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THE STAGES OF LAKE CHICAGO: THEIR CAUSES AND CORRELATIONS

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ABSTRACT. The three named stages of Glacial Lake Chicago record 1) the earliest static lake level (Glenwood), 2) a time of rapid lowering because of outlet deepening, 3) a pause in this deepening and lowering to produce the second static stage (Calumet), 4) renewed lowering because of renewed outlet deepening, and 5) a final level (Toleston) determined by a bed rock sill in the outlet channel floor. The dam for the lake was not the Valparaiso moraine but the younger Tinley moraine and its valley train. No stoping by retreat of rapids was involved in outlet deepening. The thesis of this paper is that the outlet down-cuttings (items 2 and 4) are to be correlated with times when glacial lakes in the Erie and Huron basins discharged into Lake Chicago and thus added to the erosive ability of its outlet river; the two earlier static water levels (items 1 and 3) with times when these eastern lakes discharged elsewhere. Deposition of the Valders red drift of the northern Lake Michigan basin (Early Mankato) is thought to have been contemporaneous with the intermediate stage of Lake Chicago. The Port Huron moraine is believed to be of late Cary age and, in earlier studies, to have been incorrectly correlated across Lake Michigan.

GENERAL STATEMENT

GLACIAL Lake Chicago existed in the Lake Michigan basin in front of a retreating lobe of the Wisconsin ice sheet and discharged to the Illinois River, an affluent of the Mississippi. Its three groups of shore lines record three different stages of essentially static level, separated by two stages of relatively rapid lowering from one level to another. With only one exception, all who have studied the lake's history consider that the highest stage was the earliest and the lowest the latest, that each static stage was determined by minimum erosion on the channel floor at the head of the outlet, and that each drop in lake level was caused by fairly rapid deepening at the channel head.

The landward margin of Lake Chicago was the Valparaiso moraine system which loops around the southern end of the basin in the familiar Wisconsin lobate habit (fig. 1). Two

low places in this moraine became simultaneous discharge ways, converging to become one a few miles down stream. Both continued to function during nearly forty feet of deepening from the highest (Glenwood) to the lowest (Toleston) stage of the lake. The intermediate (Calumet) shore line lies approximately in the middle of this vertical interval.

EARLIER EXPLANATIONS OF THE LAKE STAGES

Leverett, who named the lake (1897, p. 65), did not propose any specific explanation for the pauses which interrupted the down-cutting of the outlet.

Alden (1902, p. 7) suggested that an unrecorded pre-Glenwood stage was lowered to the Glenwood level by erosional deepening of the outlet. At this level, the outlet river

> ". . . found its channel resting upon rather resistant drift and rock from the head of the outlet nearly across the whole breadth of the obstructing moraine, while on the outside of the moraine there was a sharp descent. As a result there was for a period, very little cutting at the entrance of the outlet, while there was comparatively swift cutting at the rapids formed on the outer side of the moraine. These rapids gradually cut back . . . [until they] . . . had traversed the breadth of the moraine and reached the head of the outlet. Immediately on doing this, the waters would be rapidly drawn off to a level [Calumet intermediate stage] represented by the foot of the stope thus carried from the outer to the inner side of the obstructing moraine."

Alden credited T. C. Chamberlin with this idea of stoping to explain the abrupt lowering of Lake Chicago, but applied it only to the drop from the Glenwood to the Calumet level and said nothing in explanation of the next lowering, from Calumet to Toleston levels.

Goldthwait (1909, pp. 52-55) proposed a modified stoping hypothesis, his idea being that the valley train west of the Valparaiso moraine served, with the moraine, as a dam for the Glenwood stage, that trenching of this dam caused the lowering, and that discovery of a bed-rock sill determined the Calumet level. Down the far side of this sill (at Lockport) was a rapids which, by stoping, receded eastward up the valley. It eventually cut completely through the sill and abruptly

terminated the Calumet intermediate stage and introduced the lowest or Toleston stage.

Wright (1918, pp. 235-244) accepting the idea of stoping, visualized rapids whose vertical descent was the full interval between the highest and lowest shore lines. Lake Chicago, by his view, dropped from the Glenwood immediately to the Toleston level. Only glacial deposits were removed in the stoping, and the bed rock beneath stopped all further deepening. To account for the intermediate Calumet level, Wright had recourse to a known great influx of water from the east. The volume added to Lake Chicago was so great that the outlet river rose twenty feet and so remained during the Calumet stage.

There are deficiencies or internal disharmonies or conflicts with field evidence in each of these hypotheses. Alden's mechanism provides only for a drop from the highest to the intermediate lake stage, offers no explanation for the Calumet pause and the ensuing comparable drop to the Toleston level. Goldthwait's scheme is faulty in providing no abrupt drop, only a gradual lowering, from the highest to the intermediate shore line. Field evidence is to the contrary and it also includes glacial striae on the rock floor at Lemont. Wright's concept demands an enormous volume of water from the east and a long stand of the lake at the Calumet level. Even if the outlet floor was on bed rock, the walls were in drift and widening of the channel would seemingly have been inevitable. The lake, if flooded as Wright saw it, would by this widening have been gradually lowered from an initial and short-lived Calumet level back down to the earlier Toleston. The absence of minor shore lines on the lake plain, between the three already named, clearly testifies to two rather abrupt lowerings.

The three proposed explanations are defective in their lack of specific supporting field data. The writers did not neglect evidence then known, but they theorized on too slender an accumulation of facts. It was only after a detailed study of the Chicago region was undertaken for the Illinois State Geological Survey that information vital to the solution of the problem came to light. The explanation presented in this paper is still theoretical, but it takes account of much knowledge these earlier students did not possess. Most significant has been a reinterpretation of the character of the morainic belt

crossed by the outlet channels. Essential also has been the advance in knowledge of glacial lake stages in the Huron and Erie basins, contemporaneous with those in the Michigan basin.

NEW FIELD DATA AND THEIR SIGNIFICANCE

The Valparaiso morainic upland where crossed by the Lake Chicago outlet channels has proved to be composed largely of a silty, pre-Valparaiso drift (Bretz, 1939, p. 53) with a relief as well as a thickness considerably exceeding that of the overlying clayey Valparaiso till. The relief of the older drift is largely due to later but pre-Valparaiso stream erosion, the valleys only slightly obscured by the younger Valparaiso mantle.

A dozen or more of these partially obstructed pre-Valparaiso valleys are readily recognizable in the Chicago region and others have been identified farther north (Powers and Ekblaw, 1940, pp. 1329-1336). Two of them, converging to become one, were utilized by the Lake Chicago outlets. They provided the two low places which, by earlier students, had been ascribed simply to irregularities in moraine deposition. Their floors were on bed rock in places and surviving glacial straie, on these floors (Leighton and Ekblaw, 1932) testify that no rapids in the outlet river ever retreated by stoping in bedrock along the trans-morainic channels. Esker and kame deposits, built on the slopes of both valleys during Valparaiso retreat, extend down almost to the present floors. The outlet channels of Lake Chicago therefore were not notably eroded by discharging lake water after the building of the Valparaiso moraine. They were, for the most part, as deep before that drift was deposited as they are today.

But before one concludes that volume of discharge alone could have determined the water level at outlet heads, and therefore the different lake levels, another significant feature of the outlet region must be considered. That feature is a definite moraine ridge, younger than the Valparaiso moraine and built up on its eastern slope. This Tinley moraine appears to record a readvance of the Lake Michigan lobe after a considerable retreat eastward from the Valparaiso moraine. Earlier students of the region failed to recognize 1) the Tinley moraine as distinctly younger than the Valparaiso moraine belt and 2)

the pre-Valparaiso age of the valleys which became the outlet channels.

During this retreat from the Valparaiso and readvance to the Tinley moraine, meltwater and probably glacial-lake water escaped down the two trans-morainic valleys. Any minor moraine obstructions left in them by the Valparaiso ice were largely removed and free drainage was established along their floors at about the level of the future Toleston stage.

This conclusion is established from the relations of Tinley moraine and outwash to the valleys in question. The Tinley ice barely more than reached the outlet-valley heads but it built a morainic dam across each and its outwash built a valley train in each. In the Sag Valley, the southern of the two, a terrace fragment of valley train, extensively excavated and exposed just west of the moraine, is composed of poorly sorted, irregularly bedded gravel which has depositional dips away from the moraine, and contains numerous till balls and pebbles and large, irregular masses of till intimately associated with ice-thrust deformations. Although there are other gravels along these outlet valleys, not related to the Tinley moraine, the composition and structure of this deposit differ so notably from them that not alone the writer but other contemporary students of the region, including M. M. Leighton and G. E. Ekblaw of the Illinois State Geological Survey, are convinced that the terrace is a remnant of a once-continuous Tinley valley train in Sag Valley.

The northern trans-morainic valley (Desplaines) must have been similarly blocked by moraine and outwash, else it alone would have functioned during the Lake Chicago history. The two dams must have been of comparable height and bulk for whatever the conditions that caused the three lake stages, they obtained in both channels throughout all stages.

The terrace remnant of Tinley outwash is at least 20 feet thick, its lowest exposure 610 feet A.T., only 10 feet higher than the Toleston level of the lake. Thus it is clear that an open valley whose floor was as low as 610 feet drained westward through the Valparaiso moraine at the time the Tinley moraine was built. The surface of the deposit is close to 630 feet A. T., 10 feet lower than the Glenwood level of Lake Chicago. The crest of the surviving buttress of the moraine itself is 685 feet A. T. Discharge from incipient Lake Chicago,

spilling 40 or 50 feet down over the face of this moraine, must have rapidly eroded a channel down to the surface of the valley train which surely extended several miles down valley. The much thicker dam and much gentler gradient thus encountered were prime factors in determining the 635-640 Glenwood level. The same interpretation must be applied to the northern or Desplaines channel also, although no good field evidence for a Tinley valley train has yet been found in it.

Another field item in the problem is the occurrence of great numbers of boulders on several remnants of current-swept channel floor of all three lake stages. Both Leverett (1899, p. 426) and Alden (1902, p. 7) estimated a thousand to the acre showing at the surface in one tract at the head of the Sag; the writer would make the same estimate for a tract in the Desplaines channel head. These boulder fields seem clearly to be lag deposits from erosion of the till during channel deepening. Their significance is pointed out in a following paragraph.

CAUSES OF THE LAKE CHICAGO STAGES

The Tinley drift dams in both outlets were destroyed during the life of Lake Chicago. There is nothing in the composition or structure of the remaining abutments of these dams to suggest that two long pauses in their erosion should have occurred, as they did, to determine the Glenwood and Calumet stages or, expressed differently, that two times of accelerated erosion should have occurred to lower the lake about 20 feet each time. Though the Tinley dam held Lake Chicago to all levels above the Toleston, the cause of the deepening which produced the two marked lowerings seems not to be found in the outlet region. It is believed to lie far to the east of Lake Chicago; to have been determined by events in the life of contemporaneous great glacial lakes in front of the Erie and Huron lobes (Leverett and Taylor, 1915). The complicated history of those lake levels can be presented only in outline here. For a time, these eastern lakes discharged across Michigan into Lake Chicago, greatly augmenting the volume previously escaping through its outlets. Later, retreat of the Huron and Erie lobes exposed a lower spillway to the Mohawk, and Lake Chicago's discharge shrank accordingly. A still later readvance closed the eastern outlet and overflow again was turned into Lake Chicago.

If widths of the Chicago outlet channels did not notably increase during these times of increased discharge (and field evidence seems to indicate this), then depth of water in the channels must have become greater. When a stream's volume is increased without change in load, in channel shape and roughness, and in gradient, there results an increase in velocity. Doubling the discharge, with other factors unchanged, may produce as much as a 20 per cent increase in velocity.[1] Since the erosive ability of running water varies with the square of the velocity, a small increase in velocity might produce a noteworthy increase in a stream's erosive work, particularly if it is flowing on unconsolidated material. Doubling the discharge from Lake Chicago by introduction of Erie and Huron glacial water is well within the limits of probability.

Channel-deepening in glacial till when only Lake Chicago water was using the outlets would yield an increasing number of lag boulders on the floor. Finally an armor of big fragments could bring deepening essentially to an end. Only a marked increase in erosive ability of the outlet rivers could clear the channel floors and allow more deepening. These two opposed conditions: decreased erosion from accumulation of boulder pavements, and increased erosion from increased velocity, are here considered to have alternated during Lake Chicago's history. Each of the two earlier stages was determined by collection of a channel-bottom armor of fragments too large for the outlet river to remove. Each of the two times of rapid lowering was determined by large influx of water from the east, increased erosional and transportational ability in the outlets, and a consequent sweeping away of the boulders and a cutting into the Tinley till and outwash beneath.

CORRELATIONS WITH GLACIAL LAKES IN THE HURON AND ERIE BASINS

The Glenwood shore line, as noted by both Alden and Goldthwait, is not a single, simple feature. Its deposits range through approximately 10 feet vertically and its wave-cut cliff bases are generally several feet lower than the highest deposits. Part of this may well be due to variation in storm-wave work on differently exposed coasts, part is probably a

[1] Dr. H. A. Einstein, personal communication.

record of lowering lake level because of slight deepening in the outlet channels. But growth of boulder pavements during the earliest of Lake Chicago's existence is here considered to have brought about an end of this deepening and an essential stabilizing of the Glenwood lake level.

Then, without leaving any surviving shore lines, Lake Chicago rather abruptly dropped to the Calumet level as the large volume of water poured into it via Grand River, Michigan, from the eastern glacial lakes, middle and late Maumee, Saginaw, Arkona and Whittlesey, was added to its outlet rivers.

The latest of these lake stages, Lowest Arkona, was terminated when the northeastward retreating front of the Erie lobe exposed an escapeway lower than Grand River, near Syracuse, New York. The lowered lake, in the Erie and Huron basins, Lake Wayne, drained to the Mohawk and during such time the Chicago outlet again carried only Lake Chicago water. Decreased volume, much decreased velocity and a boulder-covered floor inherited from the previous stage decreed a cessation of the deepening which had been lowering Lake Chicago since Glenwood time. In the simple analysis now being outlined, this constituted the pause at the Calumet level.

A readvance of the Huron-Erie ice lobe then occurred, closing the Mohawk spillway, raising the water level back to the Grand River outlet across southern Michigan and discharging the new eastern lake, (Warren), into Lake Chicago. Renewed erosion in the Chicago outlet channels which ensued caused the lowering from the Calumet to the Toleston level. This time of erosion saw both channels cut down to bed rock, after

Tabulated, the correlation is as follows:

Huron and Erie Basins	*Michigan Basin*
Early Lake Maumee, discharging to Wabash River	Glenwood stage
Middle and late Lake Maumee, Lakes Saginaw, Arkona and Whittlesey, discharging to Lake Chicago	Lowering from Glenwood to Calumet level
Lake Wayne, discharging to Mohawk River	Calumet stage
Lake Warren, discharging to Lake Chicago	Lowering from Calumet to Toleston level
Lake Lundy (Dana), discharging to Mohawk River, and all later stages to Lake Algonquin	Toleston stage

which rapid deepening in the now low-gradient outlet ceased on the resistant substratum.[2]

Perhaps the most questionable element in this correlation of the Lake Chicago stages with the lake succession in the Huron and Erie basins is the assignment of most of Maumee's history and all of Arkona's and Whittlesey's to the first down-cutting interval, during which Lake Chicago left no recognizable shore lines. The relative duration of any glacial lake in the list, or of any stage of any lake, can at present be judged only from the development of its shore line. This is an unsatisfactory criterion because several factors other than duration influenced the result, and they varied from place to place and from time to time.

One principle that must be recognized in evaluating the duration of any lake stage by the bulk of its beach deposits is that the shore built at the close of a rising interval will be stronger than one made at the end of an interval of lowering, time and other factors being the same. This is because, during the rise, waves are constantly sweeping beach materials before them in one cumulative aggregate. During a subsidence of water level, beach materials are likely to be left behind as thin deposits spread widely over the abandoned territory. Lake Warren was such a rising stage.

Warren also was a larger lake than any predecessor and had a much longer contributing ice front. It must have discharged a correspondingly greater volume.[3]

For the sake of clarity in presenting the above principles and correlation, a feature of glacial lake history in the Lake Michigan basin has thus far been omitted. It is the occurrence of low-water stages, lower than the Toleston, at times when the ice front withdrew entirely from the Huron and Erie basins, lower outlets were discovered and the western channels went dry. In one of these stages, the lake plain emerged almost

[2] A low-water stage in the Erie basin, following Lake Warren but preceding the later Lake Lundy, is argued by Bay (1936). Since, by the view here urged, the Chicago outlets had already been deepened to bed rock, the occurrence of this "second Lake Wayne" in no way affects the proposed correlation.

[3] Fluctuations in the volume of eastern contributions, both before and after the Lake Wayne stage, which are argued for elsewhere (Bretz, in press), appear to have been fractions of Lake Chicago's total discharge, too small to have affected its outlet channel as they did the Saginaw Basin outlet.

as completely as it stands today (Baker, 1920) and much more extensively in another (Stanley, 1938). The location of the outlets of these low-water stages must have been well toward the north end of the Michigan basin and may have been the strait at Mackinac. For their functioning, similar low channels eastward out of the Huron basin also must have existed, channels now completely buried in drift.

The earliest and perhaps best established of the low-water stages was the Bowmanville (Baker, 1920) occurring between the Glenwood and Calumet high-water stages. To make a place for the Bowmanville stage, the sequence above proposed would be amended as follows:

1. Glenwood stage. After a prompt notching of the narrow Tinley moraine dam down to the level of the wider dam provided by the Tinley valley train, the lower gradient of that outwash plus an accumulation of channel floor boulders held Lake Chicago to a fairly constant level while the series of Glenwood beaches was built.

2. Contributions from middle and late Maumee began[4] and continued from its successors, lakes Arkona and Whittlesey. Discharge across the Tinley dam thus was at least doubled, and the increased velocity caused the erosion by which it became lowered to the first-attained Calumet level.

3. A marked retreat of the Michigan, Huron and Erie lobes opened some eastward discharge route. This produced the Bowmanville low-water stage when the Chicago outlet went dry.

[4] The reader who may consult Monograph 53, U. S. Geol. Survey, should be warned that plate XIV is too generalized to agree with the detailed text of either Leverett or Taylor. Taylor (pp. 260-261) says that the Grand River channel, carrying glacial-lake water westward across Michigan "at first" reached Lake Chicago west of Grand Rapids at an altitude of about 640 feet. On p. 360, "first" is defined as Lake Maumee discharge before Lake Saginaw had begun to be formed. Leverett (pp. 220, 225 and 227) describes glacial drainage channels leading south from Grand Rapids to "incipient" Lake Chicago, south of the Indiana line. This drainage had to cross a col at about 700 feet and these channels operated only when the ice stood on the Lake Border moraines, thus completely filling that part of the basin now occupied by Lake Michigan. Although the generalized map (plate XIV) shows a continuous glacial river from Lake Saginaw to incipient Lake Chicago, there are really two different channels of two different ages. The discharge southward along the eastern edge of the Lake Michigan lobe antedated the first lake discharge westward across Michigan and when the later river flowed, Lake Chicago water reached as far north as Grand Rapids.

Record of this retreat has been found, to date, only in the Lake Michigan basin although the episode must have been shared by the eastern basins.

4. Readvance of the lobes, closure of the low outlet to the east, rise of glacial lake water in all eastern basins to the Mohawk outlet level, giving origin to Lake Wayne. Concomitant rise of Lake Chicago back to the Calumet level, the waves of this rising stage sweeping beach materials forward and upward on the gentle slopes being submerged until westward discharge was again established. Thus the Calumet shore line was completed. The Calumet beach therefore is dated as later than the cutting down of the outlets to the same level.[5]

5. Further readvance of ice in the Huron and Erie basins closed the Mohawk outlet, produced Lake Warren and turned its discharge into Lake Chicago.

6. This increased discharge renewed erosional deepening in Lake Chicago's outlet channels and the lake fell from the Calumet to the Toleston level, too rapidly and too uniformly to leave minor intervening shores. The outlet channels then encountering bed rock, no further deepening occurred, whatever the volume of discharge.

Another factor which may have entered into the complex of causes for the glacial lake history was the differential uplift that occurred during the changing scenes of the glacial lakes. North of the "hinge lines," all glacial lake shore lines rise toward the northeast, the oldest ones most, the youngest ones least. It is possible that the Bowmanville low-water stage was terminated and the level of Lake Chicago raised 30 feet at the south end of the basin because of uplift, at this time, of the eastern or northeastern region where the Bowmanville outlet existed. A slow rise in lake level caused in this way would be more likely to drive the beach materials forward instead of submerging them, than would the more rapid rise caused by an ice readvance (item 4 above). Probably, however, the uplift

[5] If the origin of the Calumet shore line is correctly explained here, it must be limited to beach ridges built on gently sloping tracts where the proposed mechanism could operate. Calumet wave-cut cliffs would be possible only if considerable time elapsed after Lake Chicago rose to the level of the abandoned outlet but before Lake Warren discharge arrived. It seems significant that no cliffed Calumet shoreline is described in the literature although both Glenwood and Toleston shores have cliffs.

was too slow to have consummated this before readvance of the lobes produced the same effect on the lake.

EARLIER CORRELATIONS OF MORAINES ACROSS THE LAKE MICHIGAN BASIN

The Port Huron moraine in Michigan (fig. 1.) was built by the advance which gave rise to Lake Whittlesey. This moraine has been presumed by all previous students to be of the same age as the red drift bordering the northern half of the west side of Lake Michigan and considered by Leighton (1931), following Leverett (1929), to be earliest Mankato. But new evidence shows that before a marker among the events of Lake Chicago's history is selected as the beginning of the Mankato subage, these correlations must be critically examined.

Leverett and Taylor (1915, p. 302) described the course of the Port Huron morainic system (the Lake Whittlesey stage) from its type locality (south end of Lake Huron) northward and westward around the Saginaw lobe, thence northward along a great reentrant loop in the southern peninsula of Michigan and back southward to the shore of Lake Michigan near Muskegon. Here it was supposedly cut off by the lake shore in about the same latitude in which, on the east, it extends south of Lake Huron into Ontario. Leverett correlated this Port Huron moraine with the sheet of red drift which on the west side of Lake Michigan extends as far south as Milwaukee. The red drift is only mildly morainic, however, as compared with the Michigan phase of the supposed same drift.

Alden (1918) believed the red color of the drift north of Milwaukee was due to plowing up of slightly older lake clays which contained a sufficiently high proportion of debris from iron-rich rocks of the Lake Superior region. He accepted Leverett's moraine correlation across Lake Michigan from Muskegon to Milwaukee but was puzzled by the fact that Leverett did not report the Muskegon moraine as red drift; did not report a red till moraine anywhere on the east side of Lake Michigan south of Manistee, 65 miles north of Muskegon. Because, however, the Port Huron moraines run almost parallel to the lake shore from Muskegon to Manistee, this is no great gap when measured across the trend of the ridges. Alden correlated the Manistee moraine with a ridge along the Wisconsin shore at Two Rivers, about 15 miles back from the extreme

western edge of the red drift and almost directly across from Manistee.

In 1929, Leverett added to his mapping of the edge of the Port Huron drift in Wisconsin, Minnesota and Iowa, correlating the Des Moines lobe west of the Mississippi with the red drift north of Milwaukee and of the Port Huron system in Michigan.

In 1931, Leighton followed Leverett's correlation in proposing a terminology for the different Wisconsin sub-stages. Although he changed the proposed nomenclature two years later (1933), using Mankato, Minnesota, as the type locality for the drift of the sub-stage we are considering, he accepted Leverett's correlation as before.

Thwaites in 1937 subdivided Mankato drift into Early (red drift) and Later (Des Moines lobe west of the Mississippi) but he also followed Leverett's correlation across Lake Michigan and considered the Port Huron moraine to be Early Mankato. Thwaites discovered that the red drift of Wisconsin west of Lake Winnebago, Green Bay and Menominee River is a very thin till sheet and has no end moraines. In 1943, he announced that the mildly morainic topography of the red drift of his area is that of Cary moraines buried by the thin red (Valders) till.[6] He reasserted the lack of moraine topography in the red drift itself and thought that only a very brief advance was recorded by it. He doubted the trustworthiness of a correlation of the Wisconsin red drift with the Des Moines-Mankato drift of Iowa and Minnesota because "so vast an expanse of unsettled, little-known territory" lay between.

Although probably most workers consider the correlation of moraines across the Lake Michigan basin an uncertain procedure, they have depended on four criteria for what they have suggested or accepted: 1) the color contrast between gray till in the southern part of the basin and red till to the north, 2) the relationship of the Lake Border moraines which are traceable on land around the lake's southern end, 3) the assumption of approximate symmetry of the ice-lobe front in the open glacial lake, and 4) a belt of somewhat lesser depths of the modern lake between Muskegon and Milwaukee, supposedly the submerged Port Huron moraine.

[6] Alden (1918) reported two places where ice depositing the red drift had overridden older moraines.

Since Thwaites' discovery that the Valders red drift of his area has no moraines of its own, doubt must rise that this thin till can be the equivalent of the strongly developed Port Huron morainic system just across the lake. If the shallower belt of Lake Michigan between Muskegon and Milwaukee is the submerged massive Port Huron moraine, it should not abruptly flatten out on emergence near Milwaukee. The writer, therefore, came to suspect that the younger Cary moraines buried beneath the Valders till sheet might be Port Huron equivalents. By the thesis of this paper, the Glenwood static level was destroyed and the lake lowered by reason of Maumee-Arkona-Whittlesey discharge into Lake Chicago. Because there were but two episodes of large contribution from the east, and but two lowering episodes in Lake Chicago's history, it is reasoned that this Maumee-Arkona-Whittlesey discharge occurred before the Bowmanville-Lake Wayne episodes and therefore before the Port Huron moraine was built. The Port Huron moraine should coincide approximately with the first-attained Calumet level (fig. 2.). Suspicion therefore rose regarding the existence, as reported by Goldthwait (1908) Leverett (1915) and Alden (1918) of "faintly developed" Glenwood shore lines on the red drift of Wisconsin and the Port Huron moraine in Michigan. It seemed plausible to consider that the Valders drift, younger than Port Huron, was deposited late in Calumet time, perhaps too late to receive good Calumet shores. But all these suppositions involved challenges of earlier interpretations, and field study in Wisconsin and Michigan became imperative if the Lake Chicago thesis was to stand.

FIELD EXAMINATIONS, REINTERPRETATIONS AND RECORRELATIONS

The revision and elaboration of the geology of the Chicago region, a project of the Illinois State Geological Survey, thus came to include a restudy of considerable territory farther north. In it, some surprising conclusions were reached. Because they depart markedly from those of earlier students, some detail must be given to setting them forth.

SHORE LINES IN WISCONSIN

Alden (1906) found in mapping for the Milwaukee folio that the sheet of red drift reached southward no farther along

the Lake Michigan coast than the northern part of that city and that its overlap there on earlier drift nowhere reached more than a mile and a half back from the lake shore. Beneath it and resting on the blue Lake Border till, he found a stratified gravel, sand and clay which he interpreted as a Glenwood deposit made in front of an advancing Lake Michigan glacial lobe that finally buried it beneath the red till. He found no Lake Chicago shore lines within the quadrangle for the coastal land is everywhere too high above present cliffs. Numerous well logs showed the top of the water-laid member to be as much as 70 to 80 feet above Lake Michigan and this he ascribed to deposition in marginal ice-dammed lakes and streams of Glenwood time.

Alden interpreted a sand and gravel deposit in the valley of Milwaukee River, lying just west of the red till, as outwash contemporaneous with the red till but made no suggestion regarding its relation to Lake Chicago. The many new exposures since Alden's study amply support his interpretation that Milwaukee River valley, earlier mouthing farther north, became blocked by the red till and the closed depression thus formed was aggraded full, the glacial stream then taking a new course southward to the present mouth, crossing a tract of dense, hard, older till on which no deposit was made. Hence this Milwaukee valley train did not terminate in a Lake Chicago delta whose altitude would date the red drift episode.

Goldthwait (1907) found definite Glenwood and Calumet shore lines as far north as Racine but none thence northward to Port Washington. Six miles north of this city he found "a vague sloping platform, hardly sandy or gravelly in composition, with a doubtful bluff behind it" which he said Alden had suggested[7] might be a Calumet shore line. Two miles farther north (sec. 7, T 12 N, R 23 E) this feature is "more definite and takes the form of two low bars of gravel, the higher a short but well-formed gravel ridge. . . . 60 feet above the lake and the lower a very flat bar at 48 feet, hardly more than a flattening of the long, lakeward slope of the highest beach." Goldthwait admitted that correlation of these and other suggestive forms and deposits of that district "with the beaches of Lake Chicago south of Racine is a problem of

[7] Probably in text for the Port Washington folio, which was never published.

considerable difficulty" because of questionableness of origin and impossibility of securing definite markers for altitude measurements. Yet "the higher, less distinct beach ridges undoubtedly belong to Lake Chicago."

The writer, after examining most of this district, was far more doubtful than Goldthwait about the littoral origin of the so-called Glenwood features. The "short but well-formed gravel ridges" is composed of poorly sorted, very poorly stratified and but little worn cobble and pebble gravel with much sand and a few boulders. This material grades out laterally into sandy soil with pebbles, and that into the unmodified pink till. The hillock is a small kamey accumulation, its composition very unlike what a beach ridge would have. Its location in mid-width of the presumed wave-cut terrace proves that "vague, sloping platform" to be morainic, not littoral, in origin. Further evidence is the existence of a once closed morainic depression in this "terrace," now breached and drained by a ravine. The "very flat bar," however, is a gravelly beach ridge which Leland Horberg and the writer traced almost continuously for 2½ miles south of Goldthwait's locality.

Alden (1918) traced the red drift northward along Lake Michigan, finding that the belt along the coast widens to no more than 15 miles in the 75 miles from Milwaukee to Manitowoc. At this northern limit, however, the drift sheet is expanded westward to constitute two lobes, the western of which extends south down the Green Bay depression a few miles beyond Lake Winnebago. He found this red drift to override moraine ridges of the Lake Border system, the Kettle interlobate moraine and some Lake Border correlatives in the Lake Winnebago region. But he conceived of its own ridges as terminal and recessional red till moraines, nowhere suggesting the idea which Thwaites was later to stress; that these ridges are really older moraines entirely covered by a thin red till.

In this paper, Alden described, on the red drift between Port Washington and Manitowoc, "what appears to the writer to be the Glenwood shore line . . . . very faintly developed yet traceable . . . . along the west limit of a gently sloping flat plain or lake terrace, beyond which the surface of the drift rises more rapidly to the crest of the east ridge of the red clay series." He noted that "nowhere is there a definite beach", that "the flat terrace rises to a slight break in slope at the

Glenwood level with here and there slight traces of gravels, and west of this indefinite bank the surface becomes gently undulating", and finally that "though the phenomena in this lake border belt are scarcely definite enough to prove submergence in the waters of the Glenwood stage of Lake Chicago, they are just about what would be expected if such submergence lasted but for a comparatively short time. . . ."

Alden's conclusion was that the red drift was deposited during Glenwood time, that "north of this place (Milwaukee) there was an early Glenwood stage, then a stage of glaciation (without change in lake level) followed by a later Glenwood stage".

The writer would note that the "terrace" of Goldthwait's and Alden's quoted descriptions is far too wide and the "bluff" much too high to be the product of a short exposure to wave attack. The prism of excavated material would be greater than in any Glenwood cut shores at the south end of the lake. A "faintly developed" erosional shore would be a mere niching in the morainic slope. Furthermore, the "terrace" slopes considerably more than do wave-cut Glenwood terraces in till at the south end of the lake and it has at least one definite record of an unfilled morainic depression in it. Still further, a tracing across Sheboygan County encounters long stretches with comparable exposure toward the east where no perceptible break in slope could be recognized. And still further, the same kind of "break in slope" exists in several places well above any possibility of a Glenwood shore line, and even back between the morainic ridges.

Alden believed that a delta of Glenwood age overlay the red drift in southeastern Manitowoc County (1918, p. 330), about 100 miles north of that drift's southern limit. This Cleveland "delta" of Centerville Creek was examined in 1950 during a field conference on Pleistocene geology. A. C. Trowbridge, F. T. Thwaites, Leland Horberg and the writer agreed that: 1) The volume of the deposit is far in excess of what Centerville Creek could erode and transport in the time Alden allowed, a later Glenwood stage so brief that no definite shore lines were made, 2) The clean washed character of the "delta" sand and the lack of clayey layers in the 30-foot section record far more sorting than the creek could ever produce at this place, 3) The topographic setting indicates the deposit to be

outwash sand deposited in a low place in a morainic sag or trough when the Lake Michigan lobe of Valders age was still overlapping the local coast.

If the Glenwood shore, however faintly developed, is present on the Wisconsin red drift, that coast was surely exposed to the glacial lake during the entire Calumet stage. Alden found only "indications" of it and "a slight trace of a beach too poorly developed for certain correlation" between Racine and Sheboygan. He explained its absence as due to destruction by later wave work. Nevertheless, any remnants spared would be more than "slight traces" and "indications." Yet the only beach ridge which Horberg and the writer found was the "very flat bar", the base of whose lakeward slope was 40-45 feet above Lake Michigan. It can only be a weak Calumet shore line. The writer concludes that no record of the Glenwood level of Lake Chicago exists on the Valders red drift.

MORAINES IN WISCONSIN

A Pleistocene study by Thwaites (1943) covered portions of all of 13 counties lying west of Lake Winnebago, Green Bay and Menominee River, most of this area lying within the province of the Green Bay lobe. The western half is characterized by moraines of Cary age, the eastern half by the red drift which Thwaites named Valders. The most significant finding, from the present viewpoint, is that the southern portion of the easternmost Cary moraines are overridden by the Valders red till, yet traceable for some distance as ridged elevations in the thin Valders. Thwaites correlated his moraines with those named by Alden farther south in the Green Bay lobe, as Alden had earlier correlated his later Green Bay moraines of Cary age with units of the Lake Border system. All these correlations seem logical enough. If correct, Thwaites' Mountain moraine is the northern extension of Alden's St. Anna moraine (just south of Lake Winnebago). This, in turn, is the equivalent of the Lake Border system's easternmost ridge, a feature which reaches from the Illinois line to Random Lake, 12 miles north of Port Washington, where it disappears under the red drift. A gap of about 25 miles separates its northern visible end from the place where the St. Anna makes contact with the west side of the Kettle interlobate moraine.

Thwaites traced his easternmost and youngest Cary moraine, the Athelstane, southward and southeastward, under the Valders till cover, almost to Fox River. Its probable course thence should be northeastward, completing the loop all Green Bay moraines possess. This would bring it into the glacially unmapped territory north of Alden's and east of Thwaites' limits, there to enter the Interlobate complex and emerge on the east side as a correlative frontal ridge of the Lake Michigan lobe.

Thwaites showed on his generalized location map (fig. 1) a northward extension of the Kettle Interlobate moraine from Alden's area into southwestern and central Kewaunee County, where the coalescence of Lake Michigan and Green Bay moraines of this late Cary stage should occur. The Kewaunee County soil map depicts this interlobate area as a wedge-shaped tract, chiefly of Miami silt loam, tapering out to the north. Small irregular patches showing 8 different soil types, also peat beds and lakes, scattered throughout this area, are strongly suggestive of the Kettle moraine topography. Other soils of the county are distributed in dominantly north-south belts, the boundaries of those on the east inclining toward west of north, those on the west toward east of north, in a rough parallelism with the sides of the interlobate wedge. The county's drainage pattern largely conforms also to this northward convergence of soil belts, showing morainal sag control. When the glacial map of this district, now being made by Thwaites and Bertrand, is published it should differ only in details from this very expressive soil map.

There are at least seven morainal ridges in the red drift sheet which are cut in diagonal section by the Lake Michigan cliffs. Only one, just north of Port Washington, has been examined during the present study. It has little more than 12-15 feet of red till overlying a brown till in its cliff sections. In the sag between it and the next ridge to the west, the red till is at least 20 feet thick, its surface lying 30 feet or so lower than its base in the ridge. This is good evidence of veneering. Excavations near the power station in Port Washington show the red till to overlie older drift at various altitudes, suggesting that a Sauk Creek valley existed here before the red till was deposited.

It is therefore forecast that these red drift ridges along the Lake Michigan coast will all prove to be buried Cary mor-

aines and that both Lake Border and, farther north, Port Huron units will be identified. The absence of Glenwood records on the red drift and the existence of only a weak Calumet record indicates that this readvance of the Lake Michigan lobe came late in Calumet time, just before the high waters of Lake Warren discharge started the lowering from Calumet to Toleston levels.

Near Two Creeks, a "forest bed" and peat deposit at the base of the red till is exposed in the sea cliffs a little above the lake surface. Stumps shallowly rooted in the peat project a few inches up into this till, showing that the wood was green, tough and elastic at the time of overriding. Branches several feet long were worked over and came to rest, battered but intact, as much as 5 or 6 feet up in the red till. This deposit, therefore, is no earlier vegetal accumulation, fortuitously uncovered but spared from destruction, and then reburied. Thwaites (1937, p. 83) is justified in his picture of "knocking down of live trees by advancing ice which deposited red till." If the red till be of Glenwood age, this forest bed must be either: 1) pre-Glenwood, or 2) the record of an otherwise unknown law-water stage *interrupting* the Glenwood high-water stage. The first conclusion is obviously impossible. Only by the second could there be Glenwood shores on the red till sheet!

The writer, convinced that no such shores exist, would correlate the Two Creeks forest bed with the peat, wood fragments and shells of the Evanston district, Illinois, first reported in Dr. Edmund Andrews' classic paper (1870) and elaborately described by Baker (1920). Baker proved that the chief deposits are *in situ*, not drifted to position as Alden, Goldthwait and Leverett had suggested, and that they are post-Glenwood, pre-Calumet in age. Their low altitude (590) establishes the verity of the low-water stage which Baker named Bowmanville.

SHORE LINES IN MICHIGAN

Goldthwait (1908) reported the existence, with altitudes, of abandoned lake shores above the Algonquin strand along the east side of Lake Michigan as far north as Ludington. He remarked on the paucity and the fragmentary and "obscure" character of these shore lines from Grand River north.

Leverett's first published map of glacial features of the southern peninsula is dated 1911. It accompanied a publication dated 1917. The next map, appearing in 1915 in Monograph 53 was by Leverett and Taylor. A third map, by Leverett, with cooperation of Taylor and others, is dated 1924 and has no accompanying text. Chapter 14 of the monograph, written by Leverett, deals with Glacial Lake Chicago's shores, chiefly in Michigan.

Changes of the glacial lake shore lines in this series of maps are most marked along the Lake Michigan coast north of Grand River. Leverett's text in the monograph indicates doubt as to the location, even the existence, of the highest shore in some places where altitude and exposure would seem to promise its formation. His statement in 1917 (p. 123) was that "the highest beach is so weak as to be traced with some difficulty on the slopes of the outer ridges of the (Port Huron morainic) system from near Muskegon northward." He reported a definite Calumet shore line, saying in the monograph that it "appears throughout its course as a single ridge and a strong one." Neither he nor Goldthwait found any pre-Algonquin shore lines north of Manistee.

By the thesis of this study, Lake Chicago was lowered from its Glenwood level during the first of two episodes of large contributions from eastern lakes. The Port Huron moraine, built at the close of this first episode, therefore could not possess Glenwood shore lines along the Lake Michigan coast. Prompted by the incompatibility of the Goldthwait and Leverett statements with the attractive theory, the writer made about a thousand mile traverse in the coastal belt between Grand River and Grand Traverse Bay, following Leverett's earlier and later mapping of the Glenwood shore line. No shore was found! Questioning his own ability to recognized faint shore lines, the writer repeated most of these traverses in company with Stanard Bergquist, Leland Horberg and Morris Leighton. Without specifying details of the earlier misinterpretations and subjective recognitions, it will be sufficient here to record that all three men agreed they could identify no Glenwood shore lines in Michigan north of Muskegon.

Another feature of the Michigan shore line problem is a deltaic deposit made by Glacial Grand River in Lake Chicago. Leverett showed it on all three of his glacial maps and briefly

described it in 1915 (p. 352) as having a top level at Glenwood altitudes, trenched about 25 feet deep in places by Grand River outlet as Lake Chicago fell to the Calumet level. The outlet's last functioning was for the Lake Warren discharge. Because Leverett recognized no Toleston trenching, by implication he considered both episodes of westward discharge down Grand River to have occurred before the second lowering of Lake Chicago.

Two days of field study with the aid of the Ottawa County soil map (1922) and the Holland and Muskegon topographic maps (1928-1930) showed that this Allendale delta covers more than three times the area Leverett estimated and has two well-developed Toleston portions, one along the lower course of Grand River, the other along the Zeeland distributary. Because the Lake Chicago bottom here had a very gentle slope, most of the delta is thin, the Calumet additions lying west of the Calumet distributary channels and the Toleston portions disappearing under the great dune belt along the present Lake Michigan shore.

The two trenchings, with their deposits at Lake Chicago's second and third levels and with correlative terraces upstream along Grand River valley at least as far as Ada indicate clearly that Glacial Grand River continued to function until the Toleston level had been attained. Lake Warren's discharge, therefore, continued until that same time and the Allendale delta fits perfectly into the chronology and correlation scheme herewith presented.

MORAINES IN MICHIGAN

A strongly expressed moraine lies along the Lake Michigan shore from Manistee north, and has a lobate form around the south end of Grand Traverse Bay. This, the Manistee moraine, is of clay till about as red as the typical Valders in Wisconsin. Leverett believed that, in its further course southward, the Manistee moraine went under the surface of the lake, there curved westward and northward and reappeared in Wisconsin as the Two Rivers moraine of Alden.

The next older moraine in Michigan is the second ridge of the Port Huron system which, although containing reddish till in places (as do most till sheets), prevailingly is not at all red or pink. This system was mapped and described as

reaching the Lake Michigan shore from the northeast near Ludington and as continuing southward along the coast to include the small Whitehall moraine, about 10 miles north of Muskegon. Here it disappeared under the lake. A field conference between Alden and Leverett in 1910 led to their conviction that this Port Huron system emerged at Milwaukee as the red drift sheet. Confident of the existence of both Glenwood and Calumet shore lines on this drift, Leverett wrote (1915, p. 310) as follows: "The moraine leading north from Two Rivers has no beach higher than the third beach (Toleston) of Lake Chicago, which is there about 25 feet above Lake Michigan. But within a few miles south of Two Rivers, on the plain between the lake and one of the earlier red drift moraines, beaches and river deltas are developed up to about 60 feet above Lake Michigan. There could scarcely be better grounds for correlation than are presented in the relation of these moraines to the beaches of Lake Chicago." The writer believes, however, that there are better grounds for a better correlation.

The red drift limits, as mapped in Wisconsin and Michigan, early seemed to the writer to offer a neglected possibility of correlation, especially in view of the admitted weakness of the supposed Glenwood shores on which these students were making their correlation. Furthermore, if the Port Huron moraine did have Glenwood shores on its slopes, the Maumee-Arkona-Whittlesey discharge to Lake Chicago had not sufficed to bring about a lowering to the Calumet stage and some cause, not yet envisaged by anyone, must be found to explain those two lowerings and the two associated static levels.

In the above-noted traverses between Grand River and Grand Traverse Bay, a surprising discovery was that the red till of Michigan extends along a coastal belt for 65 miles south of Manistee. The southernmost units of Leverett's Port Huron moraine, near Whitehall, are of red or pink till or are heavily veneered with it. Lake bluffs, ravine slopes, basement excavations, road cuts, even freshly plowed fields showed this color. No till of any other hue was seen except below the red. The belt of country thus characterized extends in places 10 miles back from the lake. In some morainic tracts, the eastern part is lacking in the red till but topographically

differs little from the western part where overlaid by this younger glacial deposit. When posted on a map, the pattern indicates that the Manistee moraine-building ice, reaching far south of the limits assigned by Leverett, crowded eastward out of the lake basin to overlap the Port Huron moraine and to reach about 20 miles farther south. The outer part of that older moraine system appears to go under the lake in southern Oceana County. In these observations and interpretations, Bergquist, Horberg and Leighton concur with the writer.[8]

The Whitehall moraine therefore is interpreted as a part of the Manistee moraine, built by a readvance of the Lake Michigan lobe after an extensive retreat from the Port Huron pause and a realignment of flow lines from Canadian glacial sources sufficient to make this contrast in color of the till. Obviously, this pattern is almost identical with that of the red till in Wisconsin and a correlation is called for. It will be open to criticism, however, unless some Port Huron equivalent in Wisconsin, other than that proposed by Alden and Leverett, exists.

The revision, therefore, considers that morainic ridges emerging from the lake in Kewaunee and southern Door counties are buried Port Huron correlatives and are equivalent to the St. Anna and Athelstane moraines of the Green Bay lobe. Thus the red Manistee and Whitehall moraines are earliest Mankato drift in Michigan as the red Valders drift is in Wisconsin, and thus the Port Huron moraine becomes latest Cary.

If the Manistee and Whitehall moraines are correlative, meltwater must have flowed southward, subparallel to a continuous ice front, for 100 miles or so before it could enter Lake Chicago. Reconnaissance shows that spillways for such water, with properly related altitudes and gradients, exist among the unit members of the Port Huron system. Although undoubtedly used earlier by Port Huron meltwater rivers, the channelling that has occurred along the westernmost of these and the limitation of pitted plain character to their highest terraces seem good evidence of post-Port Huron use.

It also appears that, as the ice front shrank from the

[8] A reddish till exposed in the bluffs of Muskegon River valley at Newago, 32 miles directly east of Whitehall, lies beneath the Lake Border moraines and is not to be correlated with the pink to red drift of the Manistee-Whitehall moraine. Leighton has suggested in conversation that it may be correlative with the pink Bloomington till of Illinois.

Manistee-Whitehall moraine, the withdrawal began at the south, near Muskegon, and that more northerly and shorter routes for meltwater seeking the lake were successively opened; at White River, at Pentwater River, at Pere Marquette River and finally at Manistee River.

At the maximum of the Manistee-Whitehall advance, a lake was formed in the lower Manistee River valley by the ice dam at the valley mouth. Its pink laminated clays (at High Bridge, 15 miles east of Manistee) became buried under a valley train leading west to Lake Chicago when glacial withdrawal from the moraine occurred in this latitude but while meltwater was still being discharged across more northern portions of the moraine. The concept here advanced is that the Lake Michigan lobe, much elongated in latitude, shrank from its margining moraines in the fashion that a valley glacier, elongated in altitude, withdraws from its laterals. Detailed field study must wait until the region has been topographically mapped but the laminated clays seem impossible to explain by Leverett's and Alden's correlations.

SUMMARY

The writer believes that good evidence and reasoning support the following conclusions:

1. The Tinley moraine and valley train alone constituted the dam for Lake Chicago.
2. Only variations in discharge could have caused variations in the rate of the Tinley dam's erosion to produce Lake Chicago's successive high-water stages.
3. Only the influx of Maumee-Arkona-Whittlesey water can explain the lowering from Glenwood to Calumet levels.
4. Only the combined Bowmanville and Lake Wayne diversions can be correlated with the cessation of Lake Chicago's discharge at the first-attained Calumet level.
5. Forward sweeping of shore drift as Lake Chicago rose again from the Bowmanville low-water level produced the strong Calumet beach in the relatively short time the dam allowed.
6. Lake Warren's discharge, poured into Lake Chicago, caused outlet deepening and the lowering from Calumet to Toleston levels.
7. Beginning of Mankato time, marked by deposition of the red Valders and Manistee (revised) drift, occurred during the Calumet stage of Lake Chicago.
8. The Port Huron moraine is of late Cary age, not correlative with the Valders red drift.

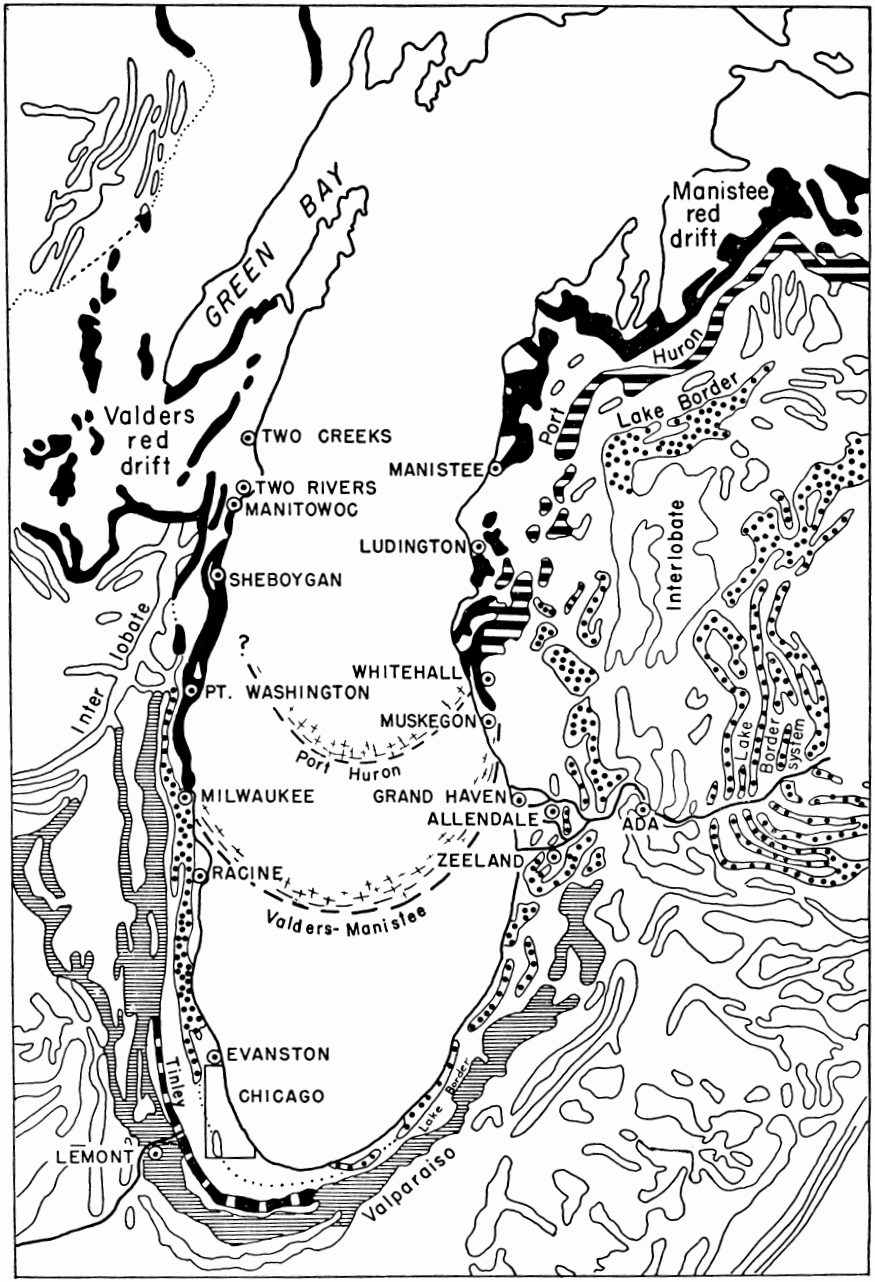

Fig. 1. Later moraines of the Lake Michigan lobe of the Wisconsin ice sheet. Modified from Glacial Map of North America, Geol. Soc. America 1945.

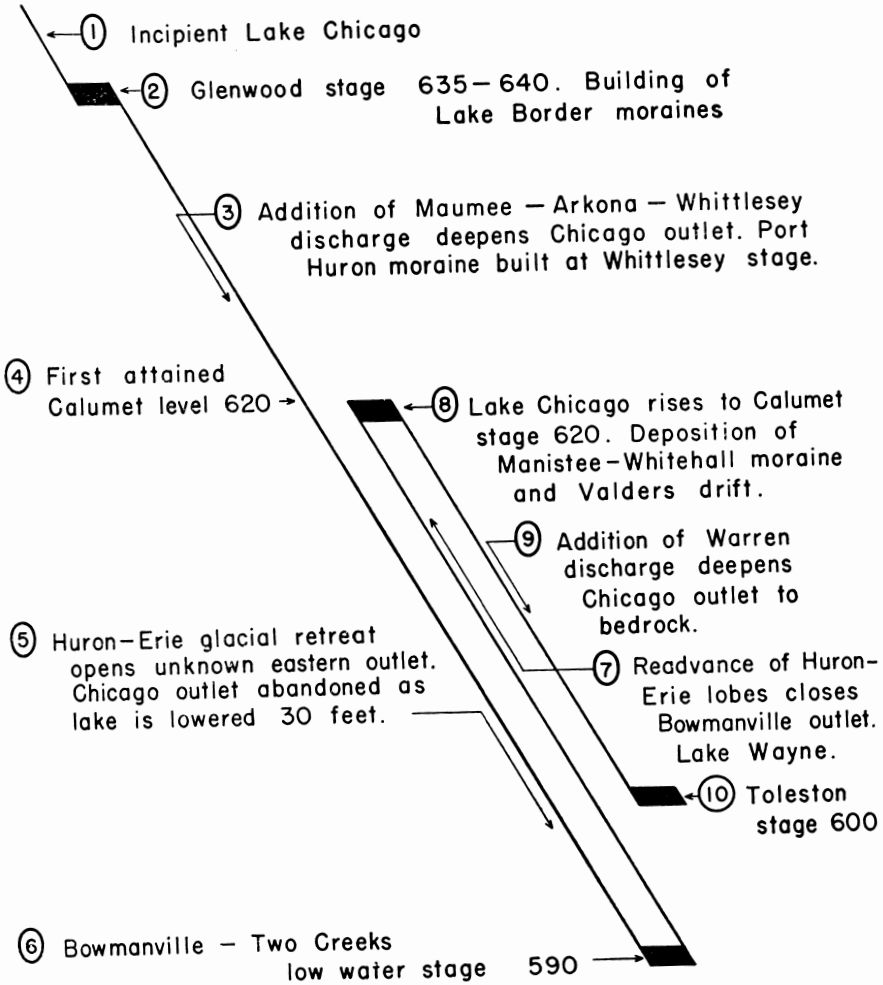

Fig. 2. Stages of Lake Chicago correlated with contemporaneous moraines and eastern lakes.

TABULATED CHRONOLOGY

Lake Chicago Events	*Ice Fronts and Moraines*	*Functioning Outlets*	*Eastern Lakes*
"Incipient" Lake Chicago.	Glacial retreat from newly completed Tinley moraine.	Tinley moraine crest eroded down to level of Tinley valley train. Boulder armor developed.	Early Lake Maumee, discharging to Wabash River.
Glenwood level.	Deposition of earlier moraines of Lake Border system, beginning in mid-Glenwood time.	Tinley dam holds up Glenwood level. Higest Allendale delta levels made by meltwater from earlier Lake Border moraines of Saginaw lobe.	
Lowering to first-attained Calumet level.	Later Lake Border moraines. Port Huron moraine.	Imlay channel. Ubly channel. Grand River trenches Allendale delta. Tinley boulder armor ineffective, Chicago outlet deepened 20 feet.	Later Lake Maumee. Lake Arkona and Saginaw, and Lake Whittlesey, all discharging to Grand River.
Bowmanville low-water stage and Two Creeks forest bed.	Pronounced retreat. End of Cary subage.	Bowmanville eastern outlet opened. Grand River and Chicago outlets go dry.	Low stage without known record.
Rise back to Calumet level.	Pronounced readvance, Manistee-Whitehall moraine and Valders drift at climax. Early Mankato subage.	Syracuse outlet active and Grand River dry, while Lake Chicago discharges over Calumet boulder armor until Warren water arrives.	Lake Wayne during part of interval, followed by rise to Warren level.
Lowering from Calumet to Toleston level.	Ice dam for Lake Warren far out in Huron and Erie basins.	Chicago outlet deepened 20 feet as Calumet boulder armor is swept away. Grand River trenches Allendale delta to Toleston level.	Lake Warren.

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