in southern Ohio and northern Kentucky where it shows the effects of leaching by the action of weather and water to a depth of two to five feet. In Michigan and Wisconsin the Illinoian drift is everywhere almost completely buried under drift of the last or Wisconsin invasion. It is exposed in the bed of the Raisin River at Monroe and in numerous stream gulleys along the shore of Lake Huron in the Thumb region. Wells drilled through the glacial drift usually encounter the hard, indurated, blue clay of the Illinoian directly beneath the brownish surface, or Wisconsin, till and immediately above bed rock in many portions of the state. Because of its hardness due to compaction by ice pressure, it is frequently mistaken for bedrock.

The Sangamon interglacial stage followed the Illinoian invasion. The Sangamon soil, composed of a dark colored gumbotil contains much organic matter and is usually buried under deposits of a very fine wind deposited silt soil commonly known as *loess.* The Sangamon gumbotil, ranging in thickness from three to five feet where best preserved, seems to bear evidence of having been developed under conditions which suggest a cool, damp climate.

Wisconsin Glaciation

The last invasion of the ice sheets from the centers of refrigeration is known as the Wisconsin glaciation. In the early part of the Wisconsin stage the ice radiated from the Labradorean center and spread southwestward across the Great Lakes region, into central Illinois and Indiana. When the ice wasted away by melting it deposited the brown drift so characteristic of Michigan. In the later Wisconsin stage the ice from the Keewatin center spread over Minnesota, Iowa and the Dakotas and laid down a considerable volume of gray drift which in places overlaps the brown drift of earlier date.

On the basis of the amount of weathering developed in the surface of the latest drift, Leverett estimates that the last remnants of the Wisconsin ice sheet left the southern tier of counties in Michigan not more than 35,000 years ago. By the same measure it is probable that the final vestiges of the ice were removed from the basin of Lake Superior some 10,000 years ago, or about the time that Cromagnon civilization was spreading in Europe.

Throughout the hundred of millions of years which followed the removal of the last, the Paleozoic, seas from Michigan and up to the beginning of the glacial epoch about a million years ago, the exposed bed rock surface of the state was subjected to widespread destruction and upbuilding by rivers, winds, rains, and frost or a prolonged *erosional* activity. The pre-glacial surface was cut almost to a plain, or a vast peneplain scored by old rivers which had carved their valleys deep into the rock floor. Because of the thick cover of glacial drift which now mantles the bed rock surface it is difficult to accurately reproduce the pre-glacial drainage of the Great Lakes region. Scattered deep well records, however, seem to indicate that before glaciation there were a number of well defined, deeply cut river valleys following in part the lines which now are occupied by the Great Lakes. Speculation is rife among glacialists and hydrologists as to the direction of drainage of the pre-glacial rivers. One school of investigators seems to favor a southward drainage into the Mississippi river. Another group is equally convinced that the St. Lawrence Valley was then, as now, the major line of discharge into the Atlantic. Still a third group would have the waters draining northward through some of the major waterways into Canada, with an outflow into the Arctic ocean. Much more subsurface research is necessary to conclusively prove this perplexing problem. In spite of the differences of opinion concerning pre-glacial drainage outlets, the general concensus of opinion is that the major lines of river development were concentrated in troughs which were, at least generally, parallel to the present basins of the larger lakes.

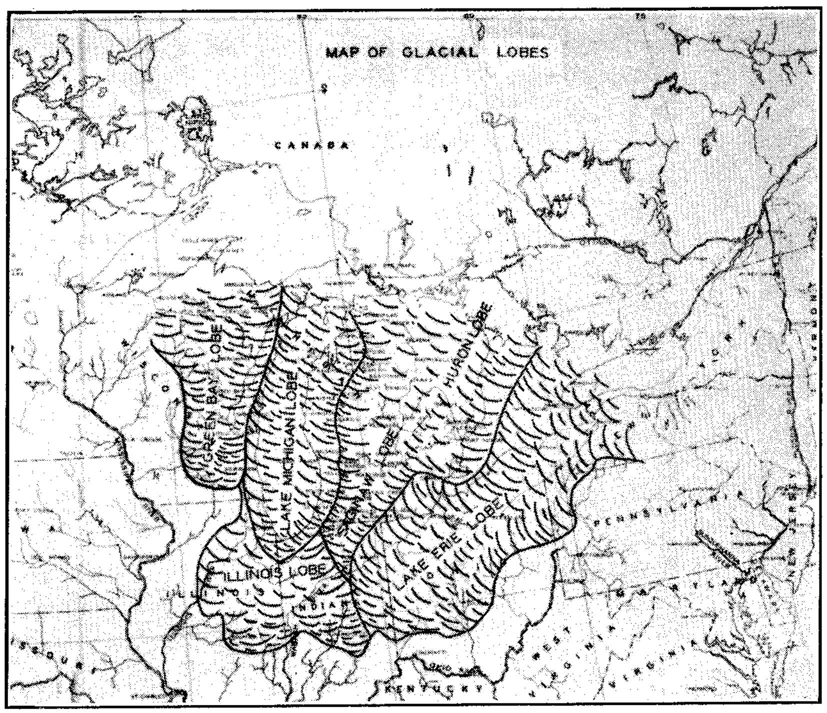


Figure 2.—Map of the Glacial Lobes.

In the Wisconsin stage of glaciation, the Labradorean ice sheet re-advanced southward across the region of the present Great Lakes. As it encountered the free drainage ways of the area, the deeper valleys served as natural thoroughfares for ice flow. The ice front then formed several large lobes and moved forward under control of the river courses. The largest of the ice lobes ploughed through the valley in which the

basin of Lake Michigan was eventually sculptured. This glacier is referred to as the Lake Michigan lobe and in its maximum extension it completely filled the basin and overflowed its rim. It expanded also southward beyond the site of Chicago to form the extension referred to as the Illinois lobe.

A second important mass of ice, the Huron-Erie lobe, was directed through a series of valleys which were later sculptured into the basins of lakes Huron and Erie. A third mass of smaller dimension was pushed out from the Huron-Erie ice extension into the basin of Saginaw Bay and became active as the Saginaw lobe. As this ice mass moved southward it nosed gradually out of the Saginaw drainage depression and onto the upland where it spread out as a relatively thin sheet of ice which eventually extended into the valley of the Kankakee River in northern Indiana. (Fig. 2).

Later still, after the glacier had left the surface of the southern Peninsula, a large lobe became centered in the Lake Superior basin. To the activities of this lobe, the northern Peninsula owes most of its glaciated characters, some of which are described in the discussion of the features of the Manistique-Tahquamenon drainage area.

Development of the Moraines

The Saginaw lobe was initiated in the Saginaw valley as a definite tongue extending out from the much larger Huron ice mass. In its greatest expansion this body of ice reached into the northwestern part of Indiana where evidences of its activity may be traced to a point somewhat south of South Bend. The Saginaw lobe moved through and beyond the present Saginaw Bay and, in the climax of its development, was confined between the Michigan and Huron-Erie lobes with which it joined during the height of the Wisconsin stage. (Fig. 2).

A study of the lines of hills, the morainic systems, distributed over the surface of northern Indiana and southern Michigan, seems to show that the ice of the Saginaw lobe melted back from the basin of the Kankakee River, disappeared completely from northern Indiana and withdrew into southern Michigan, while the Michigan and Huron-Erie lobes still filled to overflowing their respective basins.

Until the Saginaw ice began to melt back in the early Wisconsin stage, the three lobes were welded into a more or less undifferentiated mass. The early retreat of the ice in the Saginaw tongue, however, allowed the various lobes to acquire distinctive and individual characters and to build moraines at their borders. It appears also that the Saginaw lobe because of its thinner ice was unable to transport as large a load of drift as the bordering basin filled lobes, and therefore melted faster. Clean ice, or ice containing a small amount of drift material, melts faster than dirty ice where the included rock material acts like rock wool, that is, as an insulator preventing melting.

The various halts of the Saginaw lobe as it melted across Michigan are evidenced in the succession of more or less parallel moraines which are found in festoons closing in on Saginaw Bay from the southwest. (Fig. 3). In Indiana and southern Michigan, the moraines of this lobe

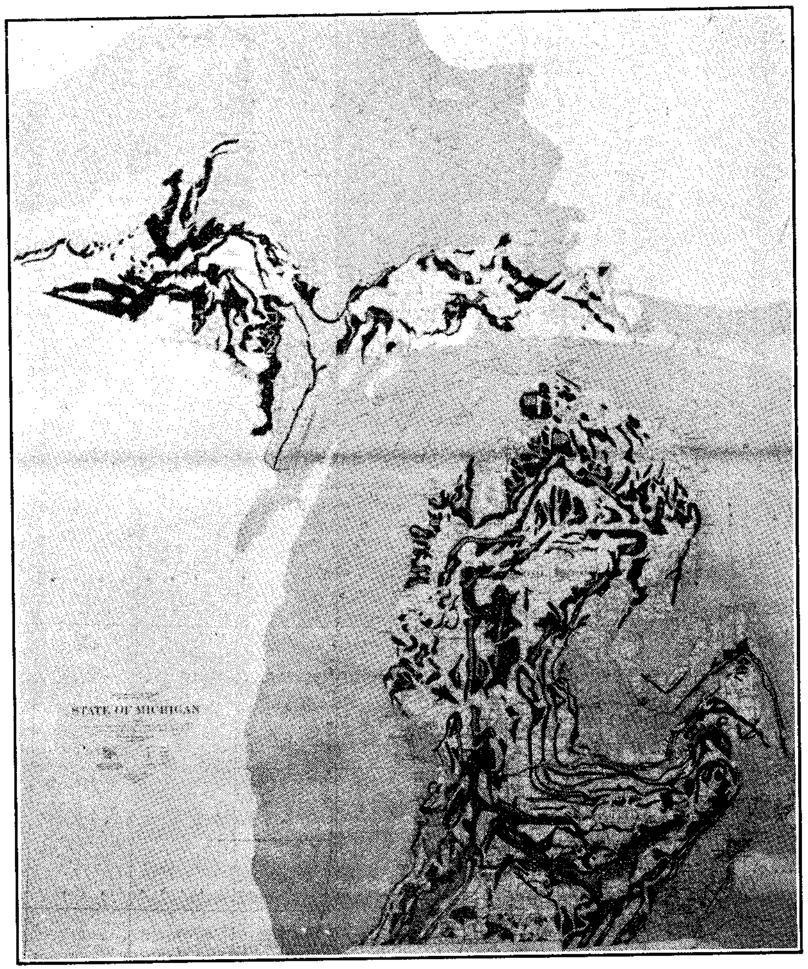


Figure 3.—Map showing the distribution of moraines in Michigan. (After Leverett).

are much more strongly developed than they are farther north. It is probable that in the area of convergence of the three ice tongues in northern Indiana and southern Michigan, a considerable amount of drift

was carried in by the Michigan and Huron-Erie lobes and loaded into the Saginaw ice for later deposition upon its retreat. The excessive loading of the southern end of the Saginaw tongue resulted in its becoming more sluggish which consequently allowed for slower retreat and the development of stronger morainic ridges. Farther north, on the other hand, the influence from the adjoining lobes except in the inter-lobate areas was insignificant and the resulting moraines are rather weak and poorly developed.

In its retreat from the Maxinkuckee moraine which marks the southernmost position of the oscillating front of the Saginaw ice in Indiana, the lobe made a succession of short halts before finally coming to rest on the Kalamazoo moraine. These short stops in the back step of the ice front are marked by a series of moraines, named in order the Bremen, New Paris, and Middlebury in northern Indiana, and the Sturgis and Tekonsha in southern Michigan. (Fig. 3.). These moraines were later partially modified by the lateral extension of the ice sheets from the Michigan and Huron-Erie basins and thus became greatly altered in relief. The first portion of Michigan to be uncovered was the St. Joseph River valley in southeastern Cass and southwestern St. Joseph counties when the Saginaw ice front rested on the Sturgis moraine.

When the retreating Saginaw ice lobe finally came to rest on the position of the Kalamazoo moraine, it stopped for a sufficiently long time to build up an extensive ridge. This moraine, extending from Hastings south and east through Kalamazoo, Marshall, and thence to Devil's Lake in Lenawee County, joins on the east with the Mississinawa moraine which outlines the outermost position of the Erie lobe in Michigan. On the west side of the state, a limb of the Kalamazoo moraine extends from Hastings southward through Kalamazoo and Cassopolis and is in a belt more or less parallel to the present shore of Lake Michigan. It marks the eastern boundary of the Lake Michigan ice lobe.

From the position of these three joined moraines, it is obvious that the Saginaw ice front had melted northward to expose a considerable portion of the surface area of St. Joseph, Branch, Kalamazoo and Calhoun counties while the ice of the Michigan and Huron-Erie lobes still covered the borders of the State. When the ice borders stood on the Mississinawa and outer Kalamazoo moraines, the main drainage of the State seems to have followed the course of the Kalamazoo River westward to the site of the present city of Kalamazoo. Thence, it was directed southward into the St. Joseph Valley past Three Rivers and into the Kankakee Valley near the site of South Bend. The water in this valley was dammed back in Indiana by the Marseilles moraine behind which it was ponded into a large lake, the Kankakee torrent, which eventually grew in places to a width of ten and more miles.

Renewed melting in the Saginaw lobe caused the ice front to retreat to the position of the Charlotte moraine. This moraine connects with the Valparaiso morainic system of the Lake Michigan lobe and may be traced from near Grand Rapids eastward through Charlotte, and Brighton to Milford. The outermost ridge of the Charlotte moraine connects with a ridge of the Valparaiso system at Dias Hill, about 12 miles south of Grand Rapids. A second ridge connects with the Valparaiso system at the bend of the Grand River directly north of Grand Rapids. A third ridge connects near Cedar Springs—some fifteen miles north of Grand Rapids. On the east side of the state near Pontiac, the Charlotte moraine connects with the Fort Wayne-Wabash systems which were formed at the same time by the Huron-Erie lobe.

At the time when the Charlotte moraine was forming, the melt water drainage from the ice in the vicinity of Milford followed the early valley of the Huron River northward to Portage Lake, near Pinckney. Then it continued westward to the Grand River valley, just north of Jackson, which it followed to Eaton Rapids. From here the water was carried through a swampy depression to the vicinity of Charlotte where it entered the valley of Battle Creek which was cut transversely across the Kalamazoo moraine.

A block of stagnant ice which covered the area extending from the site of Eaton Rapids to the vicinity of Charlotte blocked the Grand River valley and prevented discharge northward. The drainage entered the Kalamazoo River where Battle Creek now stands whence it was directed westward to the vicinity of Plainwell. From Plainwell it appears to have passed southwestward through the low area between the Kalamazoo moraine and the receding ice border to the vicinity of Dowagiac. Here a narrow lake (Lake Dowagiac) extending to the site of South Bend, Indiana, was formed in the valley of the present Dowagiac Creek. From this lake, the waters drained out through the Kankakee Valley, into the Illinois River and thence to the Mississippi.

After the formation of the Charlotte moraine and its correlatives, the Valparaiso and Fort Wayne Morainic systems, the ice along all fronts began another retreat. The next stop of the Michigan lobe and the last stop made by it south of Manistee before it retreated into the Lake Michigan basin is represented by the Lake Border morainic system, the ridges of which closely follow the margin of the lake. The Saginaw lobe correlatives of this system are the West Branch and Gladwin moraines north of the Grand River valley and a deployed group of slender moraines south of the Valley. Named in succession from the vicinity of Lansing northward, the moraines of the deployed group are: Lansing, Grand Ledge, Ionia, Portland, Lyons, Fowler, St. Johns, Flint, and Owosso. These moraines are arranged in more or less parallel concentric bands around Saginaw Bay and represent individually the various short halts made by the Saginaw lobe in its retreat from the Charlotte moraine to the position of the Port Huron moraine. The Huron-Erie correlative of the Lake Border moraine includes the Defiance, Birmingham, Mount Clemens, and Emmett ridges on the east side of the state. These ridges, in places, have been so completely modified by wave action of the later glacial great lakes that it is difficult to trace them in their entire extent.

It is significant to note that the development of the Grand River in its course from near the site of Grand Rapids, eastward to its confluence with Maple River, was dependent entirely upon the successive retreatal stops of the Saginaw lobe as it gradually back-stepped into the Saginaw Bay. During the interval when the moraines of the deployed group of moraines was being laid down, the Grand River channel was a shallow and poorly defined drainage crease in the surface of the glacial drift. Melt waters from the retreating glaciers flowing as border drainage along the outer margin of the ice sheet, especially during the intervals when the slender moraines north of the valley were being constructed, contributed appreciably to the volume of flow in the newly forming Grand River. Thus the channel was extended and deepened progressively as the Saginaw ice melted. The development of the Looking Glass River as border drainage along the margin of the ice when the Portland moraine was forming increased the volume in the Grand River and was to a large degree responsible for the early development of its present valley.

A further recession and subsequent long halt of the Lake Michigan and Saginaw-Huron lobes was responsible for the formation of the Port Huron morainic system extending from Port Huron and Saginaw Bay, north and westward to Grand Traverse County. This feature which forms the backbone of the glacial structures in the state was constructed when only the borders of Michigan were covered by ice. This strongly developed morainic system shows evidences of a long halt of the ice sheet before it finally left the surface of the Southern Peninsula in the late Wisconsin stage.

The last stand of the ice, as it was retiring from the surface of the Southern Peninsula and before it retreated into the Straits of Mackinac, is represented by the slender Cheboygan moraine which is well marked along the shore of Lake Huron immediately west of Cheboygan.

THE DEVELOPMENT OF THE GREAT LAKES

No story of the glacial history of the state would be complete without giving some consideration to the development of the Great Lakes. Michigan is situated in the center of the area of ice activities which caused the initiation, successive changes, and final growth of the lakes. As has already been stated, the Great Lakes basins occupy the sites of preglacial rivers. Into these old and established drainage depressions the continental ice mass sent out its various tongues or lobes which scoured and deepened the valleys into broad troughs.

The Great Lakes were first formed as small lakes in front of the glacier. As the tongues of ice in these broad troughs melted, the melt water collected in those parts of the troughs which were in front of the ice, thus forming lakes which were hemmed in behind morainic ridges, with shores in ice on the glacierward side. As long as the waters did not rise above the moraines or find an outlet through them, the lakes persisted. Like lakes of the present time these old glacial lakes produced shore lines, beaches, sand bars and other lacustrine features which can be traced on the present land surface. As lakes of today dry up and leave their shore lines and beaches above former water levels, so the water of the glacial lakes was drained out and left traces of former shores and beaches for us to read today. The length of time the glacial lakes existed is shown by the size and "strength" of old lake shores and beaches. Because of their level relief and relative width, the glacial lake beach ridges in Ohio, Indiana, Illinois, Wisconsin and Michigan are often utilized as sites for highway construction. As the oscillating ice front melted farther and farther back toward the centers of radiation more of the troughs were exposed and filled with melt water and the lakes increased in size. They attained their present size only after the ice lobes had completely withdrawn from the basins and drainage adjustments had become fully established. Following is a discussion of the ancestors of the Great Lakes in the order of their formation and appearance as the glacier melted northward from the continent.

Lake Maumee

The earliest lake to develop in the Great Lakes area was related to the melting of the ice front of the Erie lobe eastward from the position of the Fort Wayne moraine. This lake developed in the Maumee basin of northwestern Ohio and neighboring parts of Indiana and is referred to as Lake Maumee (Fig. 4). According to Leverett, this lake came into existence about 30,000 years ago. In its early stages, it was confined in a small basin situated between the Fort Wayne moraine and the ice front then standing on the Defiance moraine. The water level of this early basin as shown by shore lines stood at an elevation of 785 feet or 212 feet above the level of present Lake Erie. The drainage outlet was through a narrow valley or col in the moraine which led past Fort Wayne, into the Wabash River and thence south into the Mississippi. A narrow arm of this early lake extended along the border of the ice to the vicinity

of Ypsilanti where a remnant of the shore may be traced along Summit Street at an elevation of approximately 800 feet.

In its early stages, Lake Maumee occupied a relatively small depression, but as the glacier oscillated in retreat the basin was progressively enlarged with the result that the water level was forced to drop as is evidenced also by beach and shore features.

When the ice melted back and uncovered the area on the "Thumb" near Imlay City, the waters of the expanded lake Maumee found a new outlet about 35 feet lower than the Fort Wayne channel and then the waters of the lake flowed out through the "Imlay channel," at an elevation of 750 feet. From the Imlay channel the drainage water was carried west-

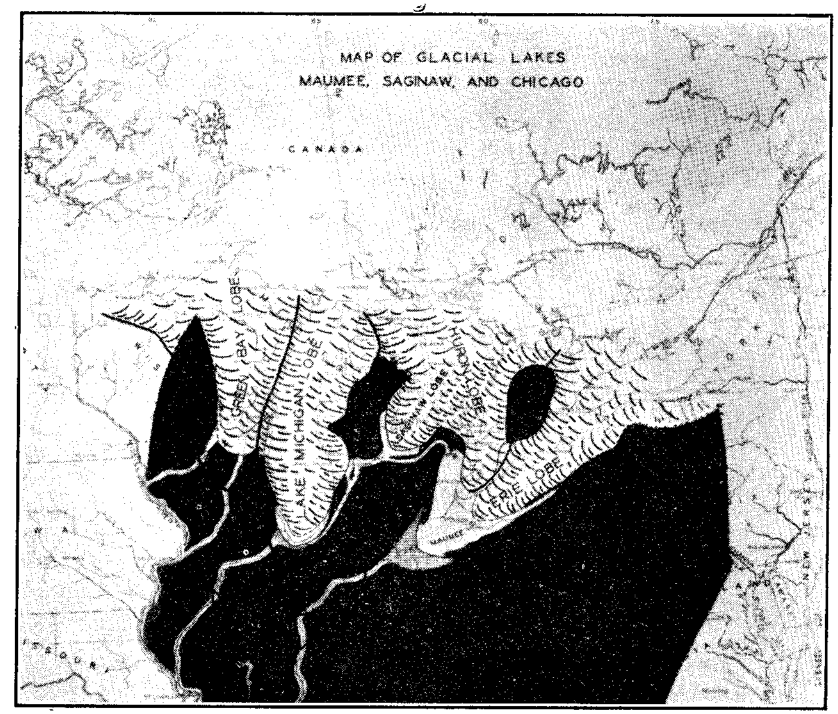


Figure 4.—Map Showing Lake Development in the Maumee Stage. (Modified after Leverett and Taylor).

ward down the Flint River valley past Flint and finally into the Grand River near Lyons. Thence by this drainage way, it flowed into Lake Chicago, the predecessor of Lake Michigan, near the present site of Grand Rapids. This ancient river which drained the ancestor of Lake Erie, is now a valley much too large for the swamp and the small streams now occupying and flowing through it.

During the Imlay outlet stage of Lake Maumee, the ice border rested on the Flint-Mayville and St. Johns moraines. When the ice of the Saginaw lobe finally melted back into the Saginaw basin sufficiently far to expose a land surface with a general slope toward it, lake waters accumulated between the ice and the westward margin of the trough to form early Lake Saginaw. This lake found an outlet through Maple River near Maple Rapids from whence it discharged its waters into the Grand River at Lyons and thus westward across the state to Lake Chicago. Shore features in the early Saginaw lake plain show the Maple River outlet to have stood at an elevation of 730 feet or 20 feet below the Imlay outlet of Lake Maumee.

Lake Arkona

In the next episode of lake history the ice front withdrew altogether from the "Thumb" of Michigan and another lake, Arkona, came into existence. The ice margin retreated to a position some 25 miles north of Bad Axe, the waters of the expanded lake Maumee fell to the level of Lake Saginaw and gradually merged with it. The drainage waters of the lake went around the "Thumb" and found an outlet through the Maple River into the Grand River. The highest beach of Lake Arkona stands at an elevation of 710 feet above sea level at the outlet. Down cutting by the large river which drained lake Arkona through the Grand River channel lowered the water plane to 694 feet. Lake Arkona was of short duration. It was not drained but a readvance of the ice over the "Thumb" separated the waters in the Saginaw and Erie basins, destroyed Lake Arkona and raised the level of the water in the Erie basin to form a larger lake which is named Lake Whittlesey.

Lake Whittlesey

During the Whittlesey stage the ice front maintained a temporary position on the main moraine of the Port Huron system (Fig. 5). The section of the moraine between Vassar in Tuscola County and Bentley in northern Bay County stood in 50 feet of water. At that time the Erie lobe had melted back to the position of Lake Ontario and formed the Erie-Ontario lobe which was separated from the Huron lobe, the ice in the Huron Basin, by an island of exposed land some fifty miles or more across, located in Ontario (See Map, Figs. 4, 5).

The waters of Lake Whittlesey discharged northward through the Black River embayment (the first stage of lower Lake Huron) along the outer border of the Port Huron moraine (now in Sanilac County) and found an outlet near the site of the village of Ubly, Huron County. From here the drainage was directed westward through the channel now occupied by the Cass River into independent Lake Saginaw where it eventually found its way out to the Grand River by way of Maple River. The highest beaches of Lake Whittlesey stand at an elevation of 740 feet. Before the close of this stage, however, the Maple River channel was deepened by scouring and the lake level dropped to 735 feet.

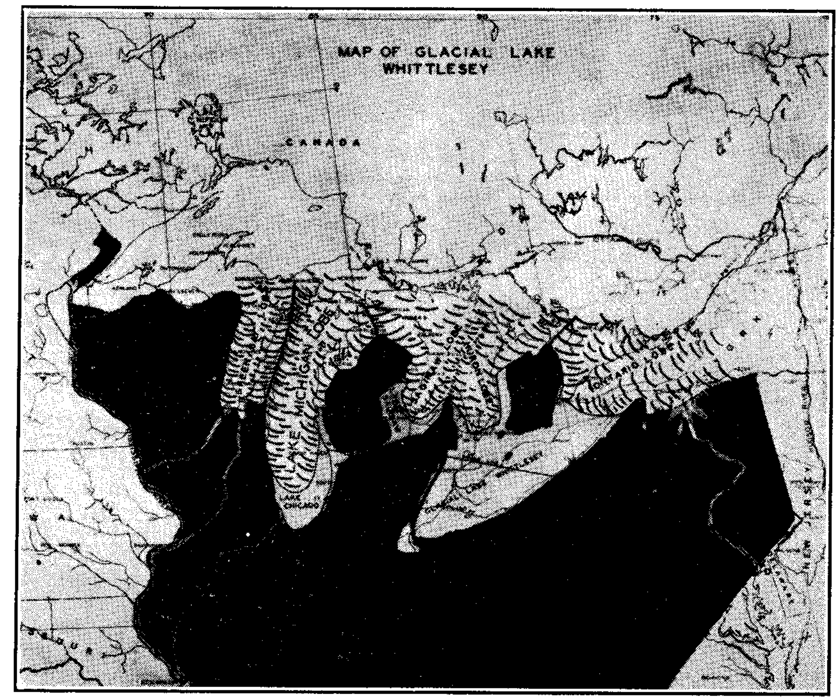


Figure 5.—Map Showing Lake Development in the Whittlesey Stage. (Modified after Leverett and Taylor).

The water of Lake Whittlesey was maintained at the level of the Ubly outlet only while the ice front rested on the Port Huron moraine. That the ice maintained this position for a relatively long interval, is manifested by the strong beaches and distinct shore features which may be traced for miles along the Lake Huron side of the "Thumb" in eastern Michigan. When the glacier finally retreated up the "Thumb," the lake level dropped so low that no water could discharge through the Ubly outlet.

When the large lake Whittlesey occupied and overflowed the Erie Basin the ice of the lake in the Lake Michigan trough had melted back far enough to uncover a small basin at its south margin which was filled with water from the melting ice to form Lake Chicago. The ice still filled the Superior basin but had started to melt slightly in the vicinity of Duluth forming Lake Duluth (Fig. 5). Small fingers of ice extending out from the Ontario lobe in New York, found their way into river valleys which were gradually sculptured into Finger Lakes. These had an independent drainage southward through the Susquehanna River into the Atlantic.

Lake Wayne

Lake Wayne, so named because its beaches are prominent at Wayne, Wayne County, followed Lake Whittlesey. It formed when the ice of the Ontario lobe in the east melted back to uncover a portion of the Mohawk valley. The Ubly outlet was abandoned and the drainage of

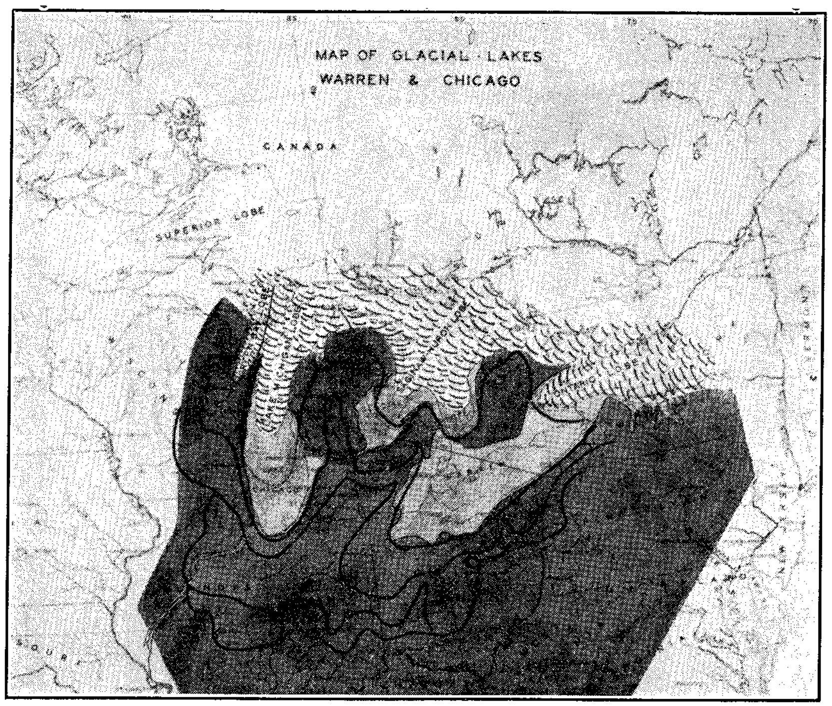


Figure 6.—Map Showing Lake Development in Warren Stage. (Modified after Leverett and Taylor).

the lake was directed eastward along the edge of the ice past Syracuse, New York, and into the Mohawk to the Hudson River. During this stage, the Finger Lakes of New York were also connected with the main line of drainage. This is the first occasion in the history of the Great Lakes that the drainage was eastward and the Grand River was not utilized for discharge. A slight readvance of the ice in the east, however, soon blocked the Mohawk outlet and brought the Wayne stage to a close.

Lake Warren

Lake Warren which followed Lake Wayne was formed in the Erie Basin when the ice barrier stood slightly north of Alpena in Michigan and south of Rochester in New York (Fig. 6). Its waters merged with those in the Saginaw basin and gradually expanded to include the water in the Huron-Erie basin as well. The western outlet was again lower than the New York-Mohawk outlet and the discharge from the lake was around the "Thumb", into Lake Saginaw and out through the Maple River. Thence westward by way of the Grand River drainage line to Lake Chicago. The Warren beach stands at 670 to 680 feet above sea level or merely a few feet higher than the outlet except in that area to be discussed later where continental uplift has upcanted the beaches like the lift of a trap door.

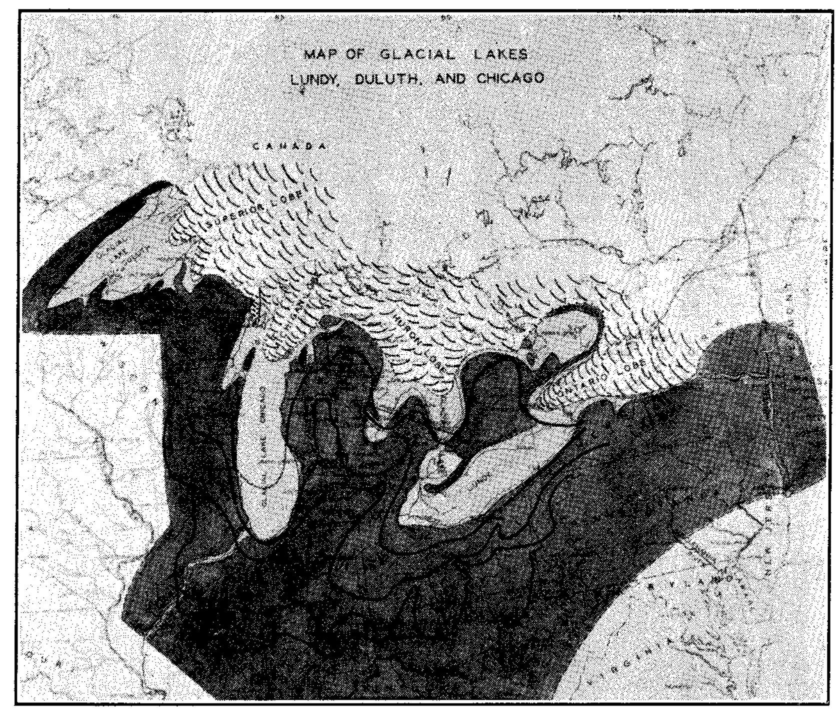


Figure. 7.—Map Showing Lake Development in Lundy Stage. (Modified after Leverett and Taylor).

Lake Lundy

Lake Lundy which followed Lake Warren was relatively short lived and was merely transitional to the succeeding stage, Algonquin (Fig. 7). In the Lundy stage the ice barrier had retreated to a position north of Alpena in Michigan and rested between the Niagara escarpment and

Lake Ontario in the region of Niagara. The outlet was similar to the outlet of Lake Wayne, as the ice in the east had retreated northward sufficiently far to again open the Mohawk outlet past Rome, New York, and so permit drainage in the direction of the Hudson River. Owing to the opening of a lower outlet, the Lundy lake level dropped to between 620 and 640 feet. Later, with the complete withdrawal of the ice sheet from the lowland area south of Ontario, the waters of Lake Lundy were drawn down to a level which uncovered the cliff at Niagara over which the waters spilled and allowed Niagara Falls to come into operation. This is the first evidence of discharge through the Lake Erie to Lake Ontario route. At the Lundy stage in the Erie-Huron Basin Lake Chicago in the Michigan Basin had enlarged northward about to Charlevoix and Lake Duluth filled the western part of the Superior Basin.

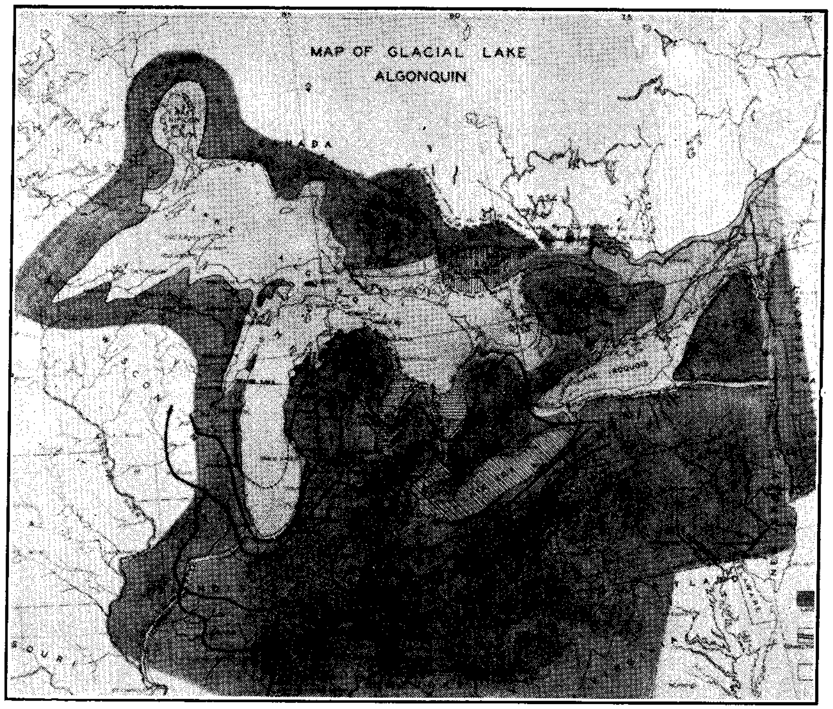


Figure 8.—Map showing Lake Development in Algonquin Stage. (Modified after Leverett and Taylor).

Lake Algonquin

The last of the glacial lakes is known as Lake Algonquin. This stage followed Lundy and represents the greatest expansion of water in the development of the Great Lakes depressions. The great mass of ice had entirely melted from the Great Lakes region. The various lakes in the different basins were merged into one vast body of water (Fig. 8), Lake Algonquin. In the culmination of this stage, the lake extended northward to include the Nipigon basin in Canada. The eastern lowlands of the northern Peninsula excepting a few small islands were submerged. During this stage the Strait of Mackinac was opened to connect the overflow lakes in the Superior, Huron, and Michigan basins.

As the weight of the ice was removed from the northern part of North America the continent began to rise, to be uptilted along several definite "hinge lines" much as a trap door is upcanted along its hinges. From Algonquin time to the present this upcanting of the continent has caused changes in the Great Lakes. These uplifts in Algonquin time caused several changes in drainage in the Algonquin lake history. An early outlet of Lake Algonquin was opened at Kirkfield, Ontario, soon after the ice had withdrawn from the Superior Basin. The discharge was then carried from Georgian Bay (of the Lake Huron Basin) through the Trent Valley to the Ontario basin and Lake Erie was cut off from the northern lakes. As differential uplifts continued, the Kirkfield outlet was raised so high that it soon became abandoned. For a short interval following the closing of the Kirkfield outlet, the discharge of the lake was divided more or less between lower outlets at Chicago and to the Mississippi and at Port Huron and back to Lake Erie and the Atlantic. At Chicago, a sill of resistant limestone effectively slowed up the process of downcutting. At Port Huron, the drainage waters passed through an area of less resistant clayey material which was readily eroded. Consequently, the Port Huron outlet was soon lowered below the Chicago outlet and the discharge from all the lakes was diverted wholly into the Port Huron line of drainage.

The beaches of Lake Algonquin which must have been level and horizontal when made present striking evidence of the uptilting of the continent. In the area of horizontal beaches south of the hinge line which crosses the state approximately from Port Huron to Manistee, the beaches of higher Lake Algonquin stand at a level of 607 feet above the sea. But at Kirkfield the shore features are at an elevation of 883 feet above sea level which means that in the distance from Port Huron to Kirkfield, the land has been raised 276 feet by differential uplift. Farther north, in the region of Georgian Bay, and the north shore of Lake Superior, the region has been raised at least 600 to 700 feet. In the high morainic hills south of Munising, the highest Algonquin shore is found at an elevation of 948 feet above sea level and a few miles south of Grand Marais, the morainic bluffs show evidences of Algonquin shore work to an elevation of 890 feet. At Grand Marais, however, the successive lower Algonquin beaches can readily be traced and show definitely the progressive changes in lake level which have taken place.

Throughout the different intervals of Lake Algonquin history, variable volumes of water flowed across the Niagara Falls. At first, when the upper lakes used the Kirkfield outlet, the Niagara River carried only the discharge of Lake Erie, which was then about 15 per cent of the present volume. Finally, as the Port Huron outlet assumed control of the drainage, a full volume of flow by this route resulted. The effects of the changes in Lake Algonquin drainage are readily observed in the gorge of the Niagara River in the section between Lewiston, on the original escarpment, and the whirlpool.

Lake Nipissing

When the glaciers had retreated northward well beyond the border of the Superior basin, the land was raised to the point where the Kirkfield outlet was permanently closed. A new and lower outlet was opened at North Bay with discharge into the St. Lawrence River by way of the Ottawa River. Thus was initiated the post-glacial or Nipissing stage of lake history.

The Nipissing Great Lakes occupied the basins of Lakes Huron, Michigan, and Superior. Lake Erie was independent of the upper lakes during the time they discharged through the Kirkfield and Ottawa River outlets. The Nipissing shore is well formed and may be easily traced along beaches which stand at an elevation of 595 feet, above sea level. Continued uplift of the land north of the hinge line eventually raised the North Bay outlet sufficiently high to close it to further discharge. The water was then directed southward into the St. Clair and Port Huron outlets and the present lake stage with its drainage through the Niagara and St. Lawrence Rivers was introduced. In this stage, Michigan attained her present physiographic complexion.

During the interval of maximum glacier invasion, the millions of cubic miles of ice resting upon the surface of the continent exerted a tremendous weight upon the rock formations below. This pressure was sufficient to cause depression of the entire Laurentian plateau with an ultimate downwarping estimated at 800 to 900 feet in the region north of Lake Superior. The downwarping of the continental block allowed salt water of the Atlantic Ocean to invade the Hudson and St. Lawrence Valleys and drown the basin of Lake Champlain and the upper end of Lake Ontario. This inundation is commonly referred to as the Champlain Marine stage. A series of clays was deposited in the waters during this stage and in the clays the remains of a few animals which could exist in cold sea water, a sub-arctic fauna, are found. The partial skeletons of two whales recently discovered by Dr. E. C. Case of the University of Michigan, in the bogs overlying glacial deposits along the

Huron shore in Michigan suggest a possible open route from the ocean to the fresh water lakes through which the whales migrated inland, but does not imply that the Great Lakes were once bodies of salt water.

The final removal of the vast sheet of continental ice and the consequent release of pressure due to melting has allowed the depressed region to partially recover its original attitude. (Fig. 10). Differential uplift, which began possibly with the first recession of ice in the Wisconsin stage, is still in progress—a fact which seems to bear out the conclusion that the recovery has not been completed. At present, the

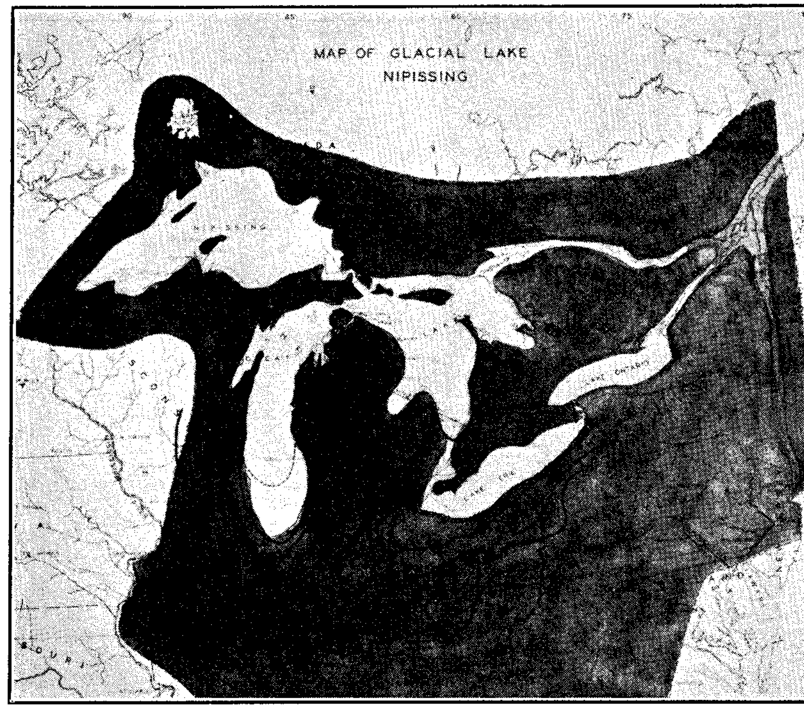


Figure 9.—Map Showing Lake Development in Nipissing Stage. (Modified after Leverett and Taylor).

land is rising at the rate of 10 inches per hundred years, or one-tenth of an inch per year for each hundred miles of distance north of the Algonquin hinge line. (The line extends as stated earlier from near Port Huron across the State to Manistee.)

The effect of the continued uplifts has been to tilt, and in some places to split, the beaches of the Algonquin and Nipissing Lakes. The amount of tilting to which Michigan has been subjected since the Algonquin Lake stage may be readily measured by comparing the present elevation of its beaches in various localities. In the area of horizontality, where

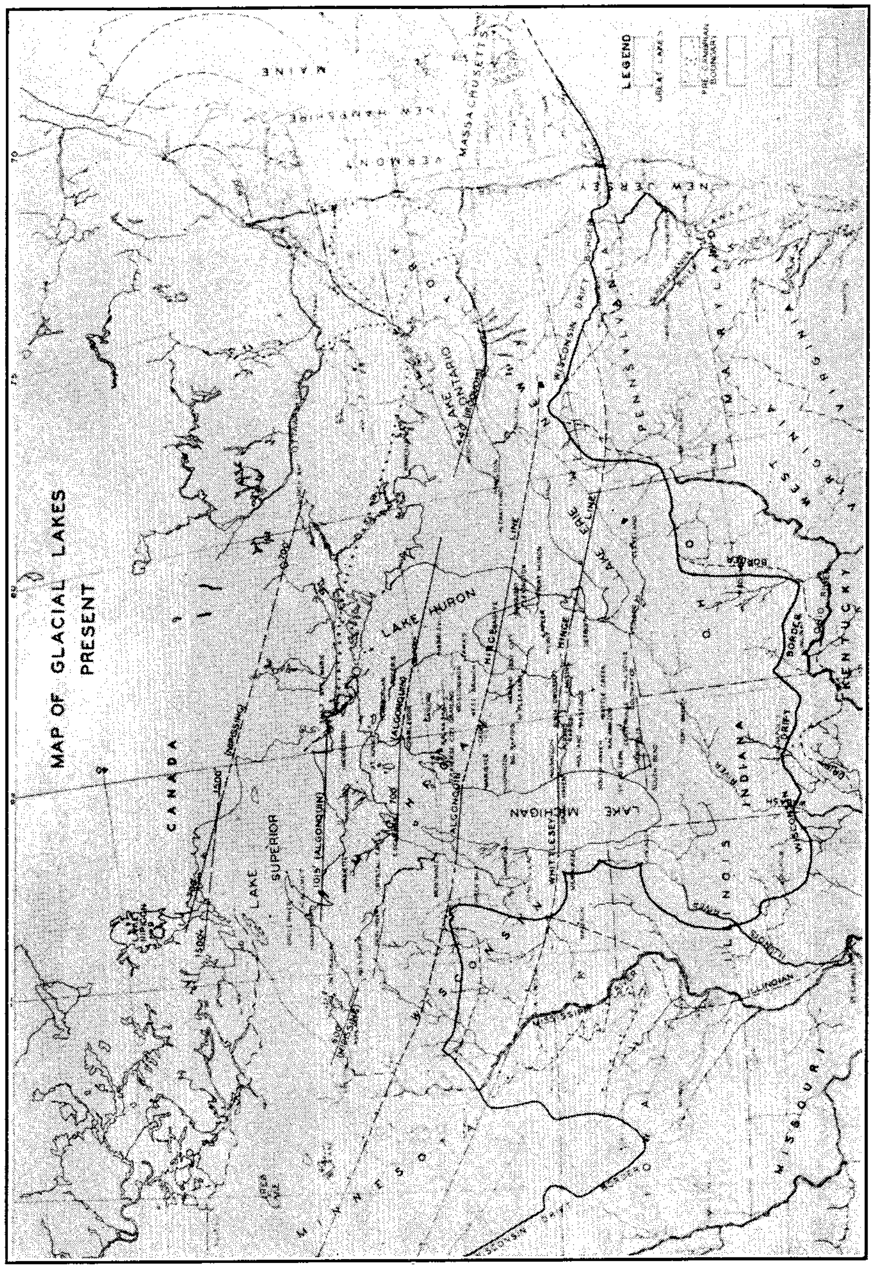


Figure 10.—Map showing position of hinge lines of uplift and present Great Lakes. (After Leverett).

no uplift has taken place, near Manistee on Lake Michigan, the highest Algonquin shore stands at 607 feet. Six miles north of the Canadian Soo, the same shore is found at 1015 feet. At Port Huron, on the east side of the state, the highest Algonquin beach stands at an elevation of 606 feet. On Mackinac Island, in the Straits, the same beach rises to 809 feet.

The Nipissing beaches likewise show the effects of differential uplift, but on a much smaller scale. In the area of horizontality near Manistee, the Nipissing shore has an elevation of 595 feet. At Sault Ste. Marie, the same shore stands at 651 feet—which evidences an uplift of 56 feet in a distance of 160 miles. At Port Huron, the elevation of the Nipissing beach is 595 feet, but at Cheboygan it is 31 feet higher, or 626 feet.

The main portion of this paper reports on an area which is within the region of the Algonquin and Nipissing Great Lakes.

SYNOPSIS

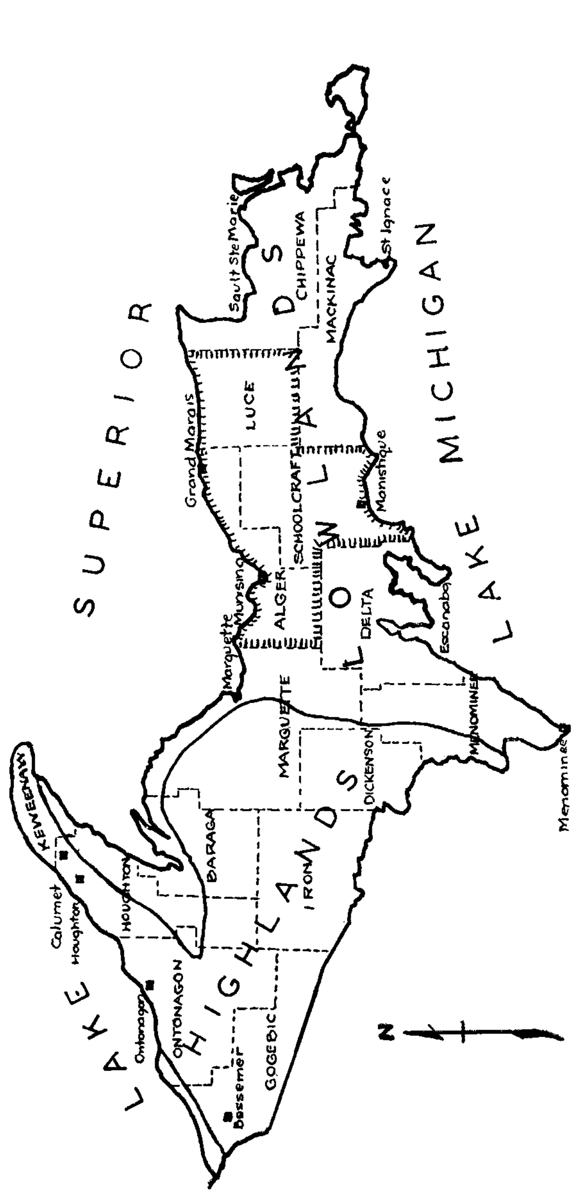
The Belted Lowland province of the northern Peninsula (Fig. 11), extending from the meridian of Marquette eastward, presents a variety of complex problems in the light of Pleistocene glaciation. This area was the locus of development of the Green Bay and Michigan lobes during the maximum extension of the late Wisconsin ice sheet. Later it became the center of renewed activity in the readvance of the independent lobe from the Lake Superior basin shortly before its final withdrawal from the surface of Michigan.

When the ice of the late Wisconsin stage finally withdrew to the north far enough to uncover the Superior region, the lowlands were inundated almost completely by the waters of Lake Algonquin. A very small proportion of the province had a relief sufficiently high to extend above this water plane. Consequently, the surface deposits left upon retreat of the late Wisconsin ice sheet were, in large measure, influenced by water and wave activity, with the result that they were subjected to widespread and differential modifications.

Moraines which were covered by the lake waters have lost, to a large degree, the characters and features possessed when laid down by the waning ice sheet. The crests were smoothed down, flattened out and in many places, reduced to level plains. Slopes of the stronger systems were washed down, subdued and subsequently became mantled with a thin veneer of lacustrine sand, which locally obscures the original till. In those areas where the moraines have lost their identity as definite features of relief, it is still possible to determine the sites upon which they originally stood, by the presence of till remnants and concentrated erratics; except where the modifying cover has developed to such a depth as to completely mask the former surface.

Post Algonquin drainage ways developed in the region, have successively cut through the morainic systems and dissected them to such a degree that they now stand as dismembered units, often widely separated by low-lying swampy and marshy tracts. The disconnected and water-modified moraines are thus difficult to trace and much of the field evidence, necessary to a satisfactory and complete interpretation of the glacial problems involved, is entirely lacking.

The successive water levels, developed along the prograding shores of glacial Lake Algonquin, are marked, either by definite wave-cut features where the water level was held up for a comparatively long interval, or, by aeolian shore ridges where retreat was more rapid. Many of the retreatal halts in shore recession were centered on morainal plains and



MAP SHOWING PHYSIOGRAPHIC PROVINCES OF THE UPPER PENINSULA AND THE LOCATION OF AREA INCLUDED IN REPORT.

FIGURE II

slopes. Here the primary relief became masked by shallow deposits of lacustrine sand which in turn was spread out locally in the form of low, wind-blown waves and ridges of variable extent.

The relief of the Belted Lowlands in the eastern half of the northern Peninsula is relatively quite low. The elevation, in general, does not exceed 250 feet above the Great Lakes, except in restricted areas where it may rise considerably above this level. The low character of the topography is reflected in the extensive tracts of poorly drained marshy, sandy plains and muskeg which abound in this region.

The largest and most continuous area of swampy lowland in the northern Peninsula lies in the drainage ways of the Tahquamenon and Manistique Rivers, confined largely within the borders of Alger, Luce and Schoolcraft counties. This region presents features which are characteristic of the Belted Lowlands as a whole, and unquestionably holds the key to a proper understanding of the problems involved in the Pleistocene glaciation of the province. The drainage basins of the Tahquamenon and Manistique Rivers lie almost wholly within the region which was invaded by a readvance of the Superior lobe of the Labrador ice sheet, following the break-up of the Michigan lobe, late in the Wisconsin stage of Pleistocene glaciation. This lobe moved from the northeast and followed a course which was directed largely by the pre-glacial depression of Lake Superior. The general direction of the ice movement was to the southwest, but it is evident from glacial striae in the eastern portion of the Peninsula, that there was also a southward trend, which was responsible for much of the glacial activity in this area.

The work of the glacier in this region was performed largely in the receding hemicycle of glaciation as stated by Hobbs (1). This is evidenced by the fact that previous to the readvance of the Superior lobe, tongues of ice representing the Green Bay, Michigan, and Huron lobes, which formerly deployed over vast areas in southern Wisconsin and Michigan, had withdrawn from their basins and become broken up completely.

In its readvance, the ice sheet removed much of the older residual soil and weathered rock waste which had accumulated through protracted periods of erosional activity. The bed rock surfaces were planed and scored and large blocks, frozen to the sole of the ice, were plucked out and moved with the glacier. Old valleys, which had been chiseled out of solid rock by pre-glacial streams and rivers, afforded natural thoroughfares for the movement of the ice tongues. They were consequently deepened and widened by the plucking and gouging activity of the deploying ice mass; the higher ridges and exposed rock areas were smoothed down to a large degree and the features in general suffered a decided reduction in relief. In the process of deglaciation which was induced by recession of the ice sheet, due to dissipation of its marginal areas, there was spread out over the rock pavement a mantle of glacial drift of variable thickness and composition. The pre-glacial valleys were filled quite completely with debris deposited by the waning ice.

The continued wasting of the glacier caused the ice front to retreat farther and farther to the northeast and allowed a slow uncovering of the basin of Lake Superior. The water from the melting ice, collecting in the growing basin, gradually filled it to overflowing and initiated glacial Lake Algonquin, a predecessor to Lakes Superior, Michigan and Huron. In the highest stage, this lake spread its waters over the greater portion of the Tahquamenon-Manistique drainage area, and was responsible for a multitude of changes in the surface expression of the region.

The complete withdrawal of the ice from the east end of the Superior basin opened up the Kirkfield outlet in Ontario and allowed the waters of Lake Algonquin to drain through the Trent Valley. The outlet past Port Huron was likewise functioning during this stage of lake history with the result that drainage was affected both to the east and to the south. The lowering of the Algonquin lake level eventually caused the waters to split along the divide between the present northward flowing Tahquamenon and southward flowing Manistique drainage ways. The parting of the Algonquin waters is definitely evidenced by the complete reversal of slopes in the east-west trending dune ridges on either side of the divide.

The final dissipation of the ice sheet in the Lake Superior basin resulted in a decided reduction of ice weight on the land surface. Differential uplift and tilting, as described by Gilbert (2), Goldthwait (3), Fairchild (4), and Spencer (5), raised the superior region several hundred feet above the normal plane. Taylor (6) ascribes the uplifting movements as due to resilience following depression by ice weight and also to crustal creep. This change in elevation was responsible for decided modifications in drainage and resulted in the development of broad, swampy, and poorly drained tracts along the borders of north-flowing streams. The southward flowing rivers, on the other hand, were simultaneously increased in gradient and, due to rejuvenated erosional power, proceeded to excavate their channels more deeply into the sandy lake floor.

The initiation of fluvial activity on the newly emerged land surface, coupled with the successive lowering of the water level in the slowly receding lake,. brought on a new set of geologic conditions. Aeolian activity became a prominent factor and translocation by the wind of sand from the river flats, newly formed lake beaches and terraces, resulted in the piling up of innumerable sand dunes and ridges. These in turn

caused diversion and blocking of river courses, with the ultimate result that the drainage systems became completely deranged and extensive swampy and marshy tracts developed. Thus, the surface features became woven into an intricate and extremely complicated pattern of undifferentiated complexes, at times very difficult to interpret.

INTRODUCTION

The field work, which represents the basis for this report, was pursued during the field seasons of 1928, 1929, 1931, and 1932. The work was carried on in connection with the Land Economic Survey which was attempting to obtain a complete inventory of conditions in certain northern counties.

The territory under consideration is, for the most part, a heavily timbered wilderness and facilities for travel are in places quite limited. All of the passable roads as well as many old railroad grades, grown over logging trails and abandoned tote roads, were traveled by automobile. Hundreds of miles of trails were followed on foot and much of the inaccessible area was covered by the ordinary pace and compass method.

In the field work of Schoolcraft County covered during part of the season of 1931 and all of 1932, a complete set of aerial photographs which were of considerable aid in working out the many details of surface structure and tying the features in to the general land net, were at the writer's disposal. These photographs prepared by the aerial parties of the United States Geological Survey were later assembled into mosaics by the State Geological Survey for use in the field.

The problem herein discussed suggested itself in connection with the complications involved as the field work progressed. The area in question seemed to contain the key to the interpretation of the surface geology of the low swampy areas which constitute such a large portion of the Lowlands province in the eastern half of the Northern Peninsula.

Known elevations were obtained from profile maps of established railroad grades. These served as the basis for running elevations by means of aneroids. The aneroid readings were checked and rechecked on the established known points and corrected each day from the records of the barograph which was located in the main camp.

ACKNOWLEDGMENTS

The author is greatly indebted to Professor I. D. Scott whose visit into the field during the summer of 1930 prepared the way for the solution of some of the intricate problems involved in the aeolian geology of the Manistique drainage basin. Also, for many valuable suggestions received from him during the progress of the work. Dr. Frank Leverett has checked the manuscript and maps and otherwise offered expert opinions concerning certain areas which seemed in the field to have very obscure geological relationships. The author is grateful to Dr. W. H.

Hobbs for suggestions and criticisms which have been offered from time to time and for his constructive interest in the problem. Dr. R. A. Smith, State Geologist, has made valuable contributions concerning field methods, and through the course of the work has shown keen interest in the developments. It is largely through his efforts that it was possible to carry the field work to completion. In field and office, Mr. L. R. Schoenmann, of the Land Economic Survey, has imparted important information concerning many features of the problem as related to soil classification. His keen observations in the field, together with the sound interpretations always made of them, have been of utmost value in checking personal conclusions.

The author wishes to express thanks to the directors of the State Geological Survey and the Land Economic Survey for the use of field equipment of all descriptions, maps and photographs which were always made available. No small amount of credit is due the men of the Land Economic Survey field crews who through the four seasons of field work have contributed much information concerning corners, boundaries, swamps, lakes, and a multitude of other features. Space does not permit the listing of the names of the many individuals who have thus shown an interest. Mr. O. F. Poindexter, of the State Geological Survey, has offered valuable suggestions in the field, and also made checks on elevations in various parts of Schoolcraft County. The drafting of the final maps from the field sheets has been the work of Allerd W. Bergquist, to whom the writer desires to express appreciation. To Miss Helen Martin who has so painstakingly edited the volume, the author is greatly indebted.

Chapter I

THE TAHQUAMENON DRAINAGE SYSTEM

GENERAL CONSIDERATIONS

Approximately 40 per cent of the total area of 910 square miles in Luce County is covered with poorly drained swamps, marshes, and low-lying sand plains. The greater portion of this region lies within the Tahquamenon drainage basin.

The Tahquamenon River rises in a series of glacial pit lakes in T. 47 N., R. 12 W., in Luce County, at an altitude of approximately 800 feet above seal level or 200 feet above Lake Superior. For a distance of ten miles from its source, the river flows generally southward, through an extensive outwash plain, a few miles east of the county line. Near the center of T. 46 N., R. 12 W., the river swings abruptly eastward, into the swampy depression, and continues in that direction across the county. Thence it turns northward, and leads out of the county in the northeast corner of T. 48 N., R. 8 W. Its waters are finally discharged into Whitefish Bay in Lake Superior, near Emerson, Chippewa County.

For much of its course in Luce County, the river flows through an extensive, poorly drained lowland, composed largely of organic matter resting upon lacustrine sand and underlain at varying depths with a reddish-colored, plastic lake clay. Many tributary streams, most of them small, gather their headwaters at the margin of this lowland and at times contribute considerable volume to the main river. Some of the larger streams of this system are fairly well developed and reach back for considerable distance beyond the swamp. The broad interstream areas are low, swampy, and poorly drained. The drainage pattern is not at all systematic, but rather, extremely haphazard in development.

From the point where its course turns eastward in T. 46 N., R. 12 W., and for a distance of fifty miles, to the Upper Falls, the river descends 26 feet. Eight feet of this fall is concentrated in a distance of three-fourths of a mile above the falls and probably represents the amount of down cutting since the rock barrier was cut through. The average gradient of the river above the Upper Falls is less than 6 inches to the mile. The channel is shallow and poorly confined, and in the periods of heavy rains and melting snows does not begin to accommodate the vast volume of water which is brought to it by the tributaries from the water soaked, spongy lowland tracts. Consequently, during the flood seasons the water overflows the channel banks, backs up into the drainage ways

PLATE I

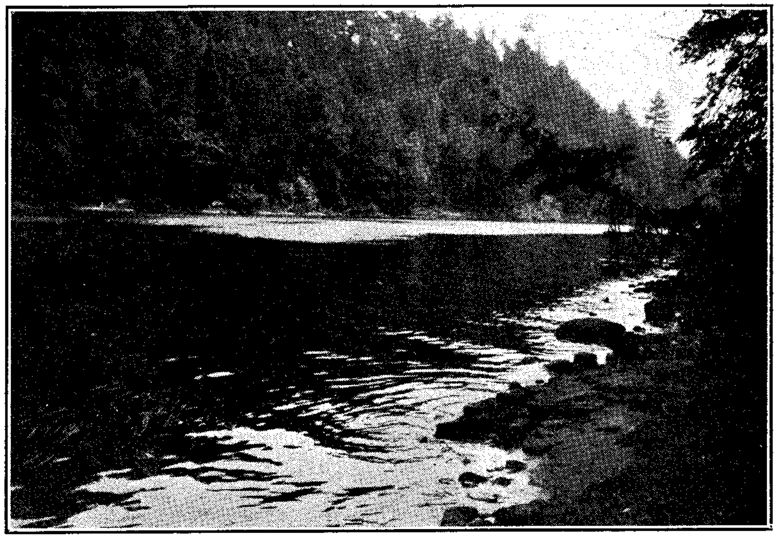


Figure 1.—Tahquamenon River above the Upper Falls.

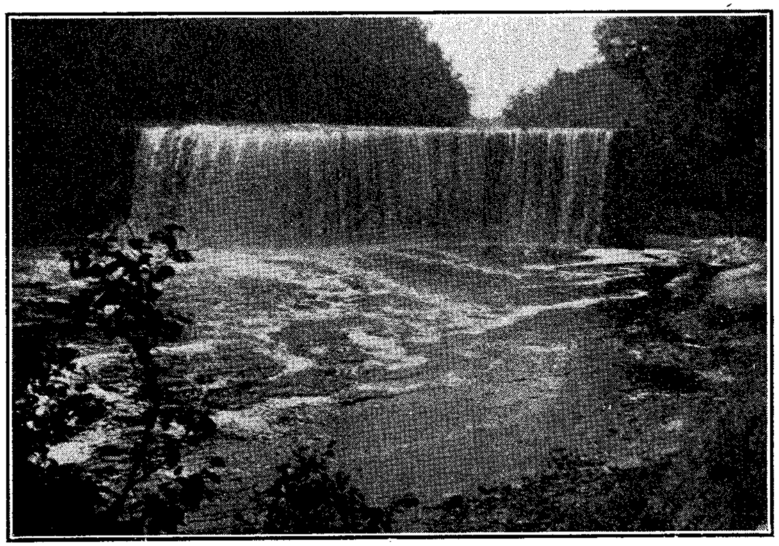


Figure 2.—The Upper Falls of the Tahquamenon River.

and spreads out over the low interfluves to form extended shallow lakes. (Plate I, Fig. 1)

At the Upper Falls, (Plate I, Fig. 2,) in Section 11, T. 48 N., R. 8 W., the river plunges over a forty foot ledge of Cambrian sandstone and for some distance below is carried through a narrow gorge which has been sculptured out of the same material (Plate II, Fig. 1). In this area the gradient is much steeper, being approximately 7 feet to the mile, in the distance of four miles between the base of the Upper and the crest of the Lower Falls. Its velocity in the gorge is very great and its cutting power at a maximum. The elevation of the crest of the Upper Falls, as determined by Wisler (7), by means of levels, is 694 feet. The Lower Falls in Chippewa County stand with the crest at an elevation of 626 feet and drop 20 feet to a level just 4 feet above the water plane of Lake Superior.

The watershed between the Tahquamenon and Manistique drainage systems lies near the line between Luce and Schoolcraft counties, a short distance north of Danaher, on the Duluth South Shore and Atlantic Railroad. The divide is in the swamp at an altitude of 720 feet, or approximately 120 feet above the level of Lake Superior.

Late in Algonquin time, the Tahquamenon depression provided a drainage connection between the Superior and Lake Michigan basins. The discharge waters from the upper basin were carried through the narrow strait, north of McMillan, across the divide and south into the Manistique River system. This outlet remained open until the level of Lake Algonquin was depressed to a plane below the level of the divide. At this stage in late Algonquin time, the two drainage systems were separated; the Tahquamenon waters were diverted into Lake Superior and the Manistique drainage leading southward into Lake Michigan.

The early development of the Tahquamenon basin is associated with geologic activity which antedates the glacial epoch. The present valley occupies in part an old broad, pre-glacial trough, (Plate II, Fig. 2), which had been excavated quite deeply into bed rock before it was invaded by Pleistocene glaciation. The old depression was fairly well filled by deposits left as the ice retreated and also by subsequent alluviation. It became the site for the present river shortly before the waters of the Superior basin had reached the Nipissing stage.

The southern border of the Tahquamenon basin is confined by the steep, northward facing slope of the Niagara cuesta. This escarpment, which forms the south wall of the basin in Luce County, (Fig. 12) has played a very important role in the geologic development of the eastern half of the Northern Peninsula. It forms the backbone structure of the section and is also the axis of Green Bay peninsula in Wisconsin. The Tahquamenon depression bears the same general relationship to the escarpment

PLATE II

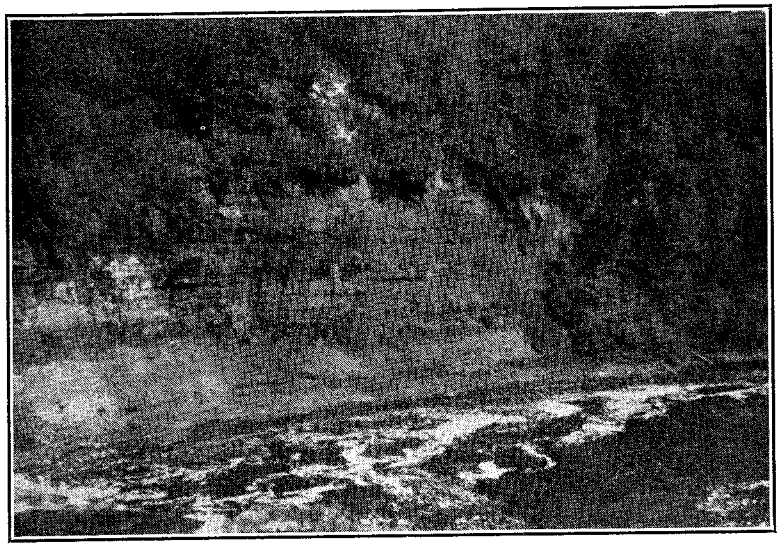


Figure 1.—Sandstone Gorge below the Upper Falls of the Tahquamenon River.

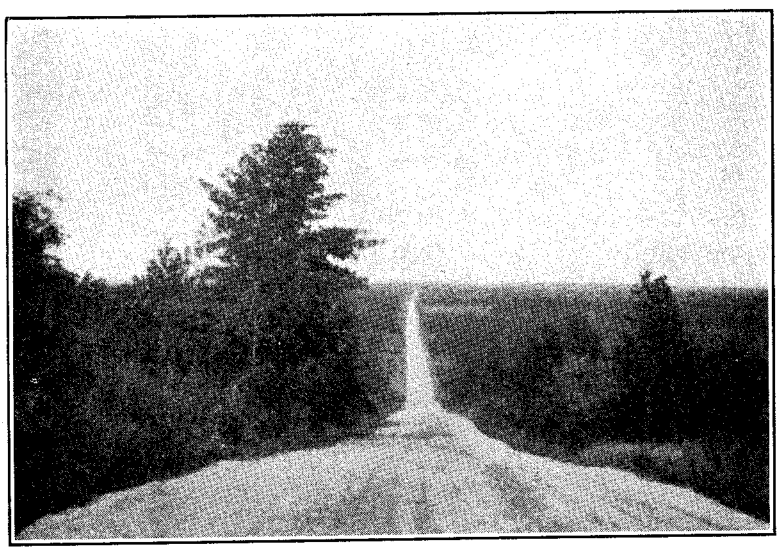
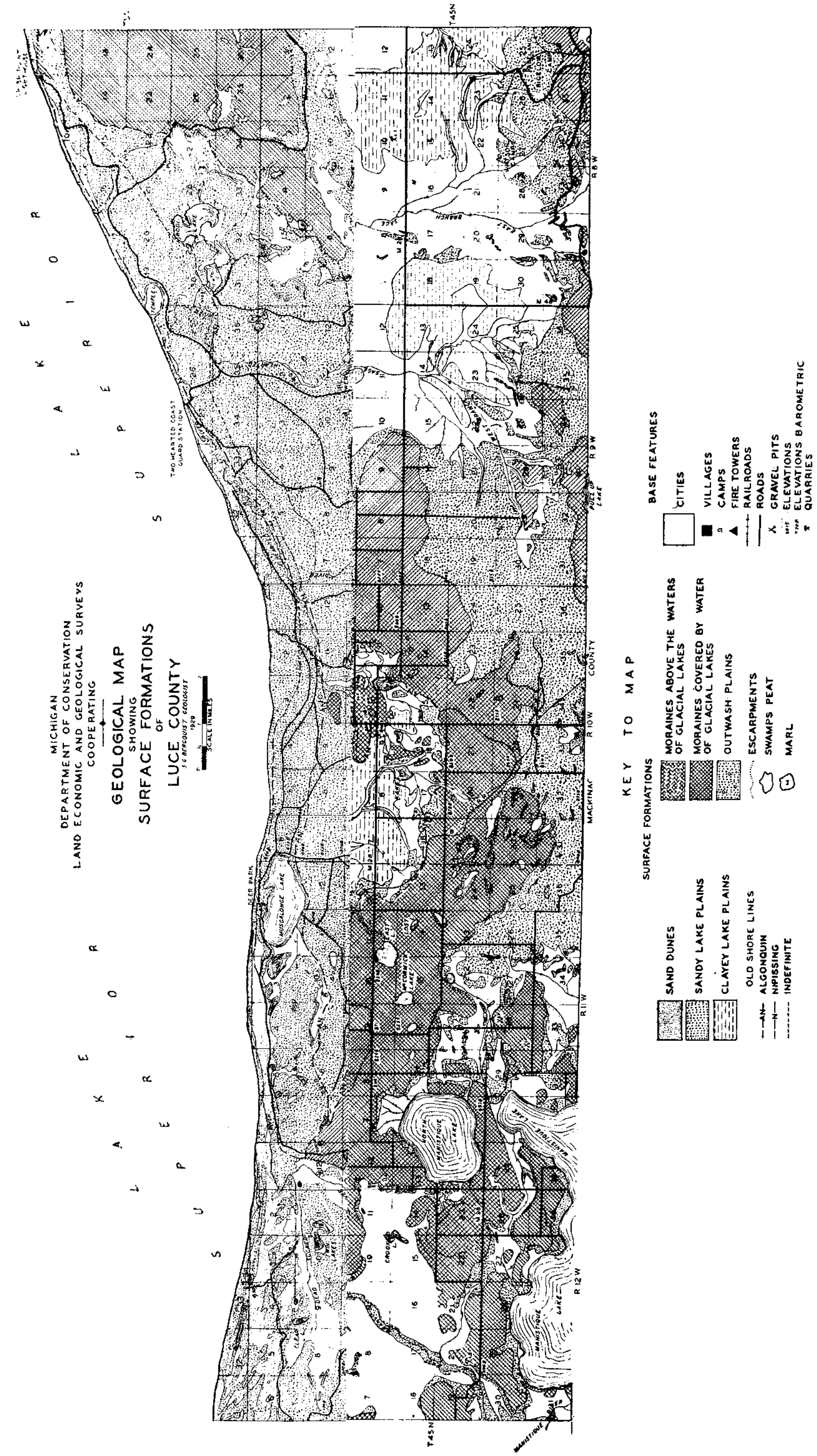


Figure 2.—Looking north across the Tahquamenon Basin from the crest of the Niagaran Escarpment, just north of Hendricks Quarry.

Geological Survey Division
Pub. 40 Geol. Ser. 34. Part I Fig. 12



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Geological Survey Division
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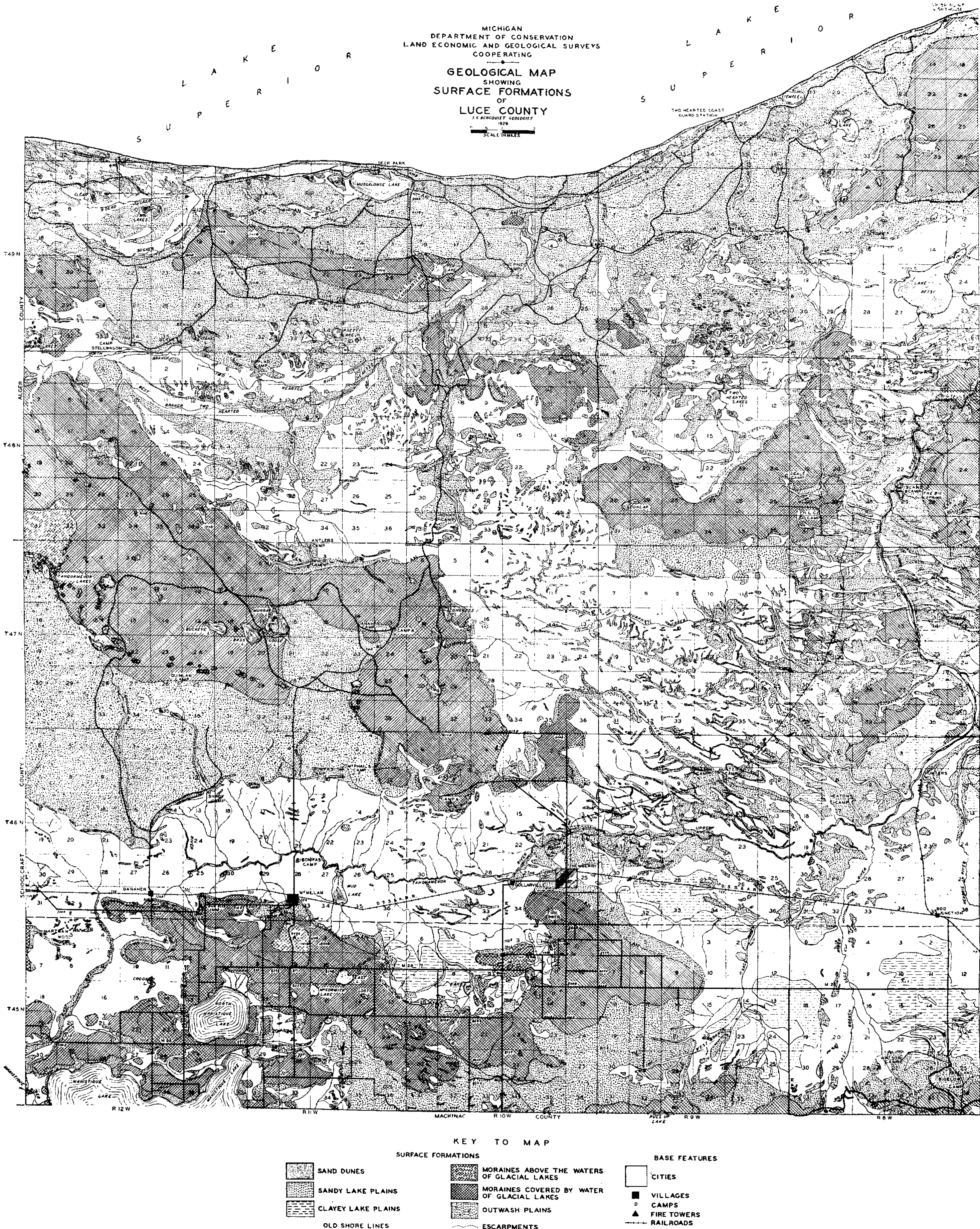

in Luce County as does the Green Bay depression to its adjoining peninsula farther south. In fact, the two depressions are somewhat continuous and possess a similar geologic origin and general structure.

The differential uplifts, which strongly affected the region during later Algonquin time, raised the rock ledge at the Upper Falls and caused a decided reduction in the upstream gradient of the river. The velocity was decreased to such an extent that degradational processes were largely terminated. The waters of the river became impounded behind the slowly rising rock barrier and were forced to spread out over the bordering lowland tracts for considerable distances back from the channel. An extensive shallow lake, thus formed in the drainage basin of the river, became the locus for sedimentation of material carried in from the higher uplands by various tributaries. Through the ingrowth of hydrophytic vegetation, the lake gradually assumed a swampy condition and became the site for successive accumulations of peat and muck.

Throughout the major swampy lowlands of the Tahquamenon and other drainage areas, an intricate system of sandy ridges and narrow plains has developed. The ridges range in size from a score of feet, to several miles in length, and from a few feet, to twenty and more feet in height. They are composed essentially of subangular grains of quartz sufficiently small to be easily transported by the wind. The ridges are not always uniform in composition and often grade into coarse sand and gravel towards their bases. In many cases they are coarse textured throughout the entire structure.

The general trend and arrangement of the ridges, together with the texture of the material contained in them, suggests an aeolian origin. Many of the ridges possess the contrasted leeward and windward slopes so characteristic of dunes. The gravelly sections of the ridges, however, are of lacustrine deposition and were probably formed as off-shore deposits along the margin of the receding Lake Algonquin. It seems logical to assume then, that the numerous ridges have had a two-fold origin and were formed by the wind blowing the finer sand up into definite features from the old water laid beaches. The transverse dunes which cross the Tahquamenon valley have their steep, leeward slopes directed universally to the south, a feature which would suggest a northward retreat of the Algonquin waters.

Along the borders of the swamps, and especially where they merge with the higher glacial features, sandy tracts have been shaped into relatively smooth, level plains. These are sometimes perched rather high up on the slopes of moraines and outwash plains, up to elevations of 750 to 800 feet. McMillan and Newberry, situated on the inner border of the outer morainic system, are both located on such a sandy plain.

The sandy ridges and narrow plains which ramify through the swampy areas, are generally covered with a growth of pine and other vegetation. They afford more or less connected thoroughfares of travel for both man and animal, through an otherwise unbroken jungle. They also provide sites for camps and shelters for hunters and trappers who invade these areas. The ridges furnish fairly suitable material for the construction and maintenance of such roads as penetrate the wilderness in this region.

In general, the areas of muck are so low and poorly drained that they cannot be utilized for agricultural purposes. Some of the clayey deposits, especially those which are high and fairly well drained, have been planted to alfalfa and clover with good results. These heavier soils, however, retain so much moisture and remain cold for such longer periods in the spring, that early planting is very difficult.

Several other drainage systems, in no way allied to the present Tahquamenon basin, but, nevertheless, important because of their association with lowland areas in Luce County, will be given brief consideration in this text. They include in order of importance:

A. The Two Hearted River System.
B. The Little Two Hearted River.
C. The Sucker Basin.
D. The Shelldrake Drainage System.

A. THE TWO HEARTED RIVER SYSTEM

The Two Hearted River has its headwaters in a series of swamps in a region north of the Munising morainic system in T. 48 N., Rs. 11 and 12 W. The river follows a northeasterly course through tracts of low swamps and higher sandy lake plains, and discharges into Lake Superior in T. 50 N., R. 9 W. This river system drains an area of 230 square miles, all in Luce County, and maintains a rather constant flow throughout the year. In its upper reaches, the river leads through an extensive swampy lowland. In the lower half of its course, through the old lake plain, it has incised its channel quite deeply into loose sand and is lined with rather steep banks. For a distance of about five miles back from its mouth, the river almost parallels the shore of Lake Superior and is prevented from directly entering the lake by a row of low sand dunes which fringe the shore.

The Two Hearted drainage system, like that of the Tahquamenon River, was greatly disturbed by the differential uplifts which affected the region. The gradient of this river was likewise reduced and the velocity and erosive power retarded. Unlike the Tahquamenon River, however, there was no rock threshold near its outlet to hold the waters back. Consequently, the river, able to deepen its channel, has not suffered the various relapses which mark the history of the Tahquamenon River.

B. THE LITTLE TWO HEARTED RIVER.

This river has its source in the group of Two Hearted Lakes in T. 48 N., R. 9 W., and drains an area of approximately 75 square miles in the northeastern part of the county. It is a more or less independent river and has relatively few tributaries and branches. The flow is generally northward, across a low, sandy lake plain and it empties into Lake Superior in T. 50 N., R. 9 W., a few miles east of the outlet of the Two Hearted River.

From near its headwaters, the river swings with a broad bend in a northeasterly direction around a group of lakes which are concentrated in the S. E. ¼ of T. 49 N., R. 9 W. These lakes apparently occupy the site of a former morainic surface, probably a continuation of the Munising morainic system which has been eroded down, possibly by stream as well as by lake action.

C. THE SUCKER BASIN.

The Sucker Basin, in the northwestern corner of Luce County, carries the waters of the Blind and Dead Sucker rivers and drains an area of 45 square miles in the County. These two rivers have very low gradients, are somewhat stagnant in flow and bordered by broad areas of low swamp. They are separated from each other by a low, sandy interfluve of sufficient elevation to have held in the waters of Lake Nipissing. No definite shore line features are traceable along this divide, however; all evidence having been erased by subsequent water action.

The south rim of the basin is marked by a steep, wave-cut escarpment, with a crest at an altitude of 730 to 750 feet. This wall served to hold in the waters of the receding Lake Algonquin as it reached its lower stages. The north edge of the basin is hemmed in by a series of dunes and sandy ridges which rise to a height of 75 to 100 feet and more above the level of Lake Superior.

The basin has been subjected to a considerable amount of scour by water action during its occupation by lakes, and still more recently by the rivers which have occupied the basin since glacial times. Differential uplifts in the region have been largely responsible for the reduction of the gradient of the rivers and also for the development of the extensive mucky areas which are enclosed by the basin.

D. THE SHELLDRAKE DRAINAGE SYSTEM.

In the northeastern corner of Luce County is an area of about 24 square miles which lies in the headwaters of the northeastward flowing Shelldrake River. This river is an independent one and has the bulk of its water-shed in the adjoining areas of Chippewa County. The greater portion of the Shelldrake drainage system in Luce County is in the region of Betsy Lake where it taps a broad, swampy, fringing lowland area.

LAKES

Several hundred lakes, most of them small and many merely ponds, are scattered through the county. They reflect an origin which is intimately associated with the activities of the glacier and lie within areas of moraines, outwash plains and lake plains. Very few lakes are found in the swamps along the major drainage ways.

Lakes which have been formed in the morainic areas are referred to as *morainal* types. They occupy depressions set in between the knolls and ridges of the more rugged topography. They are generally bordered by upland slopes which may afford favorable sites for resort development. Manistique and North Manistique lakes are the largest basins of this character; others of smaller size are widely distributed through the several morainic systems. Lake basins of this type were formed either by the gradual melting of detached blocks of glacier ice which had become buried under glacial debris, or through a process of "push and dump" by the glacier. Many of the depressions not occupied by water, were likewise formed in this manner and give character to the swell and sag expression of the surface.

Lakes which occupy the outwash and lake plain areas are generally referred to as *pit lakes*. They have a geological origin similar to that of the kettles in the moraines and often are so numerous as to give to the surface a pitted relief. Pit lakes are commonly bordered by level tracts of sandy material and are usually not so deeply depressed as are the basins in the moraines. Several large depressions of this type are located in the level plain to the north, among them being Muscalonge, Bodi, Temple and Pike lakes. Lakes of this character have a fairly good bottom and shore except where their margins have been encroached on by the ingrowth of vegetation and the deposition of peat.

Occasionally, lakes were developed with basins partially set in between morainic ridges and adjoining outwash plains. Such forms are classed as *fosse* lakes. They differ from the other types merely in position with reference to surface features; geologically, they have a similar origin. Some of the Tahquamenon lakes along the west border of the middle morainic system and others such as Murray and Goose lakes farther east present this feature.

Lakes which are situated in the drainage ways are generally bordered with low swampy tracts which make them almost wholly inaccessible.

Mud Lake, north and east of McMillan, and lake Betsy in the northeastern part of the county, are good examples.

The lakes in Luce County have a potential recreational value which is rather difficult to evaluate. They are visited each summer by hundreds of tourists who enjoy their settings in the timbered wilds. One of the chief obstacles in the way of extensive resort development among these lakes is the lack of facilities for getting to them. Roads, in certain parts of the county are entirely lacking and many of the lakes may be reached only after hours of travel over undeveloped trails, which stretch through the wilderness. With a good system of passable roads and a definite conservation policy of stocking the lakes with fish, it is quite certain that many such isolated areas would furnish playground and recreational facilities for many thousands of tourists who now are not familiar with the region.

SWAMPS AND MARSHY TRACTS

Swamps, marshes, and muskeg cover about 347.62 square miles or approximately 39 per cent of the surface in Luce County, with a distribution in the various townships as indicated in the table below.

Township	*Square Miles*	*Township*	*Square Miles*
T. 45 N., R. 8 W.	19.58	T. 48 N., R. 8 W.	9.62
T. 45 N., R. 9 W.	12.75	T. 48 N., R. 9 W.	12.05
T. 45 N., R. 10 W.	7.09	T. 48 N., R. 10 W.	22.40
T. 45 N., R. 11 W.	6.81	T. 48 N., R. 11 W.	23.36
T. 45 N., R. 12 W.	16.81	T. 48 N., R. 12 W.	11.08
T. 46 N., R. 8 W.	22.45	T. 49 N., R. 8 W.	18.19
T. 46 N., R. 9 W.	22.63	T. 49 N., R. 9 W.	5.04
T. 46 N., R. 10 W.	20.68	T. 49 N., R. 10 W.	2.57
T. 46 N., R. 11 W.	23.28	T. 49 N., R. 11 W.	.96
T. 46 N., R. 12 W.	16.87	T. 49 N., R. 12 W.	9.24
T. 47 N., R. 8 W.	10.44	T. 50 N., R. 8 W.	1.97
T. 47 N., R. 9 W.	26.41	T. 50 N., R. 9 W.	—
T. 47 N., R. 10 W.	22.71	T. 50 N., R. 12 W.	—
T. 47 N., R. 11 W.	2.05		
T. 47 N., R. 12 S.	0.58		

Some of the swampy areas are filled-in lakes of rather small dimension but generally the swamps occupy regions of underdeveloped drainage and are restricted to the low lying flats along the river systems. The swamps are unusually level and for the most part covered with shallow deposits of peat and decaying vegetation. Clay of a very tight and impervious character underlies the poorly consolidated peat in much of the lowland tract, and is responsible to a large extent for the high position of the water table and the soggy condition of the surface.

The higher outer borders of the swampy lands are generally quite heavily wooded and give growth to pole-size and often log-size trees of tamarack, cedar and spruce. The lower inner reaches, along the stream margins, on the other hand, are quite generally grown up to a tangle of alder and other low brush which makes travel exceedingly difficult. Some of the swamps are quite open and may well be classed as muskeg. Blueberries seem to find a desirable habitat in the drier open bogs and furnish a reasonable source of income to a fairly large number of people during the short season in the late summer. Many of the more poorly drained lakes and basins are margined with quaking bogs and are thus inaccessible. The drainage lines in the lowlands are not sufficiently developed to carry off the surplus water during protracted periods of heavy rains and melting snows, with the result that a large portion of the area cannot be adapted to agricultural purposes. In view of the impossibility of developing much of the land for the production of farm products, it seems that its future value lies principally in the maintenance of a forest and ground cover for the protection and feeding of wild life and the growing of timber.

The swamps have a very high capacity for absorbing water and serve as reservoirs to regulate the flow into the rivers, thus preventing excessive floods which might otherwise occur.

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Chapter II

THE MANISTIQUE DRAINAGE SYSTEM

MANISTIQUE RIVER

Manistique River, which drains the greater portion of Schoolcraft County (Fig. 13), is one of the largest streams in the northern Peninsula. It has a drainage area of about 1,400 square miles, situated mostly in the great Manistique swamp, of which it forms the eastern margin. The main stream follows a general southwesterly direction and enters Lake Michigan at the city of Manistique.

Numerous parallel tributaries, with headwaters occasionally reaching back into the Munising Moraine, within a few miles south of the Lake Superior shore, flow southeastward across the sandy, marshy lowland and enter the trunk stream almost at right angles. These flow with fairly good gradients down the warped slope of the low, marshy lake plain and supply a large volume of water to the main river.

Several large lakes, among the largest in the Northern Peninsula, are tributary to the Manistique River and contribute appreciably to its flow. The most noteworthy of these lakes, the Manistique, with an area of 15.8 square miles, the Whitefish with 6.4 square miles, and the Indian with an area of 13 square miles, have been described in detail by Scott (8).

The main course of the Manistique, from its headwater confluence with the East Branch of Fox River and Fox River, (Plate III, Figs. 1 and 2), follows closely along the eastern edge of the extensive marshy lowland. Throughout much of its distance, the river flows through a poorly drained, marshy, lake plain, and has trenched a fairly well defined channel into the loosely consolidated, spongy floor. In its more youthful upper reaches, where the gradient is higher and the velocity more rapid, the stream has succeeded in maintaining a relatively straight course. In its older, lower stretches, on the other hand, the river braids across the marshy, sandy floor in a series of broad meanders. Many of the larger bends have been entirely cut off and stand as oxbow lagoons, filled with water. The condition of stagnation which was responsible for the development of the meanders and cut-offs, to such a large extent in the lower course of the river, may be traced back to Nipissing times. Miss Stevenson (9) mentions the fact that the Nipissing shore which extends as a spit nearly to the outskirts of Manistique, turned the Manistique River westward. The development on this spit, of a row of dunes, piled up to a height of approximately 100 feet above Lake Michigan has been responsible, to a large extent, for the maintenance of this course from Nipissing

PLATE III

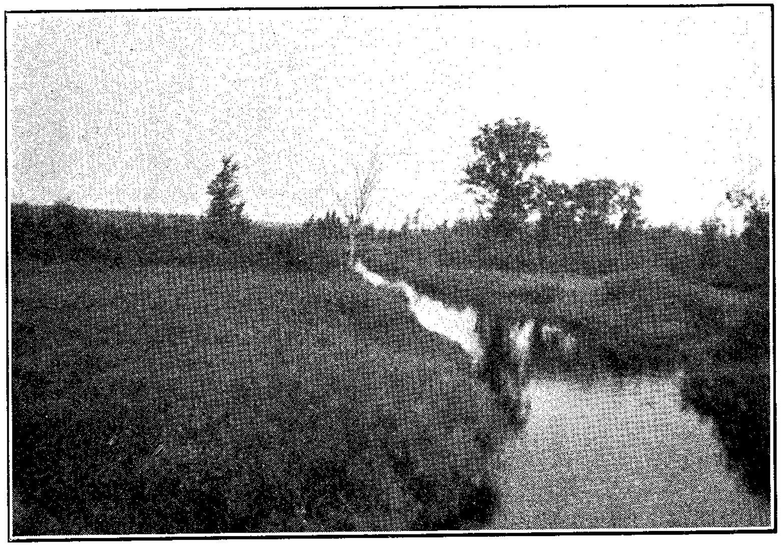

Figure 1.—East Branch of the Fox River, one of the headwaters of the Manistique River, in a muskeg swamp. Sec. 33, T. 45 N., R. 12 W.

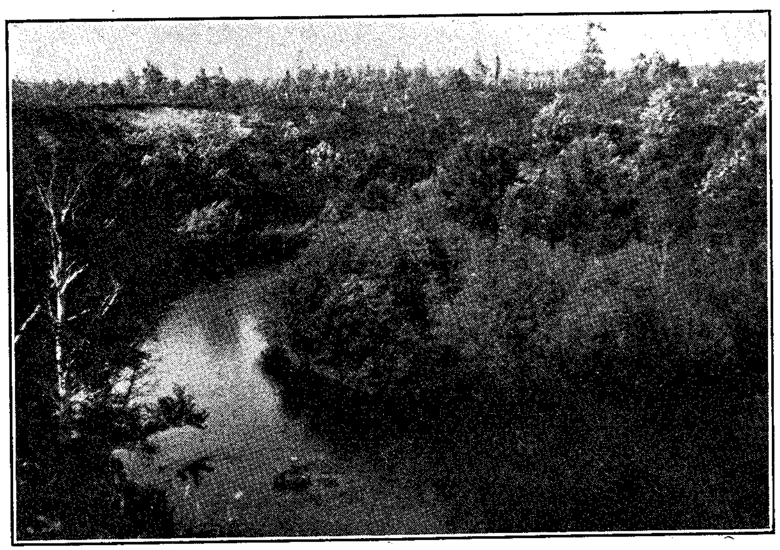

Figure 2.—The Fox River, near its headwaters, valley incised in a sandy outwash plain. Sec. 21, T. 47 N., R. 14 W.

times to the present. That the water was ponded behind the Nipissing spit is evidenced by the extensive stagnant slough which extends westward from the shore cliff.

The Algonquin uplifts, which were responsible for the damming of the north-flowing Tahquamenon, had a counter effect upon the Manistique and other south flowing rivers. The headwater reaches of this large river system were more greatly affected by the differential movements and were thus raised correspondingly higher than were the lower stretches. This caused the gradient and likewise the velocity to become increased, with the result that downcutting, rather than widespread flooding, was initiated. In its distance of 68 miles from source to mouth, the Manistique River has a total fall of 115 feet. This represents an average gradient of 20 inches per mile as compared with 6 inches per mile for the Tahquamenon above the upper falls.

The numerous tributary streams of the Manistique River flow in a southerly direction across the tilted floor of glacial lake Algonquin. They are roughly parallel in their courses and, like the master river, are bordered by extended tracts of low lying poorly drained marshes and muskeg beset with wind-blown ridges of sand.

Several of the tributaries, including the East and West Branches of Fox River, Driggs Creek, Marsh Creek and the various headwater limbs of the West Branch of the Manistique River, have extended their valleys back to the outer slope of the Munising moraine, in Alger County. Many of these streams flow for a distance of 25 to 30 miles across country before finally joining the Manistique. They drain the numerous morainal and pit lakes which are distributed through much of the upland watershed.

As has previously been inferred, the Manistique River did not come into existence as an independent drainage way until the Lake Algonquin waters had receded to about the level of the Nipissing stage. The Newberry morainic system, which now borders the swamp in fragmentary and disconnected units, was at that time no doubt a continuous feature and served as a barrier to the slope-directed flow of the various tributaries. Consequently, the massing of the drainage water against the inner slope of the moraine, resulted in the development of the major drainage line. It is quite probable that the south end of the Hiawatha segment of the moraine temporarily dammed the waters of the river and caused a ponding behind it. The large volume contributed by the tributaries soon broke through the obstruction and found an outlet into Lake Nipissing, whose margin stood close to the outer border of the moraine in this locality.

Chapter III

GLACIAL ACTIVITY

During the time of greatest advance of the Wisconsin ice sheet, a number of individual ice tongues moved southward from the basin of Lake Superior through pre-glacial valleys which had been established by stream sculpture in the older rock surface. Two of the early lobes, the Green Bay and the Michigan, deployed across the area discussed in this report and were responsible for the development of certain glacial features which have, to some degree, been left unmodified.

FEATURES DEVELOPED BY THE GREEN BAY LOBE

The Trenary Till Plain

Position Within the Axis of the Green Bay Lobe

The till plain which occupies the southwestern part of Alger County, extending from near Eben Junction and southward through Trenary, represents but a small portion of a much larger plain which may be traced westward for a distance of six to ten miles into Marquette County, and to the Ford River, some twenty-seven miles south, in Delta County.

In eastern Marquette County, the plain is limited on the west by a border moraine which extends from near the vicinity of Marquette in a general southerly direction to the village of Bark River in T. 38 N., R. 24 W., Delta County.

On the east, the till plain is bordered by the Au Train—Whitefish drainage depression, within which lie broken fragments of a moraine, flanking in part, both east and west banks of the channel. In this locality the original moraine was dismembered by the scouring action of the river which temporarily carried the drainage from the Lake Superior basin to Little Bay de Noc in Lake Michigan during the early part of Lake Algonquin times. It is now difficult to trace the complete morainal system to its former southernmost extremity. Field evidence, however, seems to point out that the disconnected and fragmentary eastern morainic limb may at some time have connected with the western limb, and formed a sinuous and more or less continuous loop around the southern end of the till plain. Thus, this moraine marks the borders of the ice in the Green Bay lobe in its final halt during retreat, and emphasizes a definite demarcation between the drumlin-till plain area of Menominee County to the south, and the Trenary esker-till plain area to the north.

PLATE IV

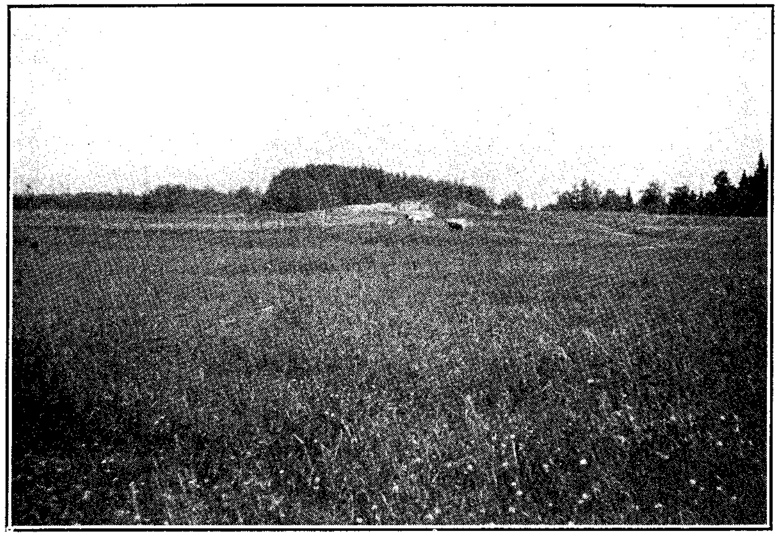

Figure 1.—Portion of Trenary till plain to the north of Trenary. Esker ridge in background.

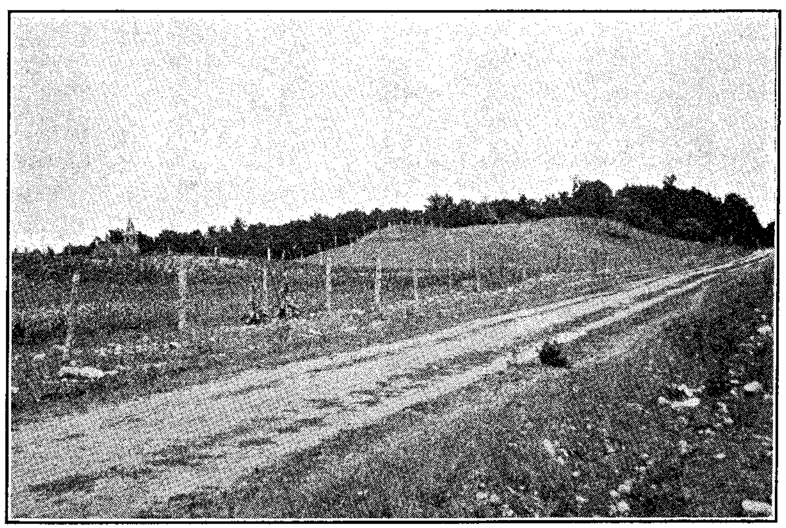

Figure 2.—Esker ridge on Trenary till plain, near Limestone.

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large erratics. A large amount of locally derived limestone and dolomite