



PART 2
SHORELINE SEDIMENT PROBLEMS



CHAPTER 5

GEOLOGIC HISTORY OF GREAT LAKES BEACHES

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ABSTRACT

The locations of the Great Lakes and many details of the lake bottom topography bear a distinct relationship to the bed rock structure. Normal stream erosion in pre-glacial time probably etched out the major topographic relief of the region, forming the major basins and even some of the present bays, in the weak rock belts.

Glacial ice, advancing over the region in several stages, followed the lowlands but reshaped them and probably deepened most of them.

The known lake history, beginning with the last retreat of the ice from the southern rims of the Michigan and Erie basins, involves a number of stages at different levels in each of the basins. These lakes discharged at various places at different times, because of readvancement or retreat of the glacial ice front and because of tilting of the earth's surface. The writer's summary of this history is illustrated by a series of sixteen maps.

The practical importance of two extremely low lake stages is pointed out. These have affected foundation conditions in the vicinity of many river mouths. The newly established recency of some of the higher lake stages (Nipissing and Algoma), and the revision of the elevations attained by them, affect estimates of the intensity of beach action and they affect conclusions regarding the time of last discharge of water through the Chicago outlet.

INTRODUCTION

Many details of the geologic history of the Great Lakes are pertinent to the study of present day shore processes and to foundation problems along the lake shores. The Great Lakes have stood at their present elevations for only a few thousand years. Recent studies suggest that Lakes Michigan and Huron reached their present elevations less than two thousand years ago. The shortness of this period should be taken into account in an evaluation of the rate of shore erosion.

COASTAL ENGINEERING

Water level in all of the five Great Lakes has been both higher and lower by considerable amounts in the past. The old higher-level stages are recorded by beach deposits, wave-cut cliffs and other features which now are abandoned. The lower stages are recorded by features such as a sand and shell zone in the deep-water clays and by deep valleys in the lower courses of rivers, now partially or wholly filled by fine-grained sediment. This fill generally constitutes poor foundation material for any major structure placed on it.

BED ROCK STRUCTURE OF THE REGION

The locations and shapes of the Great Lakes basins are intimately related to the bed rock structure. This is evident from a cursory examination of the geologic map of the region (Stose, 1946). The very old (pre-Cambrian), generally hard rocks of the Canadian shield lie north of all of the lakes and extend southward through the Superior basin into Wisconsin. These rocks include ancient sedimentary deposits, lava flows and intrusive rocks, all of which have been more or less highly metamorphosed, folded, and welded into a generally resistant mass. The shield has been worn down to a surface of low relief, and then dissected.

In the western half of Lake Superior the shores and the bottom topography are aligned parallel to the trends of bed rock structure in the pre-Cambrian shield rocks.

Outside of the Lake Superior basin, and possibly beginning in the southeastern part of that basin, the surface of the Canadian shield dips under a cover of Paleozoic sedimentary rocks.

The four lower lakes, Michigan, Huron, Erie and Ontario, lie in the Paleozoic rock province. These lake basins are elongated parallel to the strike of the rock and belts of easily eroded shale formations extend through all of the basins.

The Great Lakes basins almost certainly acquired their major topographic forms in pre-glacial time, by normal subaerial erosion acting on a variety of bed rock formations of differing resistance to erosion.

GLACIATION

It is reasonable to assume that the flow patterns of the early Pleistocene glaciers were influenced to a considerable extent by the pre-glacial topography. The ice, however, re-shaped the land somewhat by scour, deepening and smoothing the basins, as well as by deposition. Toward the end of glacial time the ice lobes conformed closely to the shapes of the present lake basins.

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The glacial stages of the Pleistocene epoch, and some of their substages, are as follows (youngest stage at top);

- Wisconsin glacial stage
 - Mankato substage
 - Cary substage
 - Fort Huron
 - Lake Border
 - Defiance-Tinley
 - Valparaiso-Fort Wayne
 - Tazewell substage (Tazewell II?)
 - Iowan substage (Tazewell I?)
 - Farmdale substage

Illinoian glacial stage

Kansan glacial stage

Nebraskan glacial stage

It is generally believed that the Nebraskan glaciation began about one million years ago. The history of lakes in the Great Lakes basins, as presented here, begins within the early Cary substage of the Wisconsin stage, at a date estimated by the writer as about 25,000 years ago (Hough, 1953b). The Mankato substage has been dated as occurring about 11,000 years ago, on the basis of radiocarbon studies (Flint and Deevey, 1951).

HISTORY OF THE LAKES IN THE GREAT LAKES BASINS

During the times between the various major ice advances of the Pleistocene epoch there may have been lakes in the Great Lakes basins, but if such existed there is no clear record of them. Our detailed record of lakes begins toward the end of the glacial period, when the last ice to completely fill the basins melted back, leaving room between the ice front and the divides to the south for impounding of water. A complicated series of lake stages followed, in which lake levels fell and rose, outlets shifted from one place to another, and sometimes back to previously used discharge channels, in response to three causes. Retreat of the glacial ice front exposed new lower outlets to the north and east, and resulted in lowering of lake levels: readvance of the ice part way into the lake basins closed the lower outlets, raised lake levels, and shifted discharge back to the south. Erosion of the beds of the outlet channels lowered lake levels. As the glacial ice front retreated to the north, uptilting of the land caused further changes in lake levels and in points of discharge.

The evidence of former higher lake levels consists mainly of abandoned beach deposits and wave-cut benches lying above the present lake shores, and of former outlet channels connected to these beaches.

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The old beaches in the southern half of the Lake Michigan basin, and in the southernmost part of the Lake Huron basin, are horizontal, indicating no tilting in these areas since the beaches were formed. Some of the older, higher level beaches rise to the north, indicating that there has been tilting of the region since those beaches were formed. The amount of uplift recorded at the Straits of Mackinac is 200 feet, and at the north side of Lake Superior and at North Bay, Ontario, northeast of Georgian Bay, the amount of uplift is 600 feet. Some evidence has been found on the bottom of Lake Michigan for a low stage of that lake.

The history of the lake stages presented in the following pages is the writer's interpretation, which is based on the work of Leverett and Taylor (1915), Stanley (1936 and 1937), Deane (1950), Bretz (1951a, 1951b), and on investigations of his own (Hough, 1953). It is emphasized that the history presented here is, in some details, almost certain to be revised as new information is obtained. The writer's proofs or arguments for many details, which are stated rather dogmatically in the present paper, are given in his report on an Office of Naval Research project (Hough, 1953).

LAKE MAUMEE AND EARLY LAKE CHICAGO

To begin the history of the lake stages we must visualize the land in the northern part of the Great Lakes region depressed, and visualize the basins filled with glacial ice. When the ice front retreated from the western end of the Lake Erie basin, a lake (Highest Lake Maumee) formed there and it discharged southwestward to the Wabash River (fig. 1). At the same time the ice front in the Lake Michigan basin probably retreated an appreciable distance northward, allowing a lake (Early Lake Chicago) to form there (fig. 1). There is no direct evidence of this lake, because any beaches which might have been developed would have been destroyed by the subsequent advance of ice in the area.

DEFIANCE AND TINLEY GLACIAL ADVANCES

A readvance of glacial ice in the Erie basin, to the position of the Defiance moraine, then occurred (fig. 2). This reduced the area of Lake Maumee but that lake apparently remained at the same elevation, about 800 feet above sea level. This advance is correlated with the advance of ice in the Michigan basin to the Tinley moraine. The Tinley ice completely filled the basin (fig. 2).

LOWEST LAKE MAUMEE AND THE GLENWOOD STAGE OF LAKE CHICAGO

The next retreat of the ice front (fig. 3) allowed Highest Lake Maumee to expand in the Erie basin, and, possibly at the same time, allowed the Glenwood stage of Lake Chicago to form in the Michigan basin.

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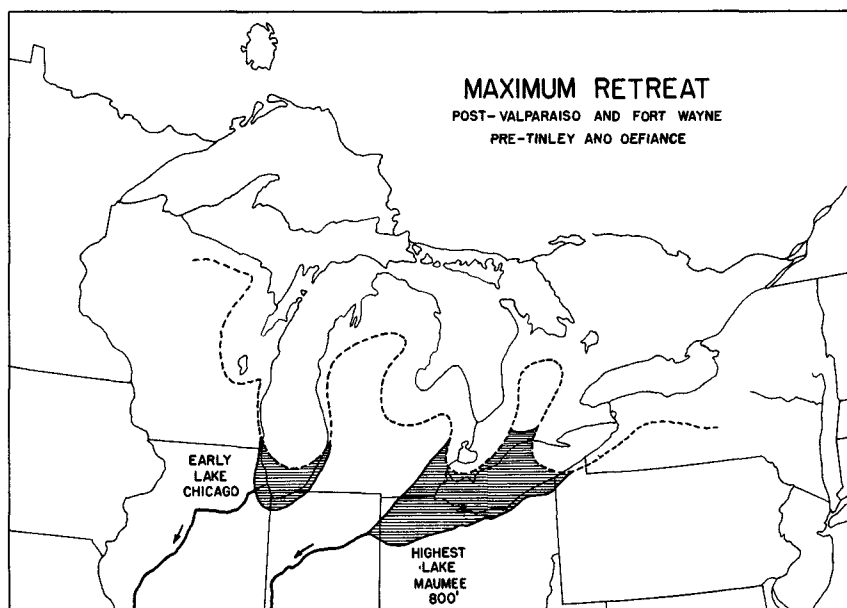


FIG. 1 - Lake stage map no. 1: Early Lake Chicago and Highest Lake Maumee.

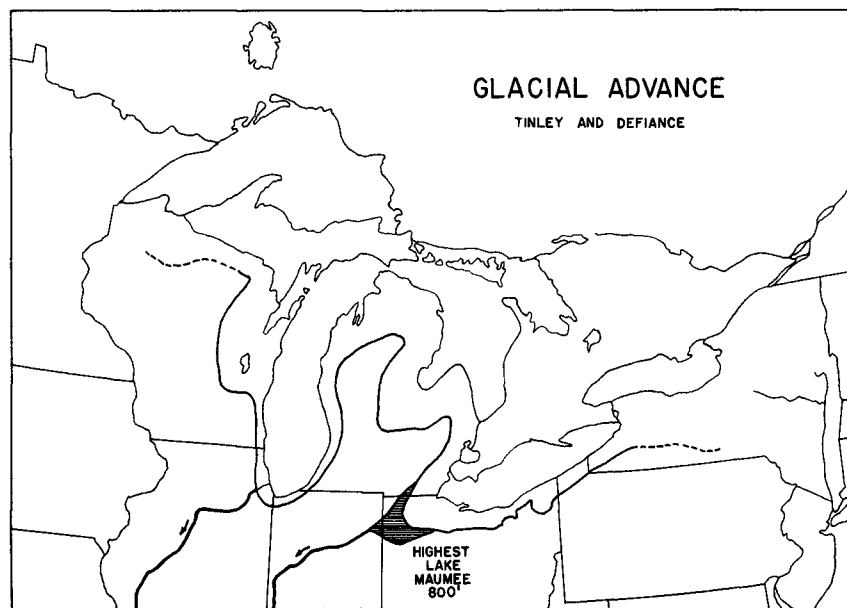


FIG. 2 - Lake stage map no. 2: Highest Lake Maumee.

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The Glenwood stage stood at an elevation of 640 feet, or 60 feet above the present Lake Michigan level, and it discharged down the Illinois River. At the time of maximum retreat in this phase of the history, Lake Maumee found a dischargeway across the "thumb" of Michigan and thence down the Grand River valley to the Michigan basin. This discharge through a lower outlet lowered the surface of Lake Maumee to an elevation of 760 feet, thus producing the second, and lowest level, Maumee stage.

LAKE BORDER GLACIAL ADVANCE AND MIDDLE LAKE MAUMEE

The advance of the ice front to the Lake Border moraines of the Erie basin (fig. 4) produced the third Maumee stage, at elevation 790 feet. This was accomplished by the ice front riding up the "thumb" of Michigan and displacing the discharge channel to a higher elevation. An advance of the ice front to the Lake Border moraines of the Michigan basin, possibly occurring at the same time as that in the Erie basin just described, reduced Lake Chicago to a narrow crescentic body of water at the southwestern rim of the Michigan basin.

LAKE ARKONA

The next retreat of the ice was more extensive, and the lake in the Erie basin expanded northward into the Huron basin and joined with a growing lake in the Saginaw Bay area to form Lake Arkona (fig. 5). This lake initially stood at an elevation of 710 feet, and it discharged down the Grand River valley to the Michigan basin. During the life of Lake Arkona the lake level was lowered from 710 feet to 695 feet, by downcutting of the outlet. In the Michigan basin, meanwhile, Lake Chicago had expanded northward with the retreat of the ice front to cover approximately the southern half of the basin. Lake Chicago was still at the Glenwood stage (elevation 640 feet), and still discharged down the Illinois River.

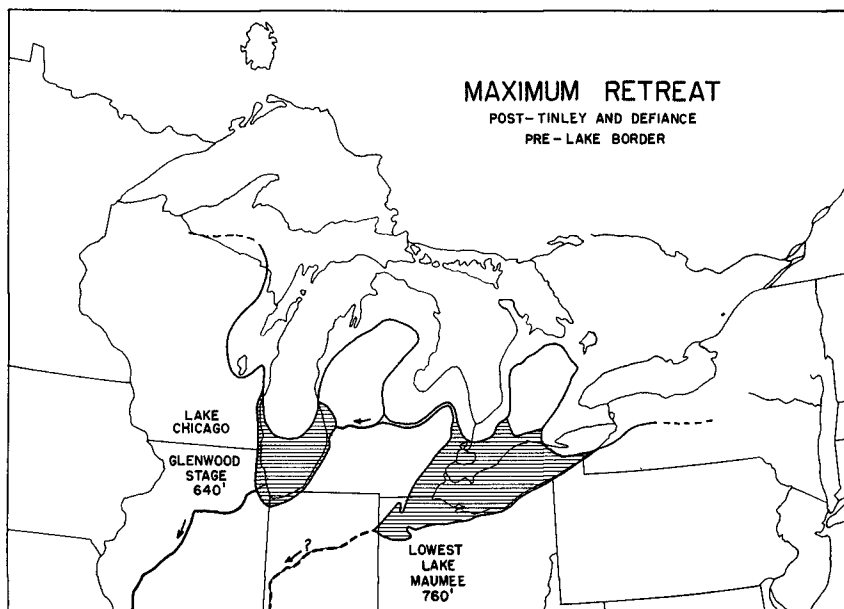
PORT HURON GLACIAL ADVANCE AND LAKE WHITTLESEY

An advance of the ice to the Port Huron moraine (fig. 6) filled the southern Huron basin and raised the lake level to the south to the Lake Whittlesey stage (elevation 738 feet). Lake Whittlesey drained across the "thumb" of Michigan, along the ice front, to Lake Saginaw. Lake Saginaw, a remnant of the Arkona 695-foot stage, drained down the Grand River valley to the Michigan basin. The Glenwood stage of Lake Chicago persisted in the Michigan basin, though the extent of the lake was reduced somewhat by the advance of ice to point a little more than half-way down the basin.

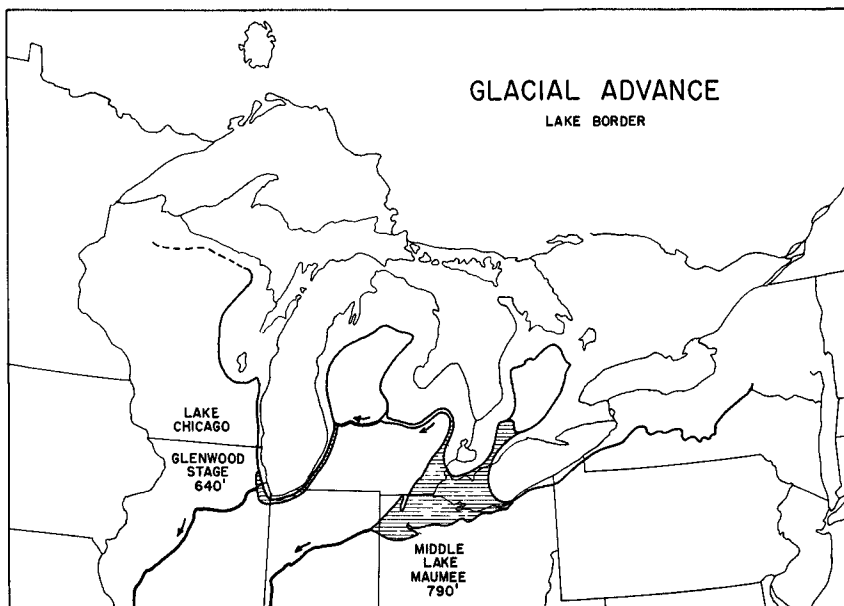
EARLY LAKE WARREN AND THE FIRST CALUMET STAGE OF LAKE CHICAGO

During the early stage of retreat of the Port Huron ice, (fig. 7) Lake Whittlesey in the Erie basin was drained down to the

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**FIG. 3 - Lake stage map no. 3: Lake Chicago
Glenwood stage and Lowest Lake Maumee.**



**FIG. 4 - Lake stage map no. 4: Lake Chicago
Glenwood stage and Middle Lake Maumee.**

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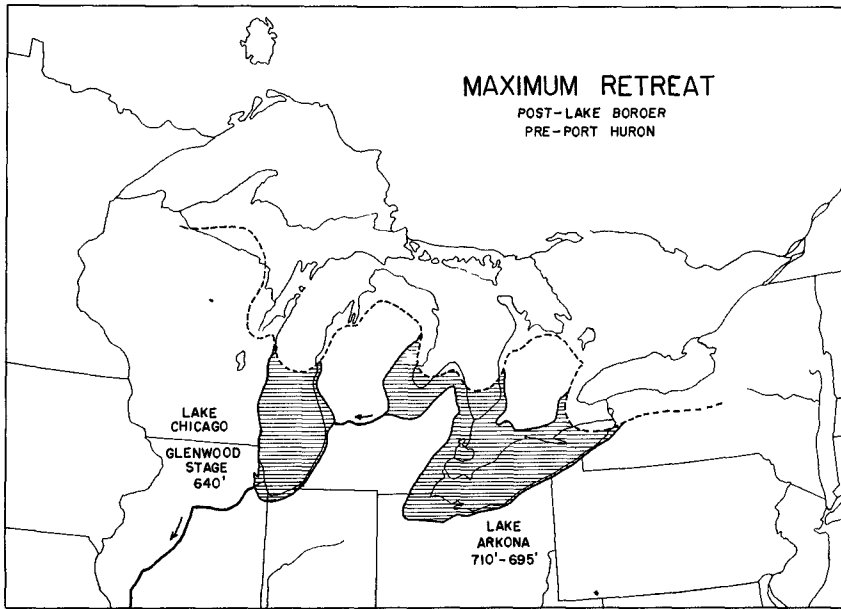


FIG. 5 - Lake stage map no. 5: Lake Chicago
Glenwood stage and Lake Arkona.

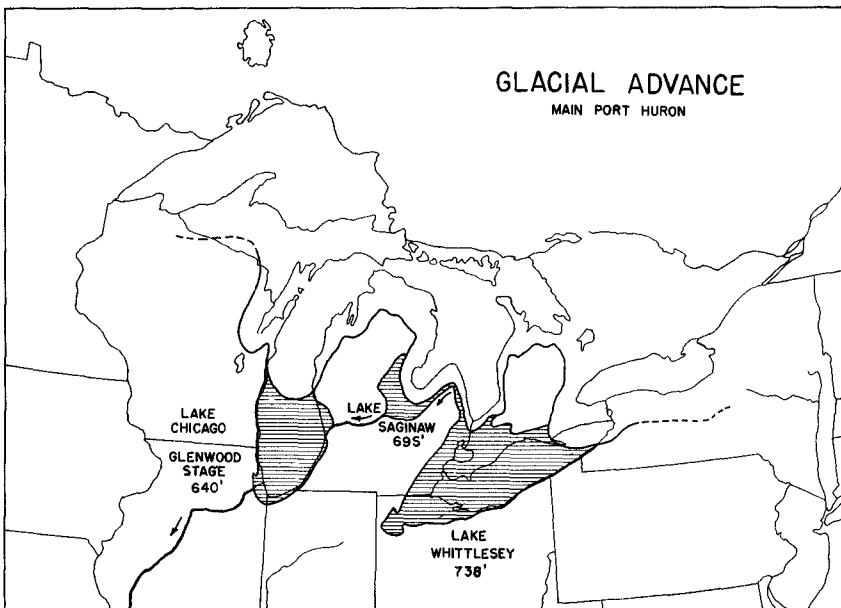
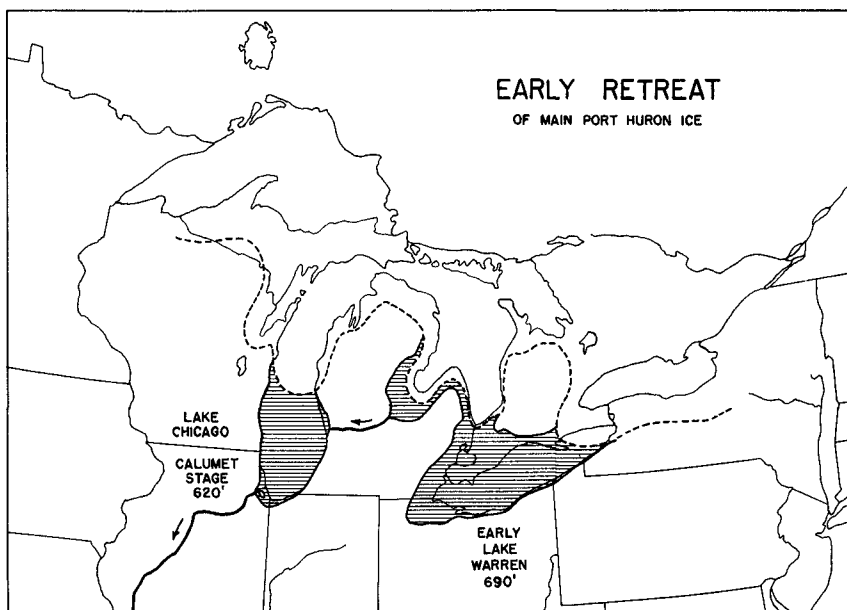
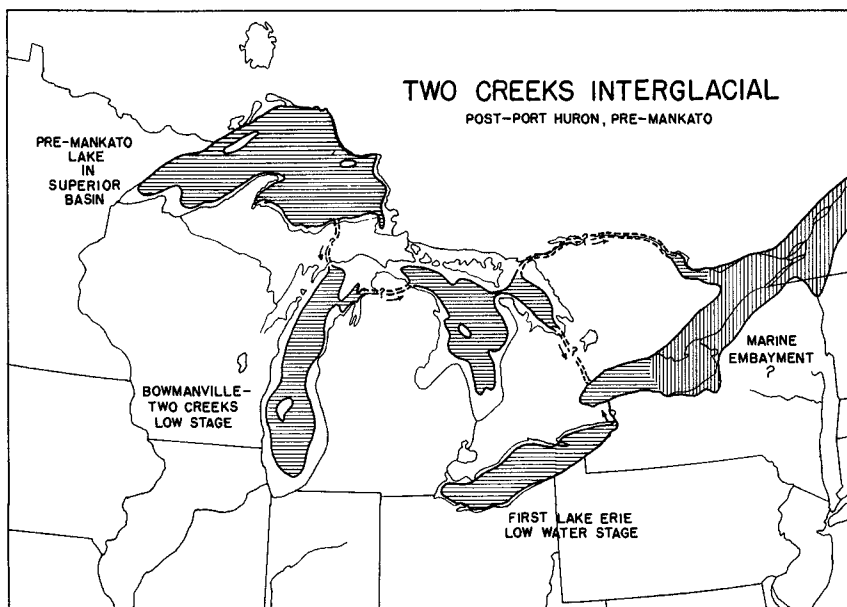


FIG. 6 - Lake stage map no. 6: Lake Chicago
Glenwood stage and Lake Whittlesey.

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**FIG. 7 - Lake stage map no. 7: Lake Chicago
Calumet stage no. 1 and Early Lake Warren.**



**FIG. 8 - Lake stage map no. 8: Two Creeks interval
low stage lakes.**

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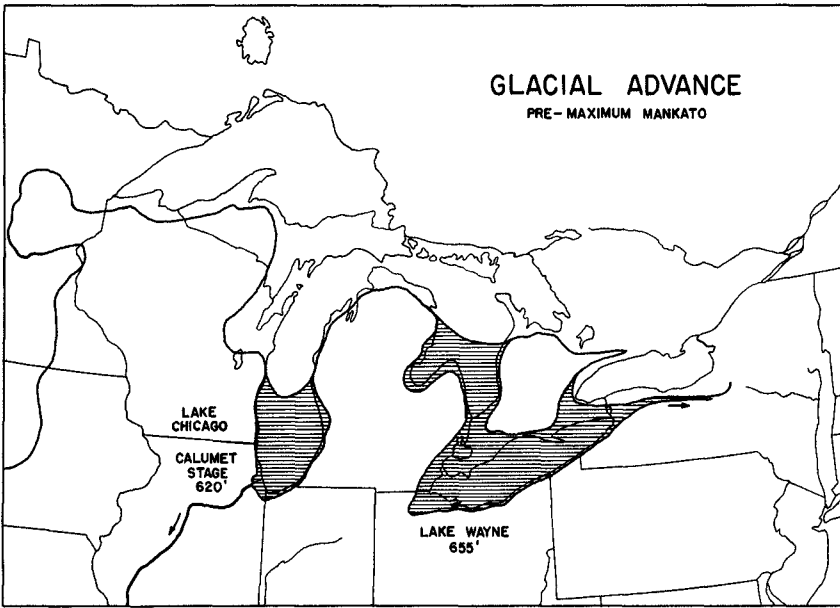


FIG. 9 - Lake stage map no. 9: Lake Chicago
Calumet stage no. 2 and Lake Wayne.

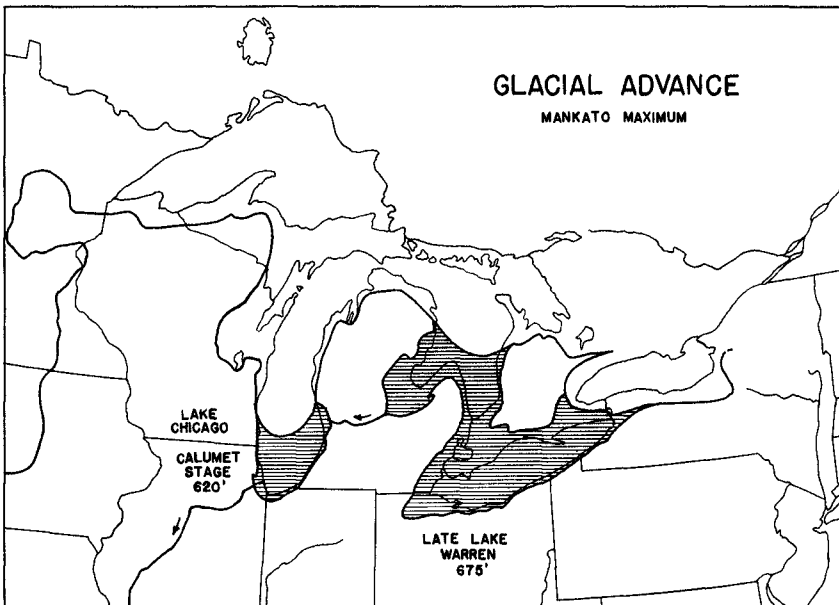


FIG. 10 - Lake stage map no. 10: Lake Chicago
Calumet stage no. 2 and Late Lake Warren.

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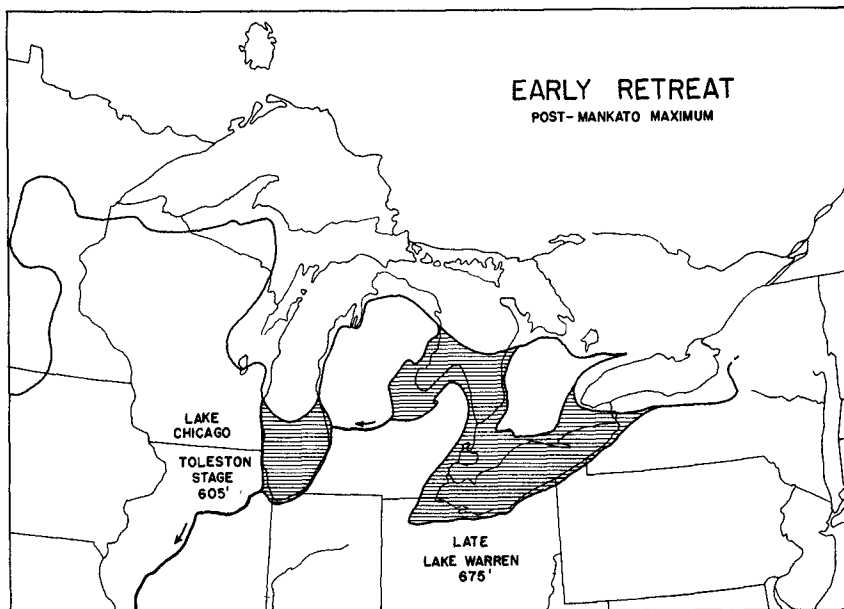


FIG. 11 - Lake stage map no. 11: Lake Chicago Toleston stage and Late Lake Warren.

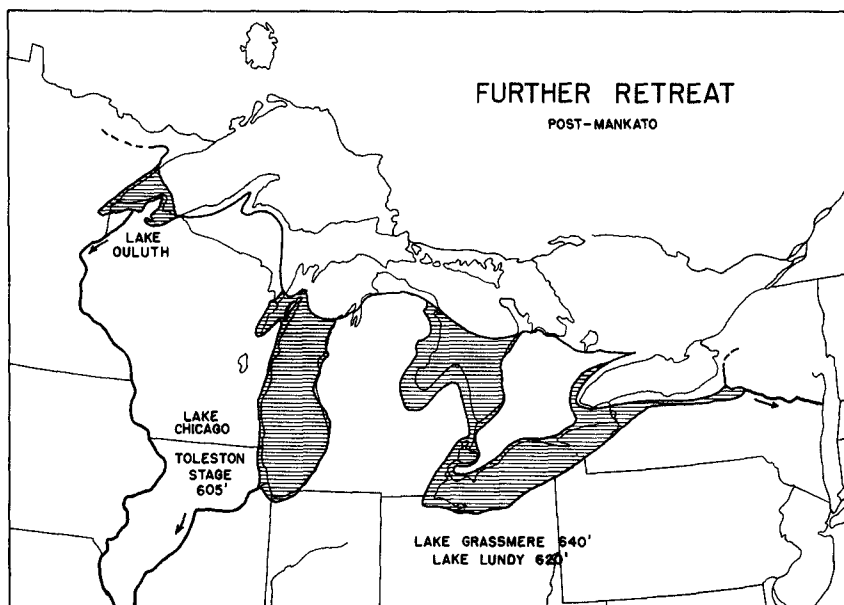


FIG. 12 - Lake stage map no. 12: Lake Chicago Toleston stage, Lakes Grassmere and Lundy, and Lake Duluth.

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level of the Saginaw Bay outlet, discharging a large volume of water in a relatively short period of time. The outlet apparently was lowered about 5 feet by erosion resulting from the increased discharge, and the next lake level, the Early Warren stage, was developed at an elevation of 690 feet. In the Michigan basin the ice front retreated northward, allowing Lake Chicago to expand. It is likely that the increased discharge from the east, resulting from the drainage of Lake Whittlesey as well as from the melting ice, so swelled the discharge of Lake Chicago that it caused a downcutting of its outlet. Lake Chicago was lowered from the Glenwood stage (640 feet) to the Calumet stage (620 feet) at about this time.

TWO CREEKS INTERGLACIAL SUBSTAGE

The post-Port Huron retreat of the ice continued until the Great Lakes basins were nearly, if not entirely, free of ice (fig. 8). This is indicated by forest remains at Two Creeks, Wisconsin (15 miles north of Manitowoc) in which logs, peat, and tree stumps in growth position occur down as low as the present lake surface, about 580 feet A.T. (Wilson, 1932, 1936). The lake must have been drained at least to that level. An outlet from the Lake Michigan basin low enough to permit this drainage can have existed only north of the Port Huron morainic system, somewhere along the northeastern edge of the basin. The most likely location of this outlet is believed to be the lowland extending from Little Traverse Bay eastward to the Huron basin. This lowland is floored by unconsolidated material, including Mankato drift which is younger than the low-water stage. The area in which the lowland lies has been warped upward since late Mankato time. If the area were depressed as much in late Port Huron time as it was in late Mankato time, it would have provided an outlet with a floor at least 100 feet below present lake level.

In order for the water in the Michigan basin to have drained down to 580 feet A.T. (it probably went lower), the water in the Huron basin to the east must have been at least that low, and a drainage course must have been open to the sea. Because there is no outlet as low as 580 feet A.T. anywhere along the western and southern borders of the Great Lakes region, the discharge must have gone down the St. Lawrence river valley. This implies a major retreat of the ice in the east.

The Lake Superior basin also apparently was essentially free of ice at this time. This is indicated by the fact that Mankato glacial till, which is younger than the Two Creeks interval deposits, possesses a strong red color and has a high percentage of clay. It is generally believed that this till is red because the ice which deposited it overrode extensive deposits of Two Creeks interval red

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lake clay and incorporated that material into the till. The red till occurs around the Lake Superior basin as well as in the northern parts of the Michigan and Huron basins.

During the Two Creeks interval water in the Lake Erie basin drained northeastward, and this discharge must have cut the gorge which lies to the west of the present Niagara Gorge and which is now filled with glacial till. The level of water in the Erie basin at this time must have been at least as low as the present lake surface.

THE MANKATO GLACIAL SUBSTAGE AND LAKE WAYNE, LATE LAKE WARREN, AND THE SECOND CALUMET STAGE

When advancing Mankato ice closed the low northeastern outlet of the Lake Michigan basin, the water rose until it spilled through the old outlet at Chicago. This outlet had been abandoned at the Calumet level, and the new lake undoubtedly rose to the same level. There was, therefore, a second Calumet stage, in Mankato time (fig. 9).

The advancing Mankato ice in the eastern part of the Great Lakes region filled the Ontario basin, and for a period of time the water in the Erie and southern Huron basins stood at the Lake Wayne level, 655 feet, while discharging eastward across New York state (fig. 9).

At the time of maximum advance of the Mankato ice the eastern outlets were overridden and closed, and the water in the Erie and southern Huron basins rose until it reached the Late Lake Warren level, 675 feet above sea level. This lake spilled westward from Saginaw Bay down the old Grand River outlet, to Lake Chicago (fig. 10).

Lake Chicago remained at the Calumet level, 620 feet, during the early retreat of the Mankato ice. This is indicated by the presence of a Calumet level beach on the southern border of the red Mankato till. The absence of a Calumet beach farther north on the red till indicates that the surface of Lake Chicago was lowered during the early stages of retreat of the Mankato ice (fig. 11). A plausible explanation of the lowering is that the volume of discharge through the Chicago outlet was increased greatly by rapid melting of glacial ice throughout the Michigan, Huron and Ontario basins and that this increased discharge cut the outlet to a lower level.

THE TOLESTON STAGE OF LAKE CHICAGO

The lowering of Lake Chicago after the early stages of retreat of the Mankato ice brought the lake down to the Toleston level, 605 feet above sea level (fig. 11). The Toleston stage persisted in the Lake Michigan basin (fig. 12) until the glacial ice front retreated northward far enough to permit a connection between the lakes of the

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Michigan and Huron basins. The Toleston stage discharged through the Chicago outlet, which was now at its lowest possible elevation, on a bedrock sill.

LAKES GRASSMERE AND LUNDY

At some time after the Toleston stage of Lake Chicago was formed, the glacial ice front in the Ontario basin retreated to a point where Late Lake Warren (of the Huron and Erie basins) could discharge through a lower outlet to the east. When this occurred, the waters of the Huron and Erie basins were lowered to the Lake Grassmere stage, 640 feet above sea level (fig. 12). Further retreat of the ice front in the east exposed a still lower outlet, and the Huron-Erie waters were lowered to the Lake Lundy level, 620 feet above sea level (fig. 12). Both the Grassmere and Lundy stages discharged eastward across New York state.

EARLY LAKE DULUTH

The history of directly-known lake stages in the Great Lakes region has, up to this point, been limited to the southern part of the region and has involved only the Michigan, Huron and Erie basins. It is inferred that a lake existed in the Superior basin during the Two Creeks interval, but the ice of the Mankato substage completely filled the Superior basin and obliterated any shore features which may have been formed there previously.

When the ice front retreated after the Mankato maximum, probably sometime after the Toleston and Grassmere stages came into existence in the lower lakes, Lake Duluth was formed in the western end of the Superior basin (fig. 12). This lake drained down the St. Croix River and thence to the Mississippi River. The earliest known stage of Lake Duluth stood at an elevation of 1100 feet above sea level. Later stages, which were more extensive because of the northeastward retreat of the ice front, occurred at elevations of 1076, 1044 and 1022 feet. The reduction in elevation recorded by these successively lower stages presumably was brought about by downcutting of the outlet to the St. Croix River.

Lake Duluth here is considered to have ceased to exist when the ice barrier on the east retreated to a point where the lake could drain eastward. Before this occurred, however, another part of the lake history ensued in the lower basins.

LAKE ALGONQUIN

The Algonquin part of the Great Lakes history is complicated, and it is a chapter which has been revised more drastically than any other in the light of recent investigations. Some of the major revisions were made by Stanley (1936, 1937) and essentially corroborated

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by Deane (1950), while others have been made by the writer (Hough, 1953).

In the Lake Michigan basin, the Toleston stage ended and the Algonquin stage began when the waters of the Michigan and Huron basins were joined by means of retreat of the ice front from the Little Traverse Bay-Lake Huron lowland. No change of water surface elevation occurred in the Michigan basin in this transition, because both stages drained through the stabilized Chicago outlet. Lake Algonquin, therefore, came into existence at the 605-foot level.

In the Huron basin, Lake Algonquin followed Lake Lundy (the 620-foot stage in the Huron-Erie basin). Leverett and Taylor (1915) have stated that Lake Lundy was drained by the opening of a lower outlet somewhere to the east of Lake Erie, and that the water surface in the Erie basin thus was lowered below the divide between the Huron and Erie basins, while glacial ice still blocked the northern part of the Huron basin. The Huron water then drained southward, and the lake surface in the Huron basin was stabilized at 605 feet because erosion of the channel bed (composed of glacial till) ceased. It appears equally possible to the writer that ice retreated from the channel connecting the Huron and Michigan basins before it vacated a lower outlet to the east, and that the Lundy stage thus was terminated by drainage to the north and west rather than to east. Under this interpretation, the initial Algonquin level in both the Michigan and Huron basins was determined by the rock-floored outlet at Chicago. Under the Leverett and Taylor interpretation, the attainment of the 605-foot Algonquin level by two separate bodies of water in the Michigan and Huron basins was a mere coincidence.

As the ice front receded, Lake Algonquin expanded until it extended throughout the Michigan basin and the greater part of the Huron basin (fig. 13), while maintaining its 605-foot elevation. During this stage one of the strongest beaches in the Great Lakes region was formed. The northern shore of the lake was across the glacial ice front in the northeastern part of the Huron basin, but it was on the edge of the crystalline rock upland in the vicinity of Sault St. Marie, Ontario. From there southwestward to Green Bay the shore was along the ice front which stood on the peninsula separating the Michigan and Superior basins. A glacial outwash delta was deposited in the lake along this shore, and the surface of the delta (now elevated) records the level of the Algonquin stage.

The beach of Lake Algonquin was well developed, largely in unconsolidated material, throughout the remainder of the Lake Michigan basin, down the western shore of the Huron basin, and along the southeastern side of the Huron basin to the vicinity of Kirkfield in Georgian Bay. The Algonquin stage lake apparently discharged through two outlets simultaneously; one was the Chicago outlet, floored with bed rock, and the other was the outlet at Port Huron (at the south end of the Huron basin), which was floored with glacial till.

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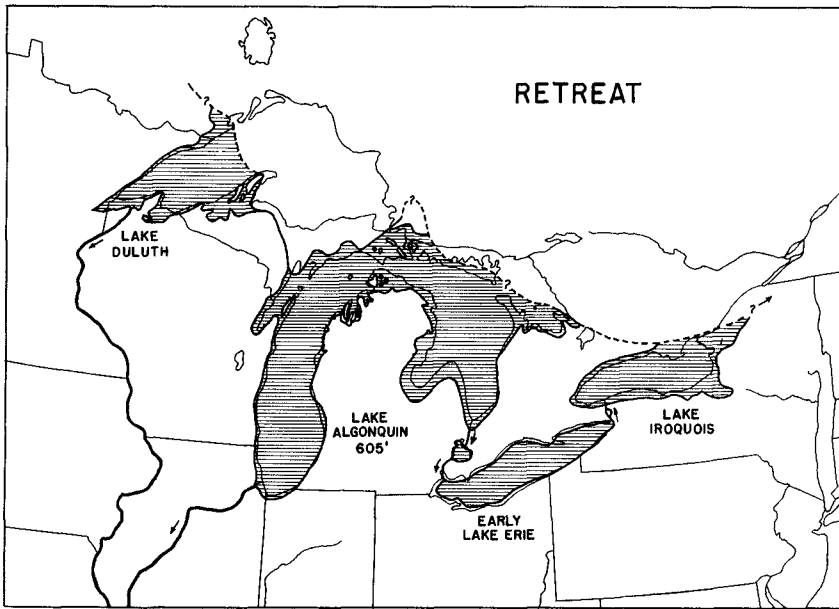


FIG. 13 - Lake stage map no. 13: Lake Algonquin, Lake Duluth, Early Lake Erie, and Lake Iroquois.

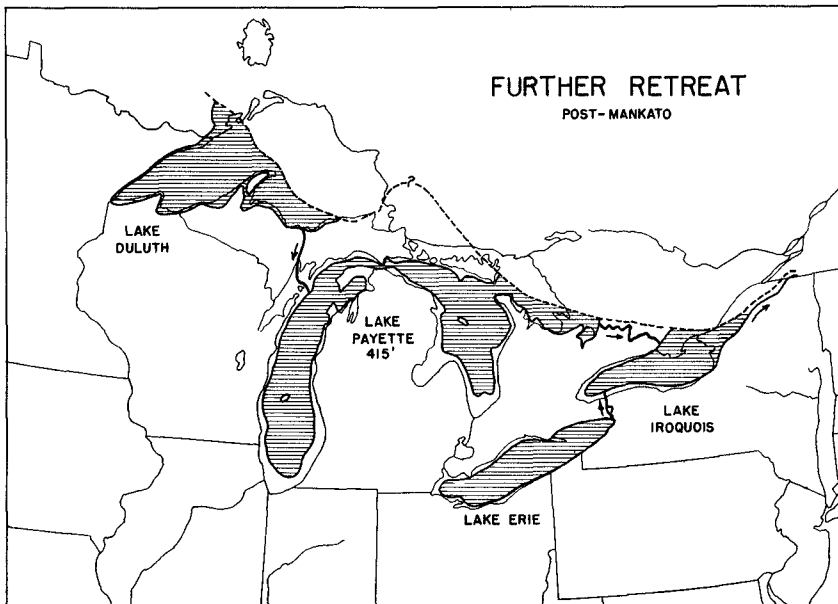


FIG. 14 - Lake stage map no. 14: Lake Payette, Lake Duluth, Lake Erie and Lake Iroquois.

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During the period of existence of the 605-foot Algonquin stage in the Michigan and Huron basins, other lakes existed in the other Great Lakes basins. Lake Duluth was expanding in the Superior basin, but was still discharging southwestward down the St. Croix River to the Mississippi. Lake Iroquois was in the Ontario basin, discharging eastward, and an early Lake Erie in the Erie basin discharged into Lake Iroquois.

POST-ALGONQUIN LOW STAGES

The Algonquin stage, as defined here, was terminated when retreat of the ice front in an area southeast of Georgian Bay exposed a lower outlet. Drainage of water through this new outlet lowered the lake surface approximately 90 feet, this initiating the first of several low-level stages which discharged through successively lower outlets made available by further retreat of the ice. The lowest of these stages which is represented by recognizable shore features is the Payette stage (fig. 14) which existed at an elevation of approximately 415 feet above sea level.

At some time after the Algonquin stage but before the Payette, the ice barrier between the Superior and Michigan basins retreated, allowing discharge of Lake Duluth water into the Michigan basin. This may be considered as the termination of the Lake Duluth phase of the Superior basin history.

THE CHIPPEWA-STANLEY LOW-WATER STAGE

An extreme low-water stage of the lakes in the Huron and Michigan basins, lower than the Payette stage, was inferred by Stanley (1936, 1938). The writer (Hough, 1952, 1953) found definite evidence for this low-water stage in core samples taken in Lake Michigan. The low stage in Lake Michigan stood at 230 feet above sea level; this has been named Lake Chippewa (fig. 15). The low stage in Lake Huron, which probably stood at least 50 lower, has been named Lake Stanley. The outlet of the Chippewa-Stanley low water stage was at North Bay, Ontario, and down the Mattawa and Ottawa valleys to the St. Lawrence valley. This outlet was made available by retreat of the ice front, and the retreat beyond this outlet marks the beginning of "post-glacial" time in the Great Lakes region. During the Chippewa-Stanley low stage the water surface in the Lake Superior basin probably was extremely low also.

TERMINATION OF THE LOW STAGE BY UPWARP

The extreme low-water stage was brought to a close by upwarp of the outlet area. A part of the upwarp occurred while the ice front was receding through the Georgian Bay area, but the greater part of the upwarp occurred after the North Bay outlet came into use. This

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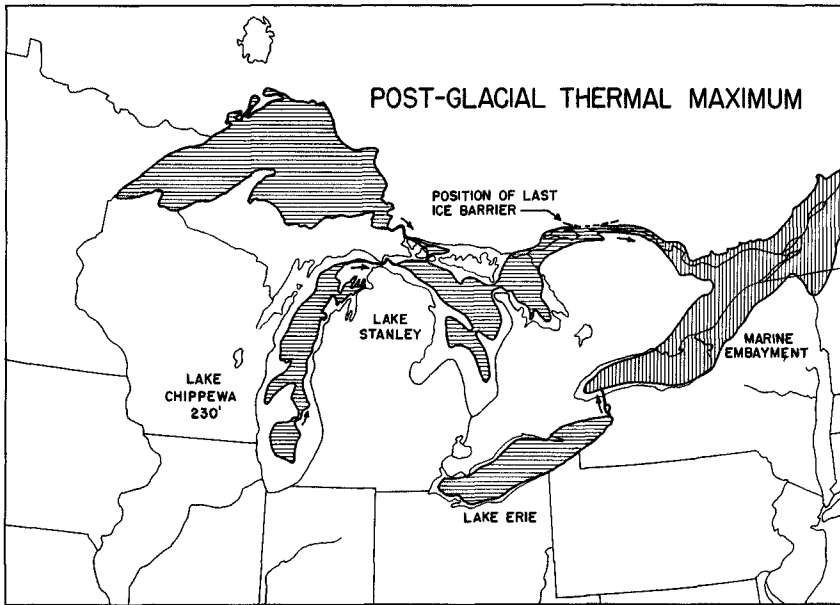


FIG. 15 - Lake stage map no. 15: Lake Chippewa, Lake Stanley, Early Lake Superior, Lake Erie, Ontario marine embayment.



FIG. 16 - Lake stage map no. 16: Nipissing Great Lakes.

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outlet served as the only dischargeway for the lake in the Huron basin until the water level was raised to the elevation of the old southern outlet channels.

THE NIPISSING GREAT LAKES

When upwarp of the land to the north raised the water level in the Huron and Michigan basins to the level of the old southern outlets at Port Huron and at Chicago, and discharge to the south began, the Nipissing stage was produced.

Because the old southern outlets had been abandoned when the lake was at the 605-foot Algonquin level, it is reasonable to assume that when a portion of the Nipissing discharge reoccupied these outlets the lake level would again stand at 605 feet. By this time glacial ice had disappeared from all of the lake basins, and the Nipissing Great Lakes extended throughout the Superior, Michigan, and Huron basins, as a single body of water. The total volume of its discharge probably was greater than that of the Algonquin stage, because during the Algonquin stage much of the discharge of the Superior basin went southwestward down the St. Croix River.

While the Nipissing stage discharged through three outlets, the rising North Bay outlet and the two stable southern outlets, the volume of its discharge through any one of the outlets was inadequate to deepen the outlet channels by scour. The development of the strong Nipissing beach probably took place during this three-outlet stage. Radiocarbon dating of peat associated with the Nipissing beach in the southwestern part of the Superior basin has given us a date of 3656 ± 640 years ago for its formation (Arnold and Libby, 1951). Similar dating of a beach deposit at the 605-foot level, at the south end of the Lake Michigan basin, has given a date of 3469 ± 230 years ago (Arnold and Libby, 1951).

When continued rise of the land to the north carried the North Bay outlet above the level of the southern outlets, the entire discharge of the Nipissing Great Lakes passed through the two southern outlets. The outlet at Chicago, floored with bed rock, could not be cut down, but the outlet at Port Huron, which was floored with unconsolidated till, was susceptible to downcutting by the increased discharge. Downcutting at Port Huron by this mechanism accounts for the termination of the Nipissing stage.

THE ALGOMA STAGE

During the lowering of lake level from the Nipissing stage to the present level (by downcutting of the Port Huron outlet) there was one well-defined static period, during which the Algoma beach was formed. In the northern, upwarped, part of the region the Algoma beach is a

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feature of moderately strong development which lies between the Nipissing and the present lake beaches. It, like the Nipissing beach, descends southward toward the unwarped southern areas but can not be traced continuously to a junction with a beach in the south. It appears likely, however, that a moderately strong horizontal beach at elevation 596 in the south is the Algoma beach. Radiocarbon dating of charcoal associated with the 596-foot level deposits (at Port Franks, Ontario) gives a date of 2619 $\pm$ 220 years ago for their accumulation (Libby, 1952). These deposits contain evidences of human occupation (Dreimanis, 1952).

ATTAINMENT OF THE PRESENT LEVEL

If the radiocarbon dates quoted above are reliable, the water surface in the Michigan and Huron basins stood at an elevation of 605 feet only about 3500 years ago, and it stood at the 596-foot level only 2600 years ago. It follows, then that the water surface was lowered to the present stage (581 feet) at a time which probably was considerably less than 2000 years ago.

PRACTICAL IMPORTANCE OF THE GREAT LAKES HISTORY

Many highways and railroad rights-of-way in the Great Lakes region are located on beaches which were formed during some of the higher lake stages. Other features, formed during lower stages, are not readily recognizable by casual inspection but nevertheless may be of great importance in engineering design. During low-water stages many of the rivers which discharge into the lakes were deeply entrenched in their valleys; when the lakes rose, the lower courses of these rivers were drowned and deposition of fine-grained materials in the resulting deep channels then occurred.

A typical example of a construction problem resulting from the lowering and raising of lake level is the bridge project at Saugatuck, Michigan (reported by Stanley, 1938). Borings at the bridge site were made in the bed of the Kalamazoo River, near its mouth, and they penetrated 85 feet in an apparently recent fill of fine sand and peat which constituted very poor foundation material. Similar valley-fill problems in the Chicago area will be described in another paper on the present program (Peck, R. B., "The influence of subsurface conditions on the design of foundations for water front structures in the Great Lakes area").

Many of the streams tributary to the Great Lakes may be expected to contain deep fill in their mouths. The problem of interpreting borings made in such fills is complicated, however, by the occurrence of more than one period of low water. Two periods of extreme low water

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were described in the foregoing history of the lakes. The first of these occurred during the Two Creeks interval, prior to the advance of the Mankato ice which extended part way down the Michigan and Huron basins and which completely filled the Superior and Ontario basins. In these areas covered by the Mankato ice, glacial till may have been deposited in the outrenched valleys, possibly overlying fine-grained alluvial fill. South of the Mankato glacial boundary (fig. 10), however, no till will be found overlying the alluvium in the valleys which were entrenched during the Two Creeks interval.

The second extreme low water period occurred after the Mankato glacial substage, during the Chippewa-Stanley stage. Entrenchment of streams at this time would remove at least a part of the pre-existing valley fill (alluvial, or alluvial and glacial where both existed). Subsequent drowning of the valleys during the Nipissing stage would permit the deposition of new alluvial fill. Again, in the valleys south of the Mankato glacial boundary (fig. 10) no till will be found overlying alluvium deposited after the Two Creeks interval. North of the Mankato boundary, however, the following sequence is possibly present in some of the valleys; Nipissing to recent alluvium at the top, Mankato glacial till, alluvium, then older glacial till or bed rock. In other words, the first till encountered in a boring in a valley north of the Mankato boundary may be thin and it may have alluvium under it. The alluvium may be expected to have a relatively small bearing capacity.

The relationships just described may be complicated further by other low water stages which occurred at earlier dates, previous to the known history of the lakes. Pre-Cary valleys cut in bed rock or in older glacial deposits are known in the area of the Cary drift in northeastern Illinois. Such valleys may contain Cary glacial till overlying alluvium deposited during some early lake stage.

REFERENCES

- Arnold, J. R. and Libby, W. F. (1951). Radiocarbon dates: Science, vol. 113, pp. 115-118.
- Bretz, J H. (1951a). Causes of the glacial lake stages in Saginaw Bay basin, Michigan: Jour. Geology, vol. 59, pp. 244-258.
- Bretz, J H. (1951b). The stages of Lake Chicago; Their causes and correlations: Am. Jour. Sci., vol. 249, pp. 401-429.
- Deane, R. E. (1950). Pleistocene geology of the Lake Simcoe district, Ontario: Canada Geol. Survey Mem. 256, p. 77.
- Dreimanis, A. (1952). Age determination of the Burley Site at Port Franks, Ontario, by geological methods: Univ. of Western Ontario Museum of Indian Archeology and Pioneer Life, Bull. no. 9, pp. 72-75.

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- Flint, R. F. and Deevey, E. S., Jr. (1951). Radiocarbon dating of Late Pleistocene events: *Am. Jour. Sci.*, vol. 249, pp. 257-300.
- Hough, J. L. (1952). Post-glacial low-water stage of Lake Michigan indicated by bottom sediments (Abstr.): *Geol. Soc. America Bull.*, vol. 63, p. 1265.
- Hough, J. L. (1953a). Final report on the project, Pleistocene Chronology of the Great Lakes region, Office of Naval Research - University of Illinois project NR-018-122, Urbana, Illinois.
- Hough, J. L. (1953b). Pleistocene climatic record in a Pacific Ocean core sample: *Jour. Geology*, vol. 61, pp. 258-259.
- Leverett, F. and Taylor, F. B. (1915). The Pleistocene of Indiana and Michigan and the history of the Great Lakes: *U. S. Geol. Survey Mon.*, vol. 53.
- Libby, W. F. (1952). Chicago radiocarbon dates, III: *Science*, vol. 116, pp. 674-675.
- Stanley, G. M. (1936). Lower Algonquin beaches of Penetanguishene Peninsula: *Geol. Soc. America Bull.*, vol. 47, pp. 1933-1960.
- Stanley, G. M. (1937). Lower Algonquin beaches of Cape Rich, Georgian Bay: *Geol. Soc. America Bull.*, vol. 48, pp. 1665-1686.
- Stanley, G. M. (1938). The submerged valley through Mackinac Straits: *Jour. Geology*, vol. 46, pp. 966-974.
- Stose, G. W. (1946). *Geologic map of North America*: Geol. Soc. America, New York.
- Wilson, L. R. (1932). The Two Creeks forest bed, Manitowoc County, Wisconsin: *Wisconsin Acad. Sci., Trans.*, vol. 27, pp. 31-46.
- Wilson, L. R. (1936). Further studies of the Two Creeks forest bed, Manitowoc County, Wisconsin: *Torrey Bot. Club Bull.*, vol. 63, pp. 317-325.