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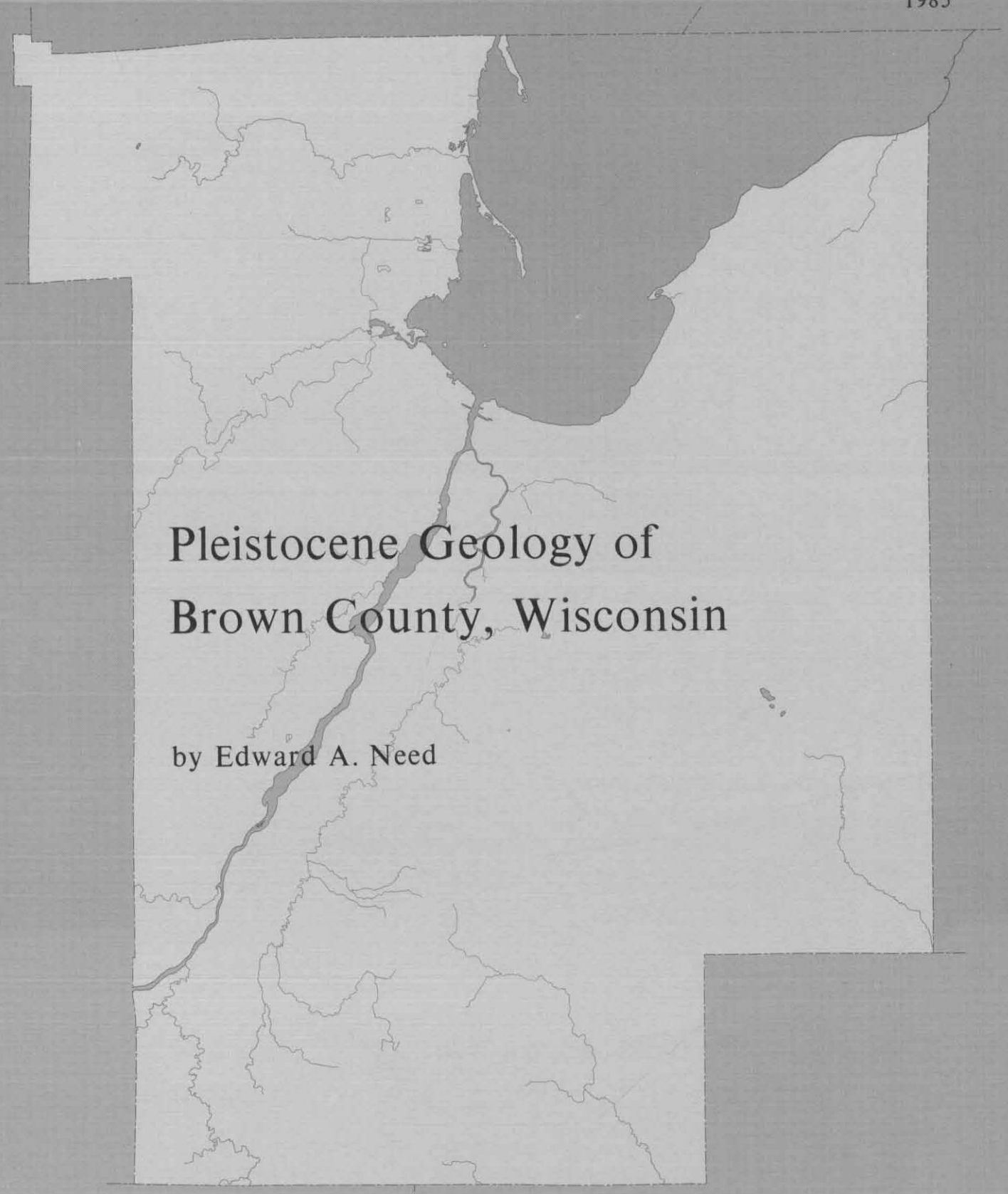

Pleistocene Geology of Brown County, Wisconsin

by Edward A. Need

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A description of the geologic materials underlying the surface soils and overlying the solid rock.

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M. E. Ostrom, Director and State Geologist

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PREFACE

Brown County is covered by geologic materials of Pleistocene age which range between 15 and 30 m thick. These materials serve as the foundation for buildings, roads, and other structures; they provide gravel and concrete aggregate; and they contain much of the groundwater in the county. This report is one of the first of a series describing the Pleistocene geology of Wisconsin counties.

The report consists of a map and cross sections showing the Pleistocene deposits of Brown County and an accompanying text which describes the physical character and stratigraphy of these deposits. This project was the result of a cooperative agreement between the Wisconsin Geological and Natural History Survey, the U.S. Geological Survey, and the Brown County Board of Supervisors.

Dr. Meredith E. Ostrom
Director and State Geologist

Pleistocene Geology of Brown County, Wisconsin

by Edward A. Need

ABSTRACT

The Pleistocene deposits of Brown County, which are up to 30 m in thickness, include seven lithologically distinct till units, silty and clayey offshore lacustrine sediment of several ages, and meltwater and stream sediment of several ages. Except for a small area of till that was deposited by the Lake Michigan Lobe in the southeastern corner of the county, the Pleistocene sediments in Brown County were deposited by the Green Bay Lobe and in the lakes and streams associated with it. Modern stream sediment, deposits of windblown sand, and accumulations of organic sediment are also present.

The oldest till present in the county is a light-colored, stony, sandy till that is part of the Wayside Member of the Horicon Formation. This unit is found only to the east of the Green Bay Lobe axis. The younger till is reddish and fine-grained and is included in six separate members of the Kewaunee Formation. These include, from oldest to youngest, the Branch River Member, the age-equivalent Kirby Lake, Chilton, and Valders Members, and the age-equivalent Middle Inlet and Glenmore Members. The Branch River, Chilton, and Glenmore Members are found to the east of the lobe axis; the Kirby Lake and Middle Inlet Members are found to the west of the lobe axis. The till of the Valders Member was deposited by the Lake Michigan Lobe.

Four episodes of glacial activity are recorded in the Pleistocene deposits in Brown County. These deposits also record the presence and fluctuation of proglacial lakes in the Fox River valley and the Lake Michigan basin. Three of the glacial events are pre-Twocreekan in age, corresponding to the classical Cary glaciation and the two Port Huron events of the Woodfordian Subage. The youngest event is post-Twocreekan, corresponding to the early part of the Greatlakean Subage. Glacial Lake Oshkosh occupied the Fox River valley during glacial events, draining west by way of the Portage outlet initially and later by way of several outlets across the Door Peninsula. Following ice retreat, fluctuating water levels in the Lake Michigan basin resulted in substantial stream incision during the Chippewa low-water episode followed by deposition of offshore sediment near the present Green Bay shoreline when the lake rose to the Nipissing level.

INTRODUCTION

This report describes the unlithified deposits of Pleistocene age present in Brown County, Wisconsin. Brown County is located in northeastern Wisconsin at the southern end of Green Bay. It comprises an area of about 540 square miles including the city of Green Bay. The purpose of this report is to provide geologists, engineers, planners, regulators, and other parties interested in the geologic resources of the county with an understanding of the origin, character, and distribution of the unlithified deposits underlying the surface soil and overlying the solid rock. The report consists of a map showing the distribution of the deposits exposed at the surface, twenty interpretive cross sections showing the subsurface extent and stratigraphic relationships of the deposits, and an explanatory text.

The map (plate 1) results from field work done during the summer of 1980, laboratory analyses of 300 samples, well-construction reports, and previous reports on the Pleistocene geology of the area. Field mapping was done on topographic maps at a scale of 1:24,000, with the aid of aerial photographs taken in the summer of 1978 (available from the Wisconsin Department of Transportation at a scale of about 1:20,000). Mapping rates ranged from 24 to 48 sq mi per day. The field maps were compiled at a scale of 1:100,000 to produce the map included in this report.

The cross sections (plate 1) are based on well-construction reports, stratigraphic relationships identified in surface exposures, and twenty auger borings. The well-construction logs were interpreted in light of the stratigraphy relationships identified in surface exposures, but without the opportunity to examine the sampled materials. Thus, there may be inaccuracies in places, and the cross sections should never be used in place of test borings when detailed information about the subsurface statigraphy is required.

The map and cross sections provide several different kinds of information about the Pleistocene deposits of Brown County. The primary distinctions between the different map units are lithologic and genetic. Till, lacustrine sediment, and stream sediment are shown on the map and cross sections by families of hues--greens, blues, and reds, respectively. Within each of these major groups, specific hues are used to make stratigraphic distinctions, and patterns are used to make selected morphologic distinctions.

The laboratory analyses and field observations were used to characterize the different kinds of deposits present in Brown County. The grain-size distributions of more than 300 samples were determined using sieve and hydrometer techniques. In addition, samples of till were analyzed to determine their magnetic susceptibility and carbonate contents. Magnetic susceptibility was analyzed using the less-than-2-mm fraction of the till, and the carbonate contents were determined gasometrically using the 0.037-to-0.063 mm fraction.

PREVIOUS WORK

The earliest work on the glacial geology of the region around Brown County was done by Whittlesey (1849), who noted extensive deposits of red clay in eastern and northeastern Wisconsin, which he interpreted as originating in freshwater lakes. Warren (1876) mapped the extent of this red clay in the Fox River valley and interpreted the red clay to have been deposited in an ancestral Lake Winnebago, which

Warren thought had an outlet to the west across the low divide between the Fox and Wisconsin Rivers at Portage. Chamberlin (1878 and 1883) also interpreted the red clay to be of lacustrine origin, eventually concluding that it was deposited in a large, ice-marginal lake that occupied the Fox and Wolf River valleys.

Upham (1903a and 1903b) also identified a proglacial lake in the Fox and Wolf River valleys, which he called Glacial Lake Jean Nicolet, and confirmed the presence of an outlet to the Wisconsin River from this lake in the Portage area. Although Upham accepted the lacustrine origin of the red clay in that region, he noted that it looked more like till than lake sediment. Weidman (1911) was the first to report shoreline elevations for the lake in the Fox and Wolf River valleys. Shorelines at 253 and 244 m (830 and 800 ft) were thought to be related to the Portage outlet, whereas shorelines at 223, 206, 198, 189, and 183 m (730, 675, 650, 620, and 600 ft) were associated with drainage to the Lake Michigan basin.

Alden (1918) demonstrated that much of the red clay was actually till deposited by glaciers and was not of lacustrine origin. As evidence, he cited the unsorted, unstratified nature of the red clay, the ridge-like character of the margin, and the absence of red clay in areas with lower elevations outside the margin. Alden also contributed to the understanding of the lake in the Fox and Wolf valleys. He noted deposits of sand and gravel and wave-cut terraces at an elevation of 244 m (800 ft) around the southern end of Lake Winnebago, which he interpreted to be shoreline deposits of a lake draining through the Portage outlet. Supporting this idea, he observed that whereas the surface of the till plain above 244 m (800 ft) in Winnebago and Fond du Lac Counties was very gently undulating, it was nearly flat below that elevation. Alden also suggested that the lower levels of this lake drained through outlets across the Door Peninsula.

Thwaites (1943) established the concept that there were two main pulses of glacial activity in the late Wisconsin glaciation of the Green Bay Lobe. These were the Cary glaciation, during which a light-grayish brown, stony, sandy till was deposited, and the Valders glaciation, during which a reddish-brown, clayey till was deposited. Thwaites interpreted the ice of the Valders advance to be thin and believed that it did not significantly modify the pre-existing landscape. As a result, the "Valders till" was merely draped as a thin blanket over the moraines and other features formed during the Cary glaciation. Thwaites also identified two lakes in the Fox and Wolf River valleys, which he named Early and Later Lake Oshkosh and correlated with the waning phases of the Cary and Valders glaciations. Thwaites thought Later Lake Oshkosh had a maximum level no higher than 250 m (820 ft) but more likely about 244 m (800 ft).

Thwaites and Bertrand (1957) extended the name Valders to the red till overlying the Two Creeks forest bed at its type section in Manitowoc County. This established the concept that there was one red clayey till in eastern Wisconsin, the "Valders till," and that it was younger than the Two Creeks forest bed. As a result of this association, the interval of time postdating the Two Creeks forest bed became known as the Valderan Subage (Frye and Willman, 1960). Thwaites and Bertrand (1957) also identified a series of four outlets for Later Lake Oshkosh across the Door Peninsula. They noted that the lake probably merged with Lake Algonquin (in the Lake Michigan basin) when the ice retreated north of Sturgeon Bay.

A number of studies were done in the

Fox and Wolf River valleys using the stratigraphic and historical framework established by Thwaites and Bertrand. Lee, Janke, and Beaver (1962) and Lee, Janke, and Horn (1972) reported on the grain-size characteristics and carbonate mineralogy of the Valders till. Piette (1963) studied the Duck Creek ridges in western Brown and eastern Outagamie Counties and concluded that they were crevasse fillings deposited against stagnant ice during the retreat of Valderan ice. Black (1966) reported finding a red, clayey till beneath a forest bed, and therefore of Cary age, that had almost the same lithology as the Valders till. Because he felt that color and texture could no longer be used to identify the Valders till, he remapped the extent of the Valderan ice using ice-flow indicators and ice-margin features.

The stratigraphic framework of Thwaites and Bertrand was brought into question by Evenson (1973), who suggested that the Valders till was not the till overlying the forest bed at Two Creek but was in fact older than the forest bed. Additional studies in that area (for example, Mickelson and Evenson, 1975) supported Evenson's hypothesis. To prevent possible confusion resulting from the Valders till not being of Valeran age, Evenson and others (1976) proposed the term Greatlakean as a replacement for Valderan. Subsequent studies (Acomb, 1978; McCartney, 1979) have confirmed that more than one reddish-brown clayey till was deposited by both the Lake Michigan and Green Bay Lobes. In each case there was only one red till younger than the Two Creeks forest bed.

STRATIGRAPHIC FRAMEWORK

As can be seen from the above review of previous work, the stratigraphic concepts pertaining to the history and deposits of Brown County have changed considerably in the past decade. McCartney and Mickelson (1982) and Acomb and others (1982) have defined

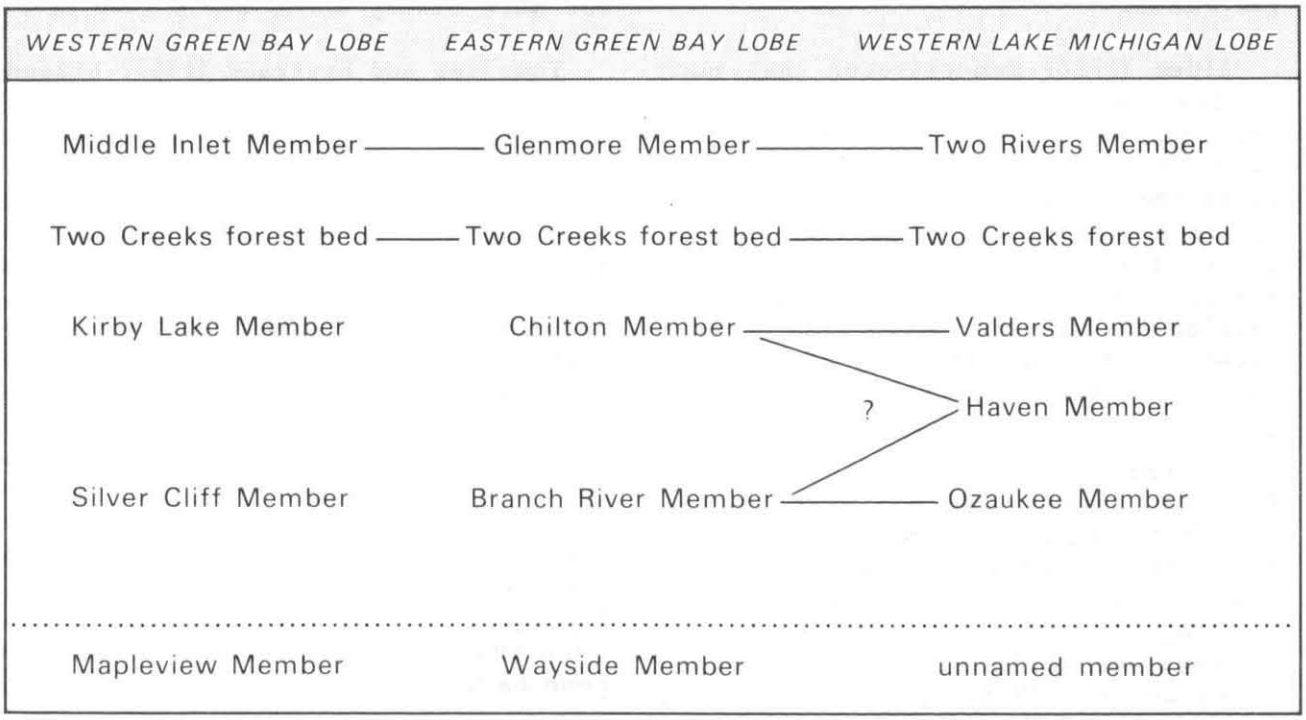

Figure 1. Correlation of late Wisconsinan units in northeastern Wisconsin.

the lithostratigraphy of the till units present in the county, but detailed studies of the associated lacustrine and stream deposits have not been made. Summaries of the lithologic characteristics of the till units identified by these workers for the Green Bay and Lake Michigan Lobes are presented in tables 1 and 2. The relationships among these till units, on the western side of the Green Bay Lobe, the eastern side of the Green Bay Lobe, and the western side of the Lake Michigan Lobe are shown in figure 1. Figure 1 also shows the relationship of these till units to the intervals of geologic time during which they were deposited.

The till materials and stratigraphic relationships that were identified during the field mapping for this report are consistent with those reported by the workers just cited. The till units and the Two Creeks forest bed served as marker horizons to which the other deposits could be related by position. Hence, lithostratigraphic units of moderately-sorted to well-sorted, fine-grained and coarse-grained materials were defined even though they had not been extensively studied (or named).

DESCRIPTION OF PLEISTOCENE DEPOSITS

Till Units

Of the four till units described by McCartney and Mickelson (1982) on the western side of the Green Bay Lobe, only the Kirby Lake Member and the Middle Inlet Member have been identified in Brown County. These till units are present northwest of the lobe axis, which coincides with the northeast trending ridge of stream sediment located 1.5 to 3 km (1 to 2 mi) northwest of the Fox River. All four till units described by McCartney and Mickelson on the eastern side of the Green Bay Lobe have been identified in Brown County. The Wayside Member, the Branch River Member, the Chilton Member, and the Glenmore Member occur southeast of the lobe axis. In addition to these till units, the Valders till described by Acomb (1978) along the Lake Michigan shoreline has been identified in the southeastern corner of the county.

The Kirby Lake Member is composed of silty clay loam till that is predominantly reddish brown (5YR 3/4). Stones (particles greater than 2 mm in diameter) generally make up less than 10 percent of the till. The average grain-size distribution of the matrix (the fraction less than 2 mm in diameter) is 16 percent sand, 46 percent silt, and 38 percent clay. The relative magnetic susceptibility of the matrix averages 7.8, and the carbonate content of the coarse-silt fraction (0.0625 to 0.037 mm) averages 48 percent, with all of the carbonate being dolomite. The physical characteristics of the till are summarized in table 3. The Kirby Lake Member is present in the subsurface throughout northwestern and west-central Brown County (Pittsfield, Suamico, Hobart, Ashwaubenon, and Lawrence Townships and the village of Howard).

The Middle Inlet Member is composed of loam till that is predominantly reddish-brown (5YR 5/4). Stones generally make up less than 10 percent of the till. The average grain-size distribution of the matrix is 40 percent sand, 40 percent silt, and 20 percent clay. The relative magnetic susceptibility of the matrix averages 5.8, and the carbonate content of the coarse-silt fraction averages 32.2 percent, with nearly all of the carbonate being dolomite.

The physical characteristics of the till are summarized in table 3. The Middle Inlet Member is the surface unit in northwestern Brown County and is

TABLE 1.--Characteristics of red-till units of the Green Bay Lobe. First parenthesis is standard deviation; second parenthesis is number of samples. From McCartney and Mickelson (1982)

	% Sand[1]	% Silt[1]	% Clay[1]	Magnetic Susceptibility[2]	% Calcite	% Dolomite	% Total[3] Carbonate	Predominant[4] Color
West Side								
Middle Inlet	64(9)(54)	28(8)(54)	8(3)(54)	6.6(1.5)(13)	6(4)(28)	26(7)(28)	32(7)(28)	5YR 5/3
Kirby Lake	36(14)(33)	47(10)(33)	17(9)(33)	6.9(1.5)(10)	7(4)(21)	24(6)(21)	31(8)(21)	5YR 5/4
Silver Cliff	61(6)(33)	32(5)(33)	7(3)(33)	6.5(1.6)(10)	5(4)(11)	22(5)(11)	27(7)(11)	5YR 5/4
East Side								
Glenmore	15(5.2)(34)	48(5.7)(34)	37(9)(34)	3.9(0.6)(34)	0.6(.8)(13)	32(6)(13)	33(6)(13)	5YR 4/4
Chilton	17(7.1)(31)	49(8.2)(31)	33(8.7)(31)	6.4(.9)(31)	0.4(.1)(11)	37(9)(11)	37(9)(11)	5YR 4/4
Branch River	34(10.1)(13)	42(NC)(4)	23(NC)(4)	6.8(.8)(13)	0(0)(5)	27(1)(5)	27(1)(5)	7.5YR 5/4

[1] Percent of the smaller-than-2-mm fraction. Boundaries used are 2 mm, 0.0625 mm, and 0.002 mm.

[2] Based on measurements of 30 g subsample of the smaller-than-2-mm fraction; expressed in arbitrary relative units of the Quaternary lab of the geology department, University of Wisconsin, Madison.

[3] Based on Chittick analysis of the smaller-than-0.0625-mm fraction for west side of lobe and 0.0625-mm-to-0.037-mm fraction on east side of lobe.

[4] Moist color.

NC: not calculated.

present somewhat discontinuously beneath the more recent lacustrine sediment in the Fox River lowland and along the western side of Green Bay (Suamico Township).

The Wayside Member is composed of loam till that is predominantly light grayish brown (7.5YR 6/4). Stones are numerous, making up as much as 30 percent of the till. The average grain-size distribution of the matrix is 39 percent sand, 47 percent silt, and 14 percent clay. The relative magnetic susceptibility and carbonate content of the till were not determined. The physical characteristics of the till are sumarized in table 3. The Wayside is exposed at the surface in southern Brown County (Morrison and Holland Townships) and in a window eroded through younger till members in northeastern Brown County (Green Bay and Scott Townships). It is thought to be present in the subsurface throughout most of the eastern part of the county.

The Branch River Member is composed of loam till that is predominantly light reddish brown (7.5YR 4/4). Stones generally make up less than 10 percent of the till. The average grain-size distribution of the matrix is 33 percent sand, 46 percent silt, and 21 percent clay. The relative magnetic susceptibility of the matrix averages 5.8, and the carbonate content of the coarse-silt fraction averages 64 percent. The physical characteristics of the till are summarized in table 3. The Branch River Member is exposed at the surface in southern Brown County (Wrightstown, Rockland, Glenmore, New Denmark, Holland, and Morrison Townships) and around the margins of the erosional window of the Wayside Member previously mentioned in northeastern Brown County (Scott and Green Bay Townships). The Branch River Member is also thought to be present in the subsurface throughout the eastern part of the county.

The Chilton Member is composed of clay loam to silty clay loam till that is predominantly reddish brown (5YR 4/4). Stones generally make up less than 10 percent of the till. The average grain-size distribution of the matrix is 21 percent sand, 44 percent silt, and 35 percent clay. The relative magnetic susceptibility of the matrix averages 6.1 percent. The average carbonate content of the coarse-silt fraction is 45 percent, all of which is dolomite. The physical characteristics of the till are summarized in table 3. The Chilton Member is exposed at the surface in southern Brown County (Holland Township) and is leached of carbonates to a depth of more than 0.7 m in this area (Mickelson and Evenson, 1975). The subsurface distribution of the Chilton Member shown in the cross sections is interpreted from well construction reports and is in agreement with the interpretation of McCartney and Mickelson (1982) about the extent of the glacier at this time. Due perhaps to a low ice-surface profile, the ice was apparently unable to overtop the Niagaran escarpment but did advance south-eastward through several breaches in the escarpment, such as the one in the east-central part of the county (De-Pere, Bellevue, and Eaton Townships).

The Glenmore Member is composed of silty clay loam till that is predominantly reddish brown (5YR 4/4). Stones generally make up less than 10 percent of the till. The average grain-size distribution of the matrix is 14 percent sand, 48 percent silt, and 38 percent clay. The relative magnetic susceptibility of the matrix averages 3.9, which allows the Glenmore till to be distinguished from the Chilton till. The average carbonate content of the coarse-silt fraction is 31 percent. The physical characteristics of the till are summarized in table 3. The Glenmore Member is the surface unit throughout most of eastern Brown County and is leached of carbonates to a depth

TABLE 2.--Characteristics of the red-till units of the Lake Michigan Lobe. First parenthesis is standard deviation; second parenthesis is number of samples. From Acomb and others (1982)

	% Sand[1]	% Silt[1]	% Clay[1]	Illite[2]	% Expandable[2]	% Chlorite[2] Kaolinite	Calcite[3] Dolomite Ratio	% Total[3] Carbonate	Magnetic[4] Susceptibility	Predominant[5] Color
Two Rivers	31(3.9)(11)	50(6.1)(11)	19(5.3)(11)	52(3.5)(42)	35(4.0)(42)	13(2.6)(42)	.17(.2)(10)	39.2(8.4)(10)	4.3(.8)(18)	5YR 6/3
Valders	30(8.6)(33)	52(8.1)(33)	18(7.9)(33)	42(3.7)(53)	46(5.0)(53)	12(2.7)(53)	.12(.1)(10)	40.2(2.7)(10)	5.4(1.6)(22)	5YR 6/2
Haven	16(7.1)(27)	56(6.2)(27)	28(6.6)(27)	56(5.0)(58)	25(4.5)(58)	19(3.2)(58)	.10(.1)(10)	36.4(9.6)(10)	5.0(1.0)(22)	5YR 6/4
Ozaukee	13(3.9)(19)	47(5.0)(19)	40(6.5)(19)	60(5.1)(20)	20(5.8)(20)	20(2.3)(20)	.31(.2)(10)	40.6(5.9)(10)	4.1(0.8)(14)	5YR 6/4

[1] Percent of the smaller-than-2-mm fraction. Boundaries used are 2 mm, 0.0625 mm, and 0.002 mm.

[2] Relative Clay mineral percentages of the smaller-than-0.002-mm fraction. Method modified from Glass (1977, personal communication). Method outlined by Acomb (1978).

[3] Based on Chittick analysis of the smaller-than-0.0625-mm fraction.

[4] Based on measurement of 30 g subsample of the smaller-than-2-mm fraction; expressed in arbitrary relative units of the Quaternary lab of the geology department, University of Wisconsin, Madison.

[5] Dry color.

of less than 0.7 m. It is also present in the subsurface in a few areas in the Fox River lowland.

The Valders Member is composed of reddish-brown loam till that is predominantly dark reddish brown (5YR 4/3). Stones generally make up less than 10 percent of the till. The average grain-size distribution of the matrix is 32 percent sand, 47 percent silt, and 18 percent clay, which is nearly the same as that reported by Acomb (1978) from his work along the shoreline of Lake Michigan. The relative magnetic susceptibility of the matrix averages 7.2, and the average carbonate content of the coarse-silt fraction is 54 percent. The physical characteristics of the till are summarized in table 3. As mentioned above, the Valders Member is exposed at the surface in southeastern Brown County (New Denmark Township), but it is not present to any significant extent in the subsurface.

Stream and Lake Sediment

Modern streams have deposited channel sediment and overbank sediment on all floodplains in Brown County. The channel sediment is sandy, the overbank sediment is silty, and unlike older stream sediment both commonly contain fairly abundant organic material.

In contrast, older stream deposits, most of which were deposited by glacial meltwater, consist of nonorganic sand, gravelly sand, or sandy gravel, with only minor amounts of silt. Unit sf occurs in the bottoms of lake spillways and consists of material washed from the channel banks. Units sob, soc, and sod consist of material washed from the glacier. Unit sob underlies till of the Middle Inlet Member in many areas, but where shown on the map (plate 1) the overlying till has been removed by postglacial erosion. Unit soc occurs beyond the southern extent of till of the Branch River Member, it is present in the subsurface below the DePere-Greenleaf terrace, as noted by Thwaites and Bertrand (1967), and it is exposed in gravel pits near Baird Creek in the city of Greey Bay. Unit sod occurs only in the subsurface, and is shown only on the cross sections (plate 1).

Lacustrine offshore deposits consist of very fine sand, silt, and clay. It is commonly horizontally stratified and has nearly flat topography. Units osn and ocn were deposited in Lake Michigan when it stood at the Nipising beach level in Middle Holocene time, and units oso and oco were deposited in Lake Oshkosh in late Wisconsinan time. Unit ocd consists of offshore sediment under the Chilton and Kirby Lake till and over Branch River till. It has been found at elevations as high as 213 m (700 ft) and therefore was deposited in a proglacial lake that filled the Fox River lowland. It is exposed at the surface in a small window eroded through younger units in northwestern Brown County (village of Howard and Hobart Township). It makes up Platten Hill and two other drumlins to the north and crops out along Duck Creek for about 3 km.

Other Deposits

Map unit w consists of windblown sand forming dunes on the plane of Lake Oshkosh, in the northern part of the county. Map unit p consists of peat in shallow depressions on till surfaces; only the larger deposits have been shown on plate 1. Map unit d consists of a complex series of stream and lake deposits making up the Duck Creek ridge west of the city of Green Bay; this material was tilted and eroded into a ridge parallel to adjacent drumlins by the glacier that deposited the Middle Inlet till.

Beaches, which consist of well-sorted sand and gravel, are shown as a

TABLE 3.--Characteristics of till units in Brown County. First parenthesis is standard deviation or range of values for fewer than 10 samples; second parenthesis is number of samples

	% Sand[1]	% Silt[1]	% Clay[1]	Magnetic Susceptibility[2]	% Calcite	% Dolomite	% Total[3] Carbonate	Predominant[4] Color
GREEN BAY LOBE								
Western Side								
Middle Inlet	40(11)(27)	40(10)(27)	20(5)(27)	5.8(1.0)(24)*	.20(.43)(25)*	32(4)(25)*	32.2(4)(25)*	5YR 5/4
Kirby Lake	16(10 to 23)(6)	46(40 to 53)(6)	38(25 to 46)(6)	7.8(2.7)(23)*	0*	48(6)(17)*	48(6)(17)*	5YR 3/4
Eastern Side								
Glenmore	14(5)(48)	48(4)(48)	38(5)(48)	3.9(0.7)(27)	0	31(4)(26)	31(4)(26)	5YR 4/4
Chilton	21(11 to 35)(5)	44(41 to 48)(5)	35(20 to 42)(5)	6.1(4.8 to 7.1)(3)	0	45(43 to 47)(3)	45(43 to 47)(3)	5YR 4/4
Branch River	33(23 to 41)(9)	46(40 to 57)(9)	21(15 to 26)(9)	5.8(4.8 to 7.1)(5)	0	64(61 to 65)(3)	64(61 to 65)(3)	7.5YR 4/4
Wayside	39(32 to 45)(5)	47(45 to 48)(5)	14(10 to 20)(5)	NM	NM	NM	NM	7.5YR 6/4
LAKE MICHIGAN LOBE								
Valders	32(18 to 42)(3)	50(49 to 57)(3)	18(13 to 25)(3)	7.2(7.0 to 7.6)(3)	0	54(51 to 57)(3)	54(51 to 57)(3)	5YR 4/3

[1] Percent of the smaller-than-2-mm fraction. Boundaries used are 2 mm, 0.0625 mm, and 0.002 mm.

[2] Based on measurements of 30 g subsample of the smaller-than-2-mm fraction; expressed in arbitrary relative units of the Quaternary lab of the geology department, University of Wisconsin, Madison.

[3] Based on Chittick analysis of the 0.0625-to-0.037-mm fraction.

[4] Moist color.

NM: not measured.

* Data from samples in Outagamie County.

dotted line on plate 1; some modern beach sediment along Green Bay is included in map unit osn. Eskers, which consist of poorly sorted gravel and sand, are indicated by a line of nested arrowheads on plate 1.

PLEISTOCENE HISTORY OF BROWN COUNTY

The unlithified deposits of Brown County record four episodes of glacial activity during late Wisconsinan time. Three of these episodes occurred before Two Creeks time and one occurred after Two Creeks time. In general the episodes are recorded by two, time-equivalent till units--one till unit to the west of the Green Bay Lobe's axis and one till unit to the east. During one of the episodes of glacial activity, the Lake Michigan Lobe advanced into the southeastern corner of the county. The unlithified deposits in the county also record the effects of changing water levels in the Lake Michigan basin during Holocene time.

During the earliest of the three episodes of glacial activity that predate the Two Creeks forest bed, the till of the Wayside Member was deposited to the east of the lobe axis. The time-equivalent till member to the west of the lobe axis, the Mapleview Member, is not found in Brown County. This episode of glacial activity corresponds to the Cary glaciation of Thwaites (1943), during which the glacier advanced as far south as the Johnstown moraine in Dane and Rock Counties. In southern Brown County, a well-developed drumlin field, containing about 50 drumlins, is developed in or draped by the Wayside Member. The drumlins trend approximately N. 25° W., indicating iceflow from the northwest at this time.

The interglacial interval following the deposition of the Wayside Member has lithostratigraphic significance in that all younger till members of the Green Bay Lobe are reddish-brown in color. However, this interval does not correspond to Two Creeks time as Thwaites (1943) and Thwaites and Bertrand (1957) believed.

During the next episode of glacial activity predating the Two Creeks forest bed, the till of the Branch River Member was deposited to the east of the lobe axis. The time-equivalent till member to the west of the lobe axis, the Silver Cliff Member, is not found in Brown County. This episode of glacial activity seems to correspond to the earlier of the two Port Huron events identified in the Lower Peninsula of Michigan. The extent of the advance at this time was much less than during the preceding episode. The prominent east-west trending moraine at Morrison marks the limit of this advance in southern Brown County. Although no till fabrics or striations were measured in this area, ice flow from the north-northwest is indicated by the general orientation of the moraine.

Two lithostratigraphic units having significant subsurface extent were deposited during the period of marginal retreat that occurred after the deposition of the Branch River Member. These are the fluvial and outwash units present beneath the DePere-Greenleaf terrace and the fine-grained lake sediment unit exposed in the Platten Hills west of Green Bay.

During the latest of the glacial episodes predating Two Creeks time, the till of the Chilton Member was deposited to the east of the lobe axis, and the till of the Kirby Lake Member was deposited to the west of the axis. The lithostratigraphic correlations of McCartney and Mickelson (1982) and Acomb and others (1982) indicate that the till of the Valders Member (one of

four reddish-brown till members of the Lake Michigan Lobe) was also deposited at this time. The Valders Member is present in a small area in southeastern Brown County.

This episode of glacial activity seems to correspond to the later of the Port Huron events identified in the Lower Peninsula of Michigan. The distribution and extent of the ice during this episode is unusual when compared with those of the preceding and succeeding episodes as was noted by McCartney and Mickelson (1982). Only a short part of the outer boundary of the advance is exposed at the surface in southern Brown County (Holland Township); however, the boundary of the Chilton Member probably lies in the subsurface along the Niagaran escarpment.

During the waning phase of this glacial episode, an extensive unit of well-sorted sand, up to 45 m thick, was deposited in the northwestern and west-central parts of Brown County. The distribution of this sand unit suggests that sediment sources were present at the lobe axis and to the west of the axis but absent to the east. This is consistent with the interpretation that the meltwater drainage of the western part of the lobe was ice marginal due to the regional topographic slope. As this water entered the lake in the Fox River lowland it would have deposited sediment in a ice-marginal deltaic environment and as turbidity flows, controlled by the topography of the lowland. Meltwater from the eastern part of the lobe drained southeastward down the dip slope of the escarpment.

The interglacial interval following the deposition of the Kirby Lake, Chilton, and Valders Members is known as Two Creeks time. Wood and other organic material have been found in several places in the county. The locations of the occurrences and descriptions of the sections at these localities are listed in table 4. At each of these sites only one reddish-brown till unit overlies the organic material. Radiocarbon dates from spruce wood have an average of 11,840 B.P. (Broecker and Farrand, 1963).

During the episode of glacial activity that postdates the Two Creeks forest bed, the till of the Glenmore Member was deposited at the east of the lobe axis, and the till of the Middle Inlet Member was deposited to the west. This episode of glacial activity took place during the early part of the Greatlakean Subage of Evenson and others (1976), and it corresonds to the Valders glaciation of Thwaites (1943) and Thwaites and Bertrand (1957) in the sense that it postdates Two Creeks time. The maximum extent of the ice of the eastern side of the Green Bay Lobe at this time is marked by the Denmark moraine. This moraine trends east-west through New Denmark and Glenmore Townships and bends around to trend somewhat north-south through eastern Wrightstown and Holland Townships. The western side of the lobe advanced to the Athelstane moraine just 20 km west into Outagamie County.

Three elongated ridges and about 30 drumlins indicate ice-flow directions during this glacial episode. The three ridges are the Duck Creek ridge, the somewhat discontinuous Highway 41 ridge about 2 km west of the Fox River, and the Allouez ridge just east of the Fox River and extending south to Wrightstown. The Duck Creek and Highway 41 ridges are parallel to each other, trending N. 32° E. for their northern 17.5 km and shifting to trend N. 42° E. for 8 to 9 km at their southern ends. The Allouez ridge trends N. 28° E. for its entire length and thus diverges from the trends of the other ridges. The drumlins to the west of the lobe axis, notably Burdon and Platten Hills, indicate flow from the northeast, and those to the east of the axis indicate flow from the northwest.

TABLE 4.--Two Creeks localities in Brown County

1. SW¼NW¼ sec. 36, T. 24 W., R. 21 E.; east wall of gravel pit:

0	to	3	ft	Lake sediment.
3	to	6	ft	Till of Glenmore Member.
6	to	6.5	ft	Lake sediment.
				Two Creeks horizon.
6.5	to	12	ft	Sand and gravel.

2. SW¼SW¼ sec. 30, T. 23 N., R. 20 E.; east wall of quarry:

0	to	6	ft	Lake sediment.
6	to	9	ft	Till of Middle Inlet Member.
9	to	12	ft	Lake sediment.
				Two Creeks horizon.
12	to	12.5	ft	Lake sediment.
12.5	to	17	ft	Till of Kirby Lake Member.
17	to	25	ft	Covered interval.
				Limestone.

3. SE¼NW¼ sec. 6, T. 22 N., R. 21 E.; south wall of gravel pit:

0	to	15	ft	Till of Glenmore Member.
				Two Creeks horizon
15	to	20	ft	Lake sediment.
20	to	25	ft	Till of Chilton Member.
25	to	27	ft	Lake sediment.
27	to	57	ft	Sand and gravel.

4. SE¼NE¼ sec. 8, T. 24 N., R. 19 E.; augered hole:

0	to	2	ft	Lake sediment.
2	to	7	ft	Till of Middle Inlet Member.
				Two Creeks horizon.
7	to	10	ft	Lake sediment.
10	to	42	ft	Till of Kirby Lake Member.
				Limestone.

5. NE¼SE¼ sec. 27, T. 22 N., R. 20 E.; augered hole:

0	to	12	ft	Till of Glenmore Member.
12	to	14	ft	Lake sediment.
				Two Creeks horizon.
14	to	17	ft	Lake sediment.
17	to	80	ft	Sand.
80	to	90	ft	Till? Lake sediment?

These features and those in Outagamie County have been compiled to produce the ice-flow pattern shown in figure 2. The pattern of ice flow and the presence of a proglacial lake in the Wolf and Fox River lowlands when the glacier was at its maximum suggest that the ice had a calving margin across the Fox River lowland and that this part of the margin was fed by an ice stream. The Duck Creek and Highway 41 ridges probably represent debris that accumulated in the shear zones at the edge of this ice stream.

The Fox River lowland was filled by a proglacial lake, glacial Lake Oshkosh, whenever the natural drainage to Green Bay was blocked by ice. Although this lake was present repeatedly, only the effects of the last in the series can be clearly identified. Unfortunately these effects do not include many well-developed beaches, but consist mainly of some lacustrine sediment and four outlet spillways.

There is a reasonable agreement among the early workers that the maximum level of glacial Lake Oshkosh was 244 m (800 ft) and that it drained through the Portage outlet while at this level. This level is identifiable because of the change in till plain

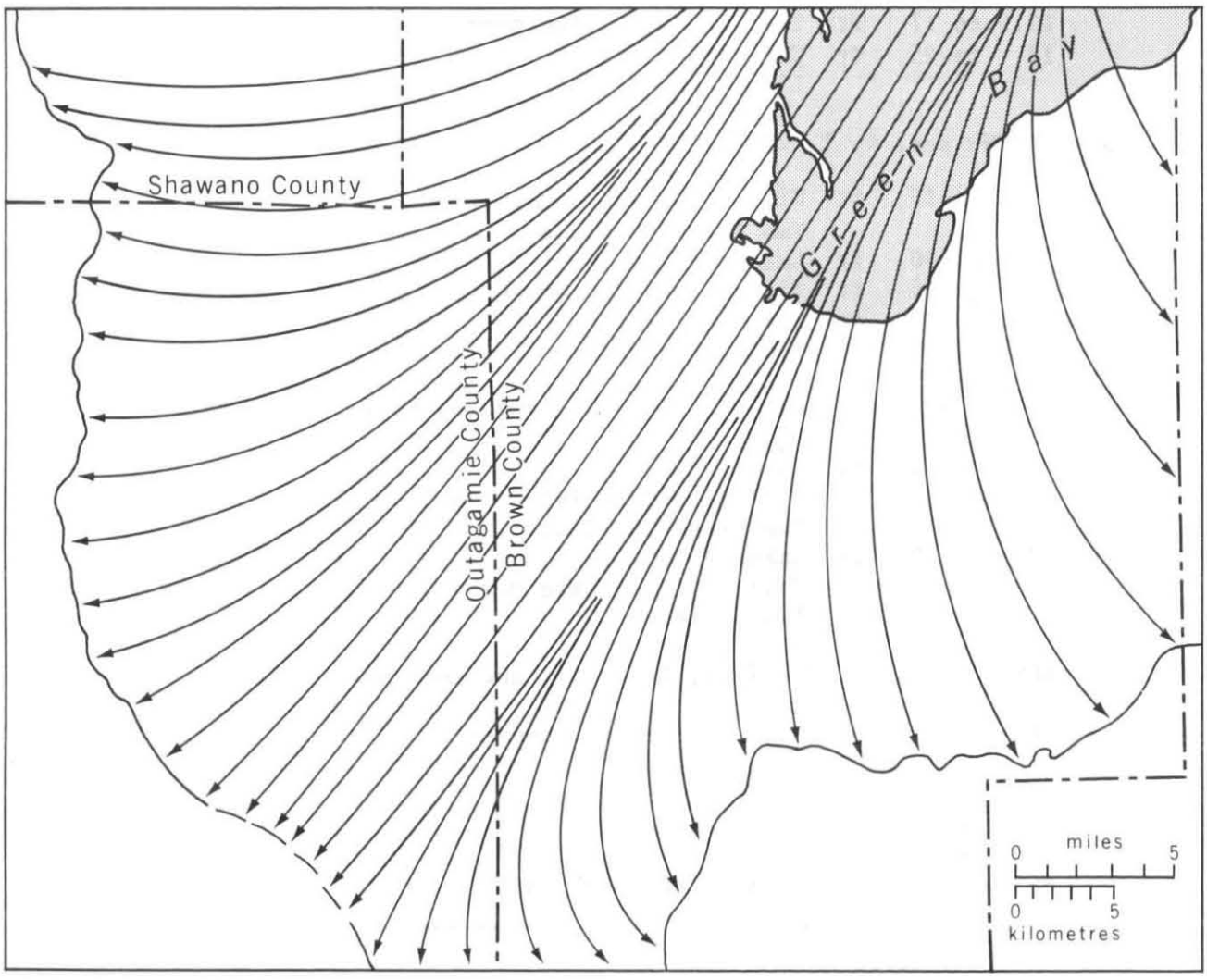

Figure 2. Ice-flow directions during last glacial episode.

morphology at this elevation: hummocky above and smooth below. As the map shows, only the lowest part of the area submerged by this lake is covered with lacustrine sediment.

As the glacier margin retreated, lower outlets across the Door Peninsula were opened. Thwaites and Bertrand (1957) suggested that the first of these outlets was by way of the Manitowoc River in Calumet County. Although the area lacks a clearly identifiable drainage channel, meltwater may have discharged from the lake by this route across stagnant or slowly moving ice. The first well-defined outlet lower than the Portage outlet begins near the center of Bellevue in central Brown County. The elevation of the divide at the bottom of the channel is about 233 m (765 ft). A broad area of somewhat channeled topography is present to the north and northeast of the channel head, and a second, more weakly developed channel head can be identified to the east. Evidently, this second channel was not downcut as fast as the first and was abandoned when the lake level fell below 244 m (800 ft).

Three lower outlet heads are present in the northeastern corner of the county. All three eventually feed into the channel now occupied by the Kewaunee River. The elevations of the bottoms of these outlets decrease from south to north and are 233 m (765 ft), 244 m (735 ft), and 218 m (715 ft). Another outlet head feeding the Kewaunee River is present just outside of the county. Its bottom divide has an elevation of 209 m (685 ft). Farther north in Door County, another outlet channel was identified by Thwaites and Bertrand (1957) along the Ahnapee River, with a divide elevation of 195 m (640 ft). Lake Oshkosh merged with Lake Michigan when ice cleared the channel at Sturgeon Bay.

The closeness of the elevations of the divides at the bottoms of these outlet channels suggests an explanation for the absence of well-developed shoreline features in the Fox River lowland. The water flowing through these outlets was probably on the order of 5 to 10 m deep. This figure is reasonable considering the large volume that must have been draining and the narrow width of the channels. Thus the level in the lake could have declined, not in a step-like fashion, but continuously and steadily as successively lower outlets opened. No shorelines formed because the water did not remain at any given elevation long enough.

Glacial Lake Algonquin occupied the Lake Michigan basin when the channel at Sturgeon Bay was opened by the retreating ice margin. Its shoreline elevation was 184 m (605 ft) and therefore its effects in Brown County are difficult to separate from those of the later Lake Nipissing, which was also present at that elevation (figure 3). Many of the features at this elevation crosscut features that must have formed during the Chippewa low-water episode and are therefore most likely of Nipissing age. As shown on the map (plate 1), eight streams in Brown County have well-defined, steep-sided floodplains that are truncated by younger lacustrine deposits. These channels formed by downcutting and headward erosion when the lake level was greatly lowered, and they were filled in when the lake rose back to the Nipissing level. The dunes in northwestern Brown County probably formed during Nipissing time, which is generally considered to have been relatively warm and dry.

SUMMARY

The purpose of this report is to provide geologists, engineers, planners, regulators and other interested parties with information about the Pleistocene geology of Brown County. The accompanying map and interpretive

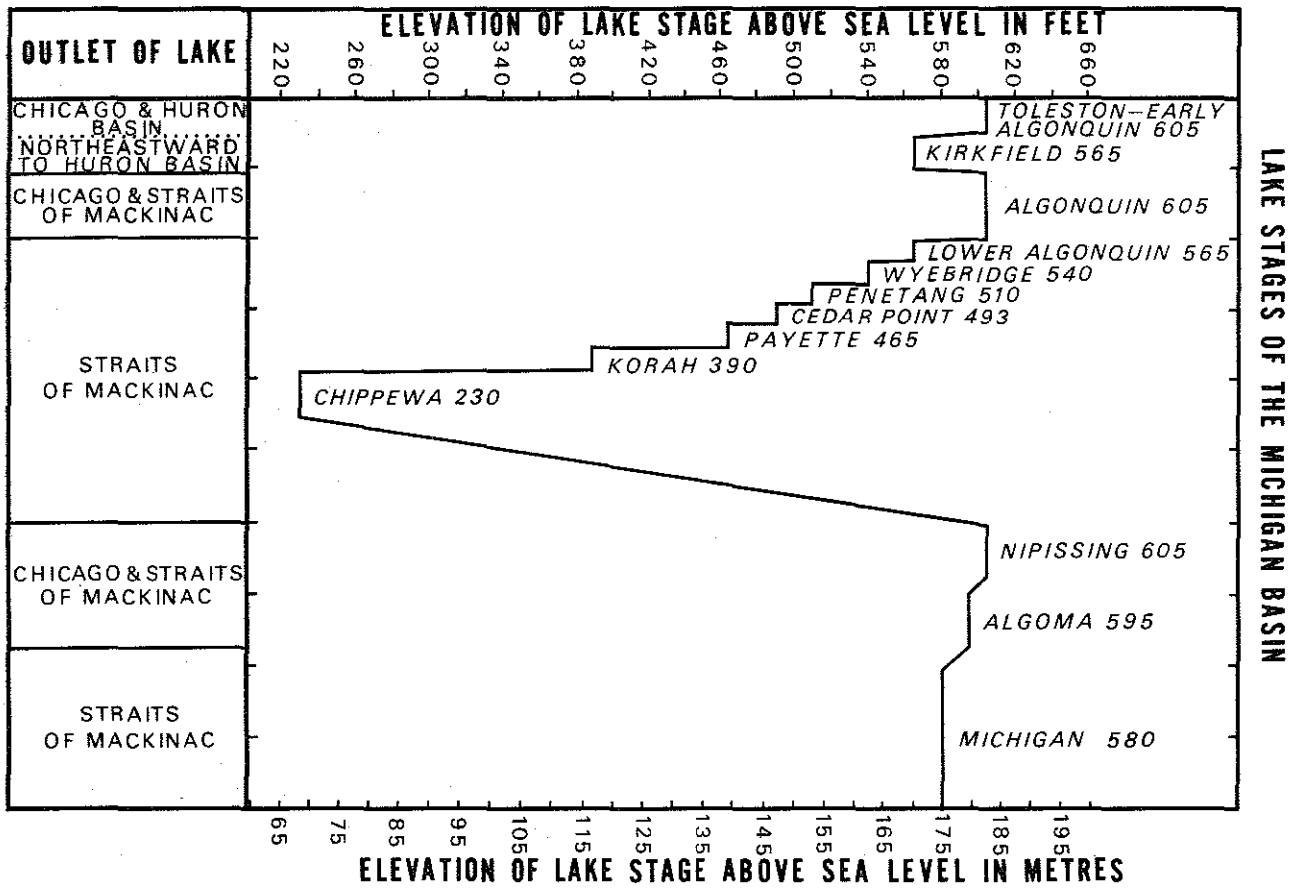

Figure 3. Postglacial lake levels in the Lake Michigan Basin.

cross sections (plate 1) represent the current understanding of the origin, character, and distribution of the unlithified deposits underlying the surface soil and overlying the solid rock. However, the information contained in this report should never be used in place of test borings when detailed, site-specific information about the subsurface stratigraphy is required.

An extensive history of Pleistocene studies in the Brown County area has been included because many of the ideas and concepts developed in these earlier studies have been applied to other areas. It shows an evolving appreciation of the geologic complexity of the past 16,000 to 18,000 years, an evolution reflected in the current stratigraphic concepts. In addition, this review provides a means of relating the current understanding of the Pleistocene geology to those earlier concepts.

Seven lithologically distinct till units have been identified in Brown County. The oldest till, which is only found to the east of the Green Bay Lobe axis, is light brown and both stony and sandy in composition. It is part of the Wayside Member of the Horicon Formation. The next youngest till, which is part of the Branch River Member of the Kewaunee Formation, is also found only east of the lobe axis, but is reddish brown and less stony. Till making up parts of the Kirby Lake, Chilton, and Valders Members (deposited west of the lobe axis, east of the lobe axis and by the Lake Michigan Lobe respectively) is reddish brown but is generally finer grained than the older

till. The youngest till, which is part of the Middle Inlet and Glenmore Members (west and east of the lobe axis respectively), is also reddish brown; however, the till of the Middle Inlet Member is loamy, whereas that of the Glenmore Member is fine grained. Two general types of offshore lacustrine sediment have been described. These consist of a silty facies composed of fine sand and silt and a clayey facies composed of fine silt and clay. Meltwater and stream sediment ranges in character from sandy to gravelly depending on the depositional environment.

The unlithified deposits of Brown County record four episodes of glacial activity during late Wisconsinan time. These deposits also record the presence and fluctuation of proglacial lakes in the Fox River valley and the Lake Michigan basin. Three of the glacial events are pre-Twocreekan in age. During the earliest recorded event, which corresponds to the classical Cary glaciation, the till of the Wayside Member was deposited. The till of the Branch River Member was deposited during the next event, which corresponds with the earlier of the Port Huron events identified in the Lower Peninsula of Michigan. The next event is recorded by the till of the Kirby Lake, Chilton, and Valders Members and corresponds to the later of the Port Huron events. The Two Creeks forest bed and related accumulations of organic material were deposited during the subsequent interglacial interval. The till of the Middle Inlet and Glenmore Members was deposited during the only post-Twocreekan event recorded in Brown County. Glacial Lake Oshkosh occupied the Fox River valley during these glacial events, draining west to the Wisconsin River by way of the Portage outlet initially. Continued ice retreat opened a series of drainage outlets across the Door Peninsula to ancestral lakes in the Lake Michigan basin. When ice retreated north of Sturgeon Bay, Lake Oshkosh merged with Lake Algonquin, which occupied the Lake Michigan basin at that time. The subsequent Chippewa low-water episode is recorded in Brown County by substantial incision along the many streams draining to the Fox River and Green Bay. When the water rose to form Lake Nipissing, sediment was deposited in the stream valleys and on the gentle lake plain that extends inland for several miles from the existing shoreline.

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