(1) Prepare profile of bluff and beach using the data posted on the website.

(2) Read the following materials:
   - Read pages 56-74 in text.
   - Read the general content of the attached two papers (Hansel and Mickelson and Hansel and others).
   - Read the general content on the website:
     http://gcmd4.gsfc.nasa.gov/Resources/Learning/sealevel.html
A Reevaluation of the Timing and Causes of High Lake Phases in the Lake Michigan Basin

ARDITH K. HAUSEL
Illinois State Geological Survey, Champaign, Illinois 61820

AND

DAVID M. MICKELSON
Department of Geology and Geophysics, University of Wisconsin, Madison, Wisconsin 53706

Received June 30, 1987

Radiocarbon age control on the type Glenwood, Calumet, and Toleston shoreline features and on the abandoned Chicago outlet at the south end of the Lake Michigan basin provides a basis for reevaluating the timing and causes of high lake phases in the basin. Radiocarbon dates suggest that Glenwood-level (195 m) shoreline features formed between 14,180 and 12,700 yr B.P. (Glenwood I and II phases), Calumet-level (189 m) between 12,760 and 11,000 yr B.P. (Calumet I and II phases), and Toleston-level (184.5 m) between 5000 and 4000 yr B.P. (Nipissing phase), and that the Chicago outlet was cutover to its present level (180 m) on bedrock while the lake was at the Glenwood level. This new chronology is inconsistent with J. H. Brett’s hypothesis (1951) American Journal of Science 249, 401-429 that the progressive lowering of lake level resulted from episodic drawdown of the outlet. Instead, the changes in lake level appear to relate to changes in the amount of glacial meltwater and precipitation entering the basin. We hypothesize that the Glenwood phases correspond with times when discharge from the Huron and Erie basins also entered the Lake Michigan basin (Lake Bonner and early Port Huron glacial phases), the Calumet phases with times when drainage was from the Lake Michigan basin alone (late Port Huron and Two Rivers glacial phases), and the Nipissing phase with the postglacial, middle Holocene transgression caused by differential uplift in the basin. Estimates of relative net inputs to the basin during the Glenwood, Calumet, and Nipissing lake phases are consistent with estimates of relative outputs (i.e., discharge through the Chicago outlet); the magnitude of relative differences in inputs and outputs between phases is sufficient to explain lake-level changes of 4.5 to 6 m.

INTRODUCTION

During and after late Wisconsinan deglaciation, the Lake Michigan basin supported a series of lakes at different levels and of different areal extent, as evidenced by the presence of abandoned outlets and beaches above the modern lake. Although the existence of these lake events has been known for nearly a century, their exact timing, their relationship to glacial events, and the rebound history of the basin have been controversial in the past few decades. The purpose of this paper is to present and evaluate radiocarbon evidence for the age of high-level lake events (or phases) represented by abandoned shoreline features at the south end of the Lake Michigan basin and to suggest reasons for the changing lake levels. The south end of the lake is the type area of the Glenwood, Calumet, and Toleston shoreline deposits (Fig. 1) and the only area of the basin in which the relative differences in elevation among the three abandoned beaches and the abandoned Chicago outlet are clear. Correlation of the type Glenwood, Calumet, and Toleston beaches with shoreline features away from the south end of the basin is difficult; shore erosion, subsequent glaciation, and differential isostatic uplift in the basin have removed, obscured, or confused much of the evidence. For this reason, discussion will focus on evidence from the type area.

113
Excavations in the urbanized area at the south end of the lake commonly expose sections in the former shoreline deposits. In addition, many of the parks and cemeteries in the Chicago area are located on former beaches and bars; these deposits are accessible for study by hand augering and drilling. Lake Michigan shore erosion has also...
exposed important sites, such as the Southport forest bed south of Kenosha, Wisconsin (Schneider et al., 1979) and the Mount Baldy and Central Avenue sections near Michigan City, Indiana (Winkler, 1962; Gutchick and Gomisiewski, 1976; Larsen, 1983b). In the past 5 yr, about 60 samples of organic material collected in the southern Lake Michigan area have been dated at the Illinois State Geological Survey (ISGS) Radiocarbon Laboratory; many of these data are presented in Table 1.

**Former Beaches and the Chicago Outlet**

Leverett (1897) recognized three well-defined beaches at the south end of Lake Michigan and on the basis of these he defined three main high levels of a glacial lake, which he named Lake Chicago. They include the 195-m (640 ft) Glenwood level named for beach deposits near Glenwood, Illinois; the 189-m (620 ft) Calumet level named for beach deposits exposed south of the Little Calumet River in Indiana; and the 184.5-m (605 ft) Tolecott level named for beach deposits on which the former settlement of Tolecott, Indiana was built (Fig. 1).

The high-level lakes drained by way of an overflow channel through the Tinley and Valparaiso Moraines at the southwest end of the lake (Fig. 1). This channel, known as the Chicago outlet, consists of a northern arm (the Des Plaines channel) and a southern arm (the Sag channel), which join to form a Y-shaped spillway through the morainal upland. Southwest of the morainal upland, the Des Plaines River joins the Illinois River.

**Previous Interpretations of Lake Level Stabilization and Outlet Downcutting**

With two exceptions (Wright, 1918; Mickelson et al., 1985), previous workers (e.g., Leverett, 1897; Alden, 1902; Goldthwaite, 1908; Brezt, 1951; Hough, 1958; Willman, 1971) related the level of Lake Chicago to the threshold altitude of the Chicago outlet; the progressive lowering of Lake Chicago (first from the Glenwood to the Calumet level, and later from the Calumet to the Tolecott level) was attributed to episodic downcutting of the outlet. This interpretation was extensively developed by Brezt (1951).

Brezt envisioned static-level phases of Lake Chicago (Glenwood, Calumet, and Tolecott) separated by two episodes of rapid lake-level lowering. He suggested that rapid lake-level lowering resulted from accelerated downcutting in the outlet during times when proglacial lakes in the Erie and Huron basins discharged into Lake Chicago. According to Brezt, the first episode of downcutting occurred when Port Huron ice was at its maximum extent, and the second episode occurred after the “Bowmanville-Two Creeks” low-water phase during a readvance of the ice margin. Brezt suggested that Lake Chicago was lowered 6 m (20 ft) to the Calumet level during the first episode of downcutting and another 4.5 m (15 ft) to the Tolecott level during the second. He argued that the outlet was incised to bedrock (180 m) during the second episode, causing Lake Chicago to stabilize at the Tolecott level (184.5 m).

The lake supposedly remained at the Tolecott level after the Straits of Mackinac were free of glacier ice, and confluent water in the Lake Huron and Lake Michigan basins formed Lake Algonquin (Brezt, 1955; Hough, 1958). According to Hough (1958), the Tolecott level was abandoned when re-treat of the ice margin opened the isostatically depressed North Bay outlet in Ontario, initiating the Chippewa low-water phase, but was reoccupied during the Nipissing transgression when differential isostatic uplift in the basin raised the North Bay outlet above the level of the southern outlets at Port Huron, Michigan, and Chicago. Incision of the St. Clair River channel at Port Huron eventually resulted in a lowering from the Tolecott level; the Chicago outlet was abandoned in favor of the Port Huron outlet (Hough, 1958).

The Glenwood has also been interpreted
<table>
<thead>
<tr>
<th>Location</th>
<th>In C yr B.P.</th>
<th>Lab No.</th>
<th>Material</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Glenwood basin</td>
<td>12,400 ± 300</td>
<td>IU-52</td>
<td>Wood</td>
<td>Schneider and Rehshin, 1970</td>
</tr>
<tr>
<td>2a Dyer split (Glenwood)</td>
<td>12,650 ± 350</td>
<td>W-240</td>
<td>Wood</td>
<td>Rubin and Fless, 1955</td>
</tr>
<tr>
<td>2b Dyer split</td>
<td>12,220 ± 150</td>
<td>W-161</td>
<td>Wood</td>
<td>Rubin and Tegel, 1955</td>
</tr>
<tr>
<td>2c Glenwood site</td>
<td>12,660 ± 140</td>
<td>ISGS-1190</td>
<td>Wood</td>
<td>Hansen et al., 1985b</td>
</tr>
<tr>
<td>3a Caanet beach (west)</td>
<td>13,470 ± 170</td>
<td>ISGS-1254</td>
<td>Sapropel</td>
<td>C. L. Liu (written communication, 1987)</td>
</tr>
<tr>
<td>3b Caanet beach (east)</td>
<td>11,315 ± 640</td>
<td>ISGS-1147</td>
<td>Sapropel</td>
<td>Scherer and Rehshin, 1982</td>
</tr>
<tr>
<td>4 Row Hill split</td>
<td>11,240 ± 100</td>
<td>ISGS-1218</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>5 Caanet beach (east)</td>
<td>11,240 ± 100</td>
<td>ISGS-1218</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>6 Row Hill split</td>
<td>11,240 ± 100</td>
<td>ISGS-1218</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>7 Sager bottom (Mansfield)</td>
<td>430 ± 150</td>
<td>W-725</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>8a Dune Plains channel</td>
<td>430 ± 150</td>
<td>W-725</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>8b Dune Plains channel</td>
<td>430 ± 150</td>
<td>W-725</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>9 Michigan City, Indiana</td>
<td>430 ± 150</td>
<td>W-725</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
<tr>
<td>10 Kenton, Wisconsin</td>
<td>430 ± 150</td>
<td>W-725</td>
<td>Sapropel</td>
<td>Hansen and Rehshin, 1982b</td>
</tr>
</tbody>
</table>

* Samples collected by R. C. Baker in 1950.

as a multiphase level (Hough, 1958, 1966). According to Bretz (1951), the Glenwood level was first stained when the outlet river cut a channel through the Tideway drift dun in the outlet, probably during the Lake Bor- der glacial phase shortly after the ice mar- gin retreated from the Tinley Moraine; it was abandoned when the outlet was cut.
down about 6 m as a result of an influx of water from the east while the ice margin was at the Port Huron maximum. Hough (1963) suggested that retreat of the ice margin between the Lake Border and early Port Huron glacial phases; (Fig. 2) resulted in an "intra-Glenwood" low-water phase, which has been interpreted as corresponding in time with the accumulation of the Cheboygan bryophyte bed (Farrand et al., 1969).

This interval was named the Mackinaw Interstadal by Dreimanis and Karrow (1972).

In this paper we question that the lowering of the lake from the Glenwood to the Calumet and Tolestone levels can be explained by downcutting of the outlet. Instead, we suggest that the outlet was cut to its present level as early as the Glenwood phases (Fig. 2) and that lake level was controlled by the amount of glacial meltwater and precipitation entering the basin. These arguments are developed after evidence for the timing of the lake phases and outlet downcutting is discussed.

**Radiocarbon Evidence for Age of Deposits**

Recent work on the chronology of lake events in the Lake Michigan basin has concentrated on establishing radiocarbon age control for the type Glenwood, Calumet, and Tolestone deposits and the deposits preserved in the Chicago outlet (Cole and Hansel, 1986; Hansel et al., 1985a,b; Hansel and Johnson, 1986a,b; Larsen, 1974, 1985a,b; A. F. Schneider and A. K. Hansel, unpublished data; Schneider and Roshkin, 1970, 1982; Schneider et al., 1979). Our overview and proposed chronology of lake events and their relationship to glacial events in the basin is summarized below and in Figure 2.

**Glenwood and Mackinaw Deposits**

The oldest radiocarbon dates are from the highest beach, the Glenwood. At present, radiocarbon age control on Glenwood-level shoreline deposits is sparse. Of the six dates shown in Table 1, four (ISGS-1190, W-140, W-161, IU-6) range between 12,600 and 12,200 yr B.P., and the other two (ISGS-1549, ISGS-1570) are more than a thousand years older. The former, discussed by Schneider and Roshkin (1970) and Hansel et al. (1985b, Table 1), are from the Glenwood beach in Indiana and the adjacent westward-growing Dyer spit (Fig. 1, location 2a; Table 1) in Illinois; the latter are new dates from the eastward-growing Glenwood spit (Fig. 1, location 2b; Table 1) in Illinois.

On the basis of the four younger dates, Hansel et al. (1985b) estimated an age of between 13,000 and 12,200 yr B.P. for Glenwood II deposits. However, as pointed out by Karrow et al. (1975) and Eschman and Karrow (1985), this age estimate appears to be too young when compared to dates from the Huron and Erie basins for correlative events (i.e., early Port Huron...
glacial phase and Whittlesey and highest Warren lake phases), that are estimated to have ended by at least 12,700 yr B.P. Similarly, recently obtained dates of 12,770 ±180 yr B.P. (ISGS-1418) and 12,500 ±210 yr B.P. (ISGS-1332) for wood from colluvium in the Chicago outlet suggest that the Glenwood level was abandoned by about that time (Hansel and Johnson, 1986a). A reevaluation of the four younger Glenwood dates indicates that two of them, 12,650 ±310 (W-140) and 12,200 ±370 yr B.P. (W-161), were determined in 1954 for wood collected from beneath and within the Dyer spit (Rubin and Suess, 1955). A third Dyer spit date of 12,660 ±140 yr B.P. (ISGS-1190), though consistent with the others, is for wood from bench slope (Hansel et al., 1985b) and may not be meaningful. The remaining "young" Glenwood date, 12,400 ±300 yr B.P. (IU-62), is for wood from eolian sand overlying lacustrine deposits of the Glenwood beach in Indiana (Schneider and Reshkin, 1970); it probably represents a minimum age for formation of the Glenwood II beach deposits.

The two new Glenwood dates are for spruce cones and driftwood from crossbedded gravel and sand of the Glenwood spit sequence. These dates of 13,870 ±170 (ISGS-1549) and 14,100 ±640 yr B.P. (ISGS-1570) are too old for shoreline deposits associated with a proglacial lake in front of the early Port Huron ice margin, estimated to have advanced about 13,000 yr B.P. (Fullerón, 1980; Eschman and Karrow, 1985; Čalík and Feenstra, 1985). The dates are slightly older than the Mackinaw Interstadial of Dreimanis and Karrow (1972) (Fig. 2). A recently obtained date for wood from Mackinaw deposits in the southern Lake Michigan basin (near St. Joseph, Michigan) is 13,470 ±130 yr B.P. (ISGS-1378; G. W. Monaghan and A. K. Hansel, unpublished data). These new dates from the spit at Glenwood document the Glenwood I phase of Hough (1958), which corresponds to the Lake Border glacial phase (Fig. 2).

All six Glenwood dates indicate that Glenwood lake phases are pre-Two Creeks in age and correspond to times when glacier ice obstructed eastward drainage, and proglacial lakes in the Huron and Erie basins drained into Lake Chicago by way of the glacial Grand Valley (Figs. 3a–3c). On the basis of radiocarbon-dated stratigraphy from outside the Lake Michigan basin, it is estimated that proglacial lakes in the Huron and Erie basins began draining eastward (via the Mohawk outlet in New York) sometime between about 12,900 and 12,600 yr B.P. (Karrow et al., 1961; Eschman and Karrow, 1985; Muller and Prest, 1985; Toten, 1985). We estimate that the Glenwood II phase ended about 12,700 yr B.P.

Two Creeks and Calumet Deposits

During the Two Creeks interstadial (between about 12,200 and 11,500 yr B.P.) the ice margin retreated far enough north that an outlet, the Illinois River lowland (according to Farrand et al., 1969; Evenson et al., 1976) was open at the north end of the lake basin (Fig. 3a). The lake was at or below present level, as evidenced by the growth of a spruce (Picea) forest at Two Creeks in eastern Wisconsin. The Two Creeks low-water phase is also documented by radiocarbon dates of wood from beneath Calumet-level shoreline deposits at the south end of the basin (e.g., Schneider and Reshkin, 1982; Hansel et al., 1985a; Cole and Hansel, 1986; Table 1). At this time, drainage must have been across isostratically depressed southern Ontario by way of the Fenelon Falls outlet near Kirkfield (Hansel et al., 1985b).

Type Calumet shoreline deposits correspond in time with the Two Rivers glacial phase (Fig. 2). During the advance of Two Rivers ice, the northern outlet was blocked and a proglacial lake once again formed in the Lake Michigan basin; overflow of this lake reactivated the Chiwawa outlet (Fig. 3e). With one exception, radiocarbon dates on wood from the Calumet beach in Indiana are Two Creeks or younger in age (A. F.
Fig. 3. Late Wisconsinan and Holocene high lake phases in the Lake Michigan basin. Radiocarbon ages are estimates. (a) Outlets and inlets important in the Lake Michigan sequence, (b) Glenwood I phase, (c) Glenwood II phase, (d) possible Calumet I phase, (e) Calumet II phase, (f) Nipissing phase.

Schneider and A. K. Hansel, unpublished data (Fig. 1, Table 1). This is also true of the Calumet-level Rose Hill spit in Illinois north of Chicago (Hansel et al., 1985a,b). In that area, the Wilmette, Rose Hill, and Graceland spits occur at progressively lower elevations and are extensions of the Glenwood, Calumet, and Toleston shore-
lines, respectively (Fig. 1). Driftwood from fine sand and silt that occur above driftwood and below within sand and gravel of the Calumet-level Rose Hill spit yielded ages of 11,870 ± 100 to 11,000 ± 80 yr B.P. (Table 1). In contrast, wood from sand and gravel of the Toleston-level Graceland spit was dated at 4030 ± 150 yr B.P. (W-725).

One date for wood from probable Calumet lacustrine deposits in Indiana is 12,400 ± 200 yr B.P. (ISGS-1218) (A. F. Schneider and A. K. Hansel, unpublished data; Table 1). This date suggests to us a possible pre-Two Creeks Calumet lake phase, which corresponds to the interval of time (late Port Huron glacial phase, Fig. 2) when proglacial lakes in the Huron and Erie basins were draining eastward prior to the Two Creeks interstadial (Fig. 3d).

Bowmanville and Toleston Deposits

When the North Shore channel was excavated in 1910 to connect Lake Michigan to the Des Plaines River, F. C. Baker described 63 sections along the canal and collected samples of shells and wood. Some of this organic material was from a bed of peat exposed near Bowmanville (Fig. 1). Baker (1920, 1926) attributed the peat to a lower water phase of the lake, which he named the Bowmanville and correlated with organic material observed beneath the Rose Hill spit. Later, Bretz (1951) correlated the Bowmanville deposits to the Two Creeks forest bed in Wisconsin. All six samples of wood and shells of Bowmanville deposits collected by Baker have yielded middle Holocene ages (Table 1). Clearly, the Bowmanville deposits are much younger (5000 to 4000 yr B.P.) than the Two Creeks forest, which, according to Broecker and Farrand (1963), grew between 11,950 and 11,750 yr B.P. The Bowmanville deposits are now interpreted to represent sedimentation that occurred in Wilmette Bay west of the Rose Hill spit prior to and during the Nipissing transgression (Figs. 2 and 3f) (Hansel et al., 1963b).

Other dated organic material collected from within and beneath Toleston-level shoreline deposits has also yielded middle Holocene ages. This includes dates of wood from the buried Southport forest bed section (Schneider et al., 1979) and the Barnes Creek section (Larsen, 1985b), both located south of Kenosha, Wisconsin; dates of wood and a paleosol from within and beneath the Graceland spit near Chicago; and dates of wood from marsh sediments beneath beach deposits near Michigan City, Indiana (Fig. 1, Table 1) (Winkler, 1962; Gutschick and Genske, 1976; Larsen, 1985b).

CHICAGO OUTLET DEPOSITS

Preliminary work suggests that an important record of lake history is preserved in the Chicago outlet (Hansel et al., 1985b; Hansel and Johnson, 1986a,b). Peat from a core near the eastern edge of the Sag channel (Fig. 1, location 7) was dated 6280 ± 70 yr B.P. (ISGS-960). Silt units above and below the peat are interpreted as Nipissing and Calumet lacustrine deposits, respectively (Hansel et al., 1986b). About a mile to the west along the south side of the Sag channel, peat units above and below silt clay were dated 3990 ± 70 yr B.P. (ISGS-1240) and 8690 ± 80 yr B.P. (ISGS-1241), respectively; these data provide limiting dates for Nipissing drainage through the outlet. Driftwood and shells from sand and gravel near the eastern edge of the Des Plaines channel (Fig. 1, location 8b) yielded ages of 4690 ± 215 yr B.P. (ISGS-1502) and 4779 ± 80 yr B.P. (ISGS-1501), respectively; these sediments represent lacustrine deposition during the Nipissing phase. In a section along the north side of the Des Plaines channel at the western edge of the Chicago outlet (Fig. 1, location 8a), eight recently obtained dates of wood from side-slope colluvium and organic accretionary deposits at a zone of groundwater discharge are 12,770 ± 80, 12,500 ± 210, 12,040 ± 160, 11,880 ± 110, 10,530 ± 200, 10,180 ± 110, 8080 ± 110, and 7900 ± 90 yr B.P. (Table 1).

These beds are underlain by glacial drift,
The colluvial deposit, which lies below the Glenwood and Calumet levels, dips about 4° toward the bedrock channel. Hansel and Johnson (196a,b) argued that the older dates indicate that the channel was cut to bedrock before the Two Creeks low-water phase, which began about 12,000 yr B.P. In fact, the oldest dates (12,770 ±80 and 12,500 ±210 yr B.P.) can be interpreted as a minimum age estimate for the fall from the Glenwood level. If this interpretation is correct, the outlet channel was cut to its present level on bedrock (180 m, 590 ft) early in the history of Lake Chicago (i.e., during the Glenwood phases).

**Summary of Radiocarbon Evidence**

Radiocarbon data from the southern Lake Michigan area confirm the existence and provide details of the timing of the five possible high lake phases in the Lake Michigan basin (Fig. 2). These include pre-and post-Mackinaw Glenwood phases during which the Glenwood shoreline features formed, pre-and post-Two Creeks Calumet phases during which the Calumet shoreline features formed, and a middle Holocene Nipissing phase during which the Toledos shoreline features formed. The pre-Chippewa Teetston-level Lake Chicago and Lake Algonquin events, both of which were proposed by one or more earlier workers (e.g., Leverett and Taylor, 1975; Goldthwait, 1905; Breze, 1955; Hough, 1966; Willman, 1971; Eschner and Farrand, 1970; Evenson, 1973), remain unconfirmed; however, this negative evidence does not preclude their existence.

Radiocarbon age control on high lake phases in the Lake Michigan basin is summarized in Figure 4. Two dates for wood from Glenwood-level deposits are 13,780 and 14,100 yr B.P.; they indicate a pre-Mackinaw Glenwood I lake phase. Evidence from the outlet and outside the basin suggests that the post-Mackinaw Glenwood II phase ended by about 12,700 yr B.P., although radiocarbon dates from the Dyer spit are slightly younger. One date for wood from probable Calumet deposits is 12,400 ±200 yr B.P. (A. F. Schneider and A. K. Hansel, unpublished data), and suggests a possible pre-Two Creeks Calumet I lake phase. Twelve dates for wood from Calumet-level deposits range between 11,870 and 11,000 yr B.P. and indicate a post-Two Creeks Calumet II lake phase. Ten dates for wood from and beneath Toledos-level deposits range between 6350 and 4030 yr B.P. Six dates for wood or shell from the Bowmausville deposits also fall within this range. These data record a postglacial Nipissing lake phase, estimated to have transgressed modern lake level about 5000 yr B.P.

Peat and wood dates from the outlet are also plotted in Figure 4. Within the exception of the possible Calumet I phase, the high lake phases fall between times when
organic matter accumulated in the outlet; thus, the outlet data appear consistent with the rest of the radiocarbon record for the Lake Michigan basin.

REASONS FOR WATER LEVEL CHANGES

If, as radiocarbon evidence suggests, the Chicago outlet was cut to its present level before the Glenwood II phase ended about 12,700 yr B.P., then downcutting of the outlet as proposed by Brez (1951) cannot be used as an explanation for the progressive lowering of the lakes from the Glenwood (195 m) to the Calumet (189 m) and then to the Toleston (184.5 m) level. Water level in the Lake Michigan basin must have been controlled by something other than the threshold elevation of the outlet. Based on radiocarbon age control of events in the Lake Michigan basin, Mickelson et al. (1985) suggested an alternative to Brez’ (1951) outlet-control model for lake-level stabilization. The coincidence in time of the Glenwood level with times when discharge from the eastern lakes also drained into Lake Chicago (Lake Border and early Port Huron glacial phases), the Calumet level with times when drainage was from Lake Chicago alone (late Port Huron and Two Rivers glacial phases), and the Toleston level with the postglacial middle Holocene Nipissing transgression, which resulted from differential uplift in the basin, is strong evidence that changes in lake level may relate to differences in input to the basin. Clayton (1984) suggested that changes in the supply of glacial meltwater to Lake Superior, in addition to glacial rebound, could explain changes in lake level recorded in the multiple Duluth beaches. Similarly, Mickelson et al. (1985) argued that changes in lake level in the Lake Michigan basin can be explained by changes in the amount of glacial meltwater and precipitation entering the basin. This discussion is an amplification of those ideas.

Based on radiocarbon dates, the Glenwood and Calumet beaches clearly formed when glaciers were in the Lake Michigan basin. The Toleston beach, however, formed long after glacier ice left the basin. Fluctuations of the late Wisconsinan ice margin certainly would have affected the size of the Lake Michigan drainage basin and the amount of meltwater runoff supplied to it. Our hypothesis is that the 4.5- to 6-m changes in lake level between the Glenwood (195 m), Calumet (189 m), and Nipissing (184.5 m) phases were produced by major changes in the net input of water to the basin between those times. Mickelson et al. (1985) used two independent methods to test whether these changes in input were sufficient in magnitude to account for the differences between the three lake levels. The first method involves an analysis of the relative inputs to the basin, i.e., precipitation and glacial meltwater; the second involves an analysis of the relative outputs (lossing depth of water in the Chicago outlet to estimate discharge).

Although it is not possible to determine absolute amounts of precipitation and glacial meltwater (ablation) supplied to the basin during the Glenwood, Calumet, and Nipissing phases, it is possible to estimate relative inputs during those phases by considering the different input conditions prevailing. The three different input conditions are:

1. Precipitation plus ablation from the combined Lake Michigan and Huron/Erie drainage basins (Glenwood I and II phases).
2. Precipitation plus ablation from only the Lake Michigan drainage basin (Calumet I and II phases).
3. Precipitation only from the Lake Michigan drainage basin (Nipissing phase).

Estimates of the relative net inputs under these three conditions can be made by assuming a constant precipitation rate (although this most certainly would not have been the case) and determining the area of the drainage basin without ice cover, the area of the drainage basin with ice cover, and the ratio between runoff from a land
surface and from an adjacent ice-covered surface. Figure 5 shows three maps of the drainage area under the different conditions described above. In Figures 5a and 5b the northern boundary is only a crude estimate of the glacial equilibrium line (i.e., northern limit of the ablation zone), but we know of no other basis for choosing one. At the beginning of the Nipissing phase the confluent lake in the Superior, Michigan, and Huron lake basins drained through three outlets (North Bay, Chicago, and Port Huron) (Hough, 1958). Although the rising North Bay outlet was eventually abandoned, we assume that only drainage from the Lake Michigan basin passed through the Chicago outlet (Fig. 5c) and that drainage from Lakes Superior and Huron was via the other outlet(s).

Table 2 indicates relative areas (obtained by overlaying a grid on the map) of the drainage basins with and without ice cover under the three different drainage conditions. Assuming that the areas are reasonable approximations, we can calculate the relative net inputs by using the data from Table 2 in the following equations.

$$I = AX + BY,$$

where:

- $I$ = net input
- $A$ = area not covered by ice
- $B$ = area covered by ice
- $X$ = annual effective precipitation
- $Y$ = annual effective precipitation plus ablation,

then

$$I_1 = 197X + 165Y$$

$$I_2 = 104X + 54Y$$

$$I_3 = 160X.$$  

$I_1$, $I_2$, and $I_3$ are the estimated relative net inputs to the Lake Michigan basin during Glenwood, Calcmet, and Nipissing phase conditions, respectively. Based on analogy with coastal Southeast Alaska (measurements by D. M. Michelson), we assumed a 3:1 ratio between ablation and precipitation over the area covered by ice, which gives

$$Y = X + 3X = 4X.$$  

Substituting this relation into the above equation gives

$$I_1 = 197X + 165(4X) = 857X$$

$$I_2 = 104X + 54(4X) = 320X$$

$$I_3 = 160X.$$  

Therefore, the ratio of net inputs to the basin during Glenwood, Calcmet, and Nipissing phase conditions would be 857:320:160, or 2.7:1:0.5. This ratio is only a crude estimate of the relative inputs; it is important to remember that it is based on several assumptions (e.g., constant precipitation rate, ablation of three times precip-
TABLE 2. Relative Areas with and without Ice Cover for Different Drainage Basin Conditions

<table>
<thead>
<tr>
<th>Relative area*</th>
<th>Without ice cover (A)</th>
<th>With ice cover (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Area of combined Lake Michigan/Huron/Erie basin (with ice)</td>
<td>297</td>
<td>165</td>
</tr>
<tr>
<td>2. Area of Lake Michigan drainage basin (with ice)</td>
<td>104</td>
<td>54</td>
</tr>
<tr>
<td>3. Area of Lake Michigan drainage basin (no ice)</td>
<td>160</td>
<td>0</td>
</tr>
</tbody>
</table>

* Obtained by overlaying a grid on the map.

\[ S = \text{slope} \]
\[ n = \text{Manning roughness coefficient}. \]

When the width of the channel is very much greater than the depth \( d \), as was the case during each of the three phases (Fig. 6), then

\[ Q = d^{0.5}. \]

Using values of 15, 9, and 4.5 m for the water depths in the outlet channel during the Glenwood, Calumet, and Nipissing phases, respectively (Fig. 6), yields a discharge ratio of 2.3:1:0.3.\(^1\) Although this ratio is an approximation at best, it is consistent with the ratio predicted by analysis of inputs (2.7:1:0.5) and suggests to us that downcutting of the outlet between phases is not required to account for the subsequently lower high levels (i.e., Calumet and Toleston). Climate reconstructions, as modelled for 4000 and 3000 yr B.P. (Webb et al., 1987), suggest that the period be-

\(^1\) Our calculations of relative discharges through the Chicago outlet during the Glenwood, Calumet, and Nipissing phases are based on classic interpretations of the altitude of the Glenwood, Calumet, and Toleston deposits (185, 189, and 184.5 m, respectively). On the basis of the altitude of foreslope deposits from vibracores collected at the mouth of the Lake Michigan basin in Indiana, Thompson (1987) has argued that lake level was actually somewhat lower (e.g., about 3 m for the Glenwood and Calumet levels) than the classic studies suggested.
Fig. 6. Channel cross section showing depth of water in the Chicago area during the Glenwood (185 ft; 640 ft), Calumet (189 ft, 620 ft), and Nipissing (184.5 ft; 615 ft) phases.

tween 5000 and 4000 yr B.P. was one of considerably less annual precipitation minus evaporation than at 12,000 yr B.P.; this might explain why relative net input during the Nipissing phase would be overestimated when using a constant precipitation assumption.

In summary, an analysis of the magnitude of relative differences in inputs and outputs between the Glenwood phase when water was derived from precipitation and ablation from both the Lake Michigan basin and the Huron/Erie drainage basin, the Calumet phase when water was derived from precipitation and ablation from the Lake Michigan drainage basin alone, and the Nipissing phase when water was derived only from precipitation in the Lake Michigan basin indicates that water levels during these phases can be explained simply by changes in input to the basin. This reasoning, combined with radiocarbon evidence that the outlet was cut to its present level on bedrock before the lake fell from the Glenwood level, presents a strong argument against the sequential downcutting hypothesis employed by most earlier workers to explain changes of water level in the Lake Michigan basin.

SUMMARY AND CONCLUSIONS

During the onset of Glenwood, Calumet, and Nipissing phases, the lake transgressed the present shoreline of Lake Michigan at Chicago (Fig. 2). Glenwood lake phases correspond in time with Lake Border and early Port Huron glacial phases, and Calumet lake phases with late Port Huron and Two Rivers glacial phases. The postglacial Nipissing lake phase began when differential uplift of the North Bay outlet caused southward transgression of the lake beyond the present shoreline; it ended when Holocene climatic changes (Larsen, 1985b) and incision of the St. Clair River at Port Huron resulted in the lowering of the lake, eventually to its present level.

The paucity of dates on Glenwood-level shoreline deposits makes the exact timing of the Glenwood phases uncertain. However, evidence for a low level in the Lake Michigan, Huron, and Erie basins during the Mackinaw interstadial about 13,500 yr B.P. suggests that the Glenwood was a two-phase level, as earlier workers postulated. Evidence that the Calumet was a two-phase level remains inconclusive, however, because the pre-Two Creeks Calumet phase is documented by only one date, i.e., 12,400 ±200 yr B.P. (ISGS-1218). This date falls within the interval of time when proglacial lakes in the Huron and Erie basins were draining eastward prior to the Two Creeks interstadial. Theoretically, using the discharge model proposed here, a pre-Two Creeks Calumet phase seems likely because the amount of discharge through the Chicago outlet at that time may have approximated that during the post-Two Creeks Calumet phase. The pre-Nipissing Toleston-level (184.5 m) Toleston and Algonquin phases postulated by earlier workers also remain undocumented in the southeastern Michigan area. Larsen (1987) has suggested that the abandoned Algonquin beaches and terraces at the north end of the basin, which have been interpreted as uplifted Toleston-level landforms (Goldthwait, 1908), actually plunge beneath the Toleston level (Nipissing) features in the area of the Algonquin "hinge line" and would be well below modern lake level at the south end of the basin.

Radiocarbon age control on type Glen-
wood, Calumet, and Toledos deposits has provided a basis for establishing a more accurate history of high-level lake events in the Lake Michigan basin. Because of differential isostatic uplift between the northern and southern parts of the basin, a record of some of the low-level lake events may be present high above lake level at the north end of the basin; an effort should be made to find datable organic material from uplifted shoreline deposits. Increased understanding of the timing of lake events has necessitated a reevaluation of the mechanisms and causes of lake-level fluctuations during late Wisconsinan deglaciation and Holocene recovery.

ACKNOWLEDGMENTS

We thank Lee Clayton, L. A. Folmer, C. E. Larsen, P. L. Monkmeier, W. J. Johnson, and A. F. Schneider for discussions on these ideas. Lee Clayton, L. E. Folmer, W. H. Johnson, and E. H. Muller reviewed and made constructive comments on the manuscript. C. L. Lins of the USGS Radiocarbon Laboratory made available unpublished data.

REFERENCES


Baker, F. C. (1920). The life of the Pleistocene or glacial period as recorded in the deposits laid down by the great ice sheets. Illinois University Bulletin 17(14).


HANSSL AND MICKELSON


LATE WISCONSINIAN AND HOLOCENE HISTORY OF THE LAKE MICHIGAN BASIN

Anth K. Hansel
Illinois State Geological Survey, 615 East Peabody, Champaign, Illinois 61820

David M. Mickelson
Department of Geography and Geophysics, University of Wisconsin-Madison, Madison, Wisconsin 53706

Allan F. Schneider
Department of Geography, University of Wisconsin-Parkside, Kenosha, Wisconsin 53141

Curtis E. Larsen
U.S. Geological Survey, Reston, Virginia 22092

ABSTRACT

Glacial Lake Chicago formed during late Wisconsinan deglaciation when ice extended into the Lake Michigan basin but still blocked northern outlets at or near the Straits of Mackinac. The lake drained southward across the Valparaiso Moraine System near Chicago. Deglaciation of the northern outlets permitted eastward drainage through the lower channels and consequent lowering of the lake level. Lake Chicago probably was at the Glenwood level (195 m, 640 ft.), twice, originally between 145 308 and 13 500 B.P. and again between 13 000 and 12 200 B.P. It fell below the modern lake level (177 m, 580 ft.) during the Two Creeks retreat, after 12 000 B.P., and it then rose to the Calumet level (189 m, 620 ft.) as the Two Rivers ice margin advanced, about 11 800 B.P. The short-lived Calumet phase probably ended when the Straits were deglaciated, shortly before 11 000 B.P. Subsequent deglaciation opened successively lower outlets across isostatically depressed southern Ontario; consequently, the lake level dropped to the low Chipewa level (116 m, 380 ft.) about 10 000 B.P. As differential isostatic rebound raised the northern outlet, the Lake Nipissing transgression recrouted the southern outlets at Port Huron and Chicago and the lake rose to the Toletton level (154 m, 505 ft.) between 5000 and 4000 B.P. Incision of the Port Huron outlet resulted in a gradual lowering to the Algoma level (179 m, 587 ft.) about 3800 B.P. and a subsequent lowering to the modern Lake Michigan level about 2500 B.P.

RÉSUMÉ

Le lac proglaciaire Chicago s'est formé lorsque la glaciation continentale couvrait le bassin du lac Michigan et bloquait les extrémités septentrionales de l'eau près des détroits de Mackinac. Le travail de ce lac se déchargeait par un écoulement méridional traversant la moraine Valparaiso près de Chicago. Lorsque les dépôts ont été libres de glace, le niveau du lac a baissé car l'eau s'est alors déversée par les extrémités nordiques moins élevés. Le lac Chicago a atteint son niveau Glenwood (195 m, 640 pieds) probablement deux fois: une première fois entre 14 500 and 13 500 B.P. puis à nouveau entre 13 000 et 12 200 B.P. Il descendit sous son niveau actuel (177 m, 580 pieds) lors de la retraite de Two Creeks qui débuta vers 12 000 B.P. pour ensuite atteindre le niveau Calumet (189 m, 620 pieds) lors de l'avancée glaciaire de Two Rivers vers 11 800 B.P. Cette courte phase Calumet se termina sans doute avec la déglaciation des détroits il y a un peu moins de 11 000 ans. La retraite glaciaire qui suivit, libéra les extrémités de plus en plus dans le sud de l'Ontario alors isostatiquement déprimé. En conséquence, le niveau du lac s'abaissa au bas niveau de Chipewa (116 m, 380 pieds) il y a environ 10 000 ans. Alors que le soulèvement isostatique élevait les hauteurs des extrémités septentrionales, la transgression du Nipissing réactiva les extrémités méridionales à Port Huron et Chicago et le lac s'élève au niveau Toletton (154 m, 505 pieds) entre 5000 et 4000 B.P. Le sommets des escarpements de Port Huron créa il y a environ 2500 ans un abaissement graduel jusqu'au niveau Algoma (179 m, 587 pieds) autour de 3800 B.P. et une baisse successive de la surface lacustre jusqu'au niveau actuel du lac Michigan.

INTRODUCTION

A series of lakes of different sizes and levels developed during and after late Wisconsinan deglaciation in the Lake Michigan basin. Evidence for these lake events comes from observations of the extent and altitudes of wave-cut cliffs, beaches, spits, and deltas, and from the altitudes of abandoned lake outlets. Differential isostatic rebound during and
after deglaciation changed the altitudes of these features, and the history of rebound in the basin is not known in detail. Radiocarbon dating has progressed considerably since the studies of Breen and Hough in the 1950s and 1960s; presentation of a summary of the new radiocarbon chronology is the main emphasis in this paper. Our discussion focuses on radiocarbon-dated stratigraphy in the southern Lake Michigan area, the type area for many of the lake events and an area in which the effects of differential neotectonic rebound are most apparent.

The chronology of events in the Lake Michigan basin is summarized in Figure 1. Lithostratigraphic units in the area surrounding the southern Lake Michigan record the principal glacial and lake phases in the basin. These phases are based on time-transgressive events and represent episodes of glacial and lake history. The names associated with the lakes that occupied the Lake Michigan basin during the past 16,000 years are indicated in Figure 1; the phases of lake history that we propose here are also indicated. The lake levels and the inlets and outlets associated with the lake history are also shown. The radiocarbon age assignments to the lake phases represent estimates based on our interpretation of the available radiocarbon evidence for events in the Lake Michigan basin area. The ages of some of the glacial and lake phases are not closely limited by radiocarbon measurements.

The lake chronology in the Lake Michigan basin proposed in Figure 1 is discussed in the main part of the paper. Mechanisms of lake level changes, relationships of glacial and lake events, and the effect of differential isostatic rebound on the lake history are discussed first.

Mechanisms of Lake Level Changes

Glacial and postglacial lake levels changed because of:
1. advance and retreat of ice margins that blocked or uncov-
ered outlets, 2. downcutting of outlets, 3. major increases and decreases in the volume of water entering the lake, and 4. differential isostatic changes in the altitudes of parts of the basin or outlets. Generally, these mechanisms worked in combination to control events.

After the formation of the Valparaiso Morainic System, a preglacial lake called Lake Chicago formed when glacial ice still extended into the Lake Michigan basin and blocked outlets at or near the Straits of Mackinac. Lake Chicago drained by way of an outlet through the Valparaiso Morainic System and the Tinley Moraine southwest of Chicago. This outlet consisted of two trans-morainic channels (Des Plaines and Sag channels). Fig. 2) leading southwestward to the Illi- nois River and ultimately to the Mississippi River. When eastward drainage of lakes in the Lake Huron, Lake Saginaw, and Lake Erie basins was obstructed by ice, the Chicago outlet also served as the “ultimate” outlet for water from the lakes that drained into Lake Chicago by way of the glacial Grand Valley across central Michigan (Fig. 3a, 3b, 3d).

Major fluctuations of the ice margin within the Lake Michigan basin occurred between 15,000 and 11,000 B.P. These fluctuations can be separated into three main glacial advance phases (the Cary, Port Huron, and Two Rivers advances) and two recessional phases (the Cary-Port Huron and Two Creeks recessions) (Fig. 1). During the recessional phases, the ice margin probably withdrew north of the Lower Peninsula of Michigan. Initial drainage was eastward through an inferred outlet in the Indian River lowland. Later it may have been through the Straits of Mackinac (Fig. 3c, 3e). When these outlets were deglaciated, the water level in the Lake Michigan basin was lowered because water in the contemporaneous lake in the Lake Huron basin drained eastward through still lower outlets—perhaps south to Lake Vinsland (Funke, 1963) or east through the Tiern Valley.

Shoreline features occur at three distinct levels in the southwestern Lake Michigan area, and on the basis of these levels, Leverett (1987) distinguished three main high levels of Lake Chicago: the Glenwood level at 195 m (640 ft.), the Calumet level at 189 m (620 ft.), and the Toledan level at 185 to 184 m (600 to 605 ft.). The lowering of the lake to progressively lower levels generally has been attributed to episodic downcutting of the Chicago outlet (e.g., Leverett, 1897; Albright, 1902; Goldthwaite, 1908; Wright, 1918; Breen, 1951, 1955; Hough, 1958), although explanations for the pauses interrupting downcutting have varied.

The most recent and most widely accepted explanation for lake level stabilization is the outlet control model of Breen (1951, 1955), who argued that the lake level during each phase was governed by the threshold altitude of the outlet. Breen speculated that the lake level was stabilized during the Glenwood and Calumet phases because erosion-resistant boulder lags formed in the outlet channels and retarded inci-
sion. He asserted that the boulder lags formed when dis-
charge came solely from Lake Chicago and that they were swept away when discharge increased greatly owing to the addition of drainage from glacial lakes in the Lake Huron- Lake Saginaw, and Lake Erie basins. After deglaciation un-
covered a lower outlet for the eastern lakes and the channels at Chicago had been downcut to bedrock, the lake was stabilized at the Toledan level.

An alternative to the outlet-control model is that of tem-
porary lake level stabilization that was adjusted to the depth and width (cross-section) of the Chicago outlet. Like the modern St. Clair River outlet of Lake Huron, which prior to 1890 had an historic sil~ depth 6 m below the mean lake level, the Chicago outlet channel also probably had a considerable depth during the Glenwood and Calumet phases. Therefore, the bedrock sill of the channel now at 180 m, 590 ft. may have been the reason for fleeting in the history of Lake Chicago than thought previously. The level of the lake may have fluctuated due to large increases and decreases in the volume of water in the lake basin (Wright, 1918). The flow through the channel, rather than a specific threshold altitude, prob-
ably controlled the lake levels because the altitude of the threshold at any given time provided only a lower limit to the lake level. For example, the depth of water flowing through the channel may have been close to 9 m when the lake was at the Calumet level, but only 3 to 4 m when it was at the Toledan level.

A second alternative explanation of lake level change involves possible, but as yet undocumented, differential iso-
static uplift of the southern Lake Michigan area following deglaciation. If differential uplift was responsible for the re-
cord of lake level changes, the Glenwood and Calumet levels could represent times when isostatic changes were offset by changes in discharge (Larsen, 1985a). Incision of the channel into the Valparaiso Morainic System and the Tinley Moraine thus may have occurred largely in response to differential uplift.

The final retreat of the ice margin from the Straits resulted in coalescence of lakes in the Lake Michigan, Lake Huron, and Lake Superior basins. The outlet of this lake, known as Lake Algonquin, was at Fenelon Falls, east of Georgian Bay, in southern Ontario. According to some current interpretations (Eschman and Karrow, 1985; Finanmore, 1985), the Fenelon Falls (Kirkfield) outlet was raised by differential uplift enough to reactivate the southern outlets at Chicago and Port Huron before the ice margin had retreated far enough to open still lower outlets near North Bay, Ontario. Kaszczzyk (1985), on the other hand, argues that the Main Algonquin water plate projected to a level approximately 46 m below present lake level in the vicinity of Port Huron and that the Kirkfield (Fenelon Falls) outlet was the sole point of discharge for Lake Algonquin prior to the deglaciation of the South River outlet near North Bay. Field evidence to support re-use of the Chicago outlet at this time (Main Algonquin) has not been found in the southern Lake Michigan area. We suggest that after the ice margin withdrew from the Straits, successively lower outlets were uncovered, and the lake level continued to fall, until the lowest (Chipewa) level was reached when the North Bay outlet was deglaciated.

The Nipissing transgression resulted from differential isostatic rebound north of the southern lakes basins. The rebound caused reoccupation of the southern outlets at Chicago and Port Huron. Because the Chicago outlet channel had been cut to bedrock previously, it was abandoned when the St. Clair River channel near Port Huron was incised into less resistant medial drift. The outlet at Port Huron, thereafter, served as the sole outlet for the postglacial upper Great Lakes. As the region continued to recover from the effects of glaciation and isostatic adjustment, further incision of the outlet at Port Huron resulted in lowering of the lake level, thereby creating Lake Algonia (1797 m, 587 ft.) and ultimately Lake Michigan (1777 m, 580 ft.).

Glacial Events and Lake Levels

Between about 15,500 and 13,500 B.P., ice of several minor readvances, each succeeding advance being of a lesser magnitude than the former, reworked lake sediments and deposited it in the Valparaiso, Tinley, and Lake Basin Moranes (Johnson, in press). Several units of grey, clayey till separated by lake sediment are present in Illinois and Wisconsin (Hansel, 1983). These units, called the Wadsworth Till Member of the Wedron Formation in Illinois (Willman and Frye, 1970) and the Oak Creek Formation in Wisconsin (Moehlson et al., 1984), show no evidence that drainage entered the Lake Michigan basin from the Lake Superior basin before advances.

After 13,500 B.P., the ice margin evidently retreated far enough to allow drainage through the Indian River lowland and the Straits of Mackinac. One or both of these northern outlets may have been used during each subsequent episode of ice margin retreat. When glacial ice was at its position of maximum expansion during the later Port Huron and Two Rivers advances, the ice margin occupied a relatively unstable position on the mid-lake high in the Lake Michigan basin; it probably was in relatively shallow water, and the glacier bed sloped northward. Thinning of the ice sheet or a rise in the lake level would have caused very rapid calving (Mickelson et al., 1981). Channels in the Indian River lowland and on the floor of Lake Michigan, near the Straits of Mackinac, may have been cut by catastrophic floods when the ice margin calved far enough northward to allow drainage across that low-land. It is ever possible that the later glacial ice margin fluctuations were enhanced by rising and falling levels of the lake.

Units of till, called the Ozaaue, Haven, and Valders Members of the Keweenawan Formation in Wisconsin and the Manitowoc and Shorewood Till Members of the Wedron Formation in the Lake Michigan basin, were deposited in rapid succession between about 13,000 and 12,500 B.P. (Acorn et al., 1982; Lineback et al., 1974, 1979). The lithologic character of these red, clayey till units suggests that red clay from the Lake Superior basin was deposited in the Green Bay-Fox River lowland and the Lake Michigan basin before and/or during the Port Huron advances and it then was reworked by Green Bay Lobe and Lake Michigan Lobe ice.

The Glenwood level was abandoned either before or as a result of the Two Rivers retreat, which began about 12,200 B.P. When the northern outlets were opened, the lake level was lowered to an altitude below that of present Lake Michigan. The Two Rivers ice advance, which began about 11,800 B.P., blocked the northern outlets and caused a rise to the Calumet level and flooding of Puce eras of the Two Creeks forest before the Two Rivers till was deposited. Lake Chicago was lowered from the Calumet level after the retreat of the Two Rivers ice margin, and it was replaced by Lake Algonquin when water in the Lake Michigan and Lake Huron basins became confluent. When the ice margin had later retreated from the Upper Peninsula of Michigan, Lake Algonquin extended into the Lake Superior basin.

The red and grey clay units of the South Haven and Sheboygan Members of the Lake Michigan Formation probably were deposited between 11,000 and 9500 B.P. (Fig. 1). Red clay likely entered the Lake Michigan basin as the ice margin retreated from the Upper Peninsula of Michigan about 11,000 B.P., and it entered again during the Marquette advance of the Superior Lobe ice between 10,000 and 9700 B.P. (Clayton, 1983; Drexler et al., 1983). Between 11,000 and 9000 B.P., when the Upper Peninsula was free of ice, lake drainage and red clay from the Superior basin could not have entered the Lake Michigan basin because the levels of eastward-draing Lake Algonquin and the post-Algonquin lakes were below those of the channels across the Upper Peninsula. As Drexler et al. (1983) have suggested, when drainage from the Lake Superior basin was cut off and the lake level was low in the Lake Michigan basin, the grey clay of the Willmette Bed probably was deposited (Fig. 1).
Differential Isostatic Rebound and Lake History

Shore features of former lakes in the Lake Michigan basin are discontinuous today because many were destroyed or obscured by more recent ice advances, shore erosion, dune development, and human modification. Thus, it is difficult to trace the shorelines and to evaluate the effect of isostatic rebound on lake levels in the basin. Despite early work by Chamberlain (1873), Goldthwait (1900, 1905, 1906), LeVesconte and Taylor (1915), and Alden (1918), and later evaluations by Bretz (1951), Hough (1966), and Evenson (1973), the uplift history in the basin remains a puzzle.

During the Glenwood and Calumet phases, the outlet was at the south end of the lake, and one would expect that the altitudes of the shorelines would rise northward because of differential rebound. The latest analysis of rebound in the Lake Michigan basin, however, suggests that no tilting of shorelines occurred south of Sheboygan, Wisconsin, on the west side of the lake and south of the Indiana/Michigan state line on the east side (Evenson, 1973). Although Leverett and Taylor (1915) recognized a rise in altitude of the Glenwood shoreline from 195 m to 201 m between the Michigan/Indiana state line and Muskegon, Michigan, a similar change was not noted in Wisconsin by either Goldthwait (1905) or Alden (1918). These observations suggested to Evenson that isobases run north-northwest/south-southeast across the southern half of the lake, and that shorelines on both sides of the lake are flat at 195 m, rise to 201 m, and are flat at this altitude between Muskegon and Manitow on the Michigan side of the basin (Evenson, 1973). Evenson concluded that Calumet shorelines are not deformed. He pointed out that it is difficult to reconcile these observations with what is known about the pattern of ice margin retreat. Recently, Taylor (1985) presented evidence of uplifted Glenwood and Calumet shorelines in the Manistee-Frankfort area along the eastern shore of Lake Michigan.

Shore features at the 184 m (Tolstoi) level are present on the Haven and Valders till south of Two Rivers, Wisconsin. On the Door Peninsula in Wisconsin, beaches interpreted as Main Algonquin and post-Algonquin shore features are related to the Rae Line. These interpreted as Lake Nipissing beaches have been inferred to be horizontal south of Washington Island in Wisconsin and south of Traverse Bay in Michigan (Gleason, 1918; Leverett and Taylor, 1915). The Main Algonquin and Nipissing shorelines appear to converge at the 184 m level at Chicago. As Hough (1933) noted, none of the old beaches in the northern parts of the Lake Michigan or Lake Huron basins can be traced to a junction with any beaches in the southern parts of the basins because the old beaches on both sides of the lake (where they supposedly approach horizontality) have been removed by erosion.

The above observations and interpretations appear to be irreconcilable with recent studies that indicate that both the northern and southern parts of the basin currently are undergoing differential uplift (e.g., see Clark and Persoglia, 1970; Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1977). Furthermore, ongoing uplift has raised the Nipissing and Algoma terraces at Port Huron above contemporary terraces at Chicago (Larsen, 1985a).

The effect of isostatic rebound on lake events cannot be resolved until the nature of rebound in the basin is better understood. Investigators have attempted to correlate beaches in various parts of the basin with outlets since Goldthwait (1905, 1906) and Leverett and Taylor (1915) originally mapped shore features but the correlations are not firmly established. Beaches mapped as Glenwood and Calumet may be beaches of later phases, and the Main Algonquin shoreline may plunge beneath the Lake Nipissing shorelines in the area to the shorelines of the two lake phases supposedly converge. Furthermore, there is no closely limiting radiocarbon age control for many of the high beaches in the central and northern parts of the lake basin.

For these reasons, relative age determination of glacial and lake phases based on the relationship of deposits to shoreline levels is tenuous.

GLACIAL LAKE CHICAGO

Lake Chicago occupied the southern part of the Lake Michigan basin at various times between 15,000 and 11,000 B.P. after retreat of the ice margin from the Valparaiso Morantic System. The lake was named by Leverett in 1897, when he first distinguished the three main high levels of the lake. In designating the lake "stages" (now referred to as phases or lake levels), Leverett selected geographic names of localities on or near the three most prominent shorelines at the south end of Lake Michigan in northeastern Illinois and northwestern Indiana (Fig. 2). Unfortunately, the type area of Lake Chicago has been overlooked by more recent workers in their reconstruction of the sequence of events that accompanied retreat of the Wisconsinan ice margin in the Lake Michigan basin. We refocus attention to this critical type area.

Pre-Glenwood Phases

The oldest recognized beaches of Lake Chicago are those of the Glenwood level. According to Bretz (1951, 1955), the Glenwood level post-dates an episode when the ice margin readvanced to the position of the Tinley Moraine on the proximal slope of the older Valparaiso Morantic System. A number of observations, however, indicate that when the ice margin readvanced to the position of the Tinley Moraine on the proximal slope of the older Valparaiso Morantic System, a number of valleys and beaches were left behind when the ice margin readvanced to the position of the Tinley Moraine on the proximal slope of the older Valparaiso Morantic System. A number of valleys and beaches were left behind.

The old beaches are located, however, in the main valley train in the outwash channels. Following Leverett (Leverett and Taylor, 1915), Bretz (1951) cited evidence that drainage from a pre-Glenwood lake, called "incipient Lake Chicago", flowed into the Tinley Moraine, and he inferred that the boulder lag that formed as a result of the drainage stabilized the lower-lake level. A number of valleys and beaches were left behind when the ice margin readvanced to the position of the Tinley Moraine. Hough (1958, p. 164) referred to a post-Valparaiso, pre-Tinley lake as "Early Lake Chicago." A still earlier (pre-Valparaiso) lake in the Lake Michigan basin, called glacial Lake Milwaukee, has been recognized...
on the basis of lithologic and stratigraphic evidence (Schneider, 1983; Schneider and Need, 1983), but no shoreline features or radiocarbon dates are available to verify the level, extent, and exact age of any pre-Lake Chicago lakes.

Glenwood I Phase of Lake Chicago

The Glenwood I phase of Lake Chicago began shortly after 14,500 B.P., when the ice margin had retreated from the Tinley Moraine. The closely spaced moraines of the Lake Border Morainic System probably were formed early in this phase. Fullerton (1980, pl. 1) introduced the term "border lakes" (phase) for this episode. During this phase, Lake Chicago was probably small and crescentic; it was dammed by the southern margin of the Lake Michigan Lobe ice and it received ice marginal drainage from the east and west (Fig. 3a). Retreat of the ice margin from the Lake Border Moraines caused Lake Chicago to expand northward (Fig. 3b). The lake attained its maximum extent just prior to deglaciation of a northern outlet channel, about 13,500 B.P.

Proglacial drainage from Saginaw Lobe ice and possibly Huron and Erie Lobe ice probably discharged into Lake Chicago by way of the glacial Grand Valley during the Glenwood I phase. Whether or not Lake Chicago actually stabilized at the Glenwood (195 m) level during the Glenwood I phase remains uncertain because all dated Glenwood sediments represent the Glenwood II phase.

Intra-Glenwood Low Phase

The intra-Glenwood low phase (Fig. 1, 3c) corresponds with the Cary-Port Huron retreat (the Mackinaw Interlude of Dreimanis and Karrow, 1972). During this retreat, between 13,500 and 13,000 B.P., the ice margin probably wasted north of the Straits of Mackinac and red clay from the Lake Superior basin was transported into the Lake Michigan.
Figure 3. Late Wisconsinan and Holocene lake phases in the Lake Michigan basin. Radiocarbon ages are estimates. a) Early Glenwood I phase b) Glenwood I phase c) Intra-Glenwood low phase d) Glenwood II phase e) Two Creeks low phase f) Calumet phase g) Kirkfield phase h) Chippewa low phase i) Nipissing I phase
Hansel (1958, 1963, 1966) regarded the Glenwood to be a multilobe lake, and he suggested (1963) that a "possible low stage" developed during the Cary-Port Huron ice retreat. Possible evidence of a low level had been reported earlier by Workman (1925). Hough was not able to document the existence of this low-level event, however, because of the uncertainty of correlations of beaches, discrepancies in radiocarbon dates from the Dyer site, and the lack of evidence for the extent of ice margin retreat between the Cary and Port Huron readvances.

Both Brenchel (1956, 1958) and Hough (1966) assigned the Glenwood-Calamet transition to Port Huron time and inferred that an influx of water from ice-dammed lakes in the eastern basins caused downwasting of the Chicago outlet. Alternatively, Lake Chicago may have risen to and stabilized at the Glenwood level during the Glenwood II phase because of the added discharges from eastern lakes, and the level may have been lowered when a lower northern outlet was veened and the eastern lakes drained eastward.

The Glenwood II phase has been abandoned before retreat of the Port Huron ice margin in the Lake Michigan basin uncovered a lower outlet and initiated the Two Creeks low phase. Evidence of the pre-Two Creeks Calumet I phase of Brezt (1951, 1959) has not been observed in the type area of the Calumet phase is the southern part of the Lake Michigan basin. All dated landforms at the Calumet level are post-Two Creeks in age (Fig. 2, Table 1). Eschman and Farrand (1970) and Eschman et al. (1973) argued that a Calumet level was formed in pre-Two Creeks time because the lowest terraces of pre-Two Creeks Lake Warren have been traced through the glacial Grand Valley to the Calumet level (189 m) in the Lake Michigan basin.

Two Creeks Low Phase

The Two Creeks low phase began between 12,000 B.P. and the Port Huron ice margin had retreated far enough to open a low outlet to the northwesternmost ice margin at Two Creeks, Wisconsin, provided evidence for the low-level phase, which was named accordingly (Thwaites and Bertrand, 1979). Hough, Brezt, and Hough (1963) suggested a period of 200 radiocarbon years (11 950-11 750 B.P.) for the growth of the forest, and Fullerton (1980) concluded that initial growth of the forest began no earlier than 12,000 B.P.

Lake Algonquin in the Lake Huron basin was contemporaneous with the Two Creeks low phase and the lakes in both basins (Michigan and Huron) ultimately drained through the region east of Georgian Bay in Ontario. Some investigators have interpreted the stratigraphy of the Cheboygan County briny phase in Michigan as indicating that the Straits of Mackinac were covered by ice throughout the Two Creeks interval (Farrand et al., 1969; Farrand and Eschman, 1974; Evenson et al., 1976). However, Fullerton (1980) noted that this interpretation is wholly dependent on the assignment of a Cary-Port Huron age to the briny phase and that that age assignment is equivocal. For this reason, in Figure 3 the ice margin is shown with both the Indian River lowland and the Straits serving as possible outlets.

In the type area of Lake Chicago evidence for a low lake event was first recognized by Andrews (1870), who noted the presence of peat and wood beneath the Rose Hill spit at Evanston, Illinois. This feature is a 25 km-long spit that was formed southward into Lake Chicago from a headland near Wilmette (Fig. 2). Its highest part consists of a ridge at an altitude of 187 to 189 m, and it is considered to be an extension of the Calumet shoreline (Andrews, 1870; Leterrer, 1897; Alden, 1902; Baker, 1920; Brezt, 1939, 1955; Willman, 1971). Baker (1952) correlated the deposits beneath the spit at Evanston with a silt bed in an area west of the spit near Bowmanville (Fig. 2). The silt bed contained wood and shells and was exposed during excavation of the North Shore Channel to the Chicago River. On the basis of these deposits, Baker (1912) proposed that a low-water phase that he named the Bowmanville stage (Baker, 1912, 1956) existed between the Glenwood and Calumet phases. Although Baker's interpretation of the deposits at Evanston and Bowmanville as evidence for a low-water phase was questioned (Goldthwait, 1908; Leterrer and Taylor, 1915; Alden, 1918; Hough, 1958), Brezt (1951) correlated the Bowmanville phase with the well-established Two Creeks low phase. Hansel recently examined the stratigraphy and collects organic material from sites in the southern Lake Michigan area. Baker's stratigraphy, as well as the faunal and macrobotanical collection he made in 1910 during the excavation of the North Shore Channel, were re-examined. Thirty new radiocarbon dates on material from either the Baker collection or new sites were measured at the Illinois State Geologi-
<table>
<thead>
<tr>
<th>Location No.</th>
<th>Years BP</th>
<th>Lab No.</th>
<th>Material</th>
<th>Altitude a.s.l.</th>
<th>Comments</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Glenside Beach</td>
<td>12 400 ± 300</td>
<td>EL-42</td>
<td>wood</td>
<td>ca. 187 m</td>
<td>Below initial sand-mud sequence in marsh margin, terrace deposits.</td>
</tr>
<tr>
<td>2</td>
<td>Over Spit</td>
<td>12 420 ± 150</td>
<td>W-146</td>
<td>wood</td>
<td>&lt;187 m</td>
<td>From peat at high tide deposits, terrace deposits.</td>
</tr>
<tr>
<td>3</td>
<td>12 480 ± 130</td>
<td>W-155</td>
<td>wood</td>
<td>&lt;187 m</td>
<td>From peat deposits.</td>
<td>Rehkowsky and Surovell, 1957</td>
</tr>
<tr>
<td>4</td>
<td>12 480 ± 130</td>
<td>USGS-1790</td>
<td>wood</td>
<td>&lt;187 m</td>
<td>Above till horizon, may have been sea of ice.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>5</td>
<td>Calvert Beach</td>
<td>11 830 ± 640</td>
<td>LG-147</td>
<td>wood</td>
<td>ca. 201 m</td>
<td>From the pre-face basin in sand and gravel above terrace sediments.</td>
</tr>
<tr>
<td>6</td>
<td>11 650 ± 500</td>
<td>LG-246</td>
<td>wood</td>
<td>ca. 201 m</td>
<td>From peat and gravel bed that underlies 3 m of peat</td>
<td>Schneider and Redikoff, 1962</td>
</tr>
<tr>
<td>7</td>
<td>11 800 ± 500</td>
<td>LG-244</td>
<td>wood</td>
<td>ca. 201 m</td>
<td>From this site and peat layer in sand in 1.5 m below MLWL</td>
<td>Schneider and Redikoff, 1962</td>
</tr>
<tr>
<td>8</td>
<td>11 740 ± 100</td>
<td>USGS-1147</td>
<td>driftwood</td>
<td>ca. 201 m</td>
<td>From sand and gravel from terrace sediments.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>9</td>
<td>Four Mile Spit</td>
<td>11 640 ± 70</td>
<td>USGS-983</td>
<td>driftwood</td>
<td>ca. 201 m</td>
<td>From terrace sediments, high tide deposits at peat from this area.</td>
</tr>
<tr>
<td>10</td>
<td>11 500 ± 85</td>
<td>USGS-987</td>
<td>driftwood</td>
<td>ca. 201 m</td>
<td>From terrace sediments.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>11</td>
<td>11 740 ± 75</td>
<td>USGS-1117</td>
<td>wood</td>
<td>182.7 m</td>
<td>Wood in peat that underlies a gravel terrace with gravel deposits.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>12</td>
<td>11 380 ± 50</td>
<td>USGS-1221</td>
<td>wood</td>
<td>182.7 m</td>
<td>Wood in peat.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>13</td>
<td>11 370 ± 100</td>
<td>USGS-1117</td>
<td>driftwood</td>
<td>182.7 m</td>
<td>Wood in peat at base of terraces.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>14</td>
<td>11 420 ± 100</td>
<td>USGS-1121</td>
<td>wood</td>
<td>182.7 m</td>
<td>Wood on top of the sand.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>15</td>
<td>11 270 ± 100</td>
<td>USGS-1180</td>
<td>driftwood</td>
<td>182.7 m</td>
<td>Wood in peat.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>16</td>
<td>North Shore Channel (Station 13, 27, Baker, 1965)</td>
<td>11 360 ± 60</td>
<td>USGS-1217</td>
<td>peat core</td>
<td>178.8 m</td>
<td>Surface 13. Stratum VIV, in interbedded sand and silt.</td>
</tr>
<tr>
<td>18</td>
<td>11 370 ± 100</td>
<td>USGS-1200</td>
<td>wood</td>
<td>178.8 m</td>
<td>Surface 13. Stratum V, from till sliver below.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>20</td>
<td>11 500 ± 75</td>
<td>USGS-1105</td>
<td>wood</td>
<td>177.4 m</td>
<td>Surface 13. Stratum II, from high tide deposits off and above channel.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>21</td>
<td>11 500 ± 75</td>
<td>USGS-1105</td>
<td>wood</td>
<td>177.4 m</td>
<td>Surface 13. Stratum II, from riverbank sediments.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>22</td>
<td>11 500 ± 75</td>
<td>USGS-1105</td>
<td>wood</td>
<td>177.4 m</td>
<td>Surface 13. Stratum II, from riverbank sediments.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>23</td>
<td>11 490 ± 75</td>
<td>USGS-1105</td>
<td>drifts</td>
<td>177.4 m</td>
<td>Surface 13. Stratum II, from riverbank sediments.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>24</td>
<td>11 470 ± 100</td>
<td>USGS-1287</td>
<td>peat core</td>
<td>177.4 m</td>
<td>Wood in peat.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>25</td>
<td>Greenbush Spit</td>
<td>10 450 ± 130</td>
<td>W-172</td>
<td>wood</td>
<td>ca. 157 m</td>
<td>Wood in peat.</td>
</tr>
<tr>
<td>26</td>
<td>10 470 ± 100</td>
<td>USGS-1287</td>
<td>peat core</td>
<td>157 m</td>
<td>Wood in peat.</td>
<td>C. L. Liu, pers. commun.</td>
</tr>
<tr>
<td>27</td>
<td>Oak Beach (Baker, 1960)</td>
<td>9 470 ± 60</td>
<td>USGS-1217</td>
<td>drifts</td>
<td>152.7 m</td>
<td>Wood in peat.</td>
</tr>
<tr>
<td>28</td>
<td>Sag Channel</td>
<td>8 390 ± 70</td>
<td>USGS-1360</td>
<td>peat</td>
<td>152.7 m</td>
<td>Riverbank sediments from fluvial terrace deposits.</td>
</tr>
</tbody>
</table>

Note: Locations shown by number on Figure 2.

* Samples collected by Baker.
suggested that the lower distal part of the Rose Hill spit, at an altitude of 183 to 186 m, was formed when Lake Chicago was lowered from the ca?nular level to the Toleston level. Driftwood and rootlet peat are interbedded with silt and fine sand beneath the lateral and distal parts of the spit, and wood samples were dated at 11,250 ± 180 B.P. (ISGS-1451) and 11,180 ± 160 B.P. (ISGS-1121) (Table 1). Thus, deposition of the sand and gravel in the lower part of the Rose Hill spit may have occurred approximately 11,000 B.P. or earlier. Because Lake Chicago ceased to exist when the Straits were deglaciated and because that event has not been precisely dated — although generally it is placed prior to 11,000 B.P. (Evenson et al., 1976; Karrow, 1976; Fullerton, 1980) — it is not clear whether the lower part of the Rose Hill spit relates to a Toleston level of Lake Chicago.

**GLACIAL LAKE ALGONQUIN**

When the ice margin retreated from the Straits, probably shortly before 11,000 B.P., water in the Lake Michigan and Lake Superior basins became confluent with Lake Algonquin in the Lake Huron basin. According to the current model, Lake Algonquin was in the Main (or lower) Algonquin phase (at the 184 m level) during this time (Fullerton, 1980); however, shore features of this phase have not been identified in the southern parts of the Lake Michigan and Lake Huron basins. The apparent absence of Algonquin landforms has been attributed to intensive Lake Nipissing waves and currents (Karrow, 1980).

Dated sediments in the southern Lake Michigan area suggest that the lake level was below an altitude of 184 m (the assumed Main Algonquin level during the Main Algonquin phase (from about 11,200 to 10,400 B.P., according to Karrow et al., 1975), Spruce wood and cones from silt at an altitude of 178 to 180 m at Baker's (1920) Stations 33 and 37 on the North Shore Channel (Fig. 2, Table 1) ranged in age from 11,010 ± 130 to 8590 ± 140 B.P. Deposition at this local level is as yet debatable, and the dates included in the stratigraphy suggest that the lake level was below the 184 m (Main Algonquin) level between 11,000 and 8600 B.P. Wood from a peat at South Haven, Michigan, at an altitude of 179 m yielded a date of 10,900 ± 160 B.P. (Lowdon and Blake, 1975) and it provides additional evidence for a level below 184 m in the southern Lake Michigan basin during Main Algonquin time.

We suggest that when the ice margin retreated from the Lake Michigan basin, Lake Algonquin drained through the relatively lower Fenelon Falls outlet, which was below the 184 m Toleston level. In the type area of Lake Chicago, there appears to be no clear evidence to support assumptions that Lake Algonquin drained through the Chicago outlet or that the lake stabilized at the Toleston level prior to the Nipissing transgression in the middle Holocene. Therefore, we suggest that the Kirkfield phase occurred in the Lake Michigan basin from about 11,000 to 10,000 B.P. and that drainage was through the Straits to the Fenelon Falls outlet (Fig. 1, 3g). The Kirkfield phase in the Lake Michigan basin corresponds in time with the Main Algonquin phase in the Lake Huron basin (Eischmann and Karrow, 1983). But we suggest that lake level in the confluent lake basins was below the 184 m level.
POST-ALGONQUIN GROUP LAKES

Deglaciation of successively lower outlets, as the ice margin retreated northward across isostatically depressed southern Ontario between 10,500 and 10,000 B.P., resulted in formation of a series of successively lower confluent lakes in the upper Great Lakes basin (Terasmae and Hughes, 1966; Lewis, 1969; Harrison, 1972; Saamotso, 1974; Drexl et al., 1983). These post-Algonquin lakes usually are relegated to an upper group (Lakes Andera, Upper Orillia, and Lower Orillia) and a lower group (Lakes Wyebridge, Penetang, Cedar Point, Payette, Sheguiandah, Kosh, and Chippewa). In the Lake Michigan basin they are represented by uplifted shorelines in the northern part of the lake basin. Deglaciation of the North Bay area about 10,000 B.P. (Harrison, 1972; Fullerton, 1980; Drexl et al., 1983) opened an outlet to the St. Lawrence Lowland by way of the Mattawa and Ottawa valleys. Ice margin then ceased to be an important factor in the changing levels of the lakes. Instead, isostatic rebound, climatic change, and outlet downcutting became the dominant variables in the hydrological system.

Stanley (1936, 1937) noted that if isostatically warped terraces below the highest Lake Algonquin terrace in the northern Lake Huron and Lake Michigan basins are projected southward they are below the modern lake surfaces in the southern parts of the basins. These terraces were considered to be evidence of failling post-Algonquin lake levels. Stanley also suggested that an extremely low post-Algonquin level, now known as Lake Stanley, formed in the Lake Huron basin (Hough, 1958, p. 236). Hough (1955, 1958), following Stanley, proposed that an extremely low level, Lake Chippewa, formed in the Lake Michigan basin. An apparent unconformity 107 m below present lake level was attributed to Lake Chippewa. Stanley (1938) proposed that Lake Chippewa drained to the Lake Huron basin through a submerged river channel at the Straits of Mackinac. However, research on ostracode faunas and the sedimentology of the Lake Michigan Formation by Buckley (1974) suggests that during this low lake phase, the water level was not more than 61 m below the present level. Erosion related to the Chippewa level may be represented by an unconformity between the Shbyboygan and Wintemeca Members of the Lake Michigan Formation (Fig. 1), but the molluscan fauna may not be indicative of water as shallow as Hough (1955, 1958), suggested (Buckley, 1974; Lineback et al., 1979).

The Chippewa low phase (Fig. 3b) was initiated about 10,000 B.P., when the North Bay outlet was deglaciated, and it was terminated about 5,500 B.P. during the Nipissing transgression, when the lake level rose to an altitude above that of the present lake. The Chippewa-Nipissing transition corresponded approximately in time with the end of the Reconstructed episode of Holocene climatic history, when the warmer and drier conditions of the early Holocene were replaced by cooler and moister conditions in the northern Midwest after 6000 B.P. (Bartlein and Webb, 1982).

POSTGLACIAL LAKES NIPISSING, ALCONA, AND LAKE HURON

Continued differential uplift progressively raised the altitude of the North Bay outlet. The lake level in the Lake Michigan and Lake Huron basins rose until it reached the altitudes of previously abandoned southern outlets at Chicago and Port Huron, about 5000 B.P. This transgression culminated in the Nipissing episode of the Great Lakes history (Figs. 1, 3b). Water in the Lake Michigan, Lake Huron, and Lake Superior basins was confluent at this time, and initially the Nipissing phase simultaneously drained through three outlets— the North Bay, Port Huron, and Chicago outlet (Hough, 1955, 1958). Uplift caused abandonment of the North Bay outlet as it was raised above the altitude of the two southern outlets (Fig. 1).

The post-Chippewa water levels in the Lake Algonquin basin were recognized by early writers (e.g., Leverett and Taylor, 1915; Bresc, 1955). However, later workers (Hough, 1955, 1958, 1961; Lewis, 1969, 1970), distinguished these three distinct middle to late Holocene lake events—Nipissing (5500 to 3800 B.P.), Algonia (3800 to 2500 B.P.), and modern Lakes Michigan and Huron (2500 B.P. to present).

The Nipissing transgression has been dated in both the Lake Huron basin (Dreimanis, 1958; Farnall and Miller, 1968; Lewis, 1969, 1970; Prest, 1970; Cowan, 1978; Terasmae, 1979; Monaghan et al., in review) and the Lake Michigan basin (Winkler, 1962; Larson, 1974, 1980; Fraser et al., 1975; Gutschick and Consigny, 1976). In general, the age control indicates a Nipissing transgression that rose above present lake level between 5000 and 5000 B.P. and attained a maximum level between 4700 and 4000 B.P.

According to Hough, the altitudes of the pre-existing outlets governed the altitude of the Nipissing phase (184 m). Incision of the Port Huron outlet into unconsolidated glacial deposits then caused lowering of the lake to the Algonia level as an altitude of 182 m, and the Chicago outlet was abandoned. Renewed incision of the Port Huron outlet about 2500 B.P. caused lowering of the lake to the modern Lake Michigan and Lake Huron level (177 m, 590 ft.).

Hough's (1955, 1958, 1963) interpretation of the Nipissing Great Lakes greatly affected subsequent work. Relying on assumed tectonic and isostatic stability of the southern Lake Michigan basin, Hough attempted to reconcile anomalous relationships between the Nipissing and Algonquin terraces in the northern and southern extremes of the basin. Nipissing beaches and terraces north of Traverse Bay, Michigan, are upwarped northward by postglacial differential isostatic uplift; those south of Traverse Bay appear to be deformed. An apparent hinge line (Leverett and Taylor, 1915), or zero isobase, transects the basin at the latitude of Traverse Bay. The area south of the hinge line was considered to have been isostatically stable. Hough assumed that the bedrock-floor of the outlet remained at the Tuleston-Algonquin altitude of 184 m. Thus, the Nipissing Great Lakes rose to an altitude of 184 m, coincident with the earlier Tuleston-Algonquin level.

Two inconsistencies affect Hough's interpretation. First, the altitude of the Chicago outlet channel as originally reported by Leverett (1897, p. 398) was 180 m. Second, studies of recent uplift discussed by Clark and Persson (1970) and the Coordinating Committee on Great Lakes Basic Hydrometric and Hydrologic Data (1977) indicate that the northern and southern parts of the basin currently are undergoing diff-
ferential uplift. Data presented by Larsen (1985a) and Kaszycki (1985) seem to invalidate the hinge-like concept. If so, an outlet-control model for the Nipissing Great Lakes, as envisioned by Hough, does not seem plausible.

Detailed stratigraphic studies in the Chicago area during the past decade indicate that the level of the lake fluctuated on a scale of 200 to 300 years during the late Holocene. We believe the Nipissing and Algoma phases were short-lived; high lake level events were separated by long periods when lake levels were lower. Apparently, there were no long periods of stable levels that were governed by occasional rapid incision of outlet channels. During an early Nipissing phase (Nipis-

ing II), the lake attained an altitude of 183 m about 4500 B.P. During a second Nipissing phase (Nipissing II), the lake reached an altitude of 180 m about 4000 B.P. During the Algoma phase, it reached a maximum altitude of 179 m about 3200 B.P. In addition, conspicuous fluctuations as high as 2 m above present lake level occurred about 1500, 1000, and 450 B.P., during a period previously regarded to be one of relatively stable lake levels. A record of late Holocene changes in lake level is preserved in stream-mouth alluvial fans near Zion, Illinois (Larsen, 1974, 1985b).

Comparison of the lake level record with late Holocene pollen and Neoglacial records (Webb and Bryan, 1972; Swain, 1978; Bernabo, 1981; Denton and Karst, 1973; Curry, 1969; Benedetti, 1973; Goldsworthy, 1966; Webb et al., 1983; Davis, 1983) suggests that the fluctuations in late level were climatically related to changes in water volume in the upper Great Lakes basins (Larsen, 1973, 1974, 1985a; Fraser et al., 1975). Thus, during the past 2000 years the lake level appears to have fluctuated around a mean level that was adjusted to the channel depth of the St. Clair River at Port Huron (Larsen, 1985a). Fluctuations during the Nipissing and Algoma phases also can be thought of as climate-related changes in lake level that were adjusted to channel depths. Such an interpretation reconciles the altitude of the bedrock sill of the Chicago outlet (180 m) that has been inferred to have controlled the Nipissing level at an altitude of 184 m (Hough, 1953, 1958, 1963; Lewis, 1969, 1970).

The altitudes of the Nipissing and Algoma terraces and beaches characteristically are lower in the southern Lake Michigan basin than they are in the southern Lake Huron basin (Larsen, 1985a). Ongoing differential uplift has raised the Port Huron outlet above the contemporaneous terraces at Chicago. The outlet incision at Port Huron previously was considered to have been responsible for the lowering from the Nipissing level to the Algoma level and then to the Lake Michigan and Lake Huron level. It probably was a more gradual process: the rate of erosion of the outlet channel partly kept pace with ongoing differential uplift.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Although the general history of lake in the Lake Michigan basin has been known for nearly a century, radiocarbon dates obtained during the past 10 years have changed inter-pretations of many details. In the Illinois and Indiana part of the basin, where shore features have been least altered by differential uplift, lake levels between 12 100 and 11 000 B.P. and between 6000 B.P. and the present are particularly well dated. Several specific conclusions about lake history are drawn on the basis of radiocarbon dates.

1) A Port Huron age Glenwood II phase is confirmed by dates from the Dyer spit. A Cary age Glenwood I phase is unconfirmed, but a lake must have existed.

2) The Two Creeks low phase is documented in the south-ern Lake Michigan area by dated sediments beneath the Rose Hill spit. This low-level phase is not the Downsville low phase, as was suggested by Baker (1926). The Bowmanville deposits are middle Holocene and they do not represent a low-level phase.

3) A pre-Two Creeks Calumet I phase is unconfirmed, but it may have existed. The Calumet beach in the type area of Lake Chicago and the Rose Hill spit sediments are post-Two Creeks in age and they were deposited during the Calumet II phase of Brez (1959).

4) All dated sediments associated with Toleston level 184 m features are middle Holocene in age and they relate to the Nipissing transgression. The 184 m Toleston phase of Lake Chicago and the 184 m Main Algonquin phase of Lake Algonquin are not documented by radiocarbon dates in the southern Lake Michigan area.

Because the uplift history of the Lake Michigan basin is not well known and very few radiocarbon dates have been obtained from the northern part of the basin, determination of the ages of beaches and terraces in Wisconsin and Michi-
gan remains a major problem. For this reason, correlation of shore features northward from the southern part of the basin is conjectural, and without age control of beaches and ter-

races in the northern part of the basin, correlation of glacial and lake events is tenuous. A greater effort should be made in the future to focus research on the rebound history in the Lake Michigan basin, especially if dates from shore features in the northern part of the basin can be obtained.

Another suggested focus for future research is the re-
lationship of the altitudes of outlet to lake levels. Larsen (1985a) suggests that middle to late Holocene lake level fluctuations were controlled chiefly by climate-related changes in the volume of water in the lake basin, rather than by episodic outlet incision. The high-level phases lasting no longer than 200 to 300 years occurred between periods of lower levels. Large changes in the volume of water entering the Lake-Michigan basin occurred during deglaciation of the Great Lakes region. There is good evidence, for instance, that at times the drainage from lakes in the Lake Huron and Lake Erie basins entered the Lake Michigan basin through the glacial Grand Valley and that drainage from the Lake Superior basin entered through channels across the Upper Peninsula of Michigan. Such large and perhaps catastrophic changes in the volume of water entering the basin probably affected lake levels and may have been a more important control of lake level in the basin than was the altitude of the outlet at Chicago.

Recent studies have documented historic uplift, even in the southern parts of the Lake Michigan basin. The possibil-
ity that differential inosastic uplift affected outlet incision at Chicago and Port Huron during the late Wisconsinan and Holocene also should be explored.
ACKNOWLEDGEMENTS
We are grateful to C. L. Liu, of the Illinois State Geological Survey Radiocarbon Laboratory, for making available unpublished data and to the U.S. Geological Survey for a joint funding agreement with the Illinois State Geological Survey to study the stratigraphic geology of the southern Lake Michigan area. We thank Lee Clayton, D.F. Eschman, L.R. Poliner, D.S. Fullerton, P.F. Karrow, C.A. Kasszycy, and W.H. Johnson for discussions and constructive comments on the manuscript.

REFERENCES


