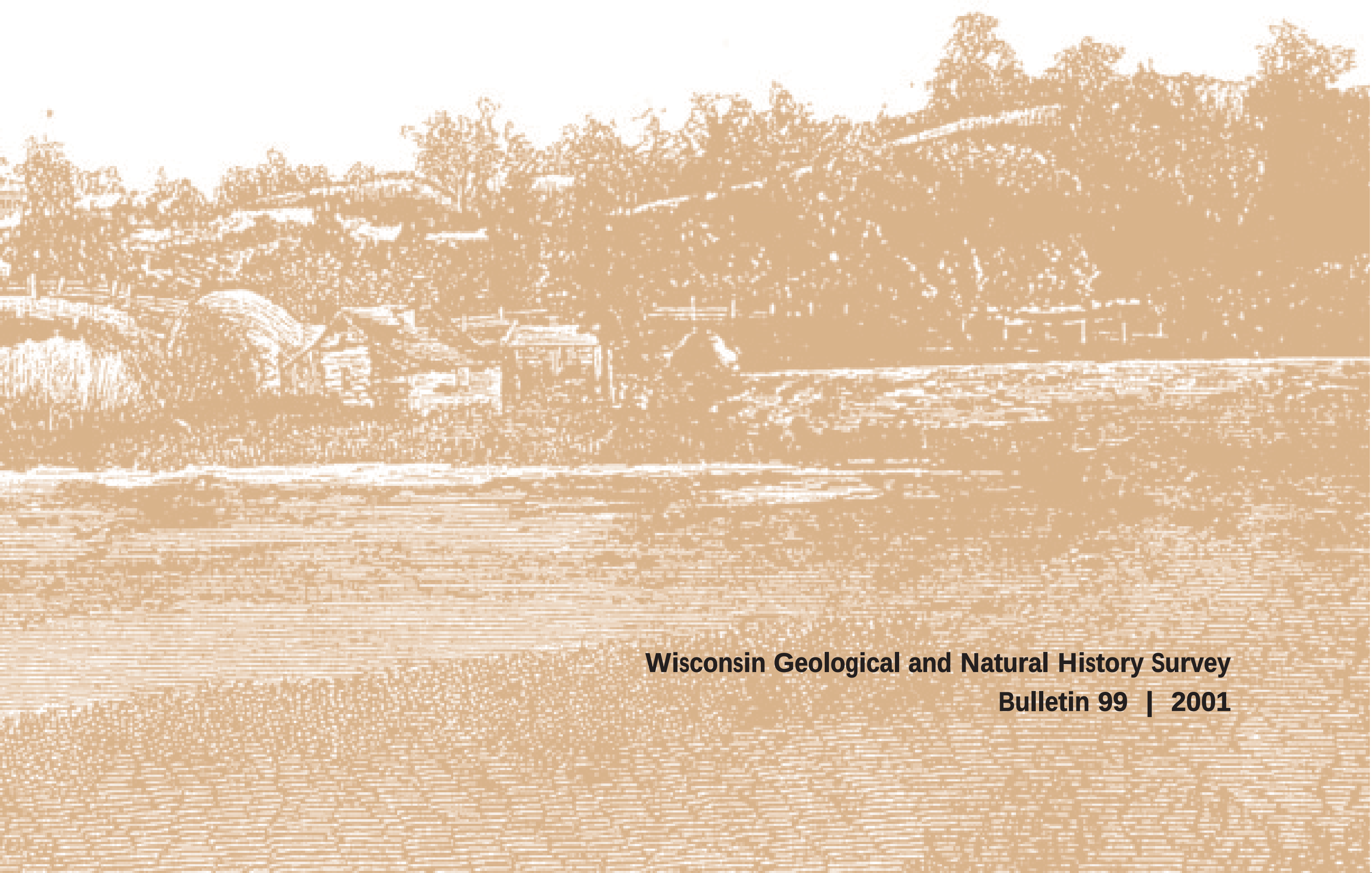
Pleistocene Geology of Waukesha County, Wisconsin

Lee Clayton



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Bulletin 99 | 2001

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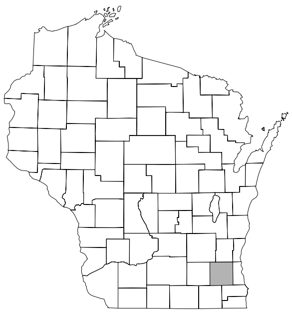

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Cover: Western face of the Kettle Moraine near Eagle in southwestern Waukesha County, from Chamberlin, T.C., 1883, Terminal moraine of the second glacial epoch, *in* Third Annual Report of the United States Geological Survey to the Secretary of the Interior 1881–'82: U.S. Geological Survey, plate XXX.

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The Survey conducts earth-science surveys, field studies, and research. We provide objective scientific information about the geology, mineral resources, water resources, soil, and biology of Wisconsin. We collect, interpret, disseminate, and archive natural resource information. We communicate the results of our activities through publications, technical talks, and responses to inquiries from the public. These activities support informed decision-making by government, industry, business, and individual citizens of Wisconsin.

FIGURES

PLATES

Pleistocene Geology of Waukesha County, Wisconsin

Lee Clayton

ABSTRACT

Waukesha County, in southeastern Wisconsin, straddles an area that was the junction of the Green Bay and Lake Michigan Lobes of the Laurentide Ice Sheet during the Wisconsin Glaciation. Most of the topography of Waukesha County formed during this glaciation. Glacial landforms include large areas of nondescript undulating topography, several moraine ridges, and several hundred drumlins. Meltwater-stream landforms include flat outwash plains, hummocky areas of collapsed supraglacial stream sediment, some small eskers, and large and small meltwater channels. The Kettle Moraine consists of a nested series of partly collapsed outwash fans and eskers, overlain by till in places, and formed at the apex of the angle between the Green Bay and Lake Michigan Lobes. Widespread offshore sediment was deposited in several glacial lakes during the last part of the Wisconsin Glaciation, including Lake Scuppernong in the western part of the county, Pewaukee Lake in the central part, and Lake Vernon in the south-central part.

The glaciers deposited yellowish-brown sandy till of the Holy Hill Formation (deposited between about 20,000 and 14,000 BP) and reddish-brown silty till of the Oak Creek Formation (deposited about 14,000 BP); possibly older glacial material is also present in the county. The thickness of Pleistocene sediment, which overlies Ordovician and Silurian dolomite and shale, ranges from 0 to at least 140 m.

INTRODUCTION

In this report I describe the Pleistocene geology of Waukesha County in southeastern Wisconsin (figs. 1–4). Emphasis is placed on the material that is more than about 1.5 m below the ground surface. Foley and others (1953) and Gonthier (1975) described the hydrogeology of the area; Steingraeber and Reynolds (1971) described the surface soil down to a depth of 1.5 m.

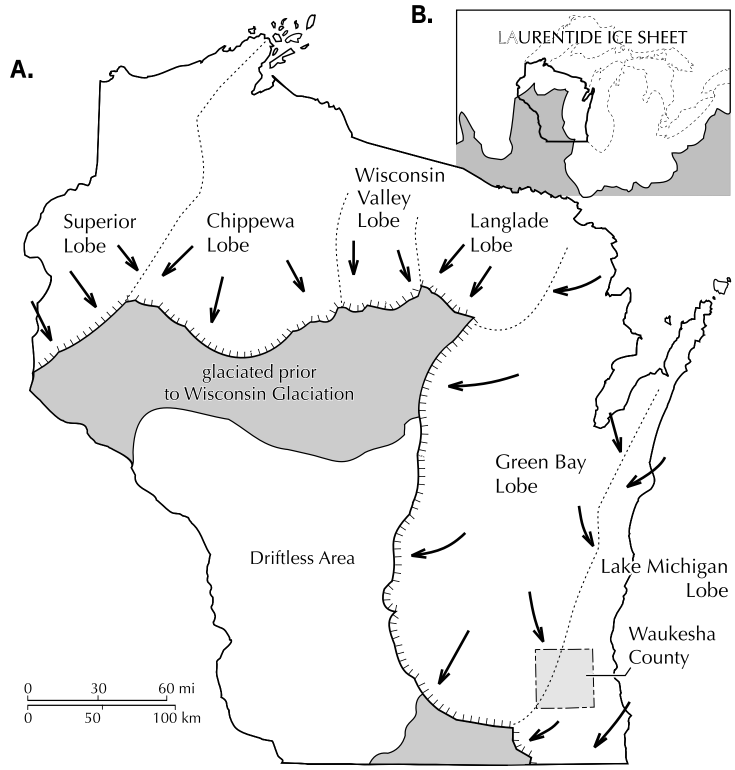


Figure 1. Location of Waukesha County in Wisconsin (**A**) in relation to the Laurentide Ice Sheet (**B**) and its lobes during the last part of the Wisconsin Glaciation. Hachures indicate the edge of the ice sheet; arrows indicate direction of ice flow.

Most near-surface Pleistocene sediment of Waukesha County was deposited during the last part of the Wisconsin Glaciation. The distribution of this material is the basis for dividing the county into the six general regions shown in figure 2.

This report is based on field work completed during the summers of 1979, 1991, and 1992. Map contacts on plate 1 were drawn on U.S. Geological Survey quadrangle maps (7.5-minute series, topographic, scale 1:24,000; 10-ft contour interval), using aerial-photograph stereopairs (scale 1:20,000) taken in 1963 for

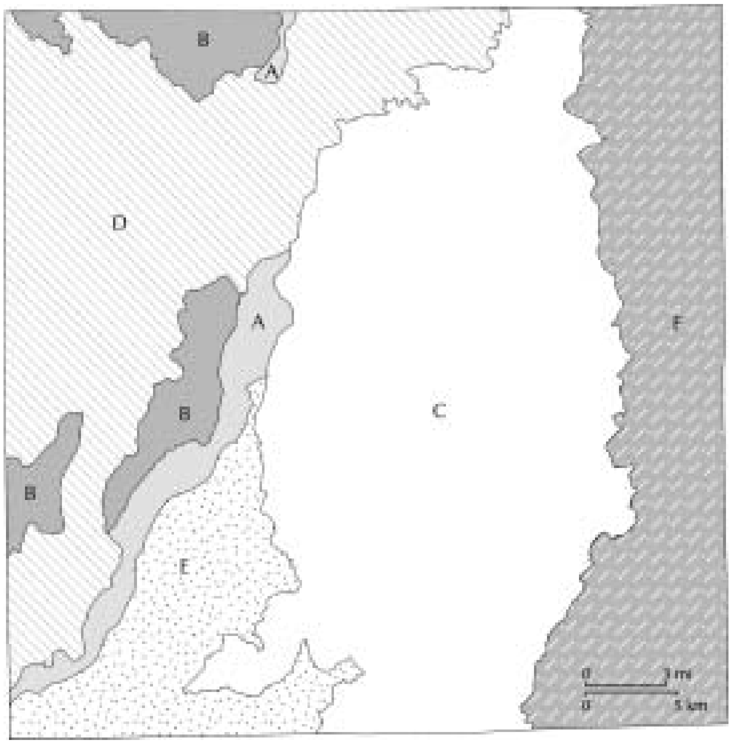


Figure 2. Major landscape regions of Waukesha County. **Area A** is the Kettle Moraine; it is the highest area in the county (see fig. 3) and is characterized by sand and gravel deposited by meltwater rivers flowing out of the junction between the Green Bay and Lake Michigan Lobes of the Laurentide Ice Sheet. **Area B** is characterized by sandy till deposited by the Green Bay Lobe; the orientation of the drumlins indicates that the ice flowed southeastward into the western part of the county. **Area C** is similar to area B, but is underlain by sandy till deposited by the Lake Michigan Lobe; the orientation of the drumlins indicates that the ice flowed westward to southwestward into the eastern part of the county. **Area D** is characterized by sand and gravel deposited by meltwater flowing westward from the Lake Michigan Lobe through a broad breach in the Kettle Moraine. **Area E** is characterized by sand and gravel deposited by meltwater flowing southward between the Lake Michigan Lobe and the southern Kettle Moraine. **Area F** is characterized by of silty till deposited by the Lake Michigan Lobe.

the U.S. Department of Agriculture. Additional lithologic information was derived from the following sources: soil maps (scale 1:15,000) (Steingraeber and Reynolds, 1971), unpublished parent-material maps (scale 1:24,000) compiled in 1971 by the staff of the Wisconsin Geological and Natural History (WGNHS) from a preliminary version of the soil maps by Steingraeber and Reynolds (1971), Wisconsin Department of Natural Resources well constructor's reports, WGNHS geologic logs, and various geologic field notes in WGNHS files.

The eight cross sections shown on plate 2 have been drawn east–west through the middle of the north and south halves of each township. They are not intended to show the material exactly at those positions, however. Instead, they are general representations of the material within 1.5 mi north and south of the line of the cross section. In most places, subsurface information was obtained from well constructor's reports; in areas of closely spaced wells, only the reports from wells near the cross-section lines were used, but in areas of sparse information, reports from wells as far as 1.5 mi away were used. The lithologic information in the well logs is variable in quality; therefore, errors should be expected in the cross sections.

Dates, such as 15,000 BP, are given in this report for events during the Wisconsin Glaciation. The BP stands for "before present," and "present" is taken by convention to be AD 1950. These dates are based on carbon-14 determinations. They were calculated using a half life of 5,570 years, and they have not been calibrated for differences in the initial content of carbon 14 in the dated samples.

ACKNOWLEDGMENTS

I thank D.M. Mickelson, W.N. Mode, and J.A. Attig for reviewing the manuscript of this report and Cathy Attig for supplying linguistic information. Deborah Patterson did the final cartographic work for the plates; Susan Hunt was the graphic designer for the report. This project was partly supported by the Southeastern Wisconsin Regional Planning Commission and the U.S. Geological Survey through its COGEOMAP program.

PRE-PLEISTOCENE GEOLOGY

Waukesha County lies on the west side of the Michigan Basin, just east of the Wisconsin Arch. Precambrian rock crops out 30 km west of the northwest corner of Waukesha County,

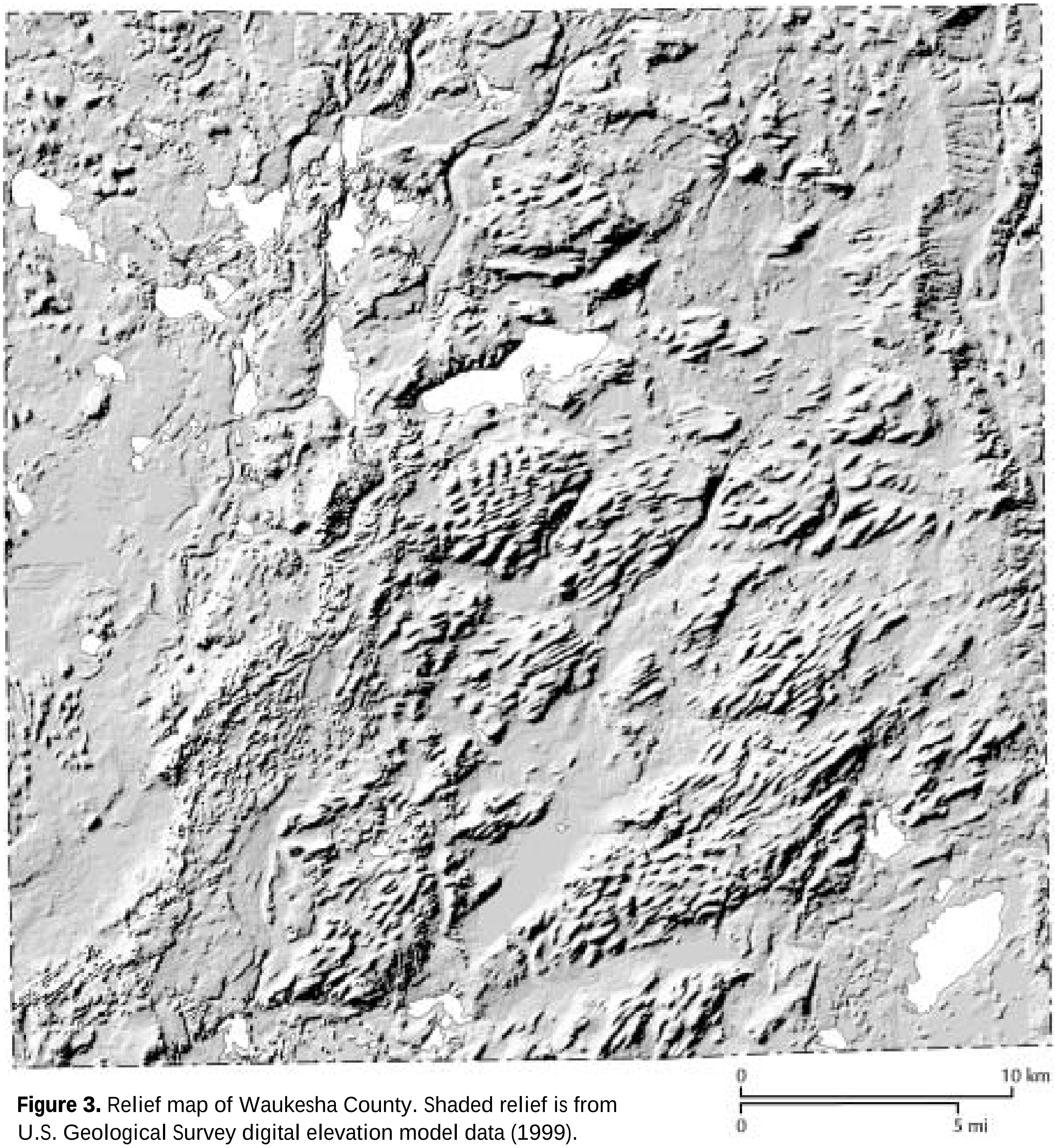


Figure 3. Relief map of Waukesha County. Shaded relief is from U.S. Geological Survey digital elevation model data (1999).

but is buried by hundreds of meters of Paleozoic and Pleistocene material eastward in the county into the Michigan Basin. Only a few wells are known to have penetrated Precambrian rock in Waukesha County. Logs from 11 of these wells have been published as WGNHS Geologic Logs WK-4, WK-20, WK-27, WK-28, WK-180, WK-723, WK-758, WK-862, WK-865, WK-888, and WK-1233, mostly from the northeastern quarter of the county; the Precambrian rock is generally described as granite or quartzite. These logs and a map by Thwaites (1957) indicated that the surface of the Precambrian rock slopes southeastward into the Michigan Basin and is about 100 m above sea level in the northwestern corner of the county, about 100 m below sea level in middle parts of the county, and at least 600 m below sea level in the southeastern part of the county.

Thousands of water wells have penetrated Paleozoic rock in Waukesha County, and logs from nearly 300 of them have been published

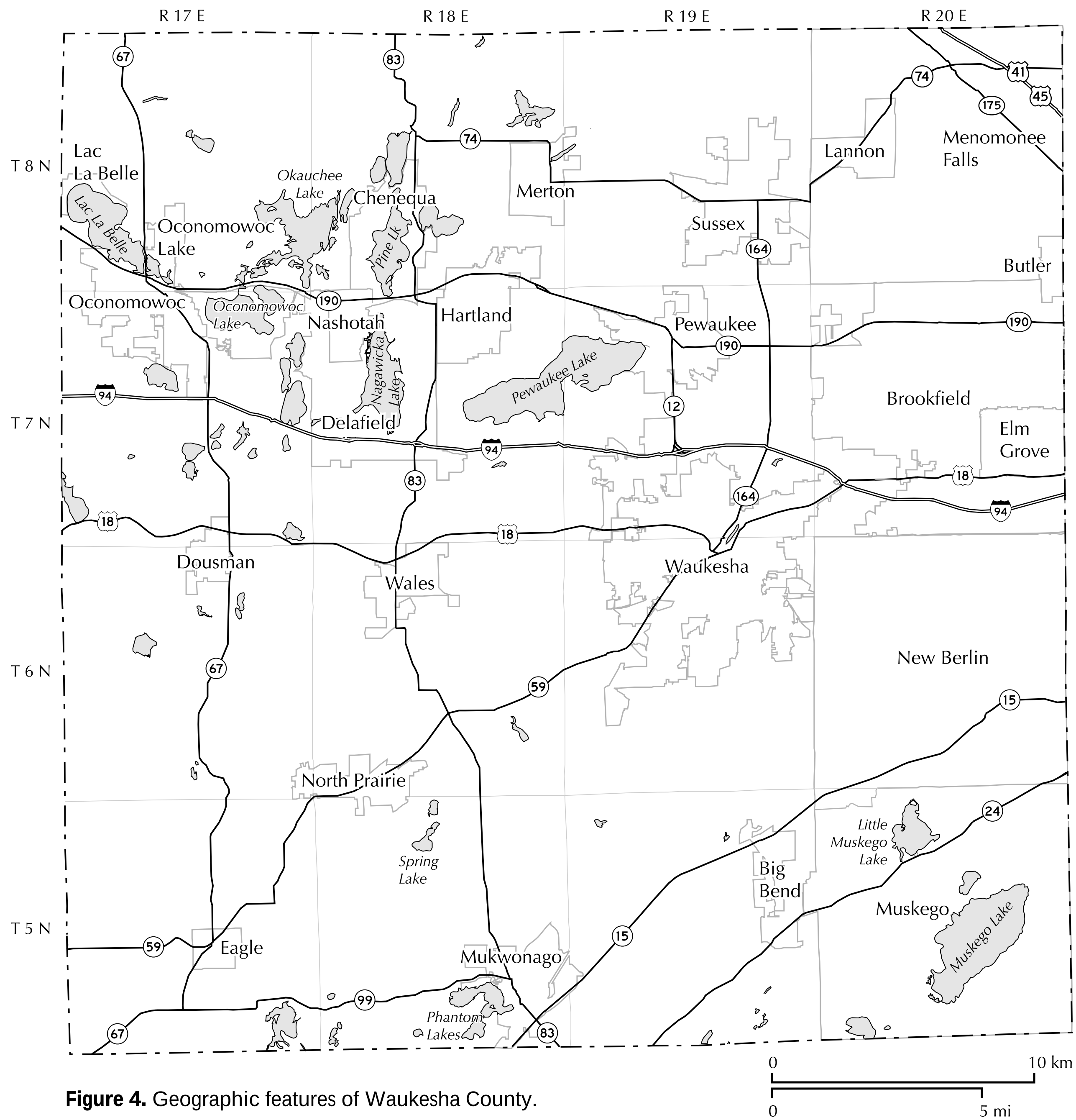


Figure 4. Geographic features of Waukesha County.

as WGNHS geologic logs. The total thickness of Paleozoic rock ranges from less than 200 m in the northwestern part of the county to at least several hundred meters in the southeastern part. The longest described section in Waukesha County (Geologic Log WK-887), showing more than 675 m of Paleozoic rock, is from a well in the middle of the county, in sec. 5, T6N, R19E.

According to recently published WGNHS geologic logs, the oldest Paleozoic (Cambrian) unit is the Elk Mound Group, which consists of a thick Mount Simon Formation overlain by thinner Eau Claire and Wonewoc Formations. The Elk Mound Group ranges from less than 100 m thick in the northwest to several hundred meters in the southeast; Geologic Log WK-887 indicated it is more than 398 m thick in the middle of the county. It is typically described as sandstone, with some finer-grained units, especially in the Eau Claire.

The Elk Mound Group is typically overlain by a few tens of meters of glauconitic sandstone of the Tunnel City Formation, which is commonly overlain by a few meters of dolomite of the St. Lawrence Formation, which in places is overlain by a few meters of sandstone of the Jordan Formation; all are Cambrian. In a few places the Jordan is overlain by a few meters of Ordovician dolomite of the Oneota Formation of the Prairie du Chien Group.

Unconformably overlying these units is the Ancell Group, which consists largely of Ordovician sandstone of the St. Peter Formation. It ranges from less than 20 m to more than 60 m thick. The sub-Ancell unconformity is as low as the upper part of the Elk Mound Group in places.

Overlying the Ancell is the Sinnipee Group, which consists of Ordovician dolomite. Where overlain by the Maquoketa Formation, it is 70 to 80 m thick. The Sinnipee includes three formations: from oldest to youngest, the Platteville, Decorah, and Galena Formations.

The Maquoketa Formation consists of Ordovician dolomitic shale that is 50 to 60 m thick where overlain by Silurian rock. The shale crops out in a few places in the western part of the county.

Silurian dolomite underlies much of the central and eastern parts of the county, where it ranges from 0 to more than 100 m thick. In most places it is overlain by Pleistocene sediment, but this dolomite crops out in a several places and is well exposed in numerous quarries. It has been subdivided into several formations in the literature, but these formations have not been distinguished on WGNHS geologic logs in Waukesha County.

SURFACE AT THE BASE OF PLEISTOCENE MATERIAL

The topography beneath the Pleistocene sediment is shown in figure 5 and plate 2. The larger elements of this landscape were probably shaped before the first Pleistocene glacier covered the area, but smaller details were shaped by glacial and meltwater erosion during the Pleistocene glaciations.

The 2-km-wide trench in the area of Vernon Marsh and Muskego Lake, in the southern part of Waukesha County and into Walworth County, was called the *Troy Valley* by Alden (1918, p. 122–124). It is not a preglacial valley, but was cut across the topographic divide of the surface at the base of the Pleistocene material along the west side of the Lake Michigan basin, where its bottom is below the level of present-day Lake Michigan. The trench is roughly the size of the Chicago spillway, an outlet of glacial Lake Michigan. The Troy trench might have been cut by pre-Wisconsin spillage from glacial Lake Michigan or by a subglacial tunnel-channel river.

PLEISTOCENE STRATIGRAPHY

The Pleistocene sediment in Waukesha County ranges from 0 to at least 140 m thick (plate 2); the thickest sediment is in the Troy channel in the southern part of the county. The stratigraphy of this sediment is outlined in figure 6.

Much of the Pleistocene sediment in Waukesha County is included in the Holy Hill Formation, but the Holy Hill is overlain by the Oak Creek Formation in the easternmost part of the county, and in places the Holy Hill Formation may be underlain by older units. However, these older units, if they exist, are deeply buried and poorly known.

The most likely older unit to underlie the Holy Hill in Waukesha County is the Zenda Formation. The Zenda Formation (Mickelson and others, 1983, p. 14, 31; Schneider and Follmer, 1983, p. 94–95) of southeast Wisconsin is characterized by red silty and sandy till that immediately underlies the Holy Hill Formation (Mickelson and others, 1984, p. A6-1–A6-2). The Zenda includes a lower unit, the Capron Member, and an upper unit, the Tiskilwa Member (Mickelson and others, 1984, p. A6-2–A6-7).

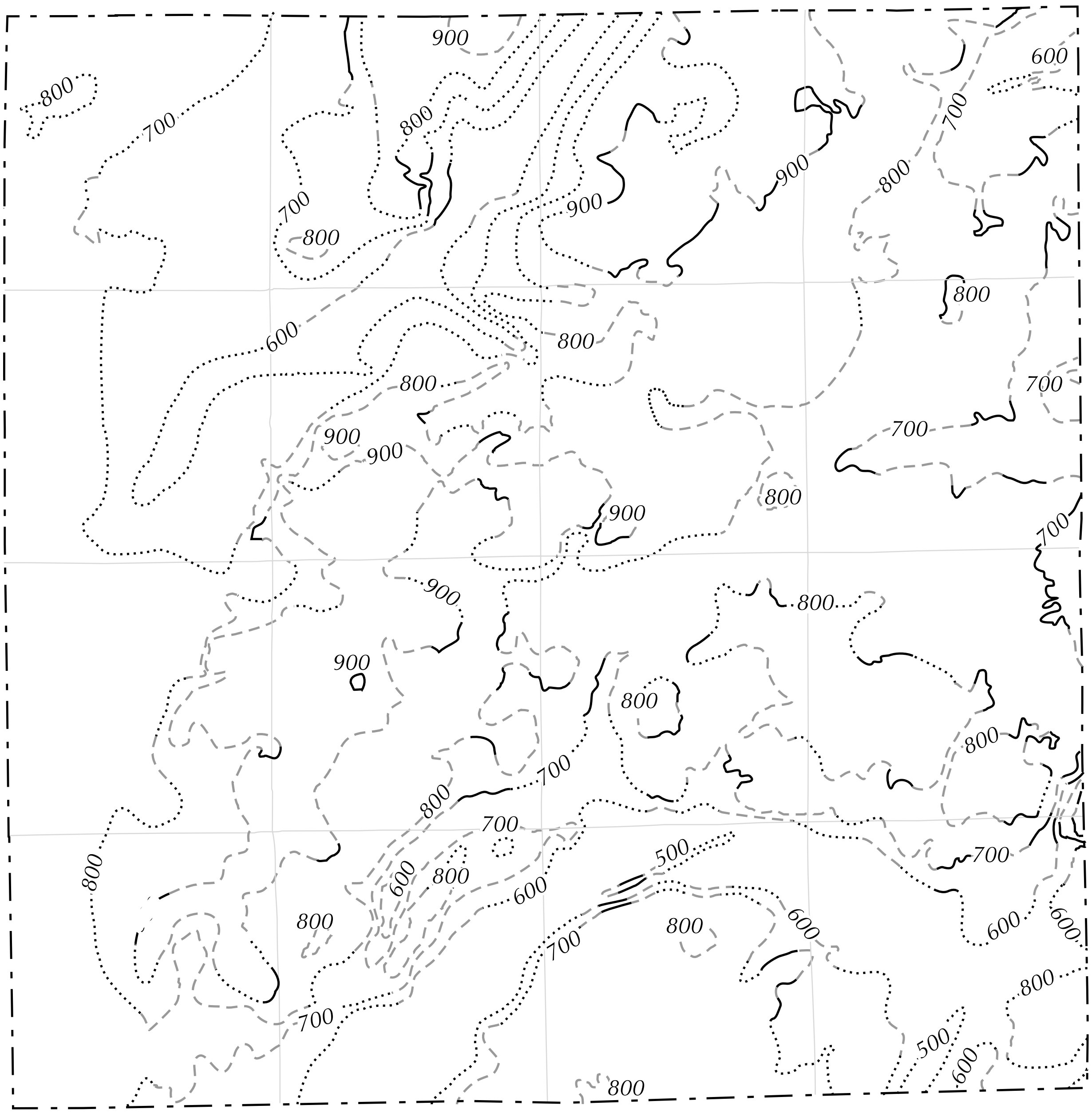


Figure 5. Map showing elevation (in ft) of the surface at the base of the Pleistocene material in Waukesha County. In most places the elevations were derived from lithologic logs given by water-well drillers in Wisconsin Department of Natural Resources well constructor's reports. Solid-line contours are most precise, typically in housing developments where each house has a well; dashed-line contours are in areas with fewer wells. Dotted-line contours are least precise in areas with few or no wells that reached the surface of the base of the Pleistocene material.

Both members are at the surface in northeastern Illinois, but they are overlapped by the Holy Hill Formation at the border between Illinois and Wisconsin, 35 km south of the southwest corner of Waukesha County (Schneider, 1983, fig. 2B and C). Because the Tiskilwa Member is up to 100 m thick in northernmost Illinois (Wickham and others, 1988, fig. 8a), it might be expected to underlie the Holy Hill Formation north from the point of overlap; in outcrops it has been tentatively identified underlying the Holy Hill Formation between

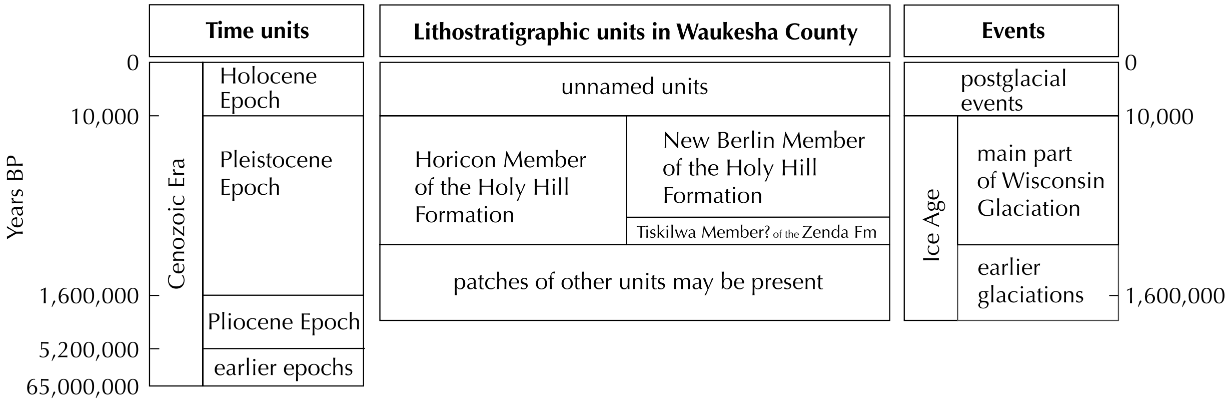


Figure 6. Outline of the chronology of Pleistocene materials and events in Waukesha County.

Waukesha County and the Illinois border (Schneider, 1983, p. 70; Fricke and Johnson, 1983, p. 29).

In Waukesha County, a few meters of Tiskilwa till may be present under the Holy Hill Formation in several gravel pits in the east-central part of the county (Stanford, 1982, p. 36–39; Mickelson and others, 1983, p. 14; Whittecar, 1976, p. 30–37). This till contains about 40 to 50 percent sand (0.063–2.0 mm), about 40 to 50 percent silt (0.0020–0.063 mm), 5 to 15 percent clay (finer than 0.0020 mm), and a few percent gravel (coarser than 2.0 mm). Older units may underlie the Tiskilwa, especially in areas of thick Pleistocene sediment filling deep depressions on the surface at the base of the Pleistocene material, but little is known about them.

The Holy Hill Formation includes most of the near-surface Pleistocene sediment in a large part of southeastern Wisconsin (Mickelson and Syverson, 1997). The Holy Hill is characterized by brown sandy till stratigraphically positioned above the Zenda Formation and below the Oak Creek Formation. In addition to the till, associated stream and lake sediment is also included in the Holy Hill Formation.

In Waukesha County, the Holy Hill till contains between 35 and 75 percent sand, 20 and 55 percent silt, and 5 and 25 percent clay, in addition to several percent gravel (Whittecar, 1976, p. 37–40; Stanford, 1982, p. 15–17; Mickelson and others, 1983, p. 14–18). It is brown, yellowish brown, light yellowish brown, or pale brown where oxidized (7.5–10YR 5–6/3–4, Munsell notation, moist field samples), and it is grayer where unoxidized (10YR 6/2–3). The till is absent in some places; in other places it can be more than 30 m thick.

The Holy Hill Formation includes two formal subdivisions in Waukesha County and adjacent areas: the Horicon Member west of the crest of the Kettle Moraine and the New Berlin Member east of it (Mickelson and Syverson, 1997; Mickelson and others, 1984, p. A7-1–A7-4 and A9-1–A9-6). The pebbles in both members in Waukesha County consist of 60 to 90 percent dolomite (based on pebble counts taken at 100 locations described in unpublished Road Materials Reports in WGNHS files). According to Alden (1918, p. 221, 234, 238, 263, 284, 293), the dolomite pebbles can be used to distinguish the till east and west of the Kettle Moraine: To the west, most of the dolomite pebbles are from Ordovician formations in the Green Bay lowland, and to the east, most are from Silurian formations in the Lake Michigan lowland. Alden (1918, p. 78–95) noted that much of the Ordovician dolomite is buff-colored and much of the Silurian dolomite is white to light bluish gray; however, it is difficult to distinguish between the Horicon and New Berlin Members.

The Oak Creek Formation overlies the Holy Hill Formation and is the surface unit along the east edge of Waukesha County (plates 1 and 2) as well as in counties to the east along the Lake Michigan shore (Brown, 1990; Hansel, 1983; Mickelson and others, 1984, p. A8-1–A8-3; Simpkins, 1989). The Oak Creek is characterized by till that is darker, redder (less yellow), and much less sandy than the till in the Holy Hill Formation. The Oak Creek Formation also contains associated stream and lake sediment overlying the till.

In Waukesha County, the Oak Creek till contains about 2 to 15 or 20 percent sand, 45 to 75 percent silt, and 20 to 45 percent clay, in addition to a few percent gravel. As in the adjacent part of the Holy Hill Formation, the gravel consists largely of dolomite derived from Silurian formations in the Lake Michigan lowland. The till is typically brown or reddish brown (5–7.5YR 5/3–4, Munsell notation, moist field samples). Along its western edge, the Oak Creek Formation is commonly a few meters thick, but in some places farther east, it is a few tens of meters thick (plate 2).

GLACIAL SEDIMENT AND LANDFORMS

The Ice Age in North America probably began during the last part of the Pliocene Epoch, two million or more years ago (Richmond and Fullerton, 1986). However, little is known of glacial events in Waukesha County until nearly the end of the Pleistocene Epoch. The following pages contain a discussion of the glacial geology of the county, with an emphasis on the last episode of the Wisconsin Glaciation, about 25,000 to 14,000 years ago, when the present landscape formed (fig. 7).

At the start of that episode, the Green Bay Lobe of the Laurentide Ice Sheet moved southward through the Green Bay lowland and southeastward into the western part of the county (fig. 1). At roughly the same time, the Lake Michigan Lobe of the ice sheet moved southward through the Lake Michigan basin and southwestward into the eastern and central parts of the county. During the height of the glacial episode, the entire county was covered with ice. Toward the end of the episode, the lobes began to waste back, separating along the line of the Kettle Moraine (figs. 2 and 7).

The mode of deposition of the glacial sediment (till) in Waukesha County has been discussed by Whittecar (1976) and Whittecar and Mickelson (1977, 1979). The till consists of a very poorly sorted mixtures of clay, silt, sand, and gravel that generally lack obvious bedding. The area mapped as till probably also includes some associated till-like re-sorted supraglacial debris as well as some postglacial solifluction deposits.

Nondescript glacial topography

During the Wisconsin Glaciation, the pre-existing topography of Waukesha County was largely obliterated and replaced with completely different topography. In the areas shown in red and blue on plate 1, the resulting glacial topography was in turn obliterated by glacial meltwater. The surviving glacial topography is shown in green on plate 1 (map units **gh** and **go**).

Much of this glacial topography is nondescript. For example, the glacial topography north of Stonebank in northwestern Waukesha County and the topography on much of the Oak Creek till in the eastern part of the county is undulating or billowy, with a few meters of local relief. The low hills are irregular, without a preferential elongation either parallel or perpendicular to the direction of ice movement; their height and diameter seem to vary erratically across the landscape. In some places, such as the Kettle Moraine (map unit **ghk**), the relief is higher and the topography is more hummocky. Elsewhere in the county, two distinct kinds of glacial landforms can be recognized: moraines and drumlins.

Moraines

The term *moraine,* as used here, refers to a ridge of till perpendicular to the direction of glacial movement and formed at the edge of the glacier as a result of some change in the glacial regime. The smaller ones are indicated on plate 1 by a line symbol; the larger ones are

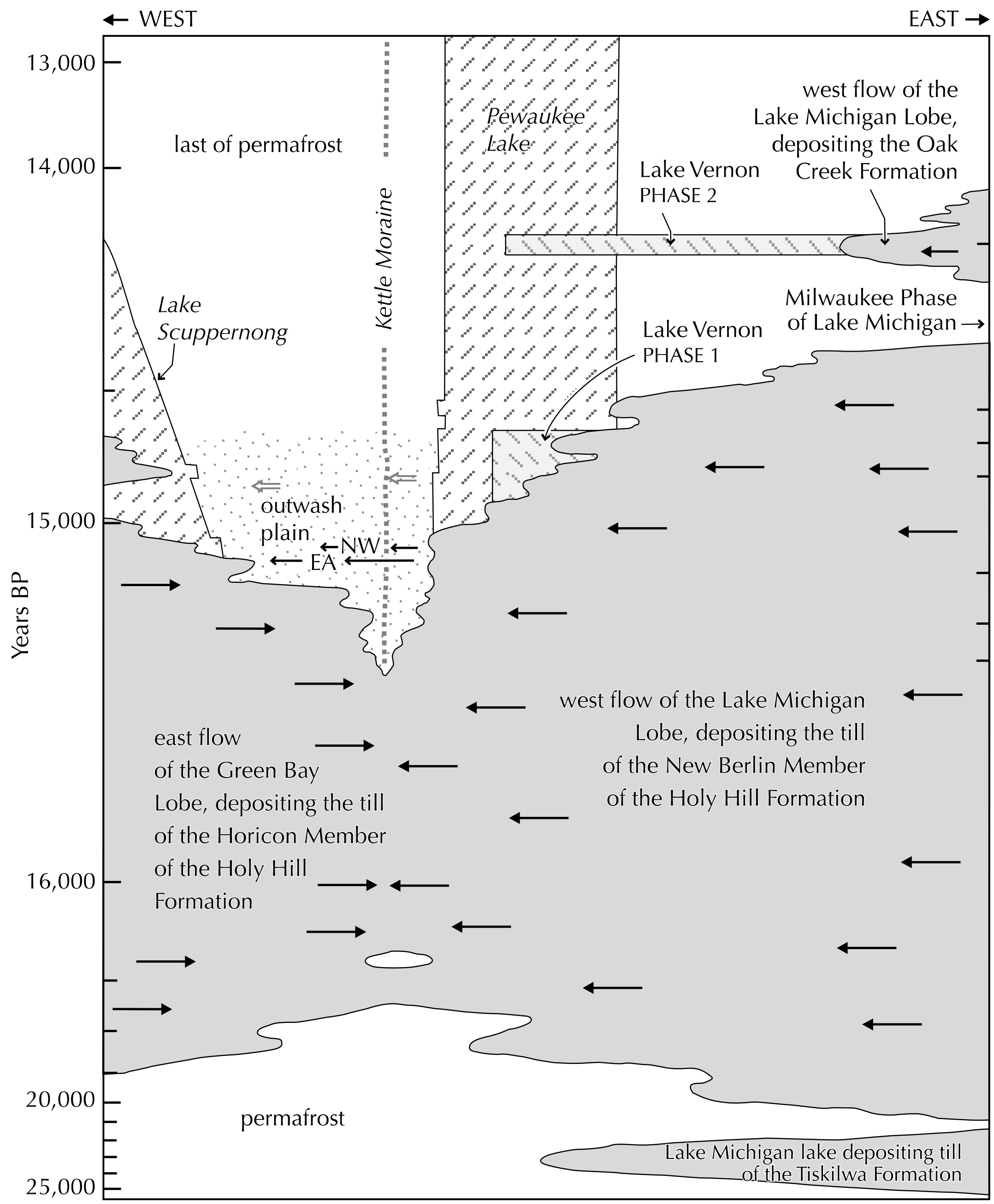


Figure 7. Schematic representation of events in Waukesha County during the last episode of the Wisconsin Glaciation. The vertical axis shows the approximate time (uncalibrated radiocarbon years before present); the horizontal axis shows distance from the western edge to the eastern edge of the county. The gray tone indicates the presence of the glacier; arrows show the general direction of glacial movement. The dashed pattern indicates the presence of lakes; dotted pattern indicates the presence of meltwater streams forming the large sand plain in the northwestern part of the county; arrows show the general direction of flow. NW represents the Naga–Waukee spillway; EA represents the Ethan Allen channel. The vertical line of squares shows the general position of the Kettle Moraine. See *Pleistocene lakes* section for descriptions of glacial lakes. The letters on the right-hand margin correspond to the glacial phases shown in figure 23.

indicated by a spotted gray pattern printed over the green map units.

Only moraines more than a few meters high are shown on plate 1. Smaller ones may

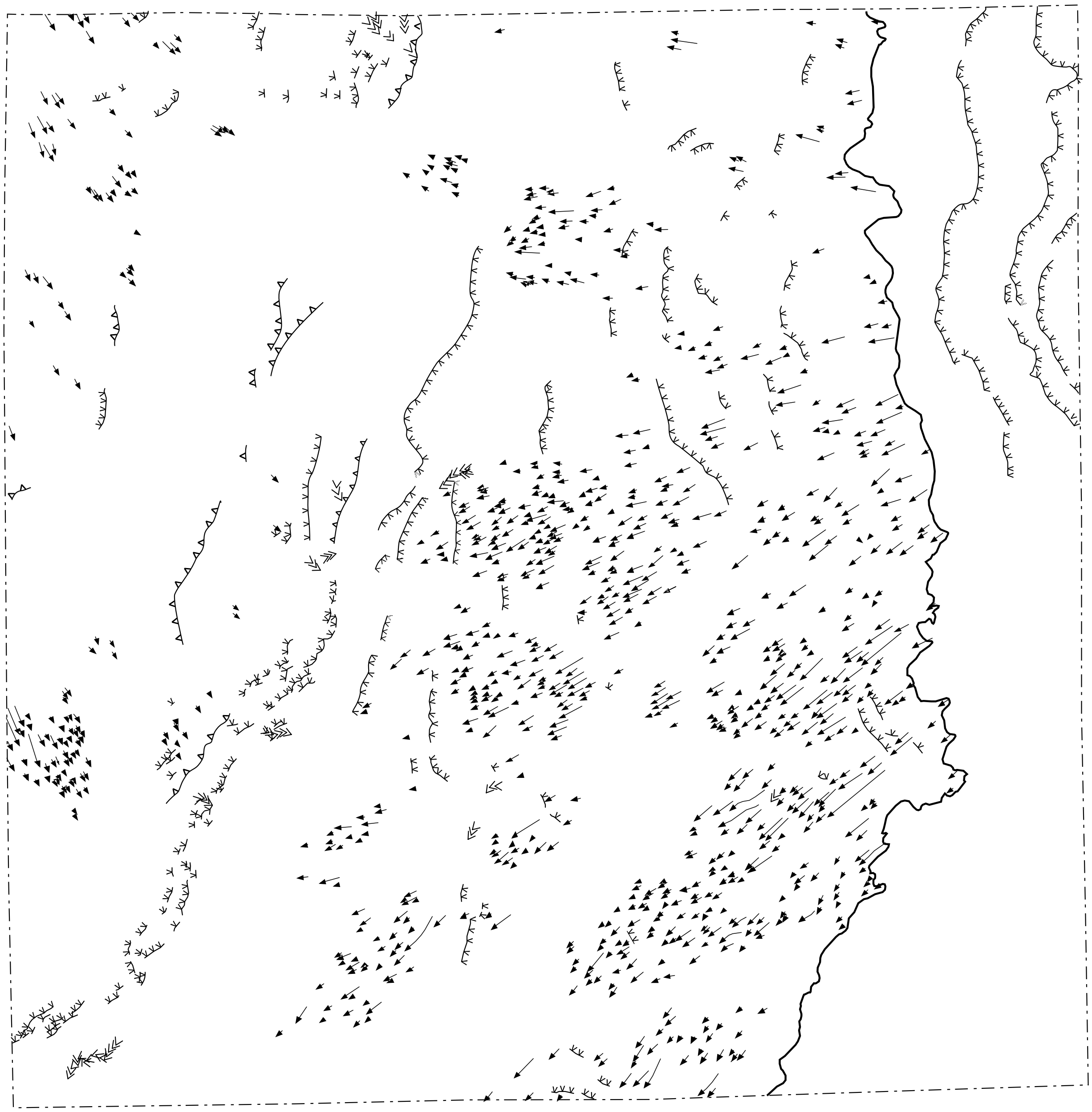


Figure 8. Features that indicate the direction of ice movement in Waukesha County. The solid arrows (drumlins) and rows of nested arrowheads (eskers) are parallel to ice movement. The heavy line (western edge of Oak Creek till), lines with arrowheads attached by their tips (moraines), and lines with triangles (ice-contact faces) are perpendicular to ice movement.

once have existed, but they have been obliterated by soil erosion, especially when permafrost was present for several hundred years after the glacier melted (fig. 7). The largest are no more than 1 km wide and a few tens of meters high.

Most moraines in Waukesha County (plate 1; fig. 8) are inconspicuous features that are more likely to be noticed on topographic maps and aerial photographs than on the ground. The most obvious are the three in the northeastern part of the county, within 5 km of the Milwaukee County border. These moraines, which are the westernmost of what Alden (1918, pl. 4) named the Lake Border moraines (fig. 9; dot pattern on plate 1), are nearly continuous ridges separated by valleys containing swamps or small streams.

Drumlins

Where the base of a glacier is below the freezing point, the glacier is fixed to its bed and can move only by flowing. But where the base is at the freezing point, the glacier moves by flowing and by sliding. Drag marks formed at the base of a sliding glacier range in size from very small (scratches, fig. 10) to huge (drumlins). The most comprehensive early discussion of drumlins in Waukesha County and adjacent areas is by Alden (1905).

Drumlins are indicated by arrow symbols on plate 1 and figure 8. In these places, the sliding glacier sculpted ridges and troughs parallel to the direction of ice movement, probably by a combination of three processes: erosion of pre-existing till, meltwater-stream sand and gravel, or other Pleistocene sediment; deposition of till by the melting out of debris carried in the base of the glacier; and rearrangement of the Pleistocene sediment by flowage and other kinds of subglacial mass movement.

The term *drumlin* is applied to ridges rather than to the troughs between the ridges. In many areas the ridges and troughs were probably equally prominent originally, as they are today in areas well above the surrounding lowlands, such as southeast of Waukesha (fig. 11). More typically, however, the troughs have been buried by stream sediment, lake sediment, and other material washed down from adjacent high areas; only the tops of the ridges protrude through this sediment.

Nearly 1,000 drumlins are shown on plate 1; in addition, many smaller ones probably once existed, but have been buried or removed by postglacial erosion. The larger drumlins are roughly oval and have length-to-width ratios of

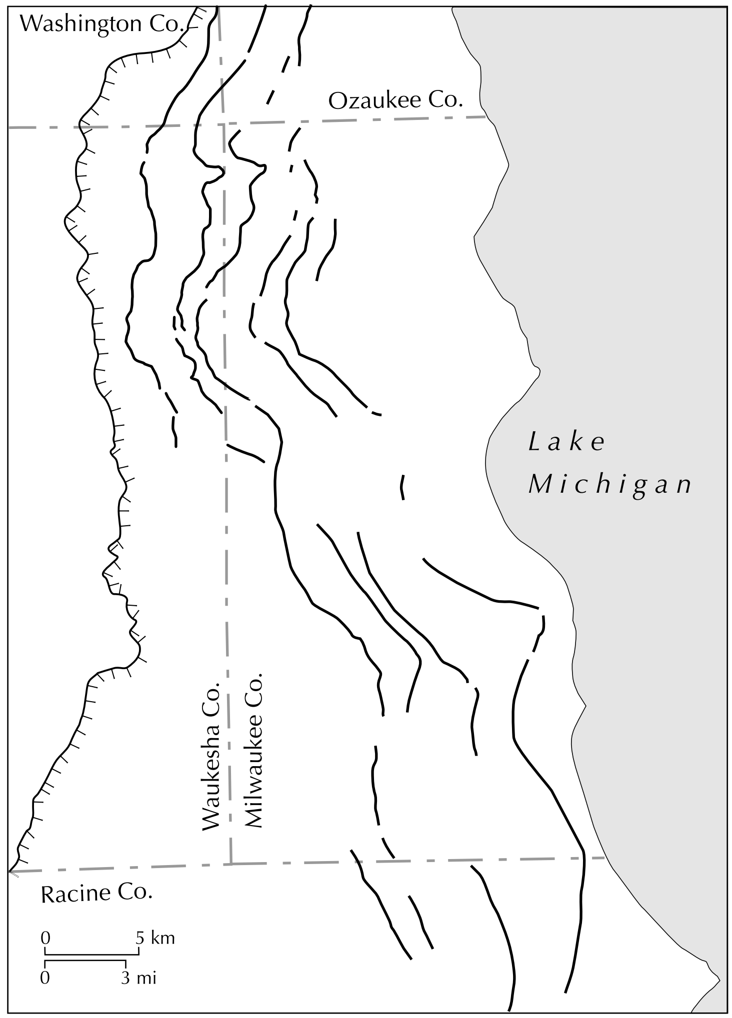


Figure 9. Map of Lake Border moraines (heavy lines) in Waukesha County and adjacent areas. The line with hachure marks is the western edge of the till of the Oak Creek Formation.

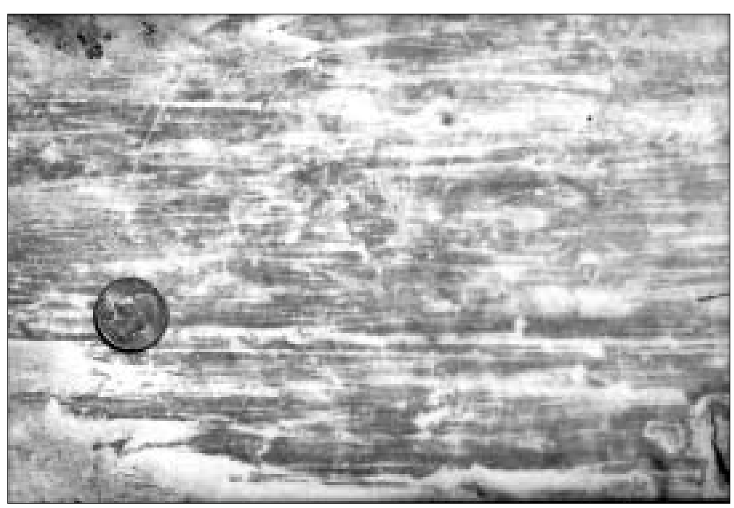


Figure 10. Typical example of subglacial scratches, on surface of dolomite in a quarry 2 km southwest of Lannon, in the SW¼ NE¼ sec. 24, T8N, R19E.

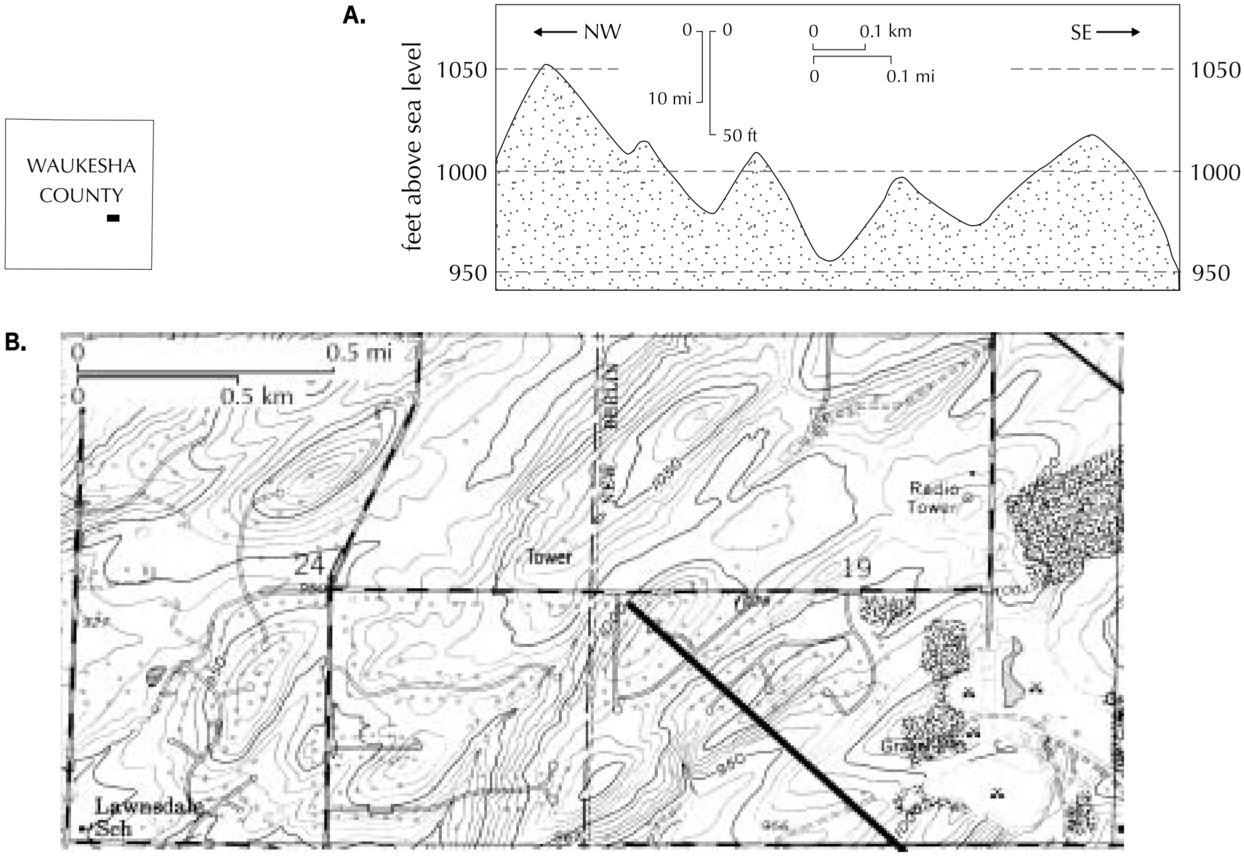


Figure 11. A. Topographic profile across drumlins in the southern half of sec. 19, T6N, R20E. **B.** Topographic map of drumlins in sec. 19, T6N, R20E, and sec. 24, T6N, R19E; thick line shows location of profile. Part of Muskego Quadrangle, Wisconsin (U.S. Geological Survey 7.5-minute series, topographic); contour interval is 10 ft.

more than 10:1 to less than 2:1. Many are 1 km or longer and as much as a few tens of meters high. The longest is called Prospect Hill, in secs. 31 and 32, T6N, R20E, 3 km northwest of Little Muskego Lake. It is approximately 2.7 km long, 0.5 km wide, and 30 m high. National Avenue (Highway ES) runs along its crest.

Many drumlins in Waukesha County are on plateau-like uplands (Whittecar, 1976, p. 23–24). In some places, the shoulders bounding these uplands are cutbanks that were eroded after the drumlins formed. Examples of drumlinized uplands with shoulders can be seen at the edges of the outwash plains in the north-central part of the county.

Elsewhere, the uplands are bounded by more irregular, gullied shoulders, indicated by map unit **ge** on plate 1. The till sheet at the surface of the drumlins extends across these shoulders, indicating that they formed before the drumlins. Many of these shoulders probably originated as cutbanks of meltwater streams before the last phase of glaciation in the area. If this interpretation is correct, many of the drumlins mapped in the county were sculpted into the uplands that existed before the last advance of the glacier across the area. If those upland surfaces were similar to the ones existing today, the drumlins must have been sculpted from a variety of pre-existing Pleistocene materials—including till and meltwater-stream sediment that had a variety of topographic forms.

This interpretation is corroborated by the thick meltwater-stream sediment present in the cores of some of the drumlins (Whittecar, 1976; Stanford, 1982). Several of the large gravel pits in eastern Waukesha County are in drumlins that have only a few meters of till over the gravel (fig. 12). In other drumlins in the county, the till is more than 25 m thick (WGNHS Geologic Logs WK-1550-F, WK-1552-F, and WK-1558-F).

A spruce log buried 18 m deep in meltwater-stream sediment in a gravel pit in a drumlin northeast of Waukesha (NW¼ SW¼ sec. 36, T7N, R19E) has been radiocarbon dated at 30,000±1,000 BP (W-901; Rubin and Berthold, 1961, p. 89). This suggests that the gravel was deposited there long before the drumlins were formed.

Figure 12. Folded fluvial sediment in a gravel pit in a drumlin in the SW¼ NW¼ sec. 18, T6N, R20E. A few meters of till have been stripped off the top of the gravel. WGNHS photo 4822 taken in 1937 for Road Materials Investigation Report 1111, location 183 (in WGNHS files).

Many gravel pits in the drumlins of eastern Waukesha County have been investigated by Whittecar (1976), Whittecar and Mickelson (1977), Whittecar and Mickelson (1979), Stanford (1982, 1983), and Stanford and Mickelson (1985). The pits commonly reveal clastic dikes, folds (fig. 12), pebble fabric, joints, and faults that are considered to be evidence that the form of the drumlins is at least partly the result of the rearrangement of the pre-existing material under the glacier.

STREAM SEDIMENT AND LANDFORMS

Roughly half of the Pleistocene sediment of Waukesha County consists of stream sediment, most of it sand and gravel deposited by meltwater streams. The meltwater-stream sediment is shown as light red (map units **su** and **sc**) and the postglacial-stream sediment is shown as brownish red (map unit **sm**) on plates 1 and 2.

Meltwater-stream sediment

The meltwater-stream sediment of Waukesha County is typically slightly gravelly sand or gravelly sand, but sandy gravel and gravel are abundant in some areas, especially close to the glacial source of the meltwater. The petrography of the grains is similar to that of the associated till. On the basis of 100 analyses in unpublished Road Materials Investigation Reports in WGNHS files, from 60 to 90 percent of the pebbles are dolomite; the remaining pebbles include a variety of igneous, metamorphic, and sedimentary rock types.

Most commonly, especially in the western half of Waukesha County, the meltwater-stream sediment forms flat outwash plains (map unit **su,** plate 1). These are the floodplains of braided streams that flowed away from the margin of the melting glacier. As the glacier melted back from the Kettle Moraine into the Lake Michigan and Green Bay lowland, its margin dropped to lower elevations. As a result, the heads of the meltwater rivers also decreased in elevation, and the rivers tended to entrench the earlier outwash plains. The resulting series of terraces commonly spans tens of meters of elevation near the Kettle Moraine. The more conspicuous terrace scarps (cutbanks) are indicated by lines with hachure marks on plate 1.

The outwash plains in Waukesha County commonly terminated downstream in glacial lakes. In places, the line of contact is marked by an obvious delta foreset face. Elsewhere, the outwash plain merges into the lake plain with no recognizable break; in these places, the contact between map units **su** and **ou** was placed on plate 1 at a lake level interpreted from other evidence.

Most gravel pits in Waukesha County are in meltwater-stream sediment, either collapsed or uncollapsed. Most of the large ones are in sediment deposited in either of two settings: at the heads of outwash plains or at a site that was later covered by a thin layer of till. The coarse gravel in the first setting extended only a few hundred meters beyond the glacier. As meltwater rivers emerged from the glacier, they had a great enough velocity to carry gravel, but they soon slowed and left behind the coarsest material. The sand was carried farther downstream, where it forms deposits having little commercial value as aggregate. Many gravel pits in the western half of the county are in sediment deposited at the heads of outwash plains.

The second typical setting was where meltwater rivers deposited gravel some time before the most recent glacier deposited a thin sheet of till across the area. Most of the pits in gravel deposited in this setting were probably originally opened where the most recently deposited till sheet was so thin that the underlying gravel was exposed by erosion on steeper hillslopes. Too little is known about the distribution of the gravel to predict its location, but many pits in the east half of the county are in sediment deposited in this setting.

Collapsed stream sediment

Where meltwater-stream sediment was deposited on stagnant masses of glacial ice, it collapsed when the buried ice melted. If the buried ice mass was small—a few tens of meters across or less—the resulting ice-block depression is commonly a pit that is conspicuous, but too small to be shown on plate 1. If the buried ice mass was more than a few tens of meters across, the resulting hummocky topography is indicated on plate 1 by a spotted pattern on map unit **sc.**

In the places that the buried ice mass was thick, the collapse depressions are deep; if the water table is not far below the level of the outwash plain, the result is a marsh, pond, or lake. Many lakes in the county, including almost all in the northwestern part, formed this way. In the places that the ice mass was thin, the depression is shallow; if the water table is well below the level of the outwash plain, the result is dry land that has hummocky topography.

In general, the collapse depressions are roughly equidimensional, or, if they are elongated, they have no obvious preferred orientation. In the southwestern and northwestern parts of the county, however, some of the elongated collapse depressions are preferentially oriented.

For several kilometers west–southwest of Mukwonago, in the southwestern part of the county, the depressions are elongated northwest–southeast, perpendicular to nearby drumlins. Many depressions are a few hundred feet wide, 1 km or more long, and 10 to 20 m deep. They are marked on plate 1 by parallel stripes of map units **su**, **sc**, **op**, and **ou**.

In the Delafield area, in the northwestern part of the county, collapse depressions are elongated in a north–south direction. A western chain of depressions is occupied by Upper and Lower Nemahbin Lakes, Upper and Lower Nashotah Lakes, the eastern part of Okauchee Lake, Moose Lake, and western North Lake. An eastern chain is occupied by Nagawicka Lake, Pine Lake, and eastern North Lake. These chains of depressions are parallel to nearby ice-contact faces (plate 1).

In the Mukwonago and Delafield areas, the depressions are elongated parallel to the glacier margin as it receded across the area. This relationship suggests that these depressions are places where ice-cored moraines were buried under the meltwater-stream sediment.

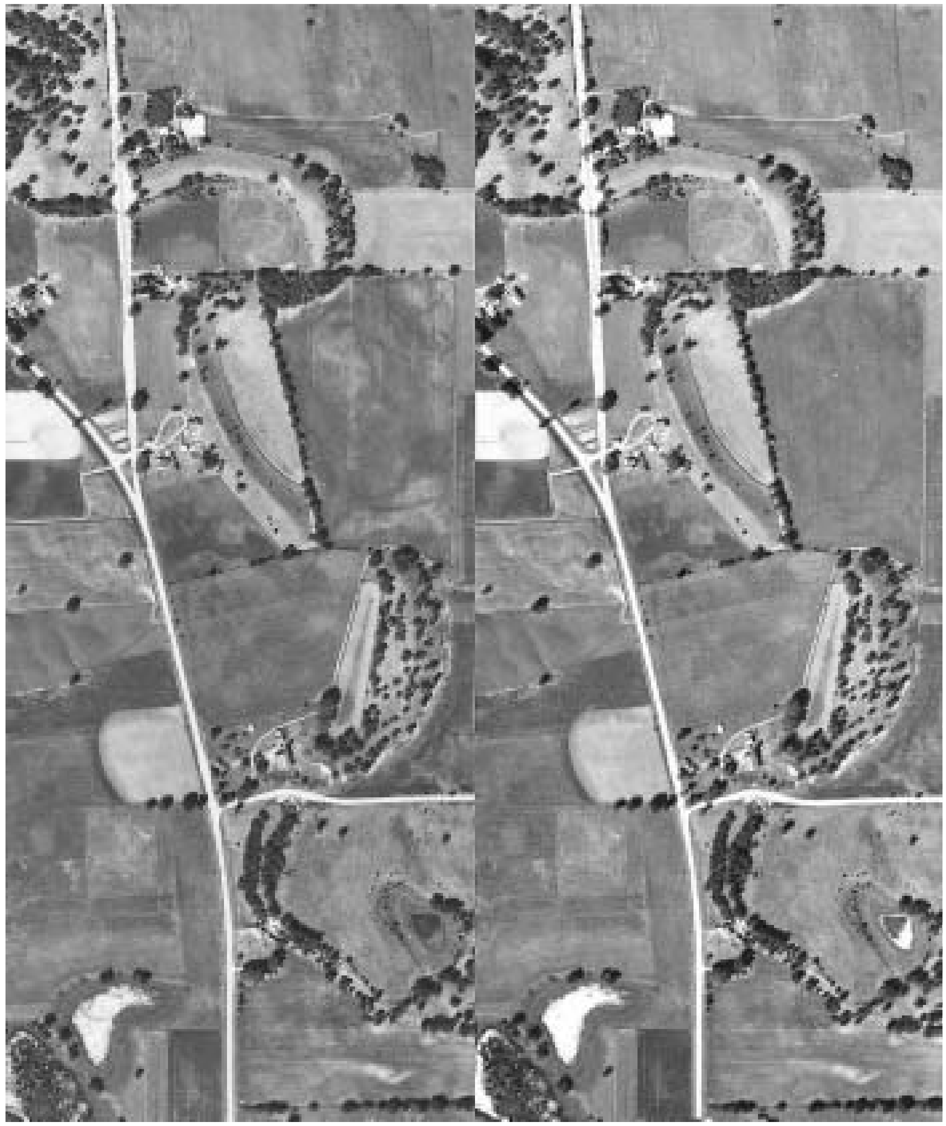


Figure 13. Stereographic pair of aerial photographs showing the esker-like ridge in the SE¼ sec. 29, T5N, R17E, southwest of Eagle. North is to the right. Area shown is 0.6 km from north to south. U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service aerial photographs WW-2DD-31 and 32, August 20, 1963.

Eskers

Where the ice at the bed of a glacier is at the melting point, meltwater may escape through a series of tunnels at the base of the glacier, roughly parallel to the direction of ice movement. If a river in these tunnels deposited sand and gravel in its beds, the resulting ridge left when the ice melts is called an esker; if the river eroded its bed, the resulting trench is called a tunnel channel.

Several small eskers in Waukesha County are shown by a line of nested arrowheads on plate 1. Most are no more than 1 km long, several tens of meters wide, and several meters high, and they are surrounded by till. At least one esker-like ridge may not be a true esker.

The most conspicuous esker-like ridge in the county is 3 km southwest of Eagle, in secs. 28, 29, and 32, T5N, R17E (plate 1; fig. 13). It is about 3 km long, 10 m high, and less than 100 m wide. It differs from typical eskers—it is surrounded by collapsed meltwater-stream sediment rather than till, and it is much better preserved than those eskers surrounded by till.

Typical eskers are surrounded by till because they are formed at the bed of a glacier, which is where till is deposited. If proglacial meltwater-stream sediment is later deposited there, the esker is generally obliterated by stream erosion or deposition.

In this region, landforms that originated during or just after the Wisconsin Glaciation, especially small ones like eskers, are poorly preserved because they went through hundreds or thousands of years of intense soil erosion that is characteristic of tundra climates with permafrost (Attig and Clayton, 1992). Landforms that originated just after the period of permafrost, such as the shore-ice collapse trenches of Adams County (Clayton and Attig,

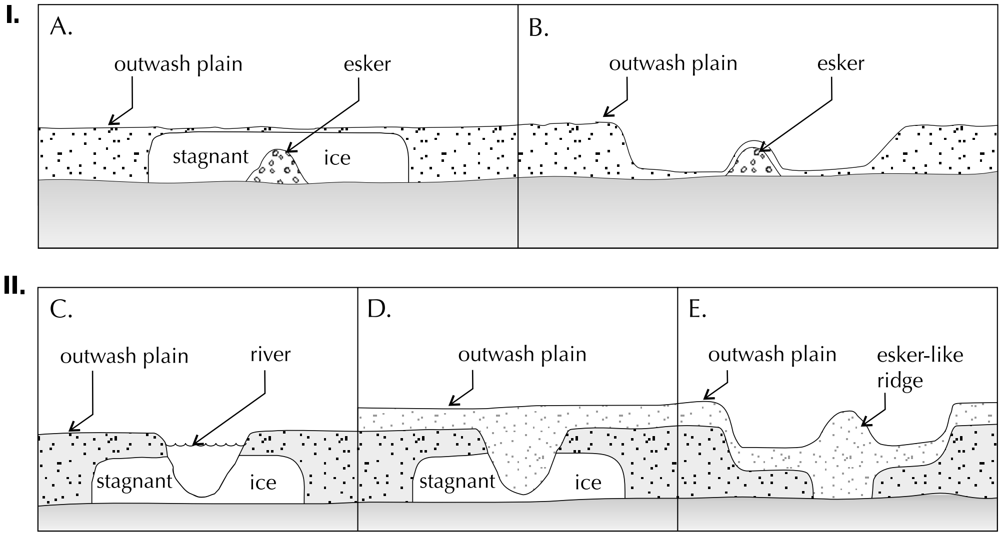


Figure 14. Two possible origins of the esker-like ridge southwest of Eagle.

1987), are much better preserved because they escaped the intense soil erosion.

The excellent preservation of the esker-like ridge southwest of Eagle indicates it escaped this intense soil erosion, and the presence of the surrounding collapsed meltwater-stream sediment indicates how this might have happened. I suggest that there are two possible explanations.

The first possibility is that it is an esker that was not exposed to soil erosion until the overlying stagnant glacial ice melted (fig. 14A and B). The ice might not have melted until the end of the permafrost period because it was insulated by a layer of stream sediment that was thicker than the seasonally thawed soil layer above the permafrost in the area. However, this stream sediment might have been thick enough to obliterate the esker or at least shroud its form after the ice melted and the supraglacial sediment was let down onto the esker.

A second possible explanation for the freshness of this landform is that it is a collapse ridge rather than an esker and that it formed at the end of the permafrost period rather than at the end of the glacial period. A meltwater river first had to cut a meandering channel through a buried mass of ice (fig. 14C), and another outwash deposit had to be laid over the previous one (fig. 14D). Then, when the permafrost period ended and the buried ice melted, an esker-like meandering collapse ridge formed (fig. 14E).

Meltwater-stream channels

The outwash plains in Waukesha County were originally marked by a complex pattern of braided meltwater channels in front of the glacier. In many places the braided channel pattern has since been obliterated by soil erosion or deposition; both processes were especially intense while permafrost was still present after the meltwater ceased flowing. In addition, the surface of the outwash plains was eroded by the wind, and the channel pattern was further obscured by deposition of a blanket of wind-blown dust as much as 1 m thick. In some areas, the braided channel pattern has been well preserved and is easily recognized from the air (fig. 15). The channels are typically a few tens of meters wide and no more than a few meters deep. The presence of recognizable channels is indicated by arrowheads in map unit **su** on plate 1.

Where a subglacial stream erodes its bed and does not deposit material, a tunnel channel rather than an esker forms. No tunnel channels have been definitely identified in Waukesha County, but the valley occupied by Pewaukee Lake is similar to the ones occupied by Lake Geneva, Lake Como, and Delavan Lake in Walworth County, which have been identified as tunnel channels by Attig and others (1989, fig. 1).

One kilometer west of the west end of Pewaukee Lake, in Naga–Waukee County Park, is the head of a meltwater channel that is 0.5 km wide, 3.5 km long, and 10 m or more deep (outlined by the cutbank symbol, plate 1). Its mouth is at the southeast corner of Nagawicka

Lake. The Naga–Waukee channel is a proglacial channel, not a tunnel channel; except at its head, its cutbanks are unmodified, with no evidence they were ever under a glacier. However, the channel is the size of a typical Wisconsin tunnel channel, indicating that it carried much more water than most esker rivers—the kind of catastrophic discharge characteristic of tunnel channels. The Naga–Waukee channel may have carried water from a tunnel channel in the Pewaukee valley. If so, it occurred before the moraine formed across the head of the channel because the moraine was draped across the channel after the large discharge ceased; later discharge from glacial Pewaukee Lake cut a smaller channel through the moraine.

An earlier and higher-elevation version of this channel extends southward from the Naga–Waukee channel, along the headwaters of Scuppernong Creek, and then westward 2 km northwest of Wales (plate 1; fig. 16); the Ethan Allen School is on its west bank. The channel is 0.4 km wide, 5 km long, and 10 to 35 m deep. Its head is about 18 m above the level of the Naga–Waukee channel. This Ethan Allen channel may also have carried water from a Pewaukee tunnel channel.

KETTLE MORAINE

The Kettle Moraine is an irregular ridge extending from northwestern Walworth County, through the southwest corner and the north-central edge of Waukesha County, and north–northeastward through Washington and Ozaukee Counties (figs. 2 and 3). It is one of the more striking glacial features in Waukesha County, and it is one of the most widely known.

The terms *kettle* and *kettle hole* have been used by glacial geologists to mean a discrete, roughly round pit in an outwash or lake plain, caused by the melting of a buried block of glacial ice. *Kettle* has also been used for any depression in an extensive area of collapsed su-

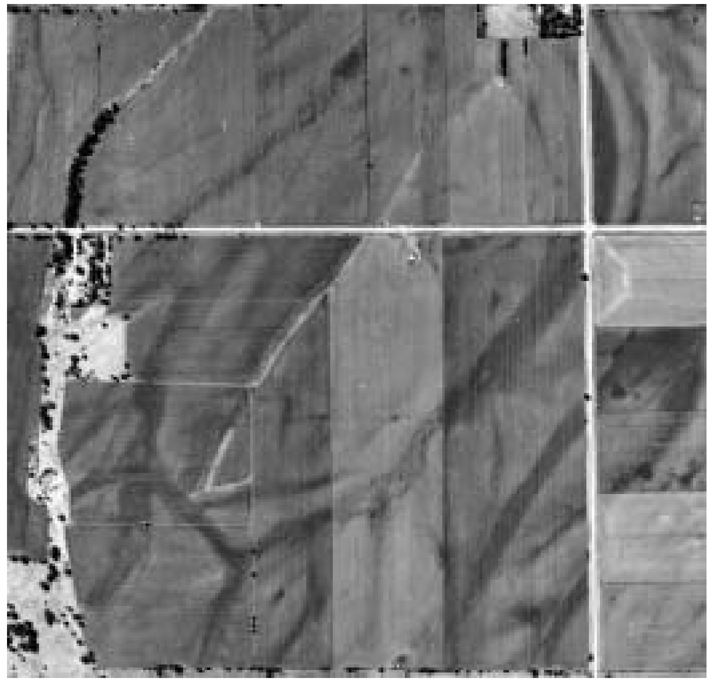


Figure 15. Aerial photograph showing channel scars on the outwash plain 2 km east of Eagle, in the southwestern part of Waukesha County. The area shown includes the NW¼ sec. 24, T5N, R17E. South is up. The area shown is 1.2 km wide. U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service aerial photograph WW-1DD-268, August 20, 1963.

praglacial stream or lake sediment, and it is occasionally used for any of the depressions between hummocks in an area of collapsed supraglacial till.

According to the unabridged Random House Dictionary of the English Language (1987), the first recorded use of the word *kettle* to mean a topographic depression was between 1880 and 1885. However, slightly earlier, Chamberlin (1877, p. 206–207, 214) was already using *kettle* to mean an ice-block depression. He seems to have borrowed the term from residents of southeast Wisconsin, who used *kettles, pots and kettles,* and *potash kettles* for circular, bell-shaped depressions generally less than about 150 m across (Chamberlin, 1877, p. 206). According to Chamberlin (in Alden, 1918, p. 13), these landforms were named after the kettles used "for boiling down ash lye into potash cakes." (Those kettles were probably the large, black, round-bottomed, cast-iron caul-

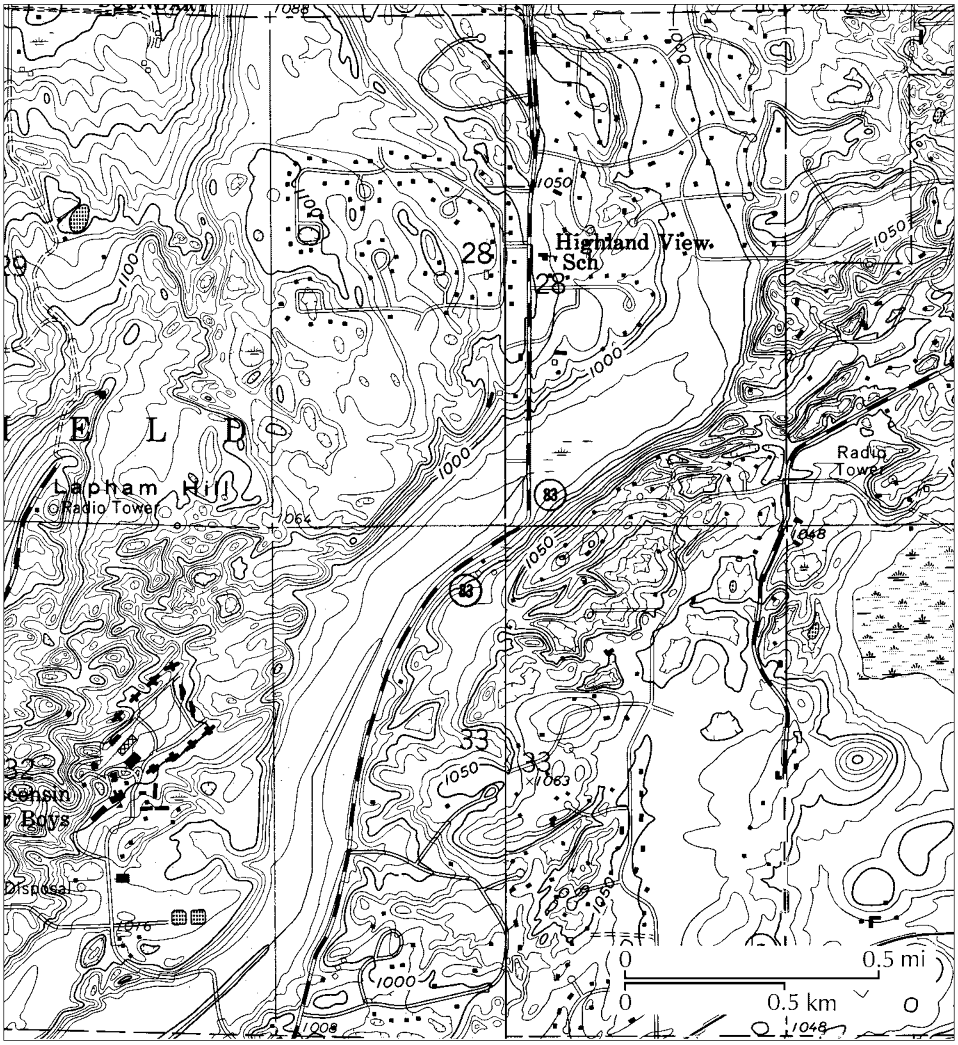


Figure 16. The Ethan Allen channel in secs. 28, 32, and 33, T7N, R18E; parts of Oconomowoc East and Hartland Quadrangles (U.S. Geological Survey, 7.5-minute series, topographic); contour interval is 10 ft.

drons seen today in front yards, filled with soil and flowering plants.) According to Whittlesey (1851, p. 56), the term *potash kettle* was being used for these depressions by mid-century, only a decade after the first Yankee settlers arrived. Apparently, the term *potash kettle* was brought westward by the settlers, because it was being used for similar depressions in northeastern Ohio (Kenyon, 1917, p. 398).

Whittlesey (1851) used the phrase *Potash Kettle country,* and Chamberlin (1877, p. 105, 205) said the names *Potash Kettle Range* and *Pots and Kettles Range* had been used for the range of hills extending through western Waukesha County. He proposed shortening the name to *Kettle Range.* All these were geographic names intended to have no geologic meaning.

Chamberlin (1877, atlas plate 2; 1878; 1883, p. 275–276) later named the *Kettle moraine* after the Kettle Range, but he intended the that term to be a geologic name for a much longer feature. Chamberlin considered the Kettle moraine to be part of the terminal moraine of the second glacial epoch (what is now called the Wisconsin Glaciation); he thought, incorrectly, that this terminal moraine could be traced along both sides and the full length of the Kettle Range. He thought it also included what today are considered to be the Johnstown and Darien moraines as well as correlatives west at least to the Dakota Territory and east to Massachusetts.

Alden (1918, p. 235) later referred to the range of hills extending through western Waukesha County as the *Kettle interlobate moraine,* but Martin (1916, p. 246; 1932, p. 260) referred to it as the *Kettle Moraine*. More recently, the name *Kettle Moraine* has generally been used. The Kettle Moraine State Forest and dozens of businesses, organizations, schools, churches, hospitals, and roads have Kettle Moraine as part of their name. That is the name used in this report; here it is used for the geographic feature, with no intended genetic implications, rather than for a geologic feature having a certain origin.

Origin

Chamberlin was the first to attempt a detailed explanation of the Kettle Moraine. He thought it consisted of two merged end moraines: one formed at the east edge of the Green Bay Lobe and one at the west edge of the Lake Michigan Lobe. He believed the whole Kettle Moraine, from its north to its south end, formed at the same time, as shown in figure 17A (Chamberlin, 1877, p. 213–214, plate 7; Chamberlin, 1883, p. 281; Chamberlin, in Alden, 1918, p. 14–15).

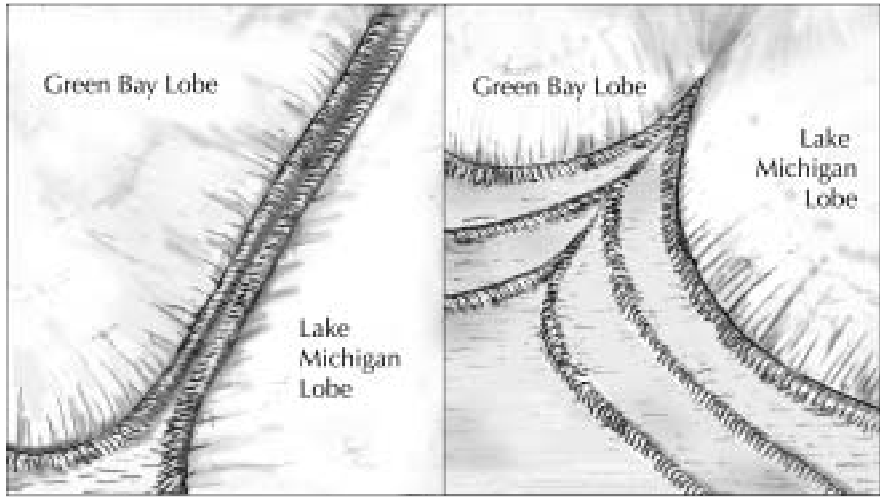


Figure 17. Two interpretations of the Kettle Moraine. **A.** Chamberlin's interpretation that it is everywhere the same age and resulted from the merger of two end moraines of two ice lobes. **B.** An alternate interpretation that it is younger northward because it resulted from the merger of separate moraines at their interlobe junctions as the ice margin receded northward.

However, Alden (1918, plate 4) mapped V-shaped moraines (as in the lower half of fig. 17B) formed along the ice margins in the interlobate area as the ice margin receded northward. This indicates that "this moraine, as it is seen today, was probably developed by stages from southwest to northeast" (Alden, 1904, p. 54). Perhaps because of Chamberlin's strong personality and because he was Alden's supervisor, Alden later recanted, or at least acquiesced, saying that "accumulation may be regarded as having taken place simultaneously along the whole extent of this interlobate belt..." before the ice margin began to recede and even to some degree while it was receding, as in figure 17A (Alden, 1918, p. 236).

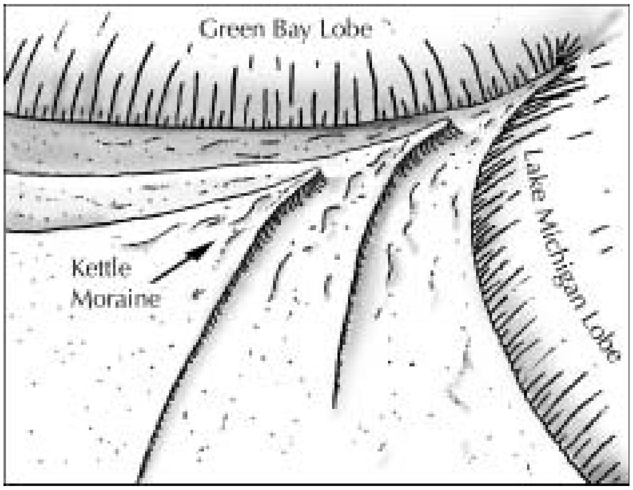
This is unlikely. The two lobes merged north of the interlobe area as shown in figure 17B. They could not have flowed south down the Green Bay and Lake Michigan lowlands if marginal flow had been directly toward the Kettle Moraine. Evidence for this is the arrangement of drumlins oblique to the Kettle Moraine rather than perpendicular to it (fig. 8). That is, most of the Kettle Moraine, not just the surface material, was deposited progressively at or near the apex of the interlobe area as the ice margin receded northward.

However, the Kettle Moraine is not all morainic till as suggested in figure 17B. In Waukesha County, the most common material in the Kettle Moraine is sand and gravel deposited by meltwater streams emerging from the interlobe junction, and the basic landform is an outwash fan that formed with its apex at the junction of the lobes. The Kettle Moraine appears to be a nested series of these outwash fans, as idealized in figure 18A. However, this idealized picture has to be modified in several ways.

Figure 18A shows evenly spaced fans of uniform size with their apexes forming the crest of the Kettle Moraine. This implies regular periods of ice-margin stability and ice-margin recession. The ice margin actually was more erratic, with slower and faster and shorter and longer periods of recession, and with some unevenly spaced periods of stability and advance, resulting in an irregularly spaced series of larger and smaller fans (fig. 18B).

In addition, the shape of the interlobe angle—and therefore the shape of the fans—varied through time. The angle was sometimes narrow and sometimes broad, and the apex was sometimes sharp and sometimes rounded.

A.



B.

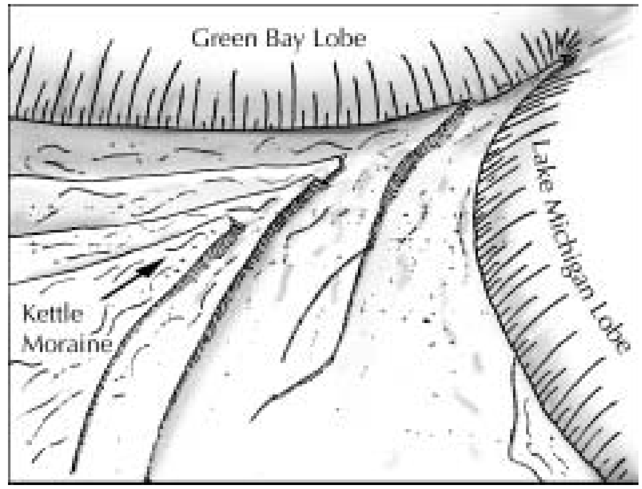


Figure 18. Formation of the Kettle Moraine. **A.** An idealized picture of three nested, evenly spaced, interlobe outwash fans. **B.** A series of less evenly spaced fans. **C.** A more realistic picture showing that the fans are hummocky in many places due to collapse during the melting of buried ice.

At times, the interlobate fan was symmetrical, when the two lobe acted in unison. At other times the lobes were slightly out of phase, resulting in an asymmetrical fan. Sometimes only a half fan formed on one side of the previous fan, when the meltwater from both lobes spilled entirely on one side of the Kettle Moraine.

The idealized fans of figure 18A and 18B are shown as if the stream sediment were all deposited on solid ground; however, much of it was deposited on stagnant masses of glacial ice. As a result, many parts of the fans consist of hummocky collapse topography formed when the buried ice melted (fig. 18C; map unit **sc** on plate 1). Collapse depressions—kettles—are abundant in the Kettle Moraine, but not strikingly more abundant than to the east and west. In addition, the Kettle Moraine includes sand and gravel deposited by meltwater streams flowing under the ice in the interlobe area. The Kettle Moraine is more nearly an esker than a moraine.

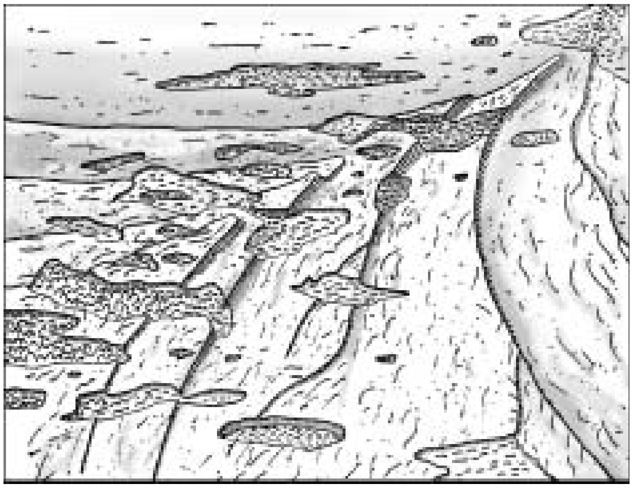
In many places, the form of the Kettle Moraine is also partly erosional where its sides have been steepened by meltwater rivers that were eroding rather than depositing.

Although much of the Kettle Moraine in Waukesha County is made up of meltwater-stream sediment, some till is also present. In places till has been draped over the ice-contact face on either side of the outwash fan or on the fan surface where the glacier readvanced over part of the fan. The till on the Kettle Moraine is more hummocky than in the rest of the county (map unit **ghk** on plate 1), and it is also sandier than to the east and west of the Kettle Moraine.

The above discussion focuses on the near-surface part of the Kettle Moraine formed during the last phases of the Wisconsin Glaciation. However, that part may have been superimposed upon material deposited earlier. It is unclear how much of its present bulk has been inherited from earlier versions of the Kettle Moraine. Similarly, in many places, the Pleistocene material of the Kettle Moraine is piled on a preglacial drainage divide, which also contributes to its prominence.

In summary, the Kettle Moraine in Waukesha County is primarily a nested series of partly collapsed outwash fans, formed at the apex of the interlobe area as it moved northward, along with eskers, and then partly covered with sandy and gravelly till. A similar conclusion was reached by Alden (1904, p. 55–63) and Attig (1986).

C.



ter table was lowered as a result of the melting of permafrost in the region, these lakes disappeared roughly 13,000 BP (fig. 7).

LAKE SEDIMENT AND LANDFORMS

Pleistocene lakes

On plate 1, map unit **on** indicates the location of several nearly flat, low-lying plains interpreted to be the sites of nonglacial lakes that existed near the close of the Wisconsin Glaciation. They are typically 0.5 to 1 km across; most are in the southern half of the county and are in or near the Kettle Moraine. The offshore sediment, especially of the smaller ones, is largely sand.

These lake plains occupy basins that resulted from the melting of masses of glacial ice that had been buried in meltwater-stream sediment. The plains lack the hummocky topography of the surrounding collapsed supraglacial stream sediment (map unit **sc**), indicating either that the topography has been flattened by wave action and by deposition of offshore sediment or that knobs were lacking from the start because the ice masses had too little stream sediment on them to produce hummocky topography.

Most of the areas mapped as unit **on** in and near the Kettle Moraine have basins that lack obvious outlet channels. This indicates that lake level fell because the water table was lowered rather than because an outlet was cut down to the level of the lake bottom. If the water table was lowered as a result of the melting of permafrost in the region, these lakes disappeared roughly 13,000 BP (fig. 7).

Lake Scuppernong

Glacial Lake Scuppernong is here so named because it occupied the valley of Scuppernong River in southwestern Waukesha County and adjacent areas. Evidence for the lake includes large areas of laminated silt and clay deposited offshore in the deeper basins of the lake (shown by map unit **ou,** plate 1). Offshore sediment is exposed in drainage ditches across the area. Clay is commonly mentioned in well constructor's reports; a report for a Wisconsin Department of Transportation bridge boring where Highway 135 crosses Mud Creek, 4 km northwest of Palmyra, identified more than 25 m of clay and silty clay.

The extent of Lake Scuppernong, however, is obscure because its beaches are poorly preserved. Those that were identified are shown by a dotted line symbol on plate 1. The most conspicuous series of Scuppernong beaches is at the east edge of an outwash delta east of Beaver Dam Lake, in the southwestern Waukesha County. Several probable beaches can be seen on aerial photographs at an elevation of approximately 265 m (870 ft) in secs. 5 and 7, T5N, R17E.

Beaches have been identified through only a short north–south distance, and they probably can be found at more than one elevation in any area. As a result, it is unclear if the beaches are horizontal or have been tilted by rebound of the Earth's crust when the weight of the ice sheet was removed. If, however, a reasonable rate of rebound is extrapolated from the area of glacial Lake Wisconsin (Clayton and Attig, 1989, p. 27–35), and if the glacier had melted from the area, and if the rock sill at the Janesville outlet had not yet been deeply entrenched, the lake would have covered approximately the area shown in figure 19.

Segments of such a lake, covering most of Jefferson County and parts of adjacent counties, have been previously recognized. Alden (1904, p. 64, 1918, p. 289 and plate 1) noted evidence for glacial lakes in this area, but he apparently visualized a lower-level lake or a series of several smaller lakes. Hypothetical Lake Scuppernong, as reconstructed in figure 19, was at about the same level as glacial Lake Yahara in central Dane County (Mickelson, 1983, p. 18–21); Lake Yahara may have flowed into Lake Scuppernong, or it may have been part of the same lake. Several paleontological sites in the middle of the area shown in figure 19, with bones of mastodon, giant beaver, and other mammals, are in clay interpreted to be offshore sediment; this sediment was probably deposited in Lake Scuppernong (West and Dallman, 1980, p. 27–32).

As the Green Bay Lobe began to waste back from the Kettle Moraine, early versions of Lake Scuppernong must have formed between the ice and the Kettle Moraine. They may have overflowed to the southwest through unknown outlets in southern Jefferson County and northern Rock County.

Once the ice had wasted back to what is now Fort Atkinson, in southwestern Jefferson County, Lake Scuppernong had to drain through the Rock River. The narrowest part of the Rock River trench is in central Rock County (fig. 19). The level of Lake Scuppernong was probably maintained by a sill of Ordovician dolomite in Riverside Park on the northwestern edge of Janesville (north part of sec. 23, T3N, R12E).

Lake Scuppernong persisted at lower and lower levels as the sill was eroded. At first it was a glacial lake, with ice along its northern shore and later with glacial meltwater rivers flowing into its north end. Once the glacier had wasted back into the Lake Winnebago basin for the last time, around 12,000 BP, no more meltwater entered the lake. According to West and Dallman (1980, p. 27–32), radiocarbon dates indicate that the lake at the paleontological sites mentioned above persisted until the early Holocene, at least until 9,000 BP. On the other hand, ice-wedge polygons are evident on a part of the bed of Lake Scuppernong that had been left dry when the lake receded to the extent shown in figure 19; this indicates that the lake had drained from at least this area by about 13,000 BP, when the last permafrost melted from the region (Attig and Clayton, 1992). In figure 7, the eastern extent of Lake Scuppernong is shown to recede through time as the Janesville outlet eroded down through the dolomite sill.

Pewaukee Lake

Pewaukee Lake, which is 7 km long, is the largest lake existing today in Waukesha County. It now drains eastward out the Pewaukee River (**p,** fig. 20). Earlier, when the Lake Michigan Lobe blocked its eastern end, Pewaukee Lake drained out higher outlets to the west (fig. 7). Few beaches remain, but the lake-level history can be reconstructed from outlet elevations and ice-margin positions.

Just after the Lake Michigan Lobe melted back from the Kettle Moraine, a small early version of Pewaukee Lake drained westward down the Naga–Waukee channel, through outlet **a** in figure 20, which cut through the moraine across the head of the channel. The shoreline, if still preserved, should be at an elevation of about 297 m (975 ft); its hypothetical location is shown with short dashes in figure 20. The lake persisted at this level until the glacier melted back to ice-margin **w** in figure 20.

With further ice-marginal recession, the lake could begin to drain through outlet **b** (fig. 20); a small alluvial fan was built on the outwash terrace at the mouth of this outlet (just east of the middle of sec. 10, T7N, R18E). The corresponding hypothetical shoreline should

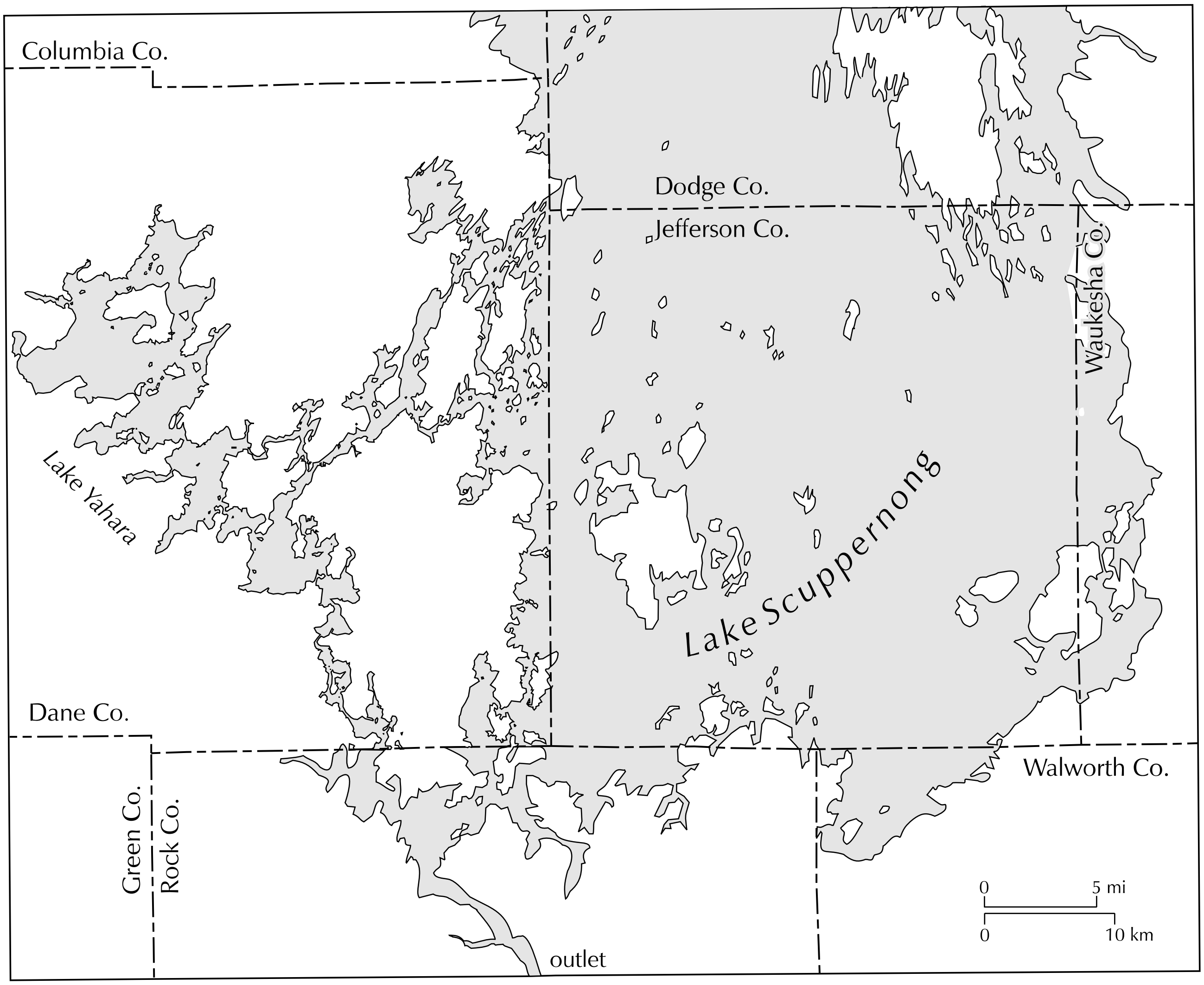


Figure 19. Hypothetical extent of glacial Lake Scuppernong, assuming crustal rebound of 0.13 m/km to the north–northeast, and assuming the glacier had receded northward from the area before the rock sill in the outlet in central Rock County had been substantially entrenched.

be at an elevation of about 290 m (951 ft), shown with a dash-and-dot line in figure 20. The beach shown on plate 1 near the southwest corner of sec. 17, T7N, R18E, is near this level.

The lake persisted at this level until a lower outlet was uncovered as the glacier receded. A low spot in the present drainage divide (at **c**, fig. 20) is at an elevation of about 285 m (935 ft). This could have been an outlet for Pewaukee Lake after the glacier wasted back from ice margin **x** in figure 20. However, there is no evidence that water ever flowed across this divide; apparently there was enough buried stagnant glacial ice here to prevent water draining this way. The lake had to stay at level **b** until the glacier wasted back to ice-margin **y** (fig. 20).

At that time, the lake dropped to the level of outlet **d** (into Pebble Creek), at an elevation of about 270 m (886 ft). The lake must have stayed at this level, shown with long dashes in figure 20, until the glacier wasted back to ice-margin **z**. Soon after, the lake dropped to near its present level, when it began to drain down the Pewaukee River (**p,** fig. 20).

Lake Vernon

Another glacial lake, here called Lake Vernon

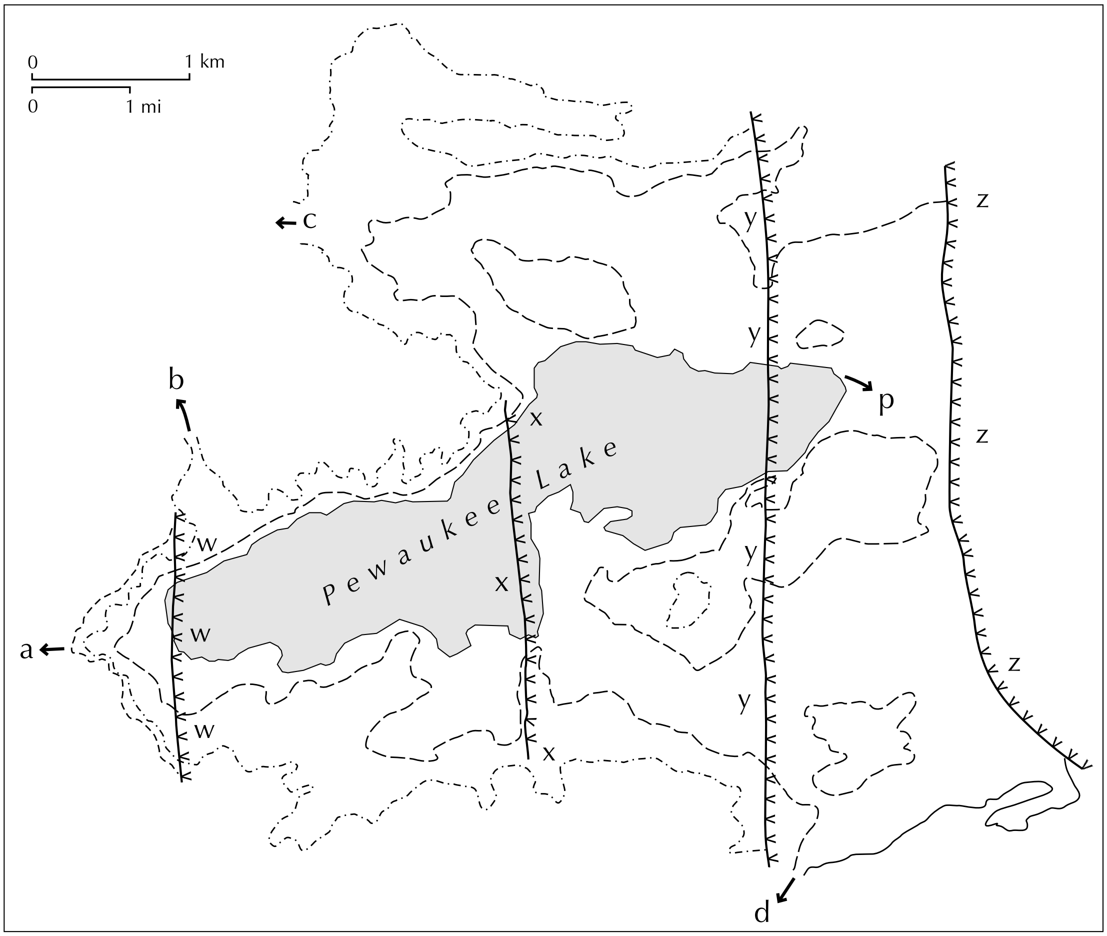


Figure 20. Glacial Pewaukee Lake. Letters on figure are explained in text.

after Vernon Marsh and Vernon Township, occupied the Fox River lowland in the south-central part of the county (fig. 21). The lake came into existence as the Lake Michigan Lobe wasted eastward across the county. During much of its existence, the lake apparently drained southward from its southwestern arm (**a,** fig. 21). The outlet was southeastward of the northeastern end of Lake Beulah, in Walworth County, at an elevation of about 250 m. It drained to the Honey Creek valley, and then to the lower Fox River valley in Racine County. Evidence for this lake includes delta foreset faces southwest of Waukesha (plate 1). The first phase of Lake Vernon persisted until the glacier melted back to expose the Fox River trench at the south edge of the village of Big Bend, allowing the lake to drain (**b,** fig. 21).

The second phase of Lake Vernon occurred when the glacier briefly readvanced into the county and deposited the till of the Oak Creek Formation (fig. 7). The glacier blocked the Fox River trench near Waterford in Racine County (D.M. Mickelson, University of Wisconsin–Madison, Department of Geology and Geophysics, verbal communication, 1992), causing Lake Vernon to refill. Its outlet was in the SW¼ sec. 17, T4N, R19E, northwest of Waterford (**c,** fig. 21); it was a few meters lower than the first-phase outlet southeast of Lake Beulah. The delta at the village of Big Bend may have formed at this time.

Other glacial lakes

Other smaller areas of proglacial lake sediment are scattered around the county (map units **ou** and **oc**), and several areas of offshore sediment deposited in ice-walled lakes are found in the southeastern part of the county (map unit **oi**).

The ice-walled-lake plains typically are 0.5 to 1 km wide, are a few meters above the surrounding till plain, and are composed of offshore silt and clay.

Holocene lakes

The lakes of Waukesha County have changed little since they formed at the end of the Wisconsin Glaciation. Most were originally floored with glacial-lake sediment, meltwater-stream sediment, or till. Since their inception, they have gradually infilled with sand near shore and around stream mouths and with silt, clay, and marl farther off shore. Some lakes and ponds have been completely filled with sediment, or the water level dropped and exposed the lake floor; the resulting lake plains are generally covered with a thin layer of peat (map unit **op**).

During agricultural-lime investigations in the mid-1930s, several dozen holes were augered in exposed bottoms of former lakes in Waukesha County (unpublished reports in WGNHS files). Typically, 1 to 3 m of peat overlies silt, clay, marl, or sand. In some places, more than 4 m of marl is present, much of it reported to be approximately 80 percent calcium carbonate equivalent.

Early in this century, marl was mined from a former lake bed 6 km north of Eagle, in the SW¼ SE¼ sec. 34, T6N, R17E and the NW¼ NE¼ sec. 3, T5N, R17N (Steidtmann, 1924, p. 145–146). The abandoned main pit is 0.5 km long and about 20 m wide. The lake bed is 1 km wide and is shown covered with peat and surrounded by a beach ridge on plate 1 (map unit **op** and symbol).

Muskego Lake, in the southeast part of the county, is shown on plate 1 surrounded by peat-covered lake sediment, which is bordered by a shoreline. This was shown as the shoreline of the existing lake on the public land survey map of the area dated 1836. A ditch was later dug to lower the outlet.

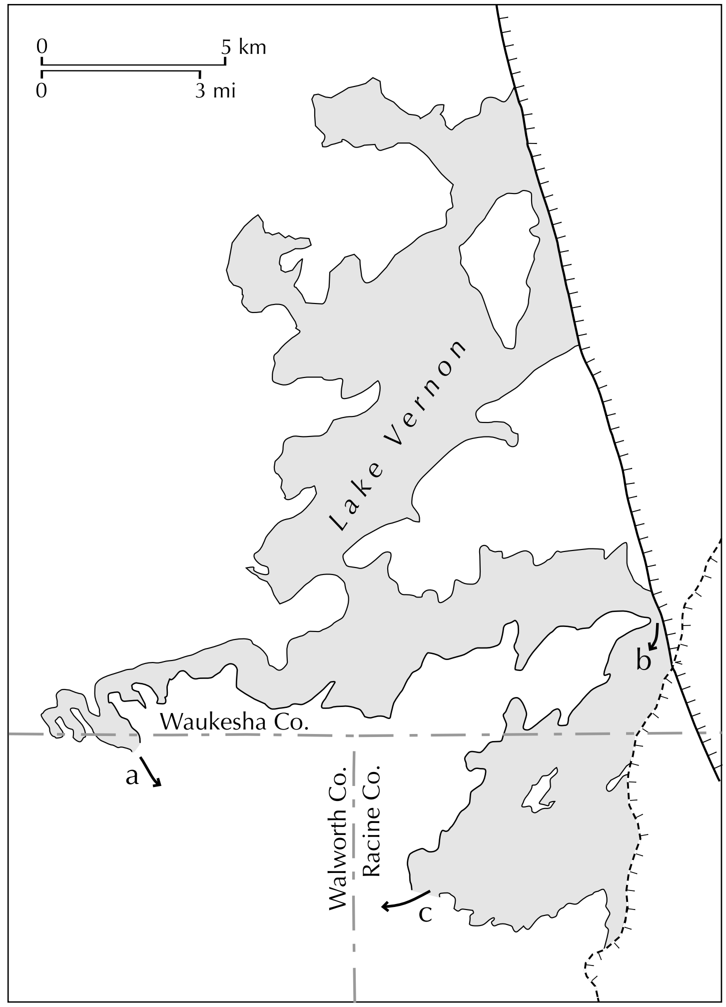


Figure 21. Glacial Lake Vernon. When ice terminated west of the solid line with hachures (shown in detail in fig. 23E), the outlet was at **a.** When the ice terminated at the solid line, the outlet was at **b.** When the ice terminated at the dashed line with hachures (shown in detail in fig. 23G), an extra bay was added in Racine County, and the outlet was at **c.**

WINDBLOWN SEDIMENT

No windblown sediment is shown on plate 1 because it is too sparse to map. Some windblown sand is on the sand plains in places in the western half of the county, but it is generally less than 1 m thick.

Windblown silt is more widespread. According to Steingraeber and Reynolds (1971), the less-eroded areas of till of the Oak Creek Formation are overlain by about 0.3 m of silty material; the till of the Holy Hill Formation is

Figure 22. Ski hill composed of artificial fill southeast of Oconomowoc, in the SW¼ NW¼ sec. 10, T7N, R17E.

overlain by at least twice that amount (Hole, 1956, p. 24–25, gave somewhat larger values). This difference is probably partly the result of the difference in age of the two formations (fig. 7); the older Holy Hill till received dust for several hundred years longer than did the Oak Creek till. In addition, the finer-grained Oak Creek till has had less infiltration of precipitation and therefore more runoff and more soil erosion.

DISTURBED LAND

No artificially disturbed land is shown on plate 1. Instead, I have attempted to show the geology before disturbance occurred. However, considerable areas in Waukesha County have been disturbed, especially the eastern part of the county during the past several decades.

The most detailed survey of disturbed land in Waukesha County was made by Steingraeber and Reynolds (1971). They determined that 1.3 percent of the county consisted of areas of cut and fill, largely in the more recent housing developments. They also showed the distribution of unreclaimed quarries and gravel pits. Considerable additional disturbance has occurred since their survey.

The landfills of Waukesha County were inventoried by Biebel and Stuber (1982). As of 1980, 49 landfills were known, 13 of which were still active. The most conspicuous hill in Waukesha County is the mound of fill on the southeast side of Oconomowoc (fig. 22), built as a ski hill in the mid-1970s.

SUMMARY OF EVENTS DURING THE WISCONSIN GLACIATION

The history of the last part of the Wisconsin Glaciation in Waukesha County is summarized in figure 7 and in a series of maps in figure 23; note that each of these maps shows Waukesha County at a time that is indicated along the right-hand margin of figure 7. At the start of the Wisconsin Glaciation, the Green Bay Lobe of the Laurentide Ice Sheet flowed into Waukesha County from the northwest and the Lake Michigan Lobe flowed in from the northeast. After several fluctuations, the two lobes merged, perhaps near the future position of the Kettle Moraine. During the height of the Wisconsin Glaciation, the county was entirely covered by ice. The drumlins in Waukesha County were probably partly shaped during this time.

Toward the end of the glaciation, perhaps between about 16,000 and 15,000 BP, as suggested in figure 7, the two lobes began to separate along the line of the Kettle Moraine. The area exposed between the two lobes was flooded by meltwater rivers, which deposited an outwash fan along the east edge of the Kettle Moraine (fig. 23A).

As the area exposed between the two lobes enlarged northward, the Lake Michigan Lobe wasted back faster than the Green Bay Lobe (fig. 23B). As a result, a trough opened between the Kettle Moraine and the Lake Michigan Lobe, down which most of the meltwater flowed. The west side of the Kettle Moraine in southern Waukesha County remained steep; the east side is marked by a descending series of terraces formed as the rivers dropped to lower levels as the Lake Michigan Lobe wasted eastward.

Later (fig. 23C), as the Green Bay Lobe wasted westward, a space opened between it and the Kettle Moraine. Meltwater rivers from the interlobe apex in northern Waukesha County flowed southward along the west side of the Kettle Moraine until they reached an early version of Lake Scuppernong. In central Waukesha County, meltwater from the Lake Michigan Lobe cut the Ethan Allen channel westward across the Kettle Moraine. To the south, meltwater rivers from the Lake Michigan Lobe spread out into a broad valley opening east of the Kettle Moraine.

Figure 23D shows a time when meltwater rivers in north-central Waukesha County were flowing westward from the Lake Michigan Lobe through a broad breach in the Kettle Moraine and then southward to an expanded Lake Scuppernong west of the Kettle Moraine. Meanwhile, Pewaukee Lake had formed and was spilling west across the divide, and Lake Vernon drained southward.

By the time indicated in figure 23E, the Green Bay Lobe had wasted entirely out of the county, and Lake Scuppernong had expanded to cover much of Jefferson County. Pewaukee Lake was now spilling southward into Lake Vernon, which continued to drain southward.

Figure 23F shows a time when meltwater from the Lake Michigan Lobe was still flowing westward down the Bark River to Lake Scuppernong. Lake Vernon had emptied, and Pewaukee Lake was flowing southward down the Fox River.

Up to the time it receded from the position shown in figure 23F, the glacier had been depositing the sandy till of the Holy Hill Formation. The glacier wasted entirely out of the county, back into the Lake Michigan basin. Clay and silt were deposited in Lake Michigan during the Milwaukee Phase, and later the glacier readvanced and eroded this silt and clay; as a result, when the Lake Michigan Lobe flowed back into the Waukesha County, perhaps about 14,000 years ago (fig. 7), it deposited the more clayey and silty till of the Oak

A.

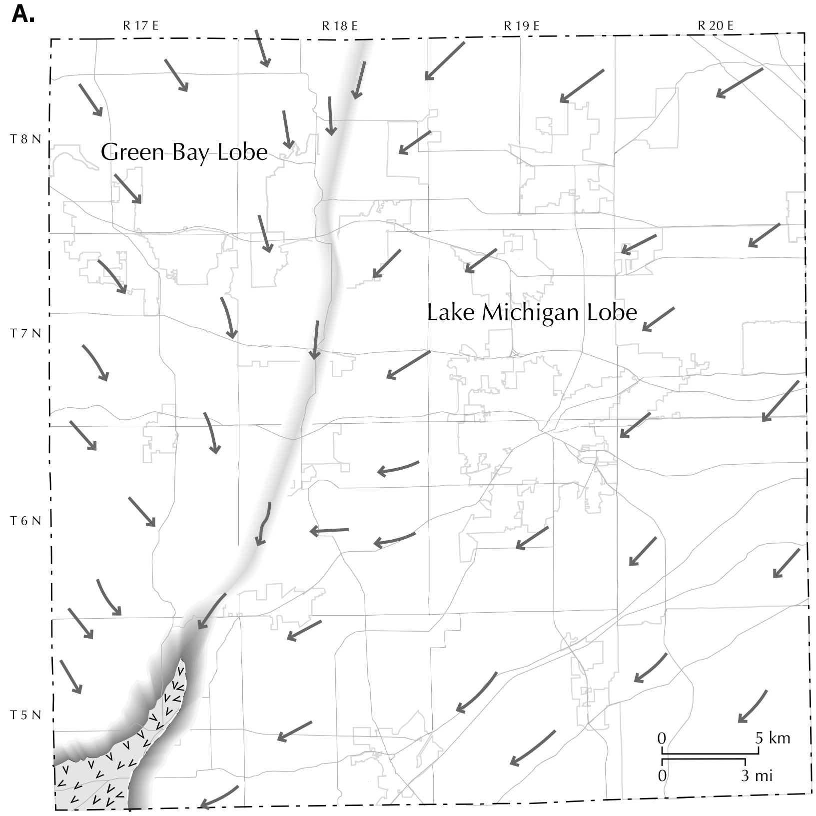


Figure 23A-G. A series of maps showing Waukesha County as the glacier wasted back at the end of the Wisconsin Glaciation. The arrows with shafts indicate the direction of ice movement; shaded band is the edge of the glacier; arrowheads without shafts in light grey areas indicate the direction of meltwater flow; dark grey tone indicates glacial lakes (nonglacial lakes are not shown). The approximate time of the events shown on each map is indicated along the right-hand edge of figure 6.

B.

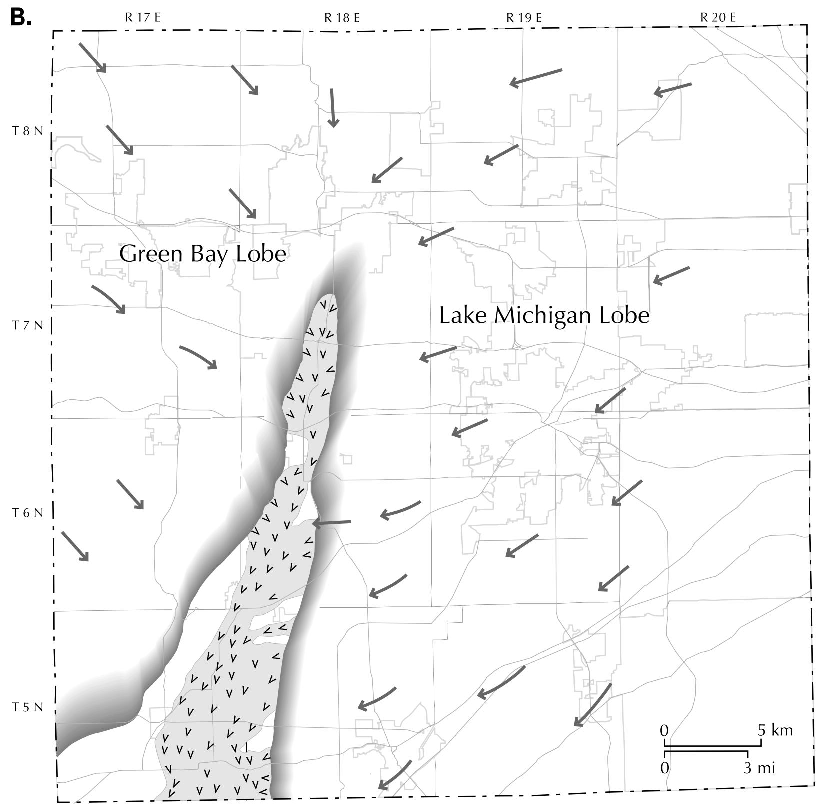


Figure 23. Continued.

Creek Formation (fig. 23G). Meltwater flowed southward into Lake Vernon, which briefly came into existence again when the ice blocked the Fox River near Waterford in Racine County. The ice again wasted back, and Lake Vernon drained. During the general wastage from the county the glacier readvanced three times to form the three Lake Border moraines at the east edge of the county (not shown in fig. 23).

C.

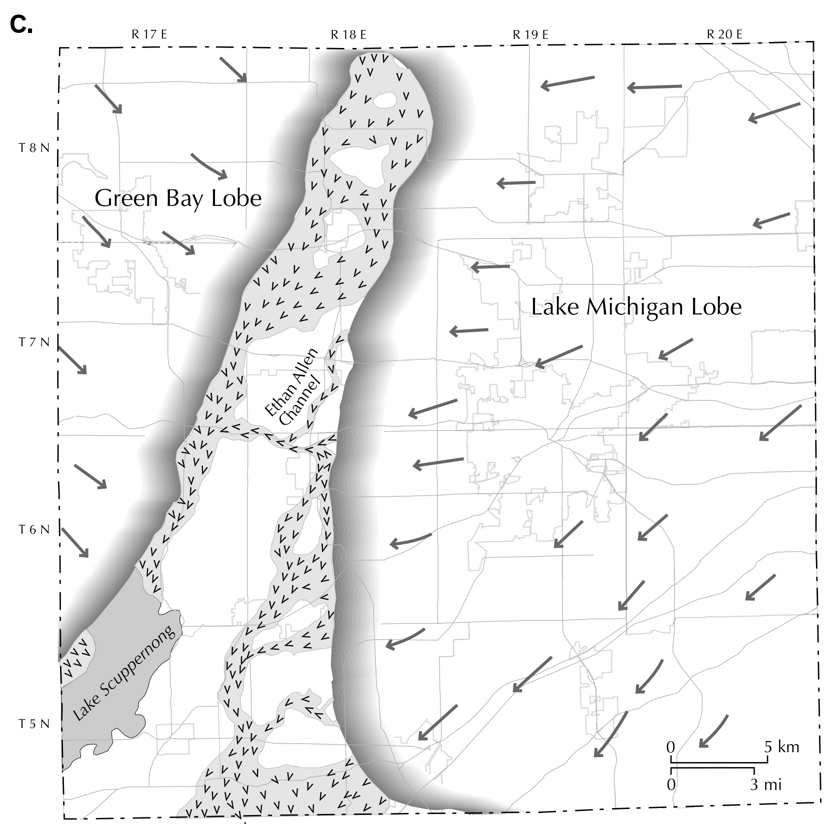


Figure 23. Continued.

D.

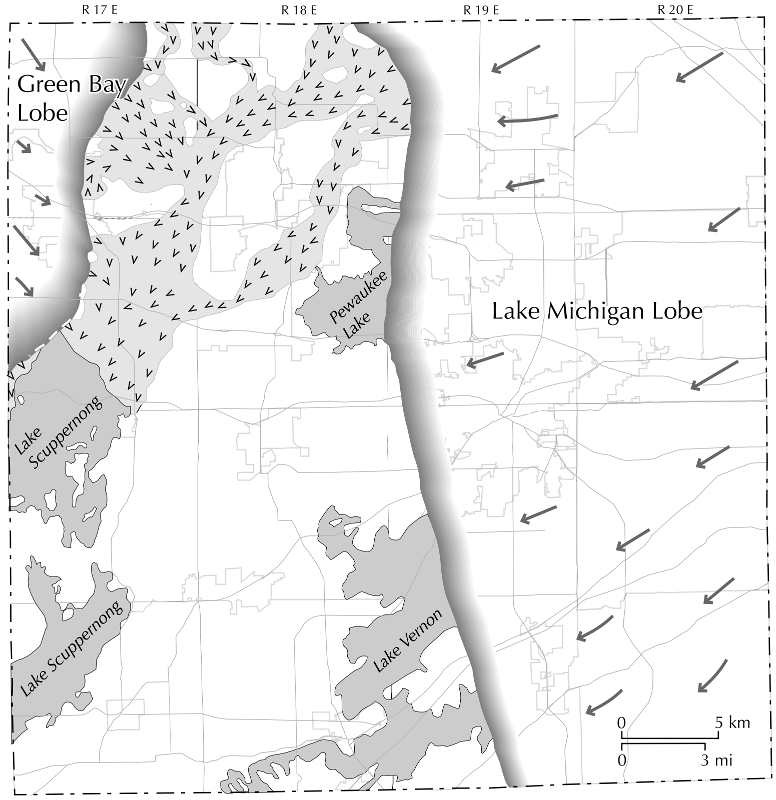


Figure 23. Continued.

E.

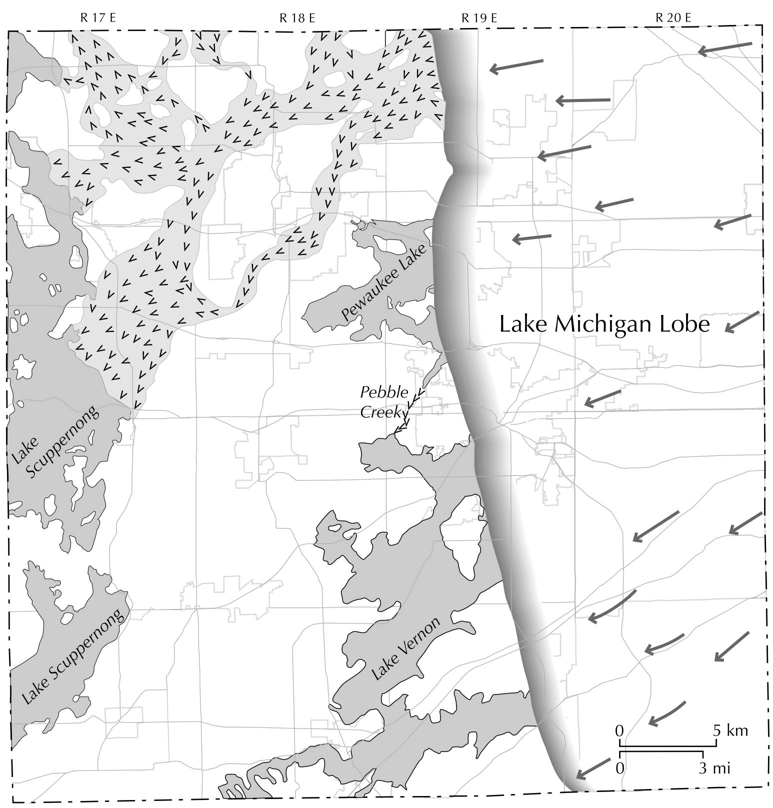


Figure 23. Continued.

F.

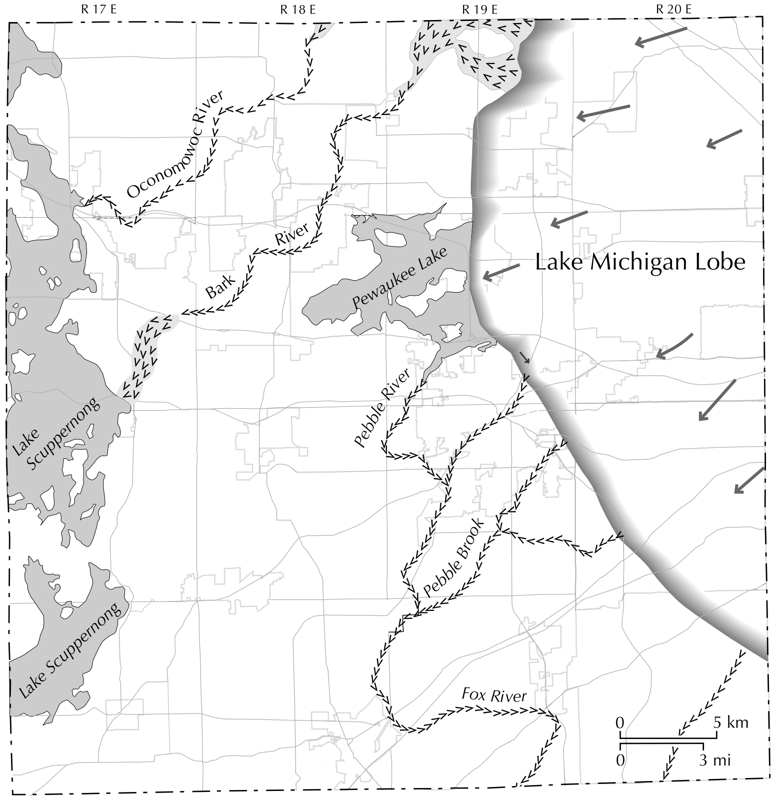


Figure 23. Continued.

G.

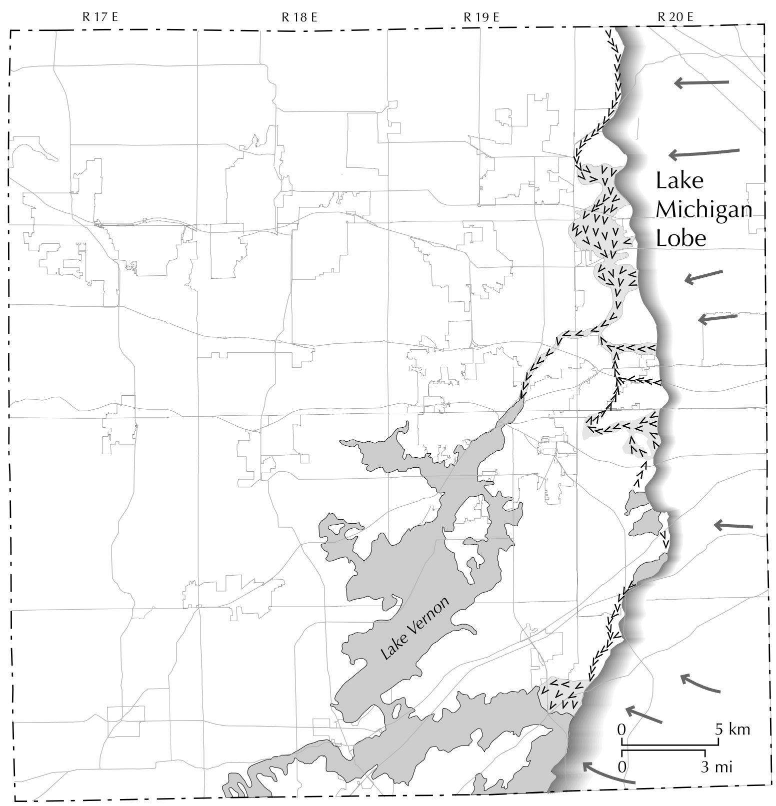


Figure 23. Continued.

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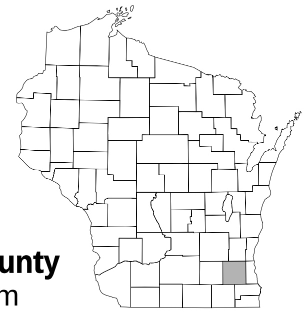
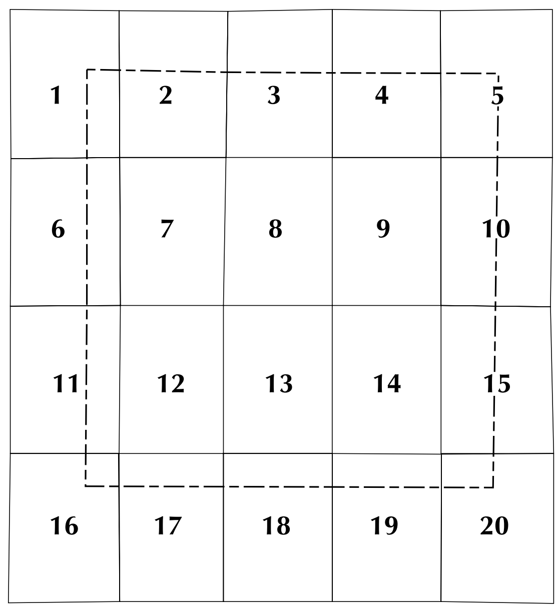


Waukesha County
location diagram

Index to U.S. Geological Survey topographic quadrangles
(scale 1:24,000)



1 Ixonia-1959 (71 PR)
2 Stonebank-1959 (71 PR)
3 Merton-1959 (71 PR)
4 Sussex-1959 (71 PR)
5 Menomonee Falls-1958 (76 PR)
6 Oconomowoc West-1959 (71 PR)
7 Oconomowoc East-1959 (76 PR)
8 Hartland-1959 (76 PR)
9 Waukesha-1959 (71 PR)
10 Wauwatosa-1958 (71 PR)
11 Palmyra-1960 (71 PR)
12 Eagle-1960 (71 PR)
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14 Muskego-1959 (76 PR)
15 Hales Corners-1959 (76 PR)
16 Little Prairie-1960 (71 PR)
17 East Troy-1960 (76 PR)
18 Mukwonago-1960 (76 PR)
19 Waterford-1959 (71 PR)
20 North Cape-1959 (71 PR)

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