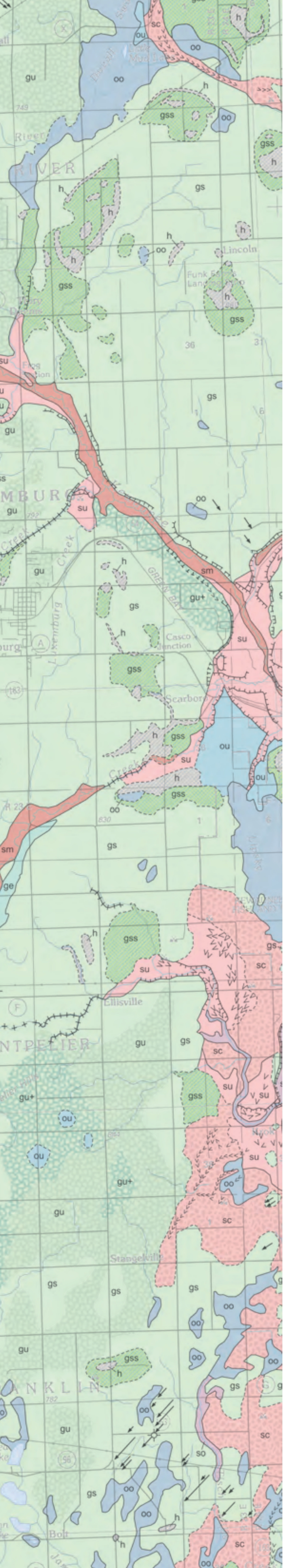

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

Pleistocene Geology of Kewaunee County, Wisconsin

Bulletin 104 • 2013

Lee Clayton

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Front: Ahnapee River, © David M. Mickelson
Back: Lake Michigan shoreline, © Bay-Lake Regional Planning Commission

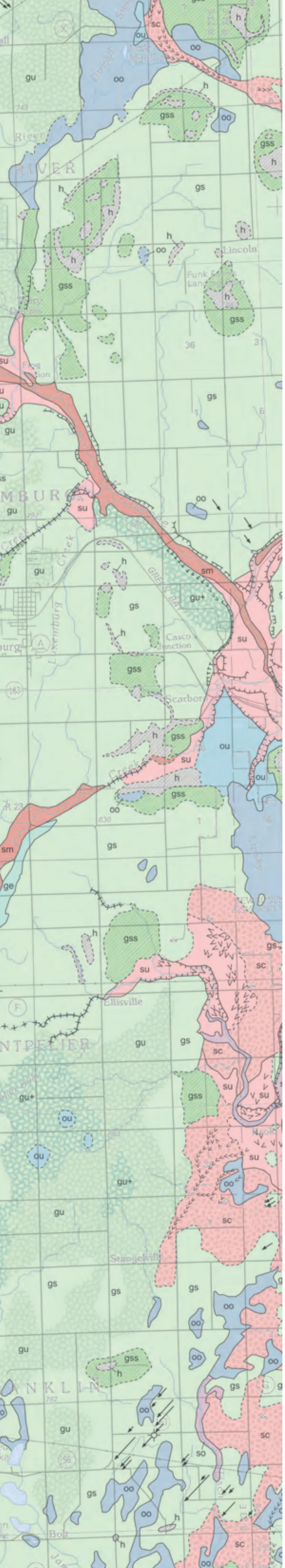

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Plate (in pocket)

Red River

William N. Mode

Bay-Lake Regional Planning Commission

Abstract

Kewaunee County straddles the Door Peninsula on the west side of Lake Michigan. In the county, a layer of Silurian dolomite is blanketed by up to 150 ft (45 m) of Pleistocene sediment, which is mostly till.

During the Wisconsin Glaciation, what is now Kewaunee County was buried under nearly 1,000 ft (300 m) of ice until roughly 14,000 to 13,000 years ago, when the south end of the glacier receded and readvanced across the county several times.

Approximately 11,000 years ago, the ice receded for the last time, leaving glacial Lake Oshkosh in the Fox River lowland, which drained across the Door Peninsula through several outlets, including the upper Kewaunee River trench, down the East Twin River spillway, and into Lake Michigan. Later, the lake drained from the upper Kewaunee River trench directly to the lower trench and Lake Michigan. When the glacier melted back to Little Sturgeon Bay in Door County, glacial Lake Oshkosh dropped to the level of Lake Michigan and became Green Bay.

The glaciers deposited two major regional till units: the Holy Hill Formation, which consists of yellowish-brown sandy till, and the overlying Kewaunee Formation, a red-tinged brown clayey till.

Five subdivisions of the Kewaunee Formation have previously been identified in outcrop in Kewaunee County: the Ozaukee, the Haven (now discontinued), the Two Rivers, the Valders, and the Glenmore Members. Members of the Kewaunee Formation are quite variable and difficult to differentiate. In addition, a few dozen till units were distinguishable in the drill hole samples, but few could be correlated with each other or with outcropping units. The till of Kewaunee County seems to have a highly complex stratigraphy: Most units are very thin and patchy, but some of the thicker units are remarkably uniform at a single drill hole.

Introduction

In this report, I describe the Pleistocene geology of Kewaunee County from the surface soil down to solid rock. My descriptions are based on field work conducted between 1998 and 2000.

About the map

Map contacts on plate 1 were drawn using the U.S. Geological Survey quadrangles (7.5-minute series, topographic; scale 1:24,000; 10-ft contour interval) and aerial photographs (scale 1:20,000) taken in 1967 for the U.S. Department of Agriculture. A truck-mounted drill was used to gather subsurface information. Additional information was derived from various sources, including Wisconsin Department of Natural Resources well construction reports, logs of Wisconsin Department of Transportation borings, published geologic and soils maps, and unpublished Road Materials Investigations Reports, which are on file at the Wisconsin Geological and Natural History Survey.

The colors used on plate 1 indicate the general environments of deposition of the mapped sediment. Reds indicate various types of stream sediment; blues indicate offshore lake sediment, overlain in many places by peat; orange indicates lake-shoreline sediment; and greens indicate glacial sediment. The general environment of deposition is also indicated by the first letter of the unit identifier: **s** for stream sediment, **o** for offshore lake sediment, **b** for shoreline (beach) sediment, and **g** for glacial sediment (till).

Laboratory analysis of till samples

Approximately 360 till samples were analyzed in the Quaternary Laboratory of the Department of Geoscience at the University of Wisconsin in Madison. The till was sampled and analyzed for characteristics useful in distinguishing stratigraphic units in Wisconsin: grain size, color, magnetic susceptibility, and content of calcite and dolomite.

Grain size was reported as a percentage of sand (0.06–2.0 mm), silt (0.002–0.06 mm), and clay (up to 0.002 mm); gravel coarser than 2 mm was excluded. The precision of these measurements is suggested by the reanalysis of 12 samples (scattered through several laboratory runs): Half the paired analyses were reported to have sand values within 1 percent of each other. The precision of measurement, as well as till-sheet uniformity, is also suggested by the sand content of samples 210 through 235 from a 26-ft (8-m) section of drill hole NR (all from a single laboratory run); all but two of these 25 analyses reported between 23.2 and 24.5 percent sand. Calcite and dolomite contents were measured using the Chittick method. Almost all calcite analyses showed that calcite content was between 1.7 and 3.6 percent, and any fluctuation was seemingly without much regard for the stratigraphy.

The color of till samples analyzed for this report was determined in three ways. First, color was casually described, without color charts, when the complete core was laid out in the field, emphasizing abrupt grain-size and color differences at contacts between till sheets. Second, sample colors were measured using Munsell Soil Color Charts in a laboratory setting with uniform lighting conditions and moist samples, and with freshly broken surfaces that had been smoothed to eliminate any hackly surface texture. Third, suspended-clay colors were determined, also using color charts during grain-size analysis, when only clay was left in the settling tube. All the analytical data from this study have been incorporated into the TILL*PRO* database (Wisconsin Geological and Natural History Survey, 2004).

Reported field colors and laboratory colors sometimes differ as a result of actual color changes on exposure to air. Field colors and suspended-clay laboratory colors were seldom identical. Field colors were generally redder by one page in the Munsell color book; values were commonly the same or one row of color chips darker; chromas were commonly duller by one or two columns of chips.

Previous researchers (summarized by Mickelson and others, 1984, and by Attig and others, 1988) generally determined till colors for this region using the suspended-clay method with Munsell Soil Color Charts. Some used dry clay on slides used in clay-mineral analysis, others made field determinations using moist or dry samples.

Geologic setting

Kewaunee County occupies a land area of 533 square miles (858 km^2) in east-central Wisconsin, at the southern end of the Door Peninsula, between Green Bay and the main basin of Lake Michigan (fig. 1). The peninsula here is about 15 mi (25 km) across. The highest point is Cherneyville Hill, at an elevation of 1,020 ft (311 m), in southwestern Kewaunee County, 0.3 mi (0.5 km) southeast of Cherneyville (figs. 2 and 3). Elevation of the peninsula is somewhat asymmetrical, with slightly steeper slopes down to Green Bay.

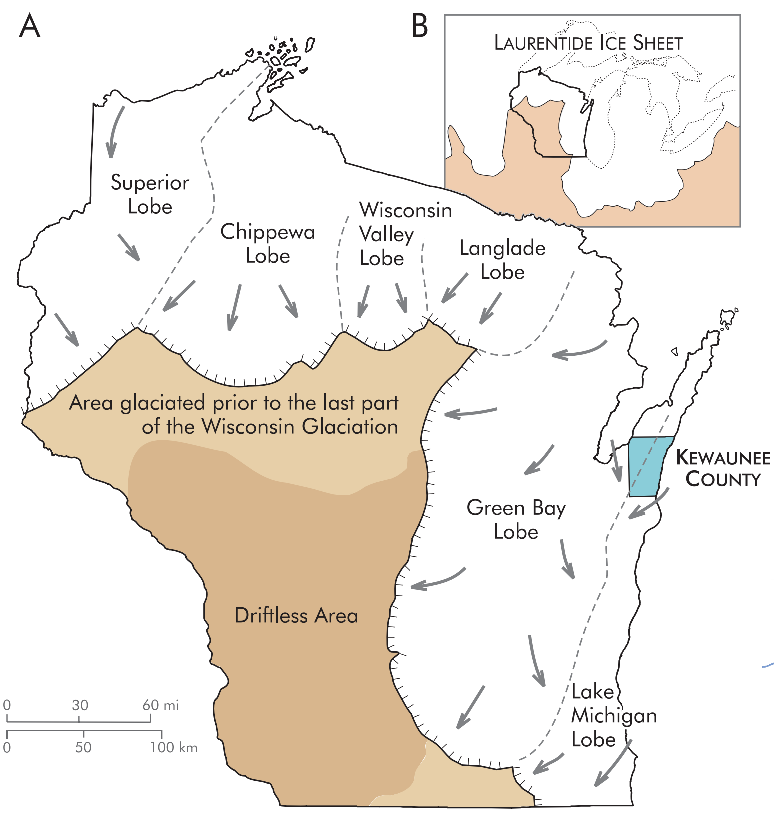


Figure 1. Location of Kewaunee County in Wisconsin (A) in relation to the Laurentide Ice Sheet (B) and its lobes during the most recent glaciation. Arrows show direction of ice flow.

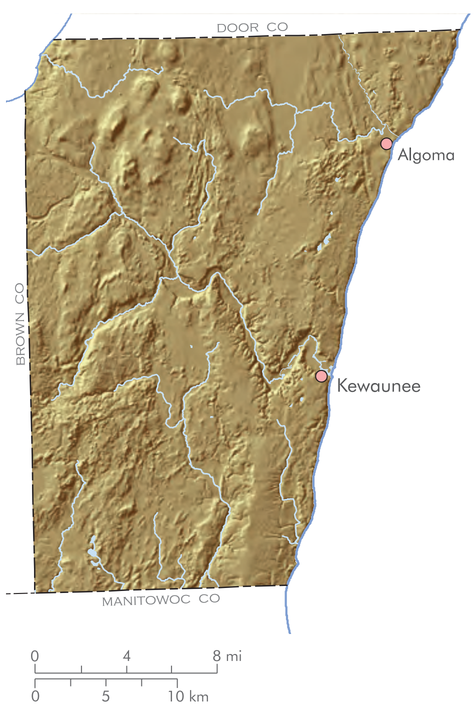
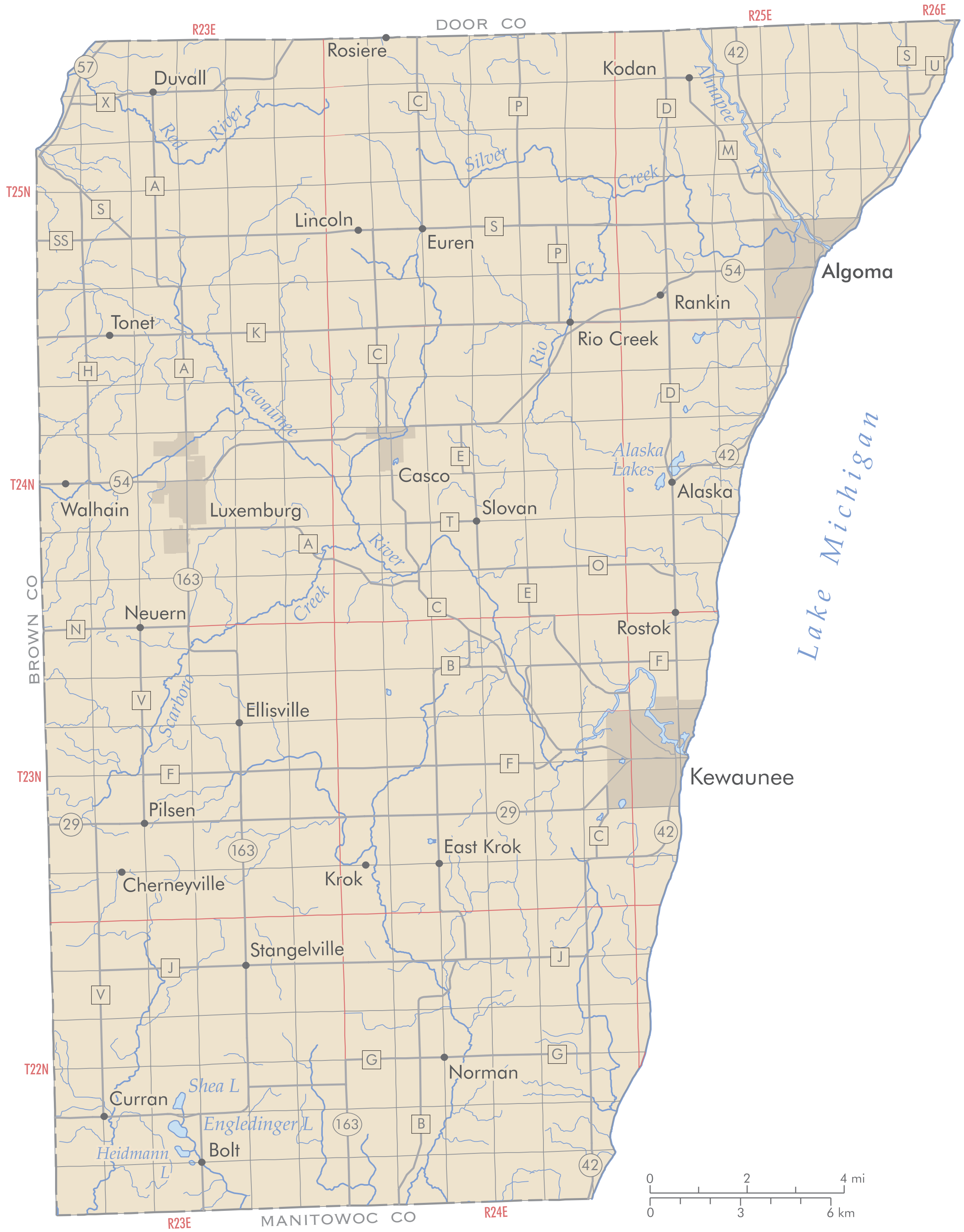


Figure 2. Shaded-relief map of Kewaunee County, from U.S. Geoogical Survey digital elevation data (1999).

Figure 3. Major geographic features of Kewaunee County.



Pre-Pleistocene geology

Regional bedrock stratigraphy

Precambrian igneous and metamorphic rock is found approximately 2,000 ft (600 m) below the ground surface in Kewaunee County. Overlying the Precambrian rock is approximately 1,000 ft (300 m) of Cambrian and Ordovician sandstone and dolomite. Above that lies approximately 400 ft (120 m) of Ordovician shale of the Maquoketa Formation, the upper part of which crops out along the shore of Green Bay; in eastern Kewaunee County, the Maquoketa is overlain by more than 500 ft (150 m) of Silurian dolomite (fig. 4).

The Silurian dolomite forms the core of the Door Peninsula and dips southeastward at about 12 m/km. In some places it crops out or is just below the surface soil, especially in the northern part of the county and in much of Door County. In other parts of Kewaunee County this dolomite is overlain by more than 150 ft (45 m) of Pleistocene sediment (figs. 5 and 6).

Figure 4. Stratigraphic units in Kewaunee County.

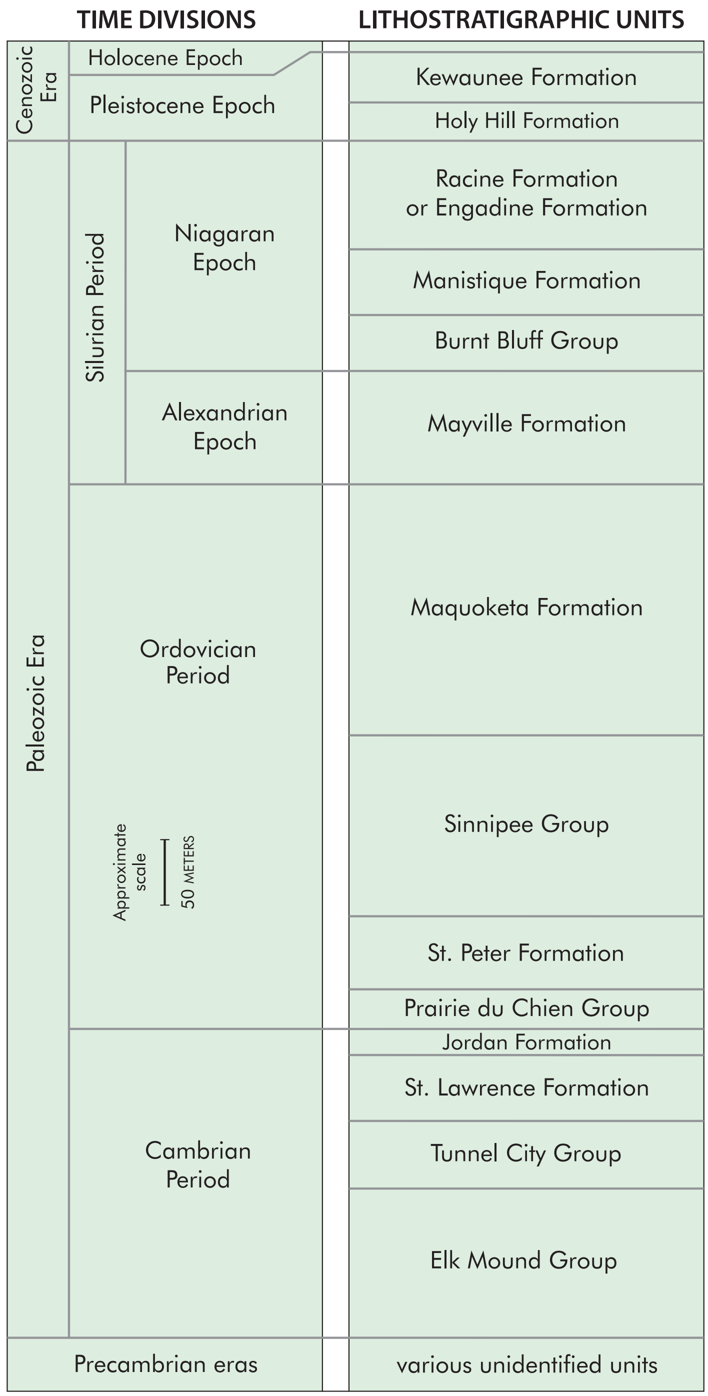


Figure 5. Depth to solid rock (thickness of Pleistocene sediment), in feet.

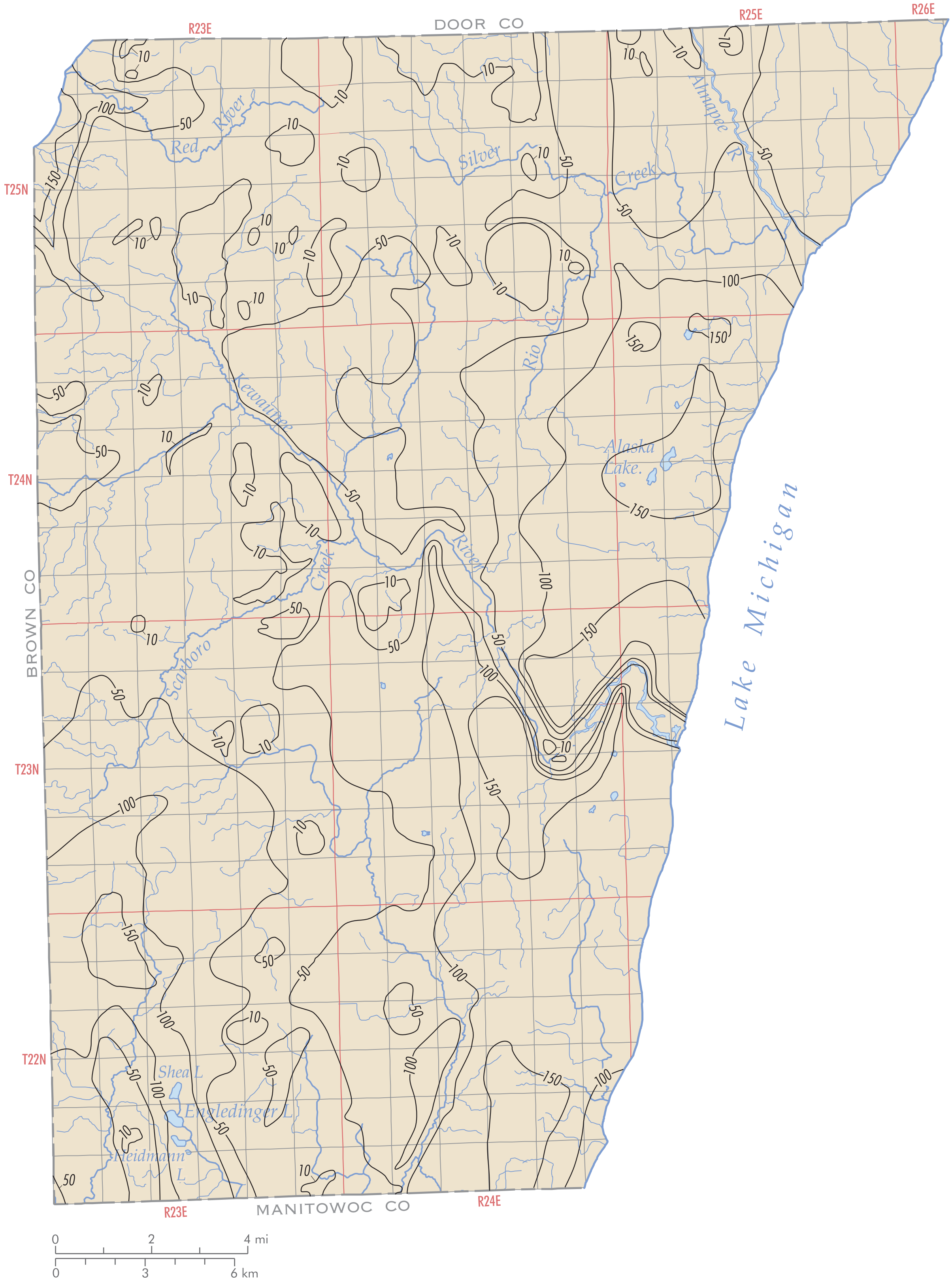
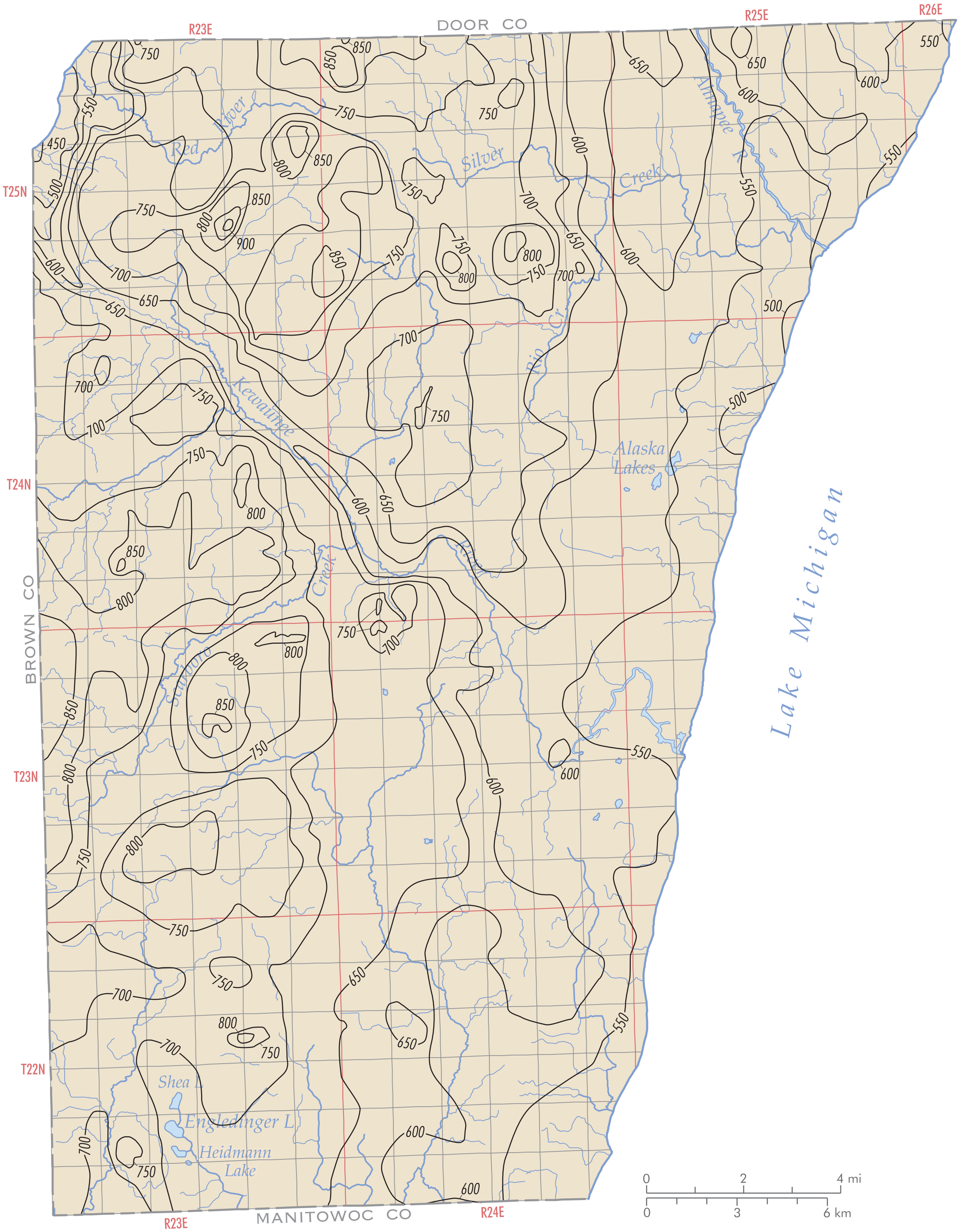


Figure 6. Elevation contours on the surface of the pre-Pleistocene rock, in feet.



Scarps

A scarp is a steep face of rock separating two gently sloping or level surfaces. Several bedrock scarps can be seen at different stratigraphic levels on the west and central part of the peninsula in Kewaunee County and adjacent areas.

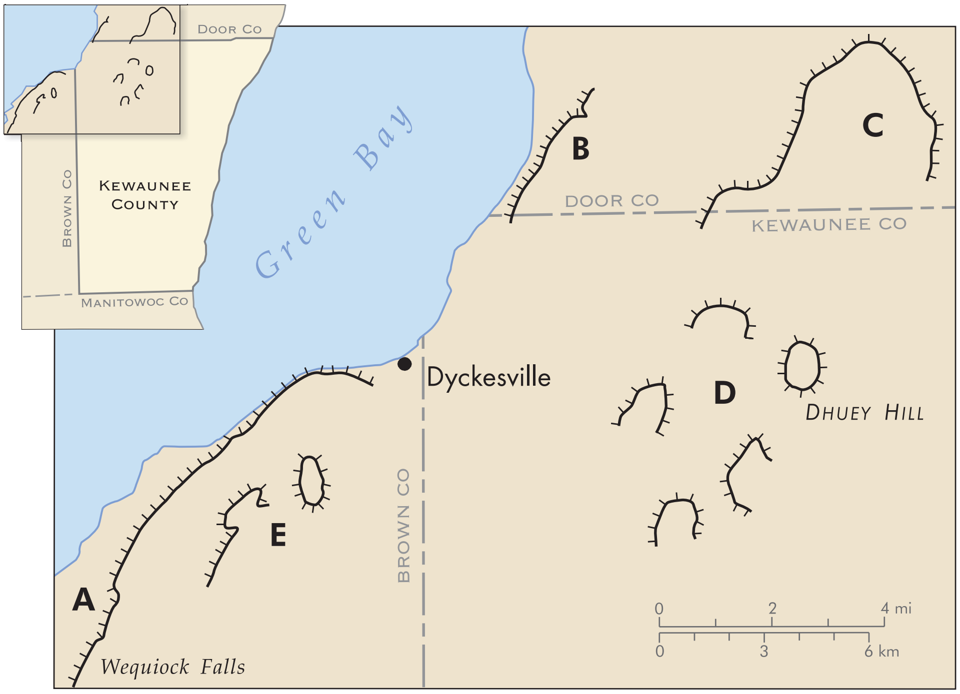
The most conspicuous scarp, the Niagara Escarpment, runs roughly parallel to the shoreline of Green Bay (*A* in fig. 7). The top of this scarp is up to 100 ft (30 m) above the present lake level. At Wequiock Falls, 8 mi (13 km) southwest of Dyckesville, most of this scarp is Maquoketa shale (Ordovician), with only the upper few feet composed of Mayville dolomite, deposited during the Silurian Period. The scarp curves inland in northeastern Brown County, where it is hidden under thick Pleistocene sediment. It reappears in northwest Kewaunee County and extends into Door County (*B* in fig. 7).

Another conspicuous scarp can be found about 2 mi (3 km) north of Kewaunee County and 5 mi (8 km) inland from Green Bay (*C* in fig. 7). The scarp is about 50 ft (15 km) high and apparently is composed of lower Niagaran dolomite. This scarp is less well defined southward into Kewaunee County.

A cluster of scarps in the northern part of Kewaunee County is marked by several flat-topped hills surrounded by scarps composed of dolomite (*D* in fig. 7). Dhuey Hill is the highest hill of the group and is probably made of dolomite of the Racine Formation.

To the west of Kewaunee County, a less-distinct scarp lies inland from Green Bay and southwest of Dyckesville (*E* in fig. 7). Its elevation is up to about 200 ft (60 m) above lake level; most of it is composed of Mayville dolomite.

Figure 7. Escarpments in Kewaunee County and adjacent areas (scarps A–E discussed in text).



Pleistocene stratigraphy

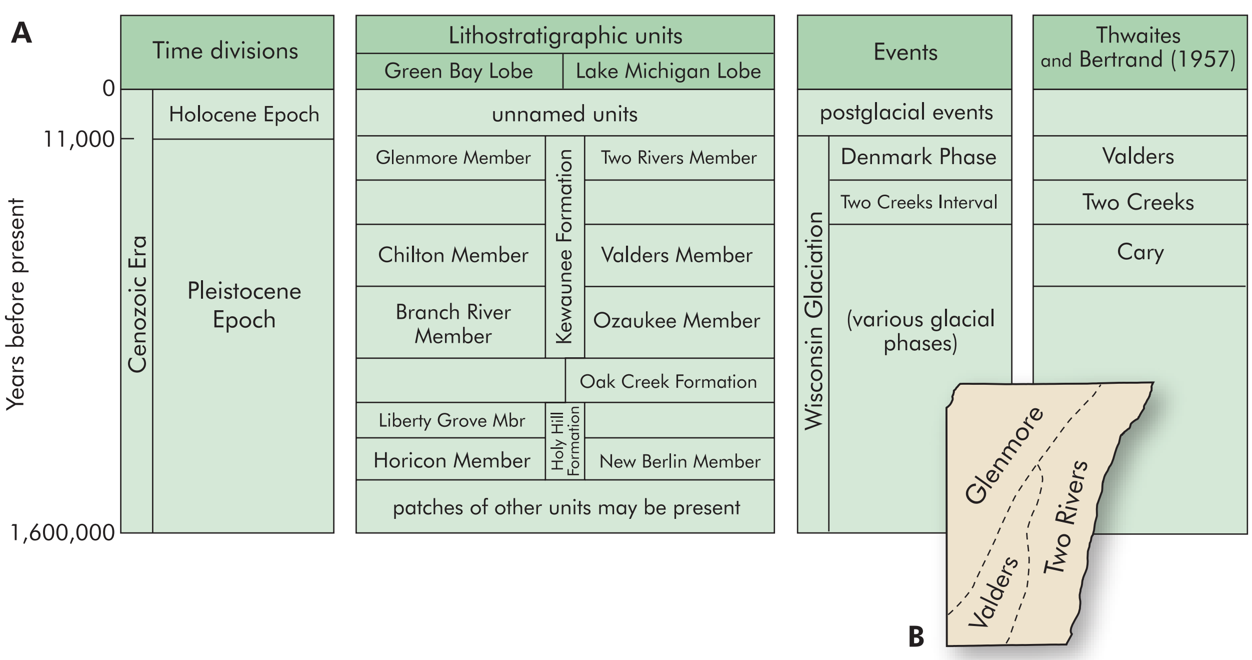
The basic outline of Pleistocene stratigraphy in the Kewaunee area has long been recognized (fig. 8). Thwaites and Bertrand (1957) reported a brown-hued sandy till, which they considered to be the Cary till, a name that has since been discontinued in Wisconsin. This sandy till is overlain in places by the Two Creeks Forest Bed, which is overlain by red-hued clayey till that Thwaites and Bertrand considered to be the Valders till.

Later, Acomb and Mickelson (in Mickelson and others, 1984) showed that reddish-brown clayey till is both over and under the forest bed. The till below the Two Creeks Forest Bed was correlated with the type Valders, and the clayey till unit directly above is the Two Rivers Member (fig. 8). Mickelson and associates (1984) also named two redder clayey units on the west side of the Lake Michigan Lobe and three more on the east side of the Green Bay Lobe. All the reddish-brown clay units were lumped together as the Kewaunee Formation (Acomb, 1978; McCartney, 1979; Acomb and others, 1982; McCartney and Mickelson, 1982; Mickelson and others, 1984).

Most of the previous stratigraphic work in Kewaunee County focused on exposures in the Lake Michigan bluffs on the east edge of the county (Acomb, 1978; Acomb and others, 1982; McCartney and Mickelson, 1982). In contrast, the stratigraphic information used in this study came largely from drill holes scattered across the county. The stratigraphic complexity revealed by these drill holes was unexpected, but perhaps explainable as the result of subglacial erosion and nondeposition, or it may be the result of the patchiness of the bed material in the source area of the till.

Glacial geologists have identified tens of significant glacial advances and recessions of the North American Ice Sheet during the Wisconsin Glaciation. If glacial fluctuations were as common during earlier glaciations, there may have been hundreds of them during the entire Ice Age, and a similar number of till sheets may have been deposited. However, it seems unlikely that many of the till sheets, especially the older ones, could be identified at any one spot because of subglacial erosion and nondeposition. The till of the most recent phase of glaciation is thin and patchy in many areas, and many of the earlier till sheets must have been even patchier due to erosion resulting from each additional glaciation. The tendency for patchiness increases northward on the Door Peninsula. Areas where bedrock is at the surface are especially common in northern Kewaunee County, and become increasingly so moving northward into Door County. For these reasons, the deeper units in a drill core are less likely to have correlatives in core from nearby drill holes. Similarly,

Figure 8. A. Outline of the chronology and stratigraphy of the Pleistocene materials and events in east-central Wisconsin. **B.** Distribution of Glenmore, Valders, and Two Rivers Members in Kewaunee County according to Acomb (1978).



John A. Luczaj

Carlson (2002) has noted that till units, such as those in members of the Kewaunee Formation in southeastern Wisconsin, cannot be distinguished using drill-core samples because they do not have contrasting lithologies.

The distance that a glacial margin recedes before the next readvance is generally not decipherable, but a recession of at least a few miles is probably needed before a glacial geologist would assign much significance to it. Evidence may be available for the minimum distance of recession, but the total extent of the recession is seldom known. An example is the recession of the glacier margin when the Two Creeks Forest was living in southeastern Kewaunee County. Radiocarbon-dated trees from that time were overlain by later glacial deposits for an up-glacier distance of tens of miles, indicating a readvance of at least that amount. For the forest to have dry land to grow on, the ice margin must have receded north at least far enough, perhaps 20 mi (30 km) or more, to allow Lake Michigan to drain northeastward through the Mackinac Straits.

Regional stratigraphic framework

The lower of the two main Pleistocene formations in east-central Wisconsin is the Holy Hill Formation. The Holy Hill Formation was named by Mickelson and Syverson (1997, p. 49–52), who described its till as yellowish brown to brown (7.5YR–10YR in field samples) and in some places reddish brown (5YR), containing from 50 to 80 percent sand. In the Kewaunee County cores described here, till identified as Holy Hill has a 10YR hue.

In Kewaunee County, the Holy Hill Formation is generally too poorly known to be subdivided, but the Liberty Grove Member of the Holy Hill Formation may be present. It was formally named by Schneider (in Mickelson and others, 1984, appendix 9b) as a member of the Horicon Formation, but is now considered to be a member of the Holy Hill Formation (Mickelson and Syverson, 1997). Schneider described Liberty Grove till as light brown (7.5YR 6/4) or brown (7.5YR 4/4 to 5/4 or 10YR 5/3) to yellowish brown (10YR 6/4 or 5/4). Commonly it is almost midway between 7.5YR 5/4 and 10YR 5/3. In many places it has a pale pink or salmon cast, which is attributed to the incorporation of ground-up Niagaran dolomite. Liberty Grove till typically has 50 to 60 percent sand and 5 to 15 percent clay. Schneider recognized the Liberty Grove only in Door County and northern Kewaunee County.

The upper of the two Pleistocene formations, containing clayey till, was formally named the Kewaunee Formation by Mickelson and others (1984, appendix 10). They characterized the till as brown (7.5YR 5/4) or reddish brown (5YR 4/4) and individual members as reddish brown (5YR 5/4, 5/3, and 4/4) and light reddish brown (5YR 6/3 and 6/4).

Most of the stratigraphic units in Kewaunee County (fig. 8) are subdivisions of the Kewaunee Formation (Syverson and others, 2011). Formally named members containing till deposited by the Lake Michigan Lobe include, from oldest to youngest, the Ozaukee, Valders, and Two Rivers Members. Those with till deposited along the east side of the Green Bay Lobe include the Branch River, Chilton, and Glenmore Members. The Branch River, Two Rivers, and Valders tills have similar grain size, with approximately 30 percent sand and 20 percent clay; the Ozaukee, Glenmore, and Chilton tills have approximately 15 percent sand and 35 percent clay. Those with similar grain size are distinguished in part by their clay mineralogy, which was not analyzed for this report, and by their stratigraphic position.

Stratigraphic units

To determine the stratigraphic framework of Kewaunee County, I used three sets of till samples: power drill with a split-spoon sampler, grab samples from outcrops scattered across the county, and outcrop samples from the shore bluffs of Lake Michigan.

Split-spoon samples

My determination of the stratigraphy of the county was based largely on the characterization of till in nearly continuous cores from drill holes at 13 locations.

In the following discussion of till samples, Pleistocene material has been grouped into lithostratigraphic units; some of these units have been formally named elsewhere in the region, but many of the units have been informally designated for this report. A lithostratigraphic unit (a named bed, member, formation, or group) is here considered to be a nongenetic, descriptive unit defined by its particular lithology and stratigraphic position.

Some of the recognized stratigraphic units are remarkably uniform vertically within individual drill holes. However, lateral correlation of most of the units from hole to hole is generally uncertain, perhaps because the till units are not uniform laterally or because they are so patchy that they are only found in one hole or a few holes.

Most contacts between till sheets in Kewaunee County are sharp and can be recognized in outcrop within a vertical distance of a few millimeters or less. At each drill site, the complete core was laid out on the ground and described; descriptions emphasized differences in color and grain size. In large, continuous outcrops, such as those in the shore bluffs of Lake Michigan, the relative stratigraphic positions of lithologically distinct units are, for the most part, obvious. However, in the cores I examined, a lithologically distinct section could be either a stratigraphic unit or a block or slab within a stratigraphic unit, detached from a different stratigraphic unit somewhere beyond the drill hole.

Because we obtained almost continuous cores from the drill holes, I judged a sequence that was lithologically distinct to be a block or slab within a stratigraphic unit if the material above the sequence was lithologically equivalent to the material below it. If different, I considered it to be a stratigraphic unit. Misjudgments may have occurred where the block was at the bottom of a stratigraphic unit with none of the enclosing stratigraphic unit under it, either because it was deposited that way or because part of the core was lost during drilling and sample retrieval.

Another potential problem was differentiating between till and resedimented till. Individual, very local layers of supraglacial mudflow can be misinterpreted as a regional till sheet. An attempt was made to avoid that problem by discounting adjacent layers having similar lithologic composition.

Lake Michigan shoreline and bluffs

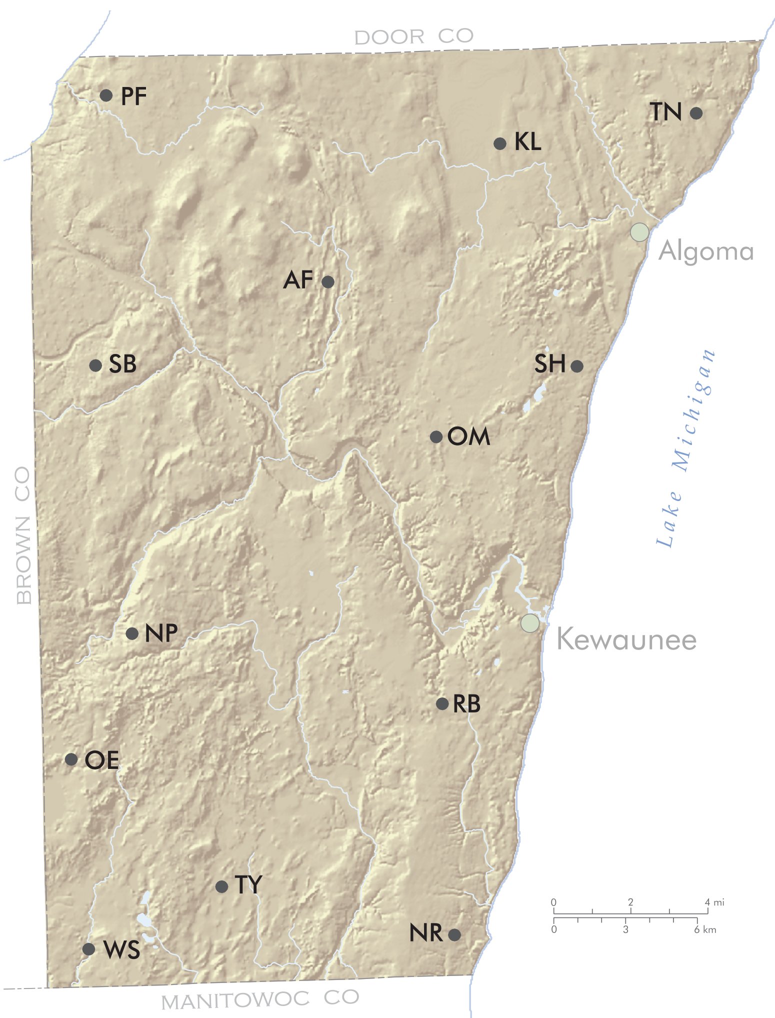
William N. Mode

This procedure resulted in the recognition of some till units as thin as an inch or two, which is thinner than generally recognized by glacial geologists, probably because drill holes provide too little sample for laboratory analysis of the thinnest units. In places where Silurian limestone is at the land surface, all till sheets in the region are absent. It should not be surprising that a till sheet was deposited unevenly, with large areas where the sheet is thin or absent between areas with thicker deposits.

Till samples from 13 sites (fig. 9) were taken using a truck-mounted power drill with a split-spoon sampler. Each sample was 2 ft (0.6 m) long and 2 in (5 cm) in diameter, and total drill hole depth was between 15 and 72 ft (5 and 22 m). Core recovery was nearly continuous, except in the lower part of a few holes. Till samples were commonly collected at approximately 8-, 12-, or 24-in (0.2-, 0.3-, or 0.6-m) intervals, but at wider intervals in the lower part of some holes.

My names for till units consist of two uppercase letters that represent the drill hole designation (fig. 9) followed by a lowercase letter, beginning with 'a' for the till unit surface nearest the surface and continuing down the sample with consecutive letters of the alphabet. For example, unit AFa is the nearest-surface till unit from drill hole AF.

Figure 9. Locations of split-spoon drill holes.
(Sample logs of each drill hole provided in figs. 10a–m.)



Reading the sample logs

The analyses presented in figures 10a–m use the following symbols.

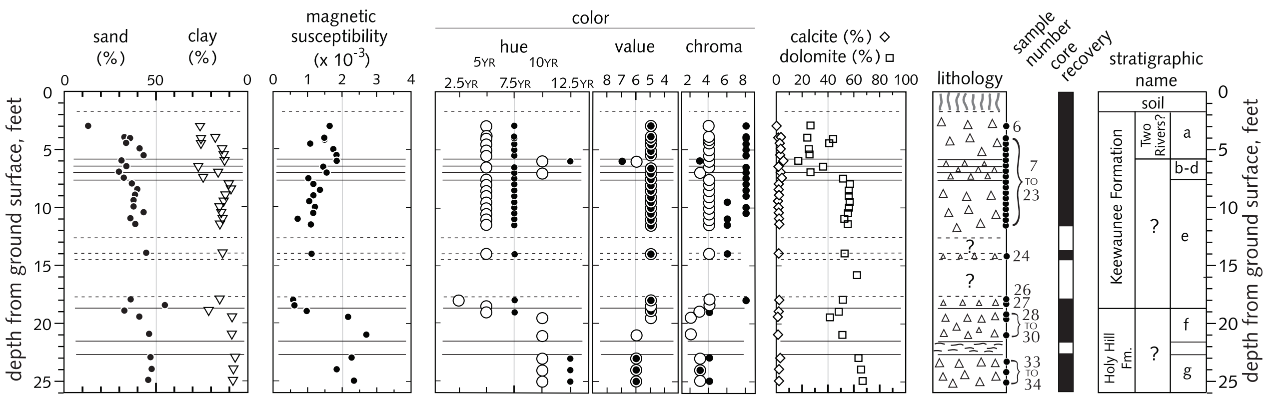
COLOR (Munsell color)
- ○ bulk sample
- • suspended clay

LITHOLOGY
- soil
- △ till
- silt and clay
- • sand and gravel
- —— sharp contact between lithologies seen in field
- - - - gradational contact seen in the field or only in laboratory data

Drill hole AF

Drill hole AF was drilled to a depth of 30 ft (10 m), roughly halfway to bedrock, 2 mi (3 km) north of Casco (fig. 10a). The drill site is near the crest of one of the band of low till ridges (about 20 ft high) and eskers that trend north–south from southwestern Door County to Casco. Core recovery was continuous, except for most of a cobbly zone between a depth of 13 to 16 ft (4 to 5 m). The surface till in this part of Kewaunee County has been mapped by Mickelson and others (1984) as the Two Rivers Member of the Kewaunee Formation (till of the Lake Michigan Lobe). The near-surface till (units AFa–e) to a depth of 19 ft (6 m) is conspicuously redder than that below, suggesting Kewaunee Formation over Holy Hill Formation (units AFf–g). This near-surface till resembles typical Two Rivers till. The upper part down to 6 ft (1.8 m), unit AFa, has higher magnetic susceptibility and considerably less dolomite than the part below 7 ft (2.1 m), unit AFe; they are probably two separate till sheets. These two sheets are separated by three thin layers: units AFb and AFd are more orange in color; AFc, sandwiched between, is slightly redder. The underlying till units (AFf–g) have typical Holy Hill colors, but are somewhat finer grained than typical Holy Hill till.

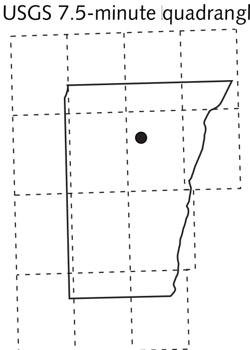
Figure 10a. Sample log for drill hole AF.

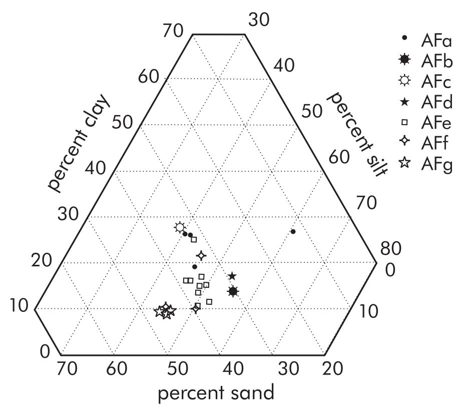


NW1/4 NE1/4, sec. 5, T24N, R24E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

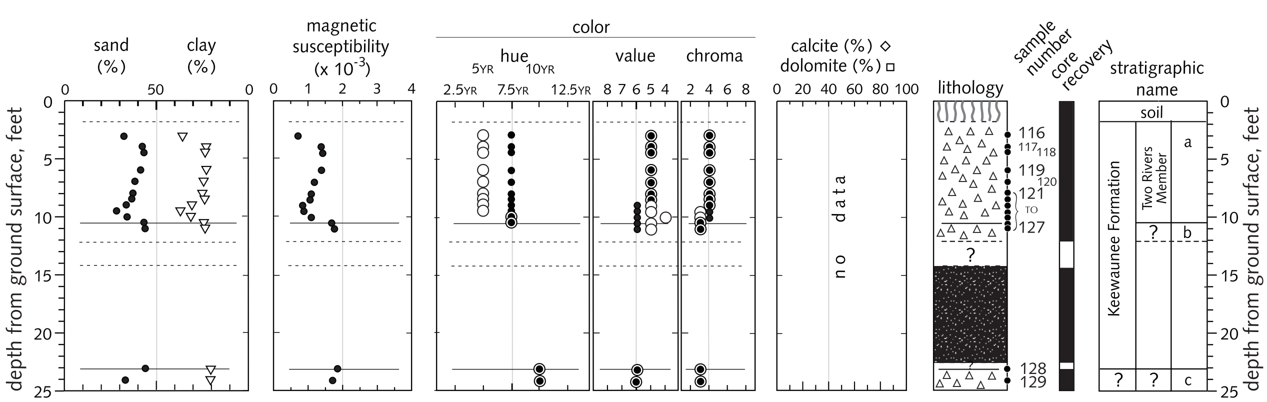




Drill hole KL

Drill hole KL penetrated 24 ft (7 m), reaching more than halfway to bedrock in a nearly level area 2 mi (3 km) southwest of Kodan (fig. 10b). The surface till in this area has been considered to be part of the Two Rivers Member, but unit KLa has less silt than most Two Rivers till. A sharp color contact (redder above and grayer beneath) was observed in the field between samples 126 and 127, but was not observed in the laboratory. Unit KLc may be part of the Holy Hill Formation, but is finer grained.

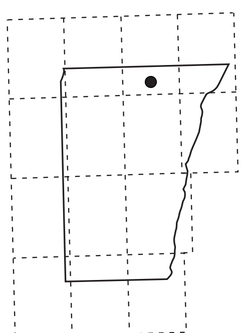
Figure 10b. Sample log for drill hole KL.

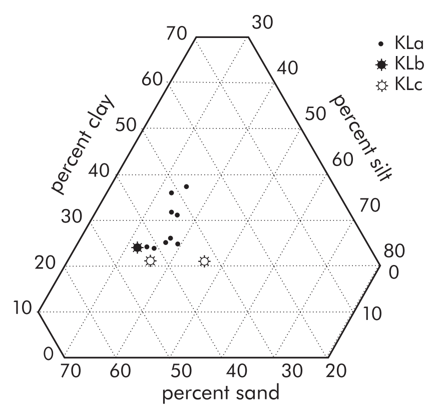


NW1/4 SW1/4, sec. 18, T25N, R25E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

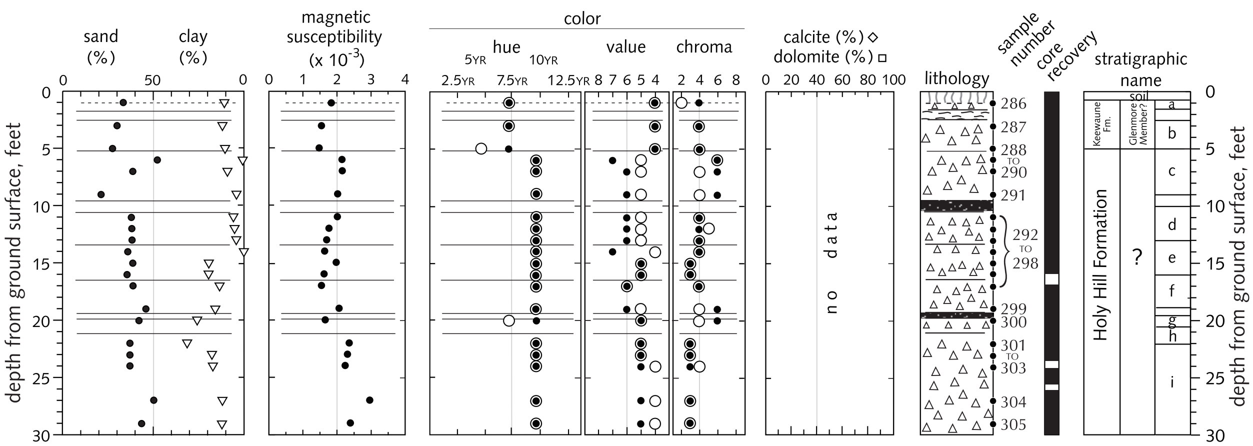




Drill hole NP

Drill hole NP reached a depth of 33 ft (10 m), nearly halfway to bedrock, in a gently sloping area 1 mi (2 km) west of Ellisville (fig. 10c). According to Acomb (1978), the site is several hundred feet west of, and therefore within, the eastern limit of the till of the Glenmore Member. However, units NPa and NPb have twice as much sand and a third as much clay as typical Glenmore. It is more similar to Two Rivers till, but has less clay. Units NPd through NPi have the right color for Holy Hill till, but have 10 percent less sand than is expected. The subdivisions NPc through NPi of the Holy Hill are based on abrupt color contacts that were obvious in the field, but were not verified in the laboratory. Unit NPd has conspicuous red-stained joints.

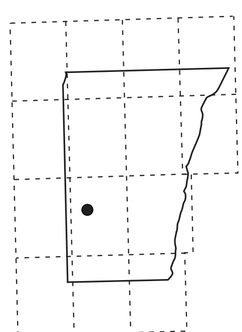
Figure 10c. Sample log for drill hole NP.

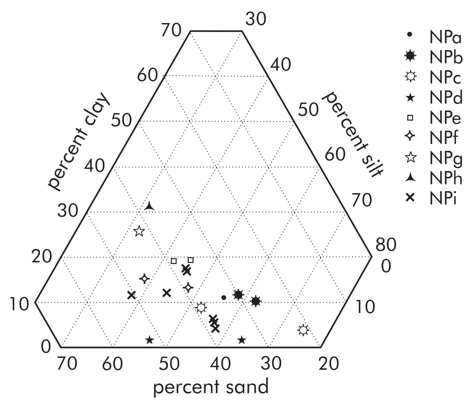


NE1/4 NW1/4, sec. 21, T23N, R23E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

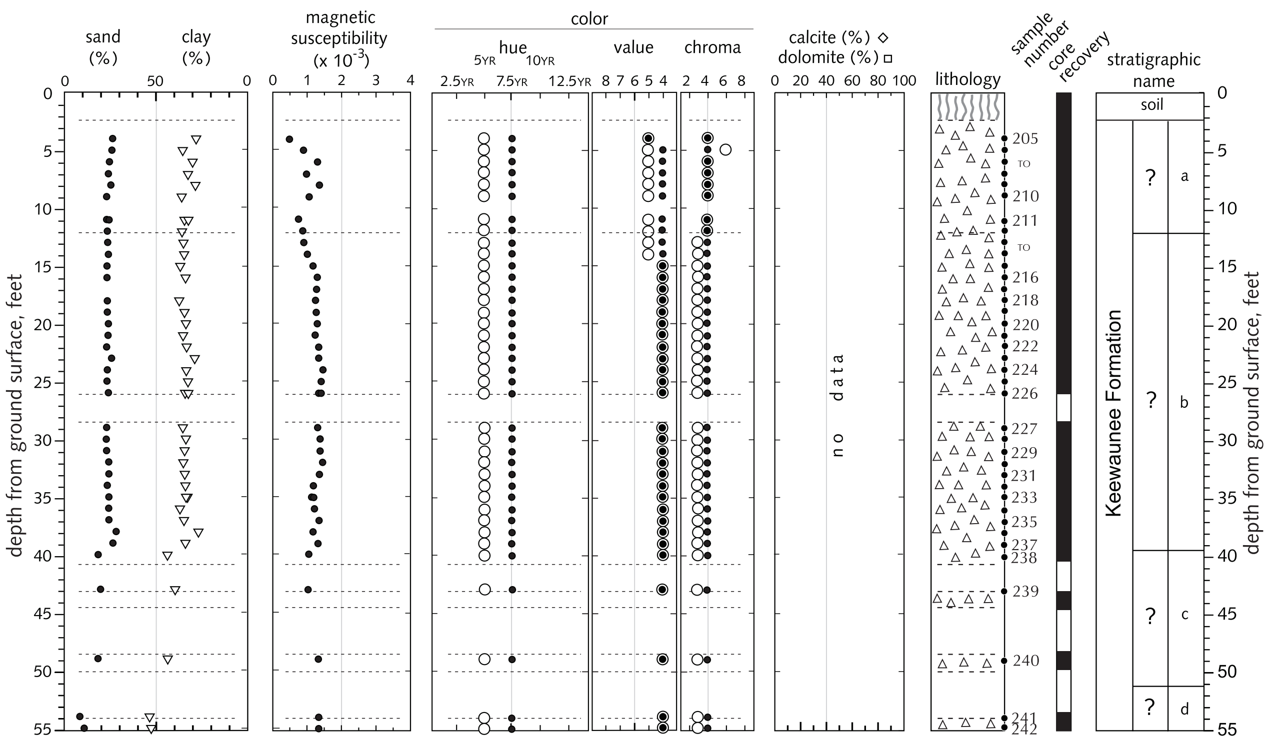




Drill hole NR

Drill hole NR reached a depth of 55 ft (17 m), more than halfway to bedrock, on a gentle slope in southeastern Kewaunee County (fig. 10d), in an area considered to have Two Rivers till at the surface. This sequence is remarkably uniform from top to bottom, especially the middle two-thirds (unit NRb). If there are separate till sheets here, the contacts are diffuse; no abrupt contacts were observed in the field. Units NRa and NRb are too clayey to be Two Rivers till and have less silt than the Glenmore, and they are too sandy to be Ozaukee till.

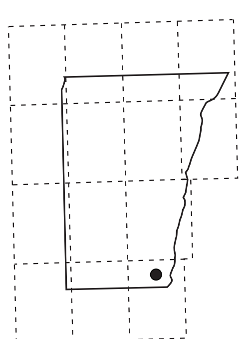
Figure 10d. Sample log for drill hole NR.

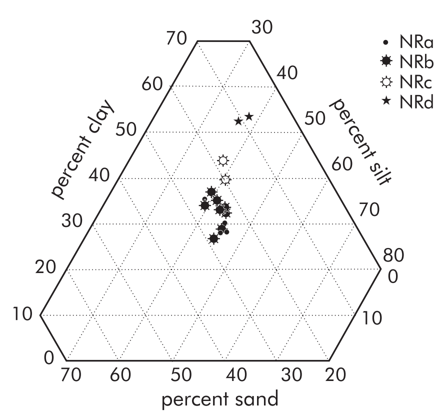


SW1/4 SE1/4, sec. 26, T22N, R24E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

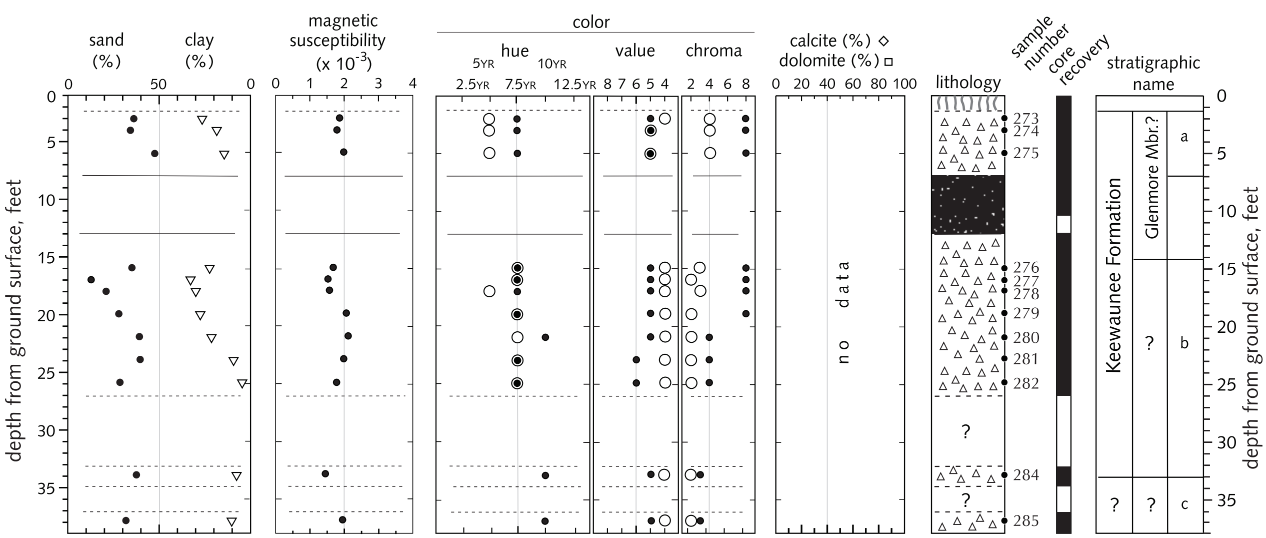




Drill hole OE

Drill hole OE penetrated 50 ft (15 m), about one-third of the distance to bedrock, on a gentle slope in the southwestern corner of the county. The drill hole was about 3 mi (5 km) west of Stangelville (fig. 10e). The site is about 1 mi (2 km) west of what has been considered to be the east edge of the till of the Glenmore Member. While the surface till here (unit OEa), at a depth of 7 ft (2 m), would be expected to be part of the Glenmore, it has more than twice as much sand as has typically been reported in the Glenmore till (Mickelson and others, 1984) and 15 percent more sand than reported for Glenmore till in southwest Door County (Brown, 2001). The next 7 ft (2 m) is sand, followed by unit OEb to a depth of 33 ft (10 m) and unit OEc. Both these units are similar to the surface unit, OEa. A sharp color contact at 33 ft (10 m) (upper unit OEb is redder; lower unit OEc is grayer) was noted in the field, but not in the lab.

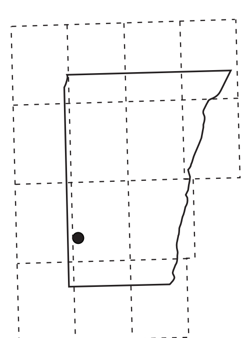
Figure 10e. Sample log for drill hole OE.

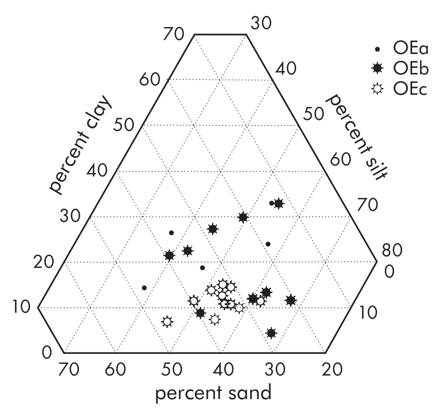


NW1/4 NE1/4, sec. 32, T23N, R23E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

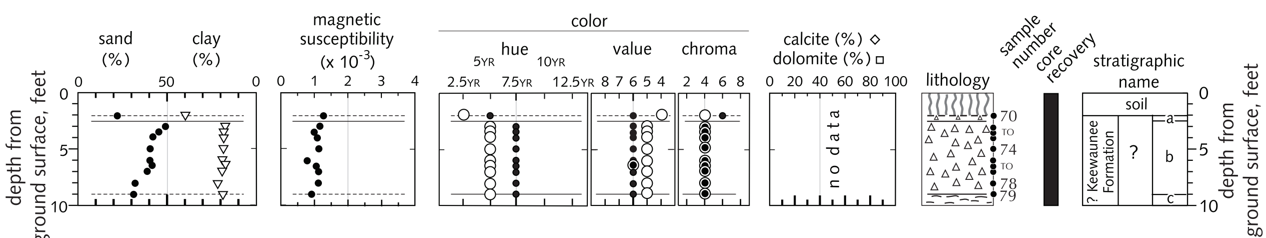




Drill hole OM

Drill hole OM penetrated 72 ft (22 m), over halfway to bedrock, but till was encountered in only the top 10 ft (3 m). The rest was lacustrine silt and clay and only the upper part is shown below. The drill hole was near the crest of a glacial hummock that was approximately 10 ft (3 m) high and located 1.5 mi (2.5 km) east of Slovan (fig. 10f). The uppermost sample (unit OMa) was from a unit identified in the field as a separate till from the rest of the samples because of the sharp contact between them. Unit OMa has much more clay than typical Two Rivers till, but that may be because it's within the zone of clay enrichment in the surface soil. Unit OMb is sandier than unit OMa.

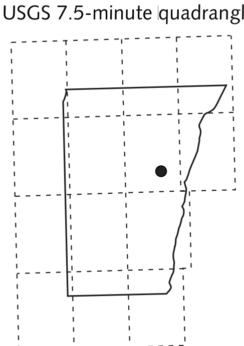
Figure 10f. Sample log for drill hole OM.

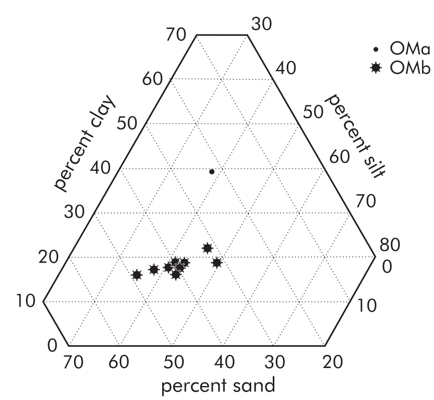


NE1/4 NW1/4, sec. 26, T24N, R25E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

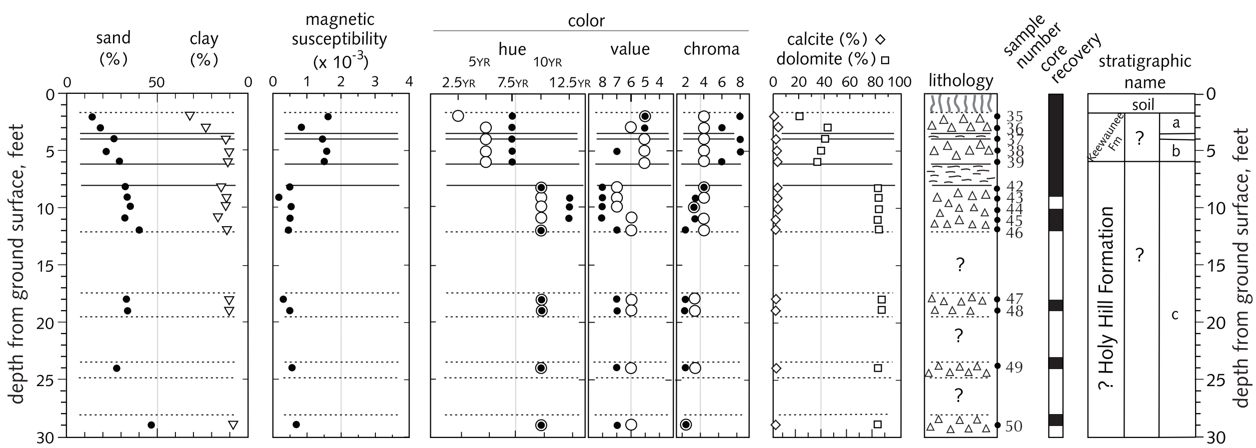




Drill hole PF

Drill hole PF was drilled to 30 ft (9 m), about one-third of the way to bedrock, 130 ft (40 m) above the level of Green Bay, 0.5 mi (1 km) west of Duvall (fig. 10g). Unit PFa, which is 2 ft (0.6 m) thick, is similar to the Glenmore till that would be expected at the surface here. Unit PFb has more sand and considerably less clay than the Glenmore. The base of unit PFb is a sharp contact with the underlying white (Munsell 10YR 8/2) limey pond sediment. The till of unit PFc, also called white in the field (Munsell very pale brown to light yellowish brown downward), is the same hue as Holy Hill till, but much lighter than is typical. The till is whiter and has more dolomite than any other unit analyzed here.

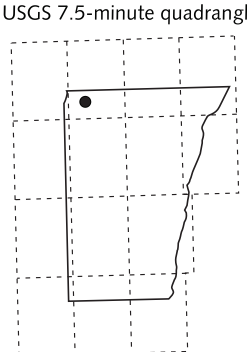
Figure 10g. Sample log for drill hole PF.

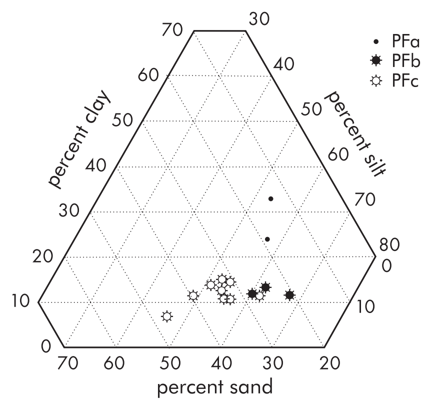


SW1/4 SW1/4, sec. 4, T25N, R23E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

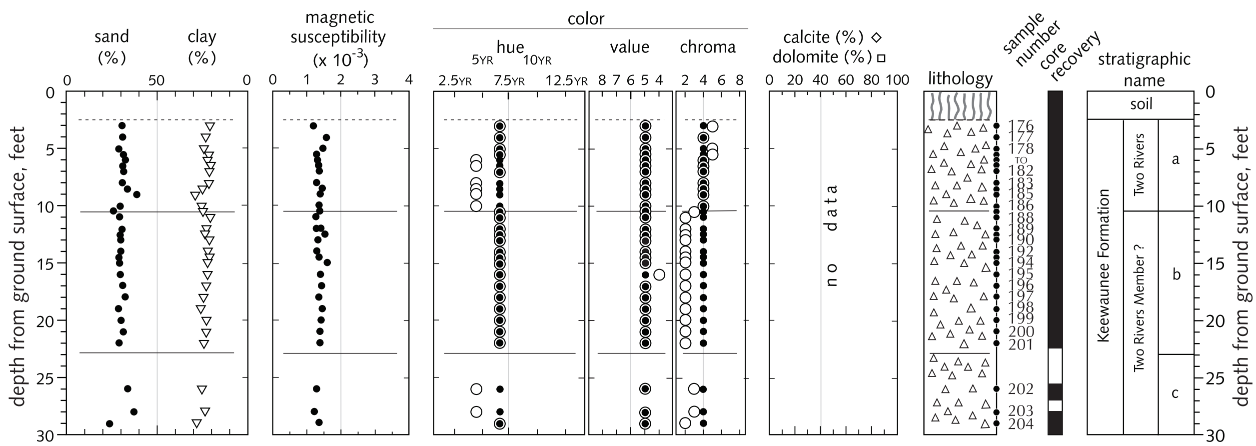




Drill hole RB

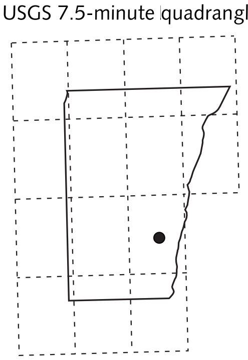
Drill hole RB, like drill hole NR, revealed strikingly uniform till from top to bottom. The drill hole was 30 ft (9 m) deep, extending approximately one-fifth of the way to bedrock, into a glacial hummock, 2.5 mi (4 km) east of East Krok (fig. 10h). Of the 13 drill holes described here, material from drill holes RB and NR might be expected to be the most similar because they are from similar geologic settings and are only 6 mi (10 km) apart. However, till from drill hole NR has 6 to 7 percent less sand and approximately 10 percent more clay, which is a greater difference than expected within a single unit in that short distance. The three units of drill hole RB (RBa–c) are within the range of regional variation of typical Two Rivers till.

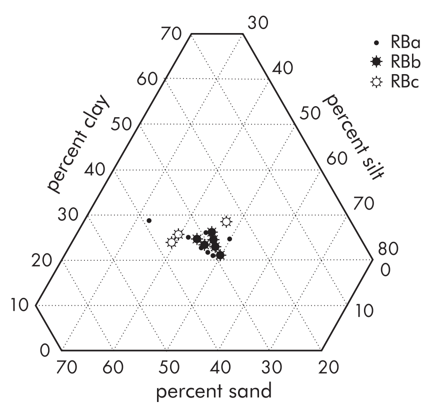
Figure 10h. Sample log for drill hole RB.



Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

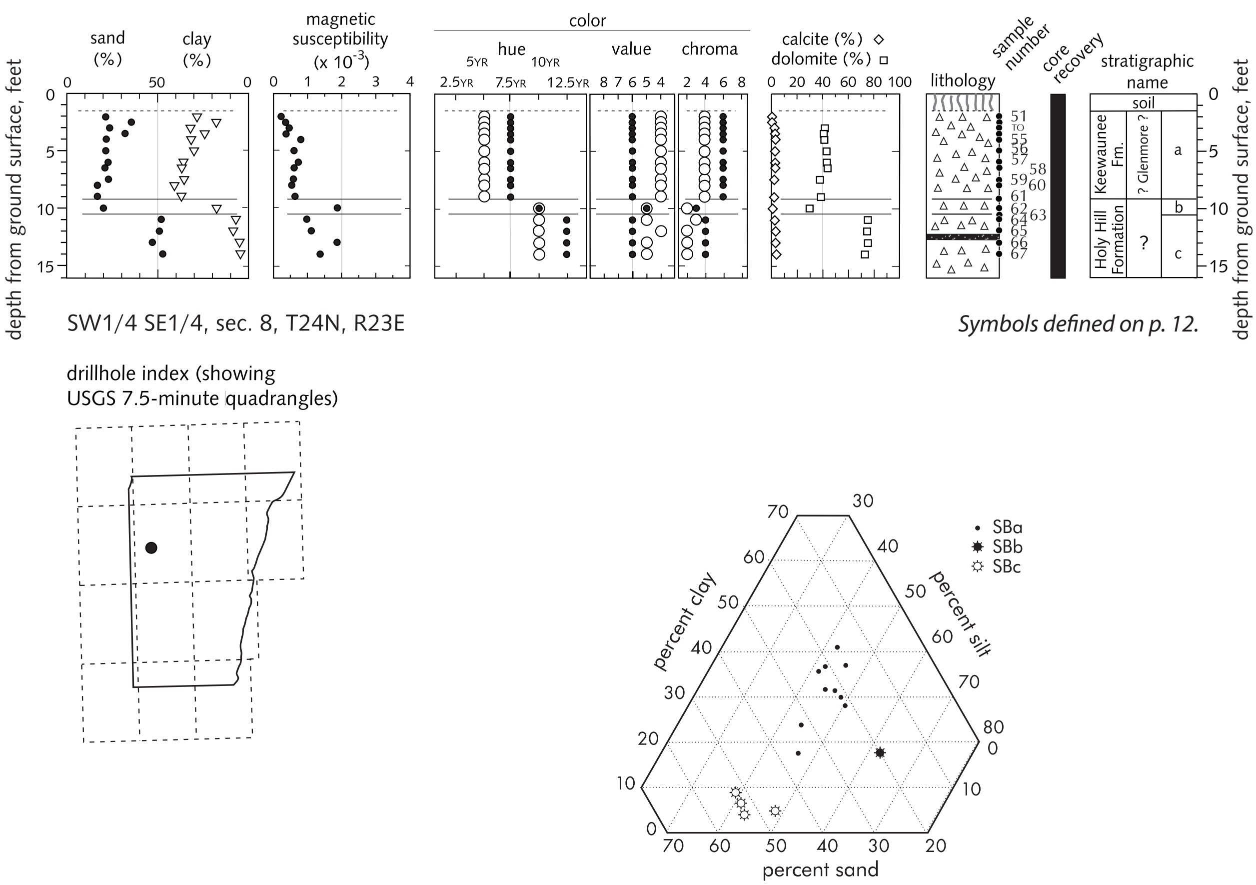




Drill hole SB

Drill hole SB was 16 ft (5 m) deep, about halfway to bedrock, on nearly level land 2 mi (3 km) south of Tonet (fig. 10i). The sequence here resembles that found in drill hole PF, 7.5 mi (12 km) to the north. Unit SBa resembles unit PFa, except that unit PFa has somewhat greater magnetic susceptibility and less clay than unit SBa. Unit SBc, like unit PFe, is mostly dolomite.

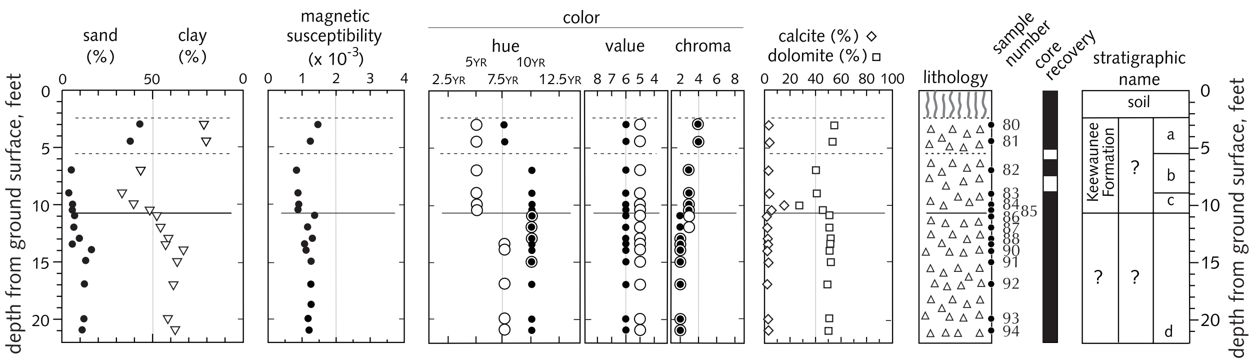
Figure 10i. Sample log for drill hole SB.



Drill hole SH

Drill hole SH was 36 ft (11 m) deep, one-quarter of the way to bedrock, in a nearly level area 1 mi (2 km) northeast of Alaska and 4 mi (6.5 km) northeast of drill hole OM (fig. 10j). Unit SHa resembles the Two Rivers Member. Units SHb and SHc have more clay than any previously recognized member of the Kewaunee Formation. Unit SHd is similar in color to Holy Hill Formation till, but contains far too little sand.

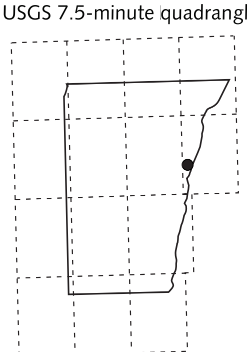
Figure 10j. Sample log for drill hole SH.

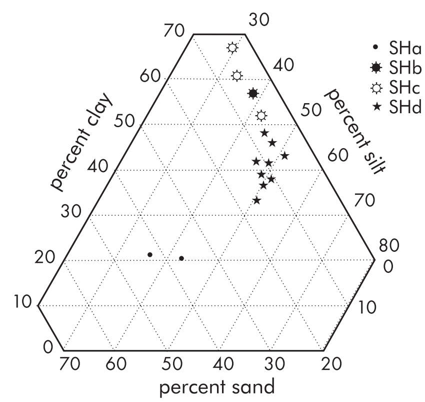


SW1/4 NW1/4, sec. 16, T24N, R25E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

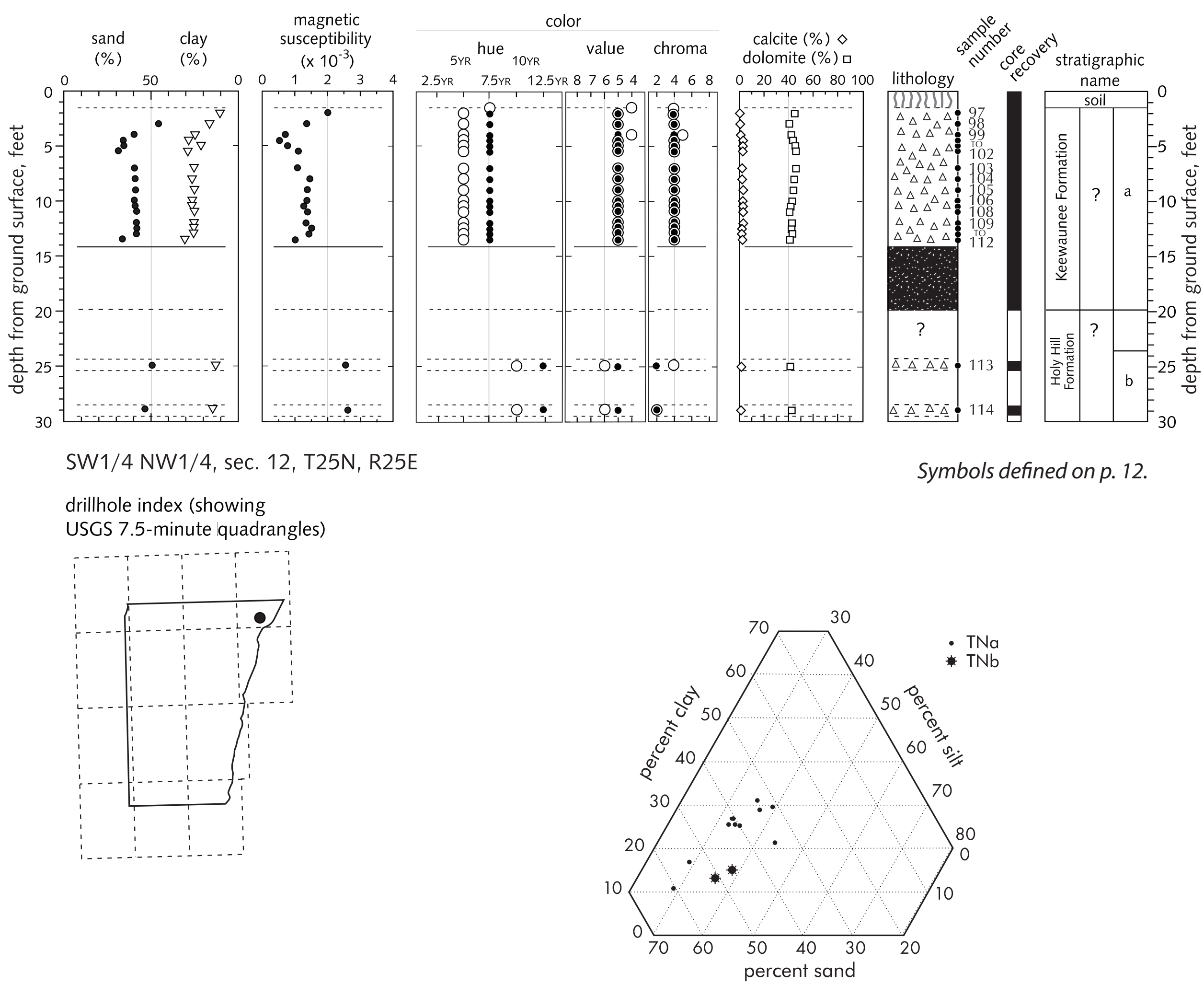




Drill hole TN

Drill hole TN was drilled to 33 ft (10 m), halfway to bedrock, in a nearly level area 2 mi (3 km) northeast of Algoma and 5 mi (8 km) northeast of drill hole KL (fig. 10k). Unit TNa is similar to unit KLa; both are presumably part of the Two Rivers Member, although they are less silty than normal. Unit TNa could represent a later glacial advance into northeastern Kewaunee County.

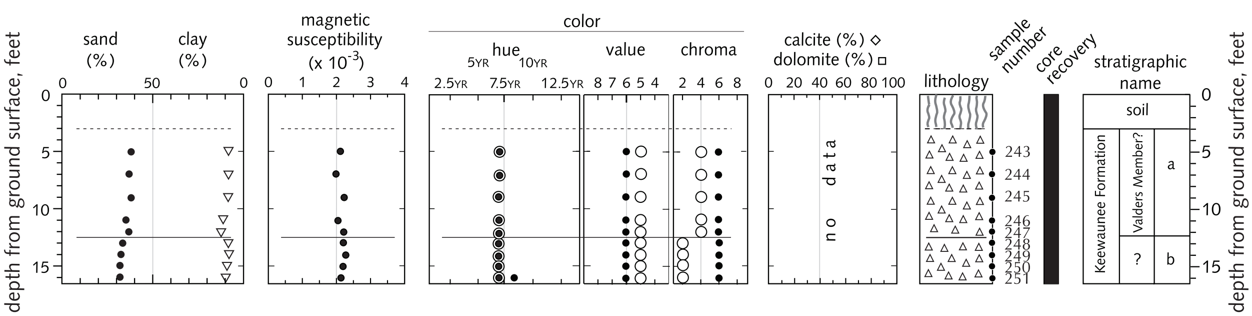
Figure 10k. Sample log for drill hole TN.



Drill hole TY

Drill hole TY was 16 ft (5 m) deep, one-third of the distance to bedrock, on the crest of a low inconspicuous drumlin, about 10 ft (3 m) high, 2.5 mi (4 km) south of Stangelville (fig. 10l). Unit TYa apparently is the surface till in the southwestern part of the county, which coincides with the Valders till mapped along the border with Manitowoc County by Mickelson and Socha (in press). Unit TYb is very similar to TYa, but is considered to be separate because of a sharp color contact observed in the field.

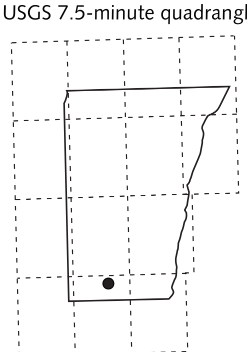
Figure 10l. Sample log for drill hole TY.

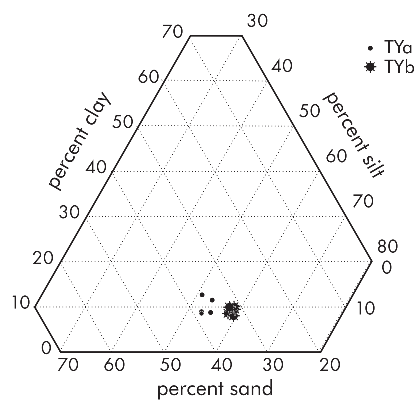


NW1/4 SE1/4, sec. 23, T22N, R23E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)

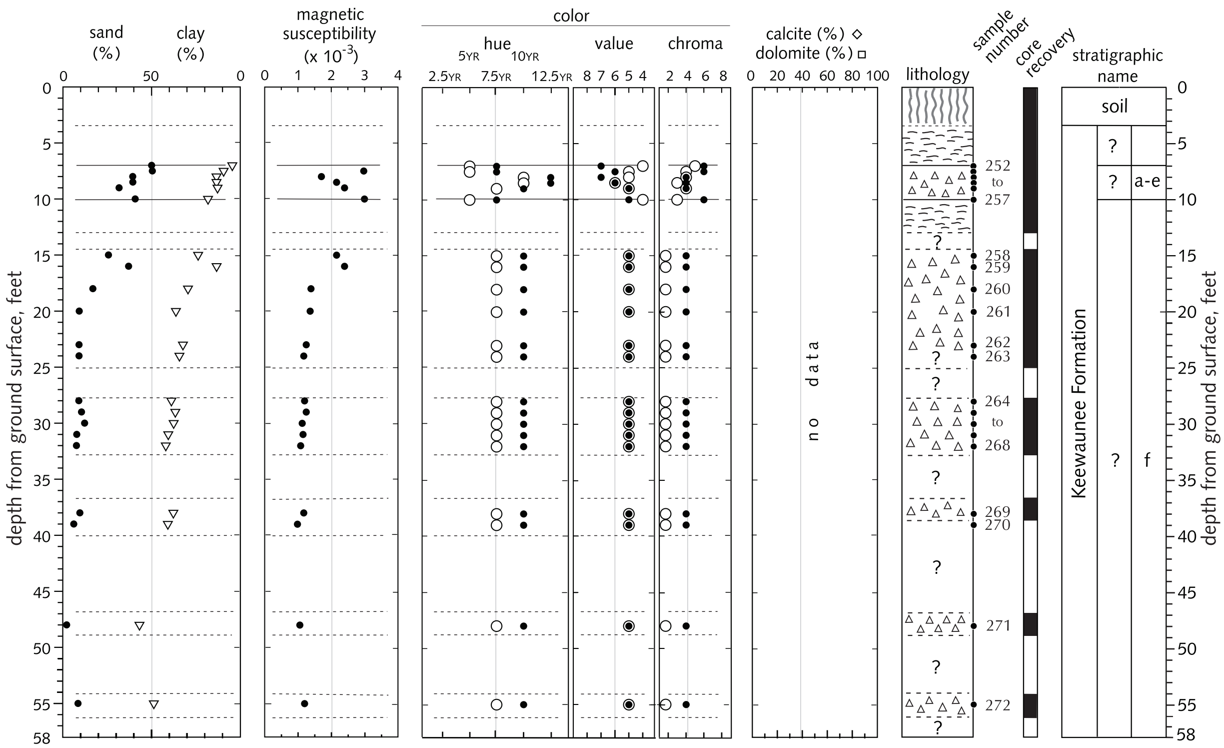




Drill hole WS

Drill hole WS reached bedrock at a depth of 62 ft (19 m), in a flat area 1 mi (2 km) south of Curran (fig. 10m). Bedrock crops out 0.5 mi (1 km) northeast. The site is 2 mi (3 km) southeast of the outer extent of the Glenmore till, adjacent to areas with Valders till at the surface (Mickelson and Socha, in press). The upper 6 ft (2 m) consists of soil and offshore sediment. Below that is a cluster of five thin till units (units WSa–e), distinguished in the field mainly by color. They overlie several feet of offshore sediment (unit WSf), which overlies a thick sequence of Kewaunee till. Except for the top part, unit WSf has much less sand than typical Valders till (fig. 8).

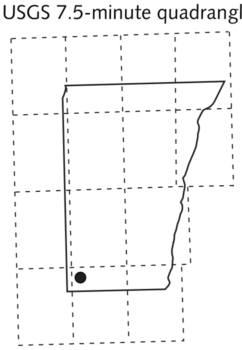
Figure 10m. Sample log for drill hole WS.

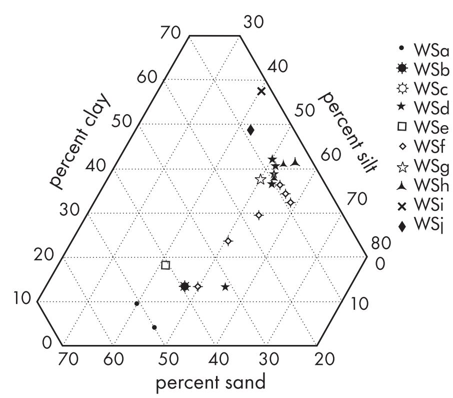


NW1/4, sec. 32, T22N, R23E

Symbols defined on p. 12.

drillhole index (showing USGS 7.5-minute quadrangles)





Near-surface grab samples

Previously published maps of the surface till (for example, Mickelson and Evenson, 1975) show the Two Rivers Member in the eastern part of Kewaunee County, the Glenmore Member in the northwest, and the Valders Member in the southwest part of the county (fig. 8B).

My laboratory analysis of surface till in this area shows greater detail. Figures 12, 13, and 14 present grain-size distribution, magnetic susceptibility, and color of grab samples collected just below the surface soil in roadcuts and other shallow exposures in these areas. I tried to sample below the soil surface, but some samples may have been influenced by the leaching of carbonates or the illuviation of clay. The near-surface till is assumed to be the till of the most recent glacial advance across an area, but where the till sheet is very thin at the sample site, an older till sheet may have been sampled instead. The surface till tends to be haphazardly variable,

Figure 11. Surface till samples grouped by lithology.

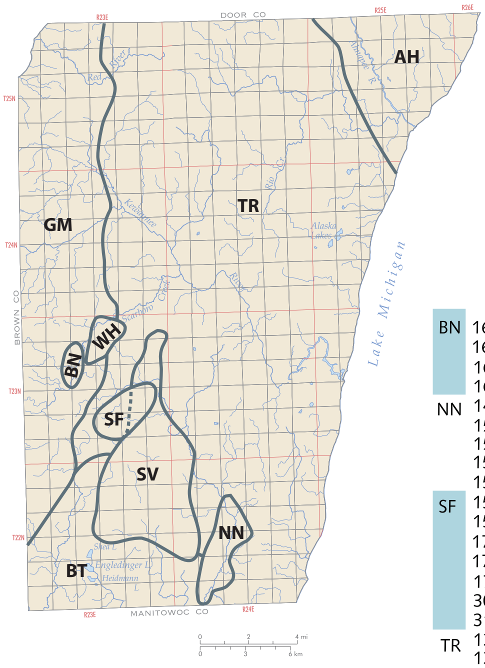
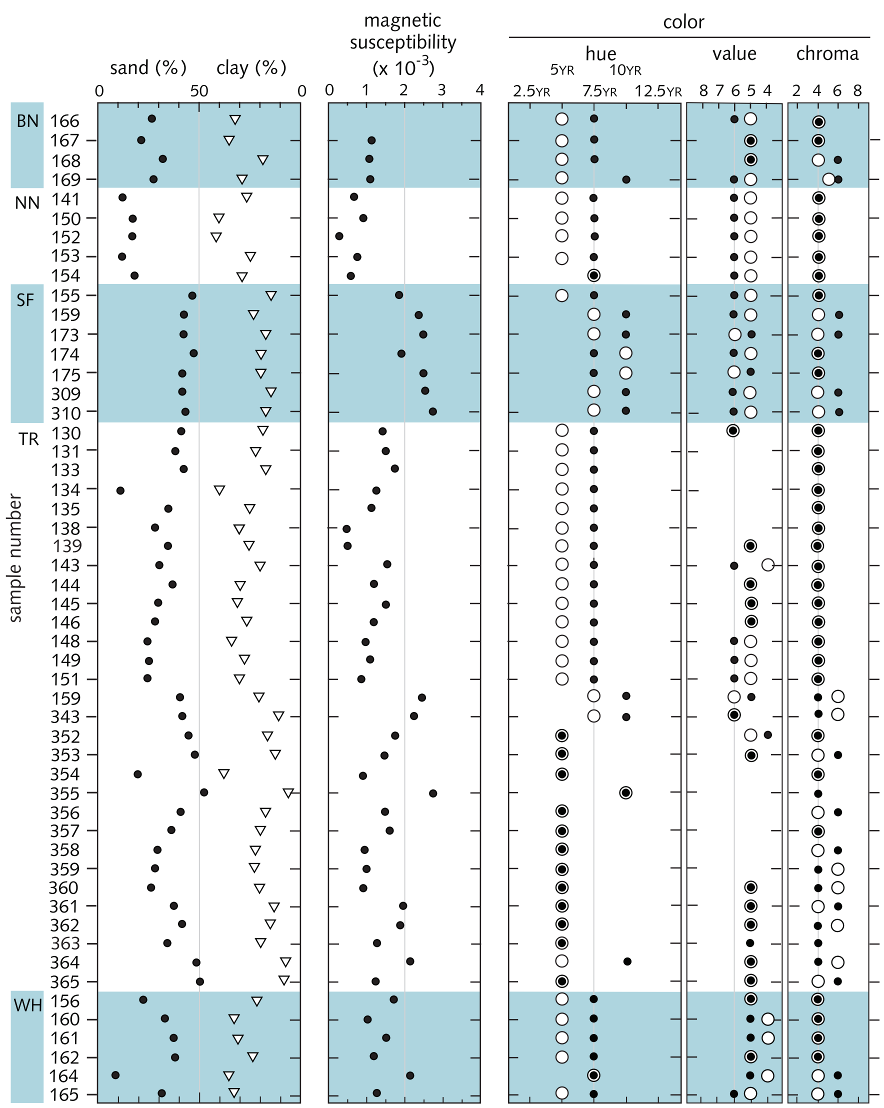


Figure 12. Analyses of surface till samples from probable Two Rivers Member in area TR. Status of surface till areas BN, NN, SF, and WH is discussed in text. Locations shown in figure 11.



but I've attempted to group areas of similar lithology together, as shown in figure 11.

The surface till of at least the eastern part of area TR (fig. 11) has been considered to be part of the Two Rivers Member (for example, Acomb and others, 1982). The type section of the Two Rivers Member of the Kewaunee Formation is near the city of Two Rivers, 11 mi (18 km) south of Kewaunee County on Lake Michigan. Two reference sections have been designated in lake bluffs 1 mi (2 km) south of the city of Kewaunee and at the southeast corner of Kewaunee County (Mickelson and others, 1984). The Two Rivers till in this type region averages 31 percent sand, 50 percent silt, and 19 percent clay, with reddish brown to pink hues (5YR and 7.5YR); these are approximately the characteristics of all the coarser members of the Kewaunee Formation (Mickelson and others, 1984). In Kewaunee County, the apparent equivalent of the Two Rivers (in areas AH, NN, SV, and TR of fig. 11) ranges from approximately 10 to 50 percent sand, 35 to 60 percent silt, and 5 to 40 percent clay, on the basis of laboratory analysis of 50 samples collected just below the surface soil. Most field samples are reddish brown (5YR 5/4).

The surface till of the westernmost part of the county (areas BN, GM, and WH, fig. 11) is considered part of the Glenmore Member (Mickelson and others, 1984). The type section of the Glenmore is 12 mi (20 km) west of Kewaunee County, south of Green Bay. Compared to Two Rivers till, in its type area the till of the Glenmore has twice as much clay (37 percent versus 19 percent) and half as much sand (15 percent versus 31 percent) (Mickelson and others, 1984). In the field in Kewaunee County, no contacts between the two were identified, and too few samples from the western part of the county were analyzed in the laboratory to make a distinction. However, two clusters of samples from west-central Kewaunee County contained 20 to 34 percent sand and 9 to 47 percent sand (areas BN and WH, respectively, fig. 12), suggesting the till in these areas is too sandy to be Glenmore till and more closely resembles Valders till. In neighboring Door County, Brown (2001) analyzed 97 till samples, mostly from the southern part of the county, but he also failed to identify a contact. He assigned it all to the Glenmore Member, most with 15 to 65 percent sand; however, type Glenmore till has only 10 to 20 percent sand (McCartney and Mickelson, 1982, fig. 3).

The eastern edge of area GM as shown in figure 11 marks the eastern extent of the soil of the Kewaunee Series, which is said to be developed on slightly finer till than soil just to the east (Link and Frings, 1980). This soil boundary could be considered to be the contact between Glenmore and Two Rivers, but across the border in Door County, the east edge of the Kewaunee soil is mapped 5 mi (8 km) farther east (Link and others, 1978).

The surface till in the Norman area (area NN, figs. 11 and 12) in the southern part of the county is represented

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by a cluster of five surface samples that contain between 12 and 19 percent sand. This till has been considered part of the Two Rivers Member, but it has considerably less sand than typical Two Rivers till, which averages 31 percent sand (Syverson and others, 2011), perhaps resulting from a lateral change caused by a more clayey source upglacier. Alternatively, the till of the surface in the Norman area may be an older unit at the surface where Two Rivers till is too thin to be recognizable.

The surface till in the Ahnapee area (area AH, fig. 11) in the northeastern part of the county, northeast of the Ahnapee River area, is composed of approximately 50 to 60 percent sand (Link and Frings, 1980). According to Brown (2001), the till of the adjacent area of southeastern Door County contains 35 to 65 percent sand. This till is much sandier than typical Two Rivers till; Brown (2001) considered it part of the Glenmore Member, which contains even more clay than the Two Rivers.

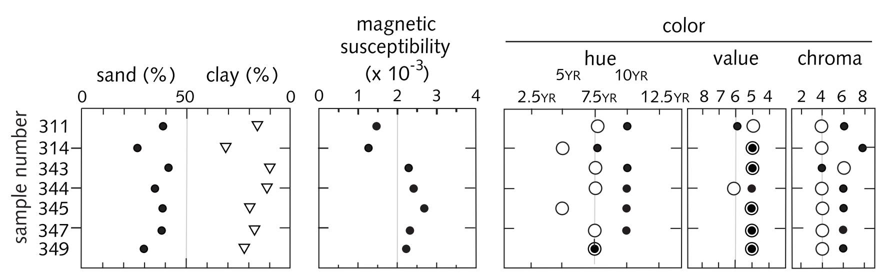
The tills of the areas NN and AH (fig. 11) have been considered to be part of the Two Rivers Member; if so, they are atypical. Even without the tills in these areas, the Two Rivers seems to have too broad a range of lithologic characteristics to be a good lithostratigraphic unit; its continuity in the Lake Michigan bluffs indicates it should be considered a single lithostratigraphic unit. However, if the analyses of till in areas NN and AH are added to the analyses of red surface till in the eastern part of the county, the resulting composite "Two Rivers" unit will have 10 to 60 percent sand in Kewaunee County, a greater range than seems reasonable in a single till sheet, even if the Glenmore is excluded, especially in light of the remarkable vertical homogeneity in some of the cores described above.

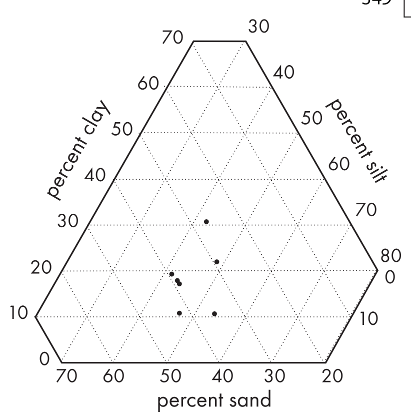
The surface till of area SF in south-central Kewaunee County (figs. 11 and 12) is characterized by seven samples. The till is the same color as Two Rivers till, and it is as coarse as the coarsest Two Rivers, but it is distinctly finer grained and redder than the till of Stangelville area (see below), which is presumably older. However, the stratigraphic relationships between these tills have not been worked out.

The surface till near Bolt (area BT, figs. 11 and 13) in southwest Kewaunee County is part of the Valders Member, according to Mickelson and Socha (in press), who have traced it from the Valders area to the northern edge of Manitowoc County. To the south of Kewaunee County, the Valders and Two Rivers tills are similar and have been distinguished by their clay mineralogy (which was not analyzed for this study) and by their stratigraphic position. Where area BT till overlies or incorporates Two Creeks wood (13,300–14,100 years ago), I have interpreted it to be Two Rivers till; where it underlies Two Creeks wood, I have interpreted it to be Valders till or older.

The surface till near Stangelville (area SV, figs. 11 and 14) is a distinctive brown-hued sandy till that was

Figure 13. Analyses of samples of surface till from probable Valders Member in area BT. Location shown in figure 11.





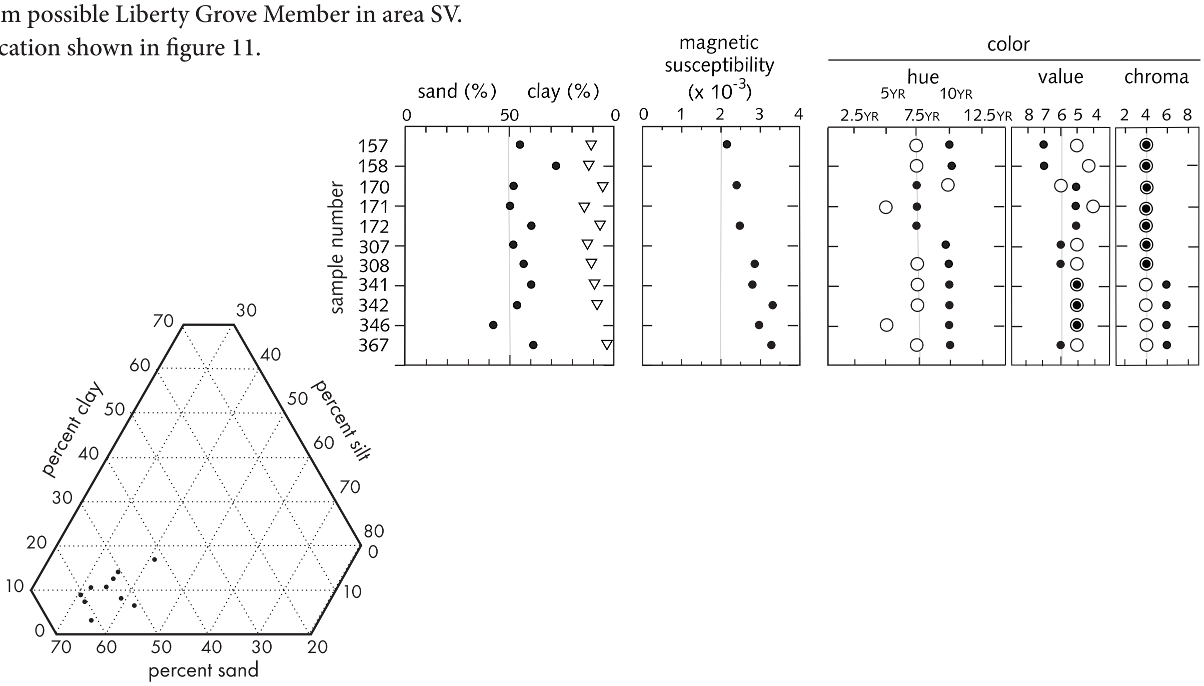
observed in dozens of shallow road cuts in an area 5 mi (8 km) wide in the south-central part of the county. Its thickness is unknown. Analysis of 11 near-surface samples from this area showed a range of 50 to 60 percent sand and 2 to 15 percent clay (fig. 14). Bulk color was mostly 7.5YR, and the color of suspended clay was 10YR. Area SV till is distinctly sandier than the till in surrounding areas. This till and that in the Bolt area might be Valders, but the Stangelville till has 20 percent more sand and 10 percent less clay than the Bolt till (figs. 13 and 14). The till in the Stangelville area closely resembles till of the Liberty Grove Member of the Holy Hill Formation in Door County (Brown, 2001; Mickelson and others, 1984) and till in the Lake Michigan bluffs near Algoma (Acomb, 1978).

The till near Stangelville (area SV, fig. 11) is the most distinctive surface till unit in the county, but its stratigraphic relationship to the till in the neighboring Bolt area (area BT, fig. 11) is obscure. I postulate that the surface till in the Stangelville area was deposited before any of the till in the Kewaunee Formation and likely was deposited at the same time as the Liberty Grove till in Door County. If the Stangelville till does correlate with the Liberty Grove till, it must be older than the Valders till because the Liberty Grove is apparently older than Valders or any other member of the Kewaunee Formation (Mickelson and others, 1984).

It's possible that the Stangelville area was later glaciated in Valders time without any till having been deposited. A similar scenario occurred over most of Door County when it was apparently glaciated three or four times between about 12,800 and 15,000 years ago with no till having been deposited on top of the Liberty Grove till (Brown, 2001). Further supporting this theory, the eskers and drumlins in the Stangelville and Bolt areas are similar in size, shape, and orientation. They seem to be a uniform set, suggesting that they were formed at the same time. This could have occurred when either the Bolt till or the Stangelville till was deposited.

The significance of these observations is unclear, but the following interpretation seems most likely: The surface till in the Stangelville area was deposited before any of the till in the Kewaunee Formation, probably at the same time as the Liberty Grove till in Door County. The eskers and drumlins of the Stangelville and Bolt areas were formed at this time during glacial movement to the southwest. Following at least one recession and readvance of the glacier, Valders till was deposited in the Bolt area, but not in the Stangelville area. The glacier that deposited the Valders till did little to obliterate the eskers and drumlins in either area.

Figure 14. Analyses of samples of surface till from possible Liberty Grove Member in area SV. Location shown in figure 11.



Samples from Lake Michigan bluffs

The shore bluffs of Lake Michigan are several tens of feet high. They can be reached by way of the shore bench exposed during low lake levels, as during the fieldwork for this project. Access to the vertical parts of the bluff is provided in many places by slumps and debris fans, but these slumps and fans hide much of the lower part of the bluff. During high lake levels, access is more difficult because the shore bench is under water, and a rope or ladder is required to sample the upper parts of the cliffs where the slumps and debris fans have been washed away. The locations of the bluffs that were sampled are shown in figure 15 and on plate 1.

The glacial stratigraphy of the bluffs, as deciphered by Acomb and others (1982), is shown in figures 8 and 15. The uppermost till is considered to be part of the Two Rivers Member. The grain size, color, and other characteristics observed in samples from the bluffs (fig. 16) are generally similar to those observed in the surface grab samples (described previously) as well as in the core samples and in the samples collected from Door County by Brown (2001), although he considered the Door County till to be part of the Glenmore Member. The Two Rivers till is generally 3 to 10 ft (1 to 3 m) thick in the shore bluffs. Inland, at higher elevations, similar thicknesses were observed. Thicker till that may be part of the Two Rivers was observed in a few of the cores described above.

The Two Rivers till exposed at the top of the bluffs, such as that in the shallow grab-sample exposures discussed previously, has a wide range in grain size; this might be expected if several separate till sheets had been inadvertently included in a single unit. However, the apparent continuity of the unit as seen in the nearly continuous bluff exposures suggests that the Two Rivers till is in fact a single till sheet, but one that is highly variable.

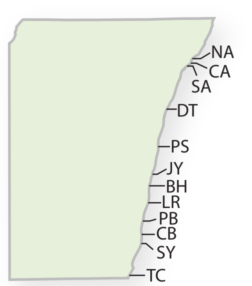
Only the upper parts of the bluffs were well exposed when samples were collected for this study. The upper part of the Ozaukee Member was widely observable; it is slightly finer grained than the overlying till, not as red, and commonly has a slightly higher magnetic susceptibility.

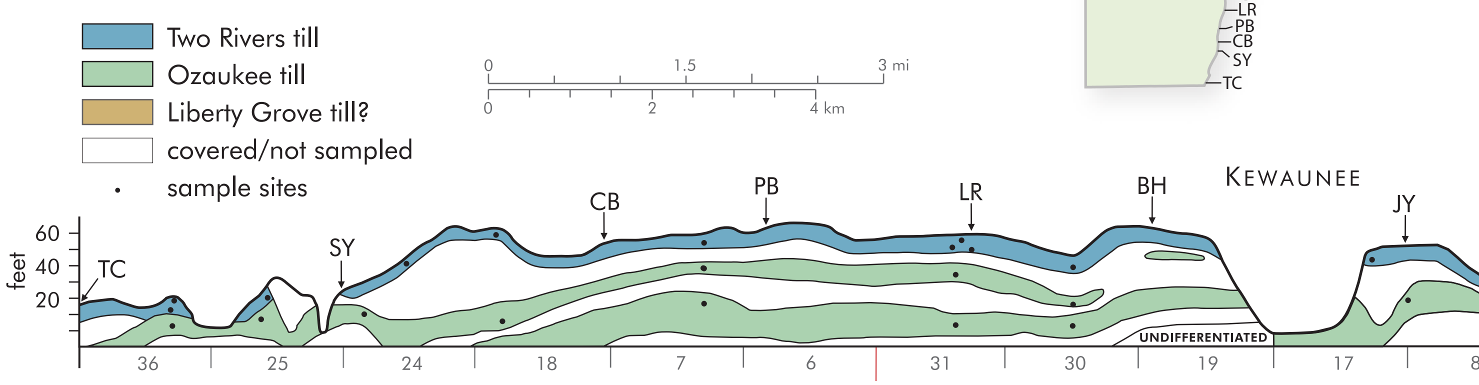
In bluffs SA and CA (fig. 15), the Ozaukee till seems to have been replaced by till that is much sandier and has greater magnetic susceptibility, but is about the same color or slightly less red. This till is much more like the Liberty Grove of Door County (Brown, 2001) and the surface till in the Stangelville area.

Stratigraphic summary

The distinction between the Kewaunee Formation and the underlying Holy Hill Formation seems fairly obvious in most places. The upper part has red clayey till, and the lower has reddish-brown sandy till. However, the two formations cannot yet be confidently subdivided into formal members in most parts of Kewaunee County. The Two Rivers Member (the uppermost member in the Kewaunee Formation) seems to be traceable as a distinct stratigraphic unit, but to the west its relationship to the Glenmore Member is unclear, and in map view it is distinguished from the Valders Member only by the presence of the coarser intervening surface till in the Stangelville area. The wide range in lithologic characteristics in the Two

Figure 15. Till units along the Lake Michigan bluffs in Kewaunee County (modified from Acomb, 1978). Numbers at bottom indicate sections and townships. Double letters are bluff designations (locations shown at right and on plate 1). Dots are Acomb's sample sites.



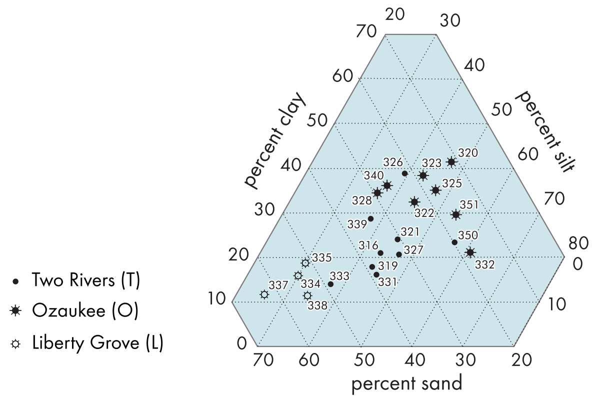


Rivers till suggests the possibility that two or more units have been confused with each other. Another possibility is that the till may be more variable than normal in this area, but that is countered by the remarkable uniformity of some sequences of till in the individual drill holes.

Even though the Branch River and Chilton Members of the Kewaunee Formation have been identified within a few miles of the western edge of Kewaunee County (Need, 1985), they have not been recognized in the county.

The Liberty Grove Member of the Holy Hill Formation is present in the lake bluffs at Algoma, but its relation to the surface till in the Stangelville area is unclear.

In general, the till stratigraphy of Kewaunee County is more complex than expected. To resolve the stratigraphy, drill holes will have to be much more closely spaced, with a short sampling interval (15 cm or less), and a greater variety of analytical techniques will be needed.



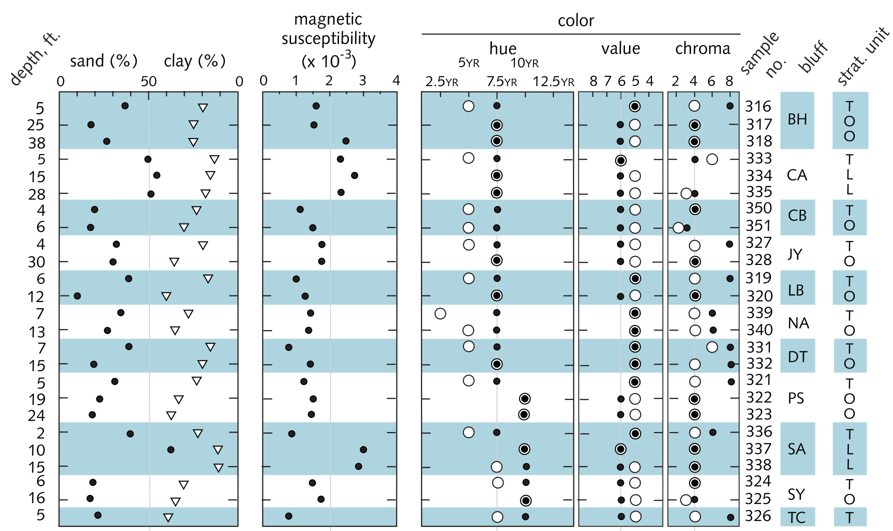
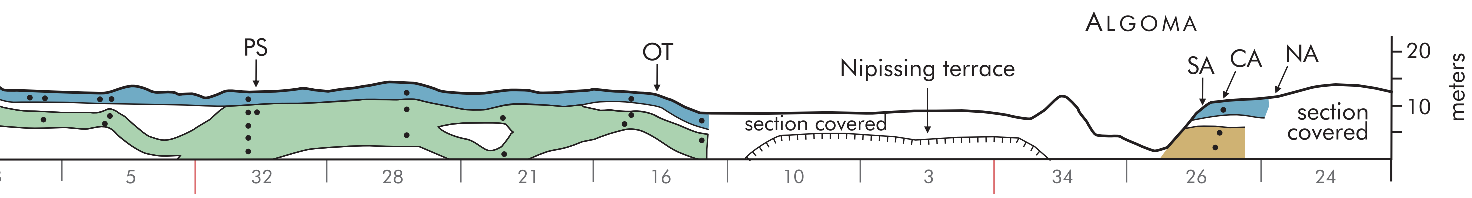


Figure 16. Analyses of samples from the bluffs of Lake Michigan. Locations shown in figure 15 and on plate 1.



Glacial sediment and landforms

Kewaunee County has been overrun by North American ice sheets many times. Before the Ice Age, the Door Peninsula was probably a limestone upland, as it is today, but glaciers must have preferentially eroded the less-resistant rock because the bottom of the deep main basin of Lake Michigan, east of the peninsula, is 330 ft (100 m) below sea level. During at least the most recent glaciation, the glacier tended to be channeled into the lowland areas on either side of the Door Peninsula. Because the main basin of Lake Michigan is deep and aligned north to south, more or less parallel to the direction of ice flow, the Lake Michigan Lobe of the ice sheet reached farthest south, into southern Illinois. The basin of Green Bay is shallower than that of Lake Michigan, and the Green Bay Lobe of the ice sheet extended only to southern Wisconsin.

The local details of the present landscape of much of Kewaunee County are the result of the cumulative effects of glacial erosion and deposition, especially during the last few glacial episodes. The small limestone plateaus in the north-central part of the county, shown as map units **h** and **gss** on plate 1, have probably been hills since preglacial time, but have been slightly reshaped during each glaciation.

The remaining areas shown in green on plate 1 are composed of till that is at least a few feet thick. Although it is typical till deposited by the glacier with little or no reworking by meltwater, the topography in areas of map unit **gs** has few glacial characteristics. Because it was draped across a preexisting landscape with considerable relief, it was too thin to have much influence on the existing topography, and any glacial topography that did exist, such as drumlins and hummocks, was obliterated by various postglacial hillslope processes. Although most of the preexisting topography was also composed of till, it too was primarily shaped by nonglacial hillslope processes. In a few places, the underlying material is lacustrine or fluvial sand and gravel. The topography of unit **gs** is a composite, created through several phases of erosion and deposition by a variety of processes.

The green map units **gu** and **gu+** (plate 1) are also composites, but with small-scale topography that was modified by postglacial processes but still is basically of glacial origin. The glacial topography consists mostly of inconspicuous collapse hummocks that have been slightly modified by postglacial hillslope erosion on their upper parts, with accompanying deposition in the depressions between the hummocks. The diameter of the hummocks is several tens to a few hundred feet, with heights ranging from several to a few tens of feet (map units **gu** and **gu+**, respectively). The thickness of the till of the most recent advance is typically more or less equivalent to the height of the hummocks. They are thought to have formed where debris on the glacier collapsed when the glacier melted out from under it.

Kewaunee Marsh

Alyssa Sellwood

In the southeastern part of the county, the hummocks tend to be preferentially elongated in a north to south direction, perpendicular to the probable direction of glacial movement, from east to west out of the Lake Michigan basin (fig. 17). They are up to several feet high, several tens of feet to a few hundred feet long, and about a quarter to half as wide.

The topography of map unit **gc** is similar to **gu** and **gu+** (plate 1), except that the till of the most recent glaciation was deposited on sand and gravel that still had older glacial ice under it. When the ice melted after the last glacial phase, the till and the sand and gravel collapsed.

The topography of map unit **ge** is the result of postglacial gullying of steep valley sides. Generally, till of the most recent glacial episode appears at the top of the valley sides, but below that is a variety of material, typically till of earlier glacial episodes and in places Silurian limestone, near the bottom of the valley sides. The bottoms of the gullies contain erosional debris washed down from above.

Other glacial landforms include a few small inconspicuous drumlins that are a few feet high, tens of feet wide, and up to a mile long. These may have formed during the most recent glacial phase, rather than an earlier one, because they seem too well preserved to have survived a subsequent glacial readvance. However, that interpretation is at odds with the stratigraphy (see discussion of significance of till in Bolt and Stangelville areas on p. 29).

In the southeast corner of the county, a broad ridge of unknown origin rises in places more than 165 ft (50 m) above Lake Michigan on the east, is roughly 100 ft (30 m) above East Twin River on the west, and about 2 mi (3 km) wide. Its north end is 2 mi (3 km) southeast of East Krok, and it extends several miles south into Manitowoc County. The ridge is perpendicular to the probable direction of movement of most recent glacier in the area as well as the ice-marginal channels between it and the lake. These relationships suggest it is a moraine, but it, like the ice-marginal channels, probably formed before the most recent glacial advance because the pattern of elongated hummocks extends across and beyond the ridge without interruption.

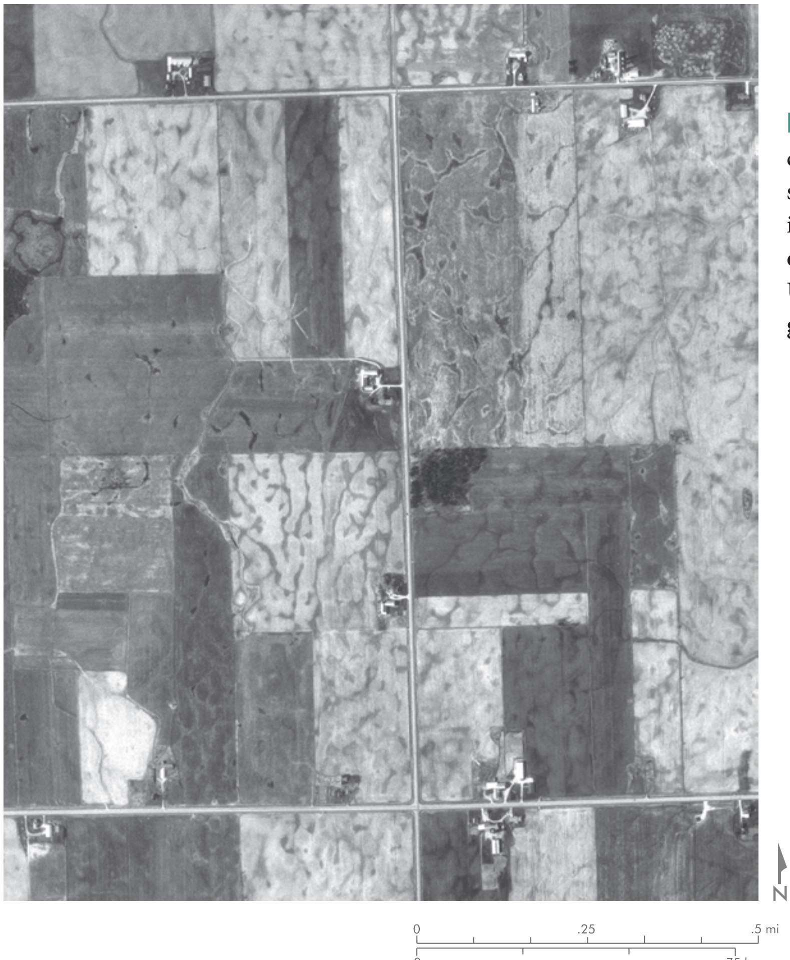


Figure 17. Aerial photograph of glacial collapse hummocks elongated north to south, perpendicular to the direction of ice movement, 4 mi (6.5 km) southwest of Kewaunee (sec. 2 and 3, T22N, R24E). U.S. Department of Agriculture photograph BHU-2HH-258.

River sediment and landforms

Modern river sediment consists of sand, silt, and gravel deposited on the floodplains of modern rivers (map unit **sm,** plate 1); it typically differs from meltwater-stream sediment (map units **su** and **sc,** plate 1) in having dispersed fine-grained organic material. Sand and gravel deposited by glacial-meltwater rivers is found mainly in a north–south band down the center of the county (shown in shades of red on plate 1). Some areas (map unit **sc**) lack channel scars, but instead have irregular topography consisting of low mounds and depressions that are interpreted as the result of the collapse of stream sediment when buried masses of glacial ice melted out from under it. Other uncollapsed areas (map unit **su**), have a pattern of braided river channels characteristic of glacial outwash plains. Most of it was deposited when the most recent glacial ice receded from the county, but some could have been deposited before that glacial advance in areas where the glacier deposited little till and did little erosion. In places, the outwash is covered by peat (map unit **so**).

Other meltwater features include eskers that are approximately parallel to the direction of ice movement as indicated by the orientation of drumlins. However, some could be palimpsest features—eskers could have formed during an earlier glacial advance and were unaffected by the most recent advance. The eskers shown on plate 1 are ridges up to 2.5 mi (4 km) long and 30 ft (10 m) or more high. The esker complex north of Casco, in the north-central part of the county, is 12.5 mi (20 km) long and is intermingled with elongated till hills and depressions of unknown origin, possibly eroded by subglacial water.

Other features formed by glacial meltwater are river channels, indicated on plate 1 by symbols. Some could be palimpsest, as shown by the symbol; those south of Kewaunee may have been ice marginal.

I distinguish between channels and trenches. A channel is the bed of a river, filled with water from bank to bank and shaped by the river. A trench, as I use the term, is a larger feature with a more complex history, with a river flowing in its bottom, but never filled bank to bank.

Esker with stratified sand and gravel

William N. Mode

Lake sediment and landforms

Aside from Lake Michigan and its Green Bay, Kewaunee County has only a few present-day lakes, the largest about 0.5 mi (0.8 km) long. Of the most notable, four are clustered in the southwestern corner of the county and the Alaska Lakes are in the northeast between Kewaunee and Algoma.

Other short-lived glacial lakes existed within the Kewaunee trench where the trench was dammed by the Michigan Lobe or outwash fans (discussed in the next section). When the last glacial ice melted off the county, it left behind a few larger lakes. They were shallow and quickly filled with offshore silt and clay brought in by glacial meltwater and later by postglacial streams. More recently, they evolved into swamps, with tamarack, black ash, and white cedar. The four largest that have names: Duvall Swamp in the northwest, Black Ash Swamp in the northeast, Lipsky Swamp in the middle, and Section 7 Swamp in the southwest. Little is known about the material underlying these and many dozen smaller swamps, but their flatness suggests considerable offshore sediment (map unit **ou,** plate 1), which is overlain by unknown thicknesses of peat (map unit **so,** plate 1).

Kewaunee spillway

William N. Mode

In addition, there were temporary glacier-dammed lakes including Lake Oshkosh in the Green Bay lowland and the late-glacial phases of Lake Michigan. Evidence for glacial Lake Oshkosh has been found in its outlets (such as the Kewaunee spillway) and offshore sediment deposited in its various basins to the south of Kewaunee County (Alden, 1918; Thwaites and Bertrand, 1957).

The late-glacial history of Lake Michigan has received attention for more than a century, with emphasis on its beaches (Goldthwait, 1907), but I know of no evidence in Kewaunee County for the pre-Holocene history of postglacial Lake Michigan. Modern shore bluffs rise well above any older beaches along most of the Kewaunee County coast. The highest pre-modern beach sand and gravel is seen between 20 and 30 ft (6 and 9 m) above present-day Lake Michigan, the elevation of the highest mid-Holocene Nipissing beach (Goldthwait, 1907). Above that in Kewaunee County is unmodified glacial topography. Pre-Holocene beaches first begin to rise above the Nipissing level just north of the Door–Kewaunee border.

Sequence of late Pleistocene events

The late Pleistocene history of eastern Wisconsin has been studied by numerous geologists since the middle of the nineteenth century, including Chamberlin (1877, 1883), Goldthwait (1907), and Thwaites and Bertrand (1957). Many times during the Ice Age, glacial lobes flowed south from the Laurentide Ice Sheet down the Green Bay and Lake Michigan lowlands. The latest major advance and recession occurred from roughly 25,000 years ago until about 10,000 years ago during the Wisconsin Glaciation. During the middle of this last major glacial episode, Kewaunee County was covered with ice for several thousand years; that is the time when the glacier deposited the brown sandy till of the Holy Hill Formation. Before the red-hued clayey till of the Kewaunee Formation was deposited, the glacier receded far enough northward that a considerable amount of red-hued offshore clay could be deposited. The glacier advanced again, eroding the red lake clay and incorporating it into the reddish-brown clayey Kewaunee till (Murray, 1953).

After a few episodes of advancement and recession of the glacier margin during the most recent glaciation, till of the Valders Member was deposited by ice flowing southwest across southern Kewaunee County, judging by the orientation of the drumlins and eskers.

From about 13,300 to 14,100 years ago, the area was free of glaciers. During this time, known as the Two Creeks Interval, a spruce forest grew across much of eastern Wisconsin, and Lake Michigan was well below its present level.

Following the Two Creeks Interval, the most recent glacier advanced across all but the central and southwestern part of Kewaunee County, depositing a thin till of the Two Rivers Member, during the Denmark Phase (named by Need, 1985) of the Wisconsin Glaciation. The outwash plain formed by meltwater flowing from the Lake Michigan Lobe 2 mi (3 km) east of Ellisville (fig. 18A) was abandoned

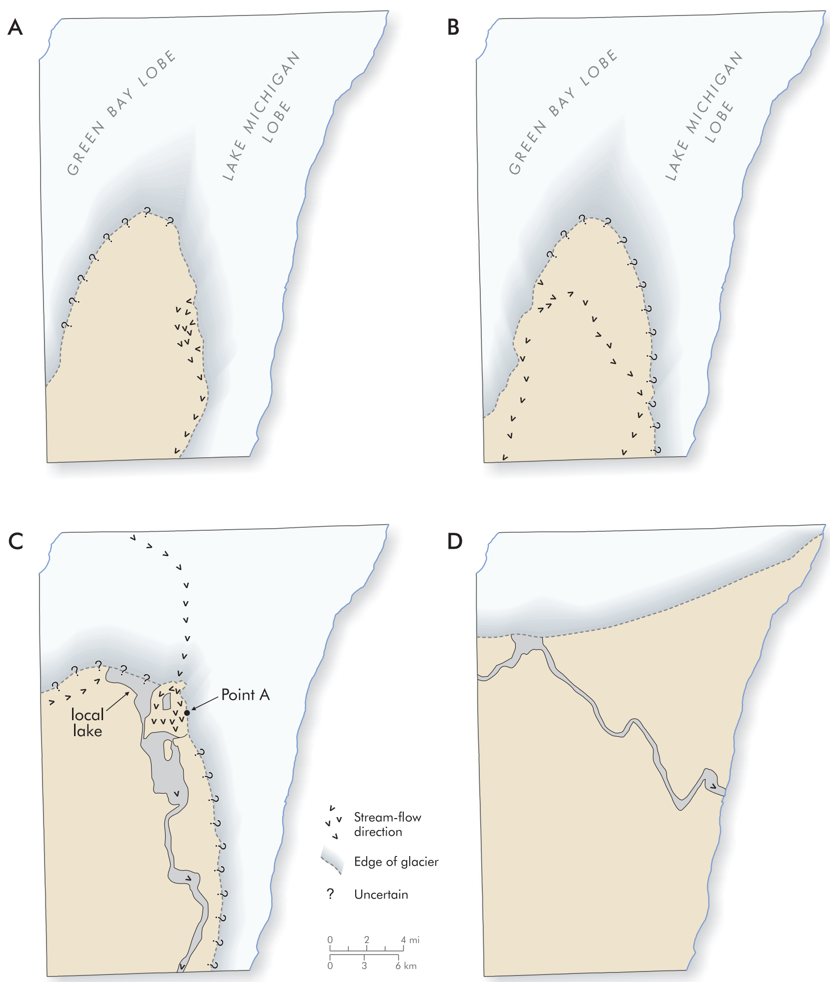


Figure 18. Hypothetical stages in the deglaciation of Kewaunee County. An outwash plain forms from meltwater flowing from the Lake Michigan Lobe (A). The outwash plain is abandoned and later entrenched by meltwater flowing from the Green Bay Lobe (B). As the Green Bay Lobe recedes, it exposes the Fox River and Green Bay lowlands (C). The glacier continues to melt northward, exposing lower outlets into the Lake Michigan basin (D).

and later entrenched by meltwater flowing southeast from the Green Bay Lobe (fig. 18B). (The entrenchment is marked by cutbank symbols on plate 1.) This indicates that the Lake Michigan Lobe reached its maximum extent slightly before the Green Bay Lobe.

As the Green Bay Lobe melted back (fig. 18C), the Fox River and Green Bay lowlands were gradually exposed, starting in the south. While the northern part of the lowland was still dammed by the glacier, the ice was replaced northward by water of glacial Lake Oshkosh, which filled the lowland up to the elevation of its lowest available outlet to the southwest, past the present location of the city of Portage to the Wisconsin River. As the glacier continued to melt northward (fig. 18D), lower outlets were exhumed eastward across the Door Peninsula and into the main basin of Lake Michigan.

One of these spillways (West Twin spillway, fig. 19) is now occupied by the Neshota River, just beyond the southwest corner of the county. Another trench, the dominant landform in the county, is now occupied

Figure 19. The Kewaunee spillway. Relationship of the spillway to associated features. Arrowheads indicate direction of water flow. Inset map shows the spillway at point A.

by the Kewaunee River. Along most of its length, the Kewaunee trench is between 0.1 to 1 mi (0.2 to 1.6 km) wide and between 33 and 115 ft (10 and 35 m) deep. Its mouth was at the location of the city of Kewaunee, and its head was near the northwest edge of the county, several miles south of Dyckesville (fig. 19). The Kewaunee trench as it exists today is the result of a complex series of now mostly obscure events. The more obvious and most recent of these events are outlined here.

The Kewaunee trench was probably initially cut by glacial meltwater flowing out of glacial Lake Oshkosh across a low point in the preglacial drainage divide. The trench was subsequently modified or partially obliterated every time a glacier readvanced into the Green Bay lowland, and it was rejuvenated every time the lake reformed then spilled through the trench as the ice again wasted back northward. This probably happened several times. Evidence of modification of the trench during the most recent glacial advance across the area includes till with hummocky topography draped down into the trench at least to within about 33 ft (10 m) above the elevation of the present river, such as east of Frog Station (south edge of sec. 34, T25N, R23E).

Although the Kewaunee trench is 1 mi (1.6 km) wide in places, the last time glacial Lake Oshkosh discharged through the trench, it occupied a river channel in the bottom of the trench that was as narrow as 0.1 mi (0.2 km)—nearly the same as the upper Neshota spillway through the Denmark moraine and northward, but only about half as wide as the Neshota south of the moraine.

Just before the glacier wasted off the upland south of Dyckesville for the last time, glacial Lake Oshkosh stood at an elevation of about 768 ft (234 m), which is the level that had been maintained for some time by the Neshota River spillway (fig. 20). Discharge from the lake then shifted from the Neshota outlet to the highest Kewaunee outlet, which was about a few feet lower than the Neshota outlet. This outlet is now occupied by the unnamed creek south of Servais Road and by the creek south of Champion (in Brown County) that joins the Kewaunee River just west of Frog Station (fig. 21A). As the glacier's snout continued to melt back, the head of the Kewaunee spillway shifted northeastward about a mile three more times (fig. 21B, C, D), each time to a channel that was several feet lower, finally stabilizing at the outlet from the embayment 3 mi (5 km) south of Dyckesville, when glacial Lake Oshkosh was at an elevation of about 690 ft (210 m) (fig. 21E).

When glacial Lake Oshkosh first flowed into the Kewaunee trench after the Two Rivers till was deposited, it used the Servais–Champion spillway. Water discharged into the middle part of the main Kewaunee trench and was

Figure 20. Topographic profile along the drainage divide of the Door Peninsula, showing water levels in Lake Oshkosh as the glacier margin receded northward, opening lower outlets. The five saddles at the mouth of the Kewaunee spillway (figs. 19 and 21) correspond to the five outlet levels shown here. Water surfaces are shown tilted 1 ft/mi, based on tilt of the oldest beaches in Door County (Goldthwait, 1907).

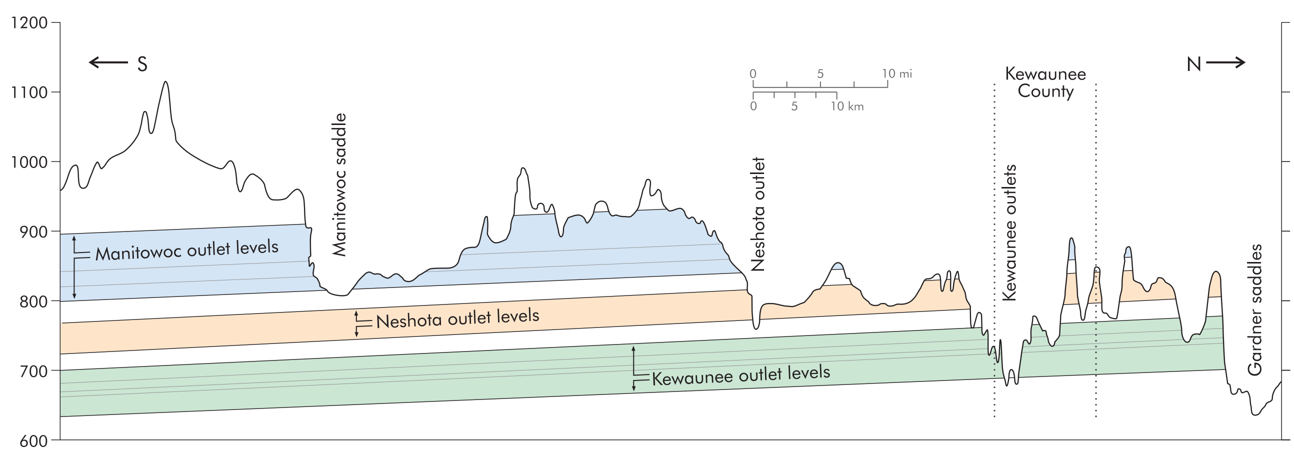
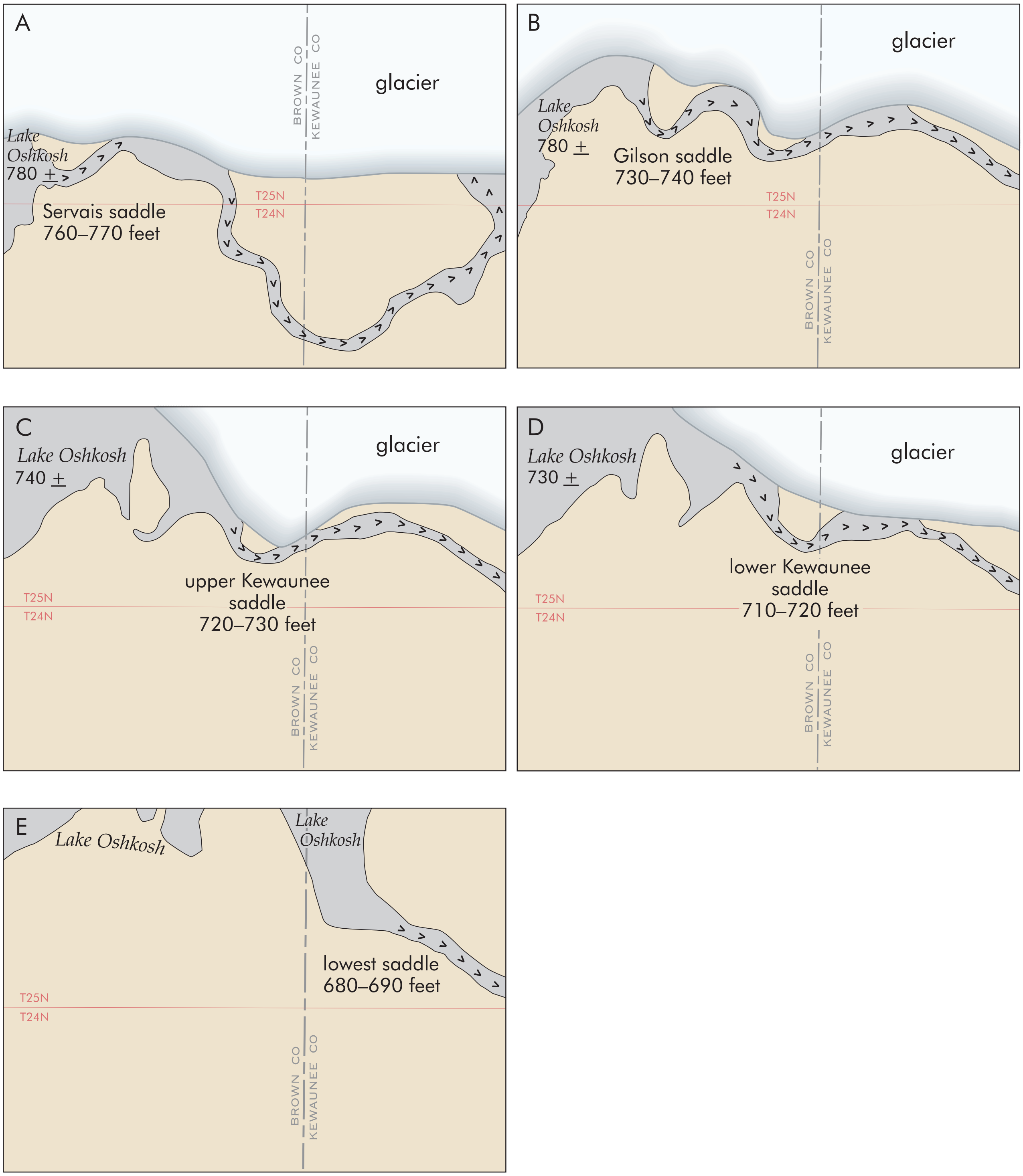


Figure 21. Some stages in the deglaciation of the head of the Kewaunee spillway in northern Kewaunee County and adjacent Brown County.

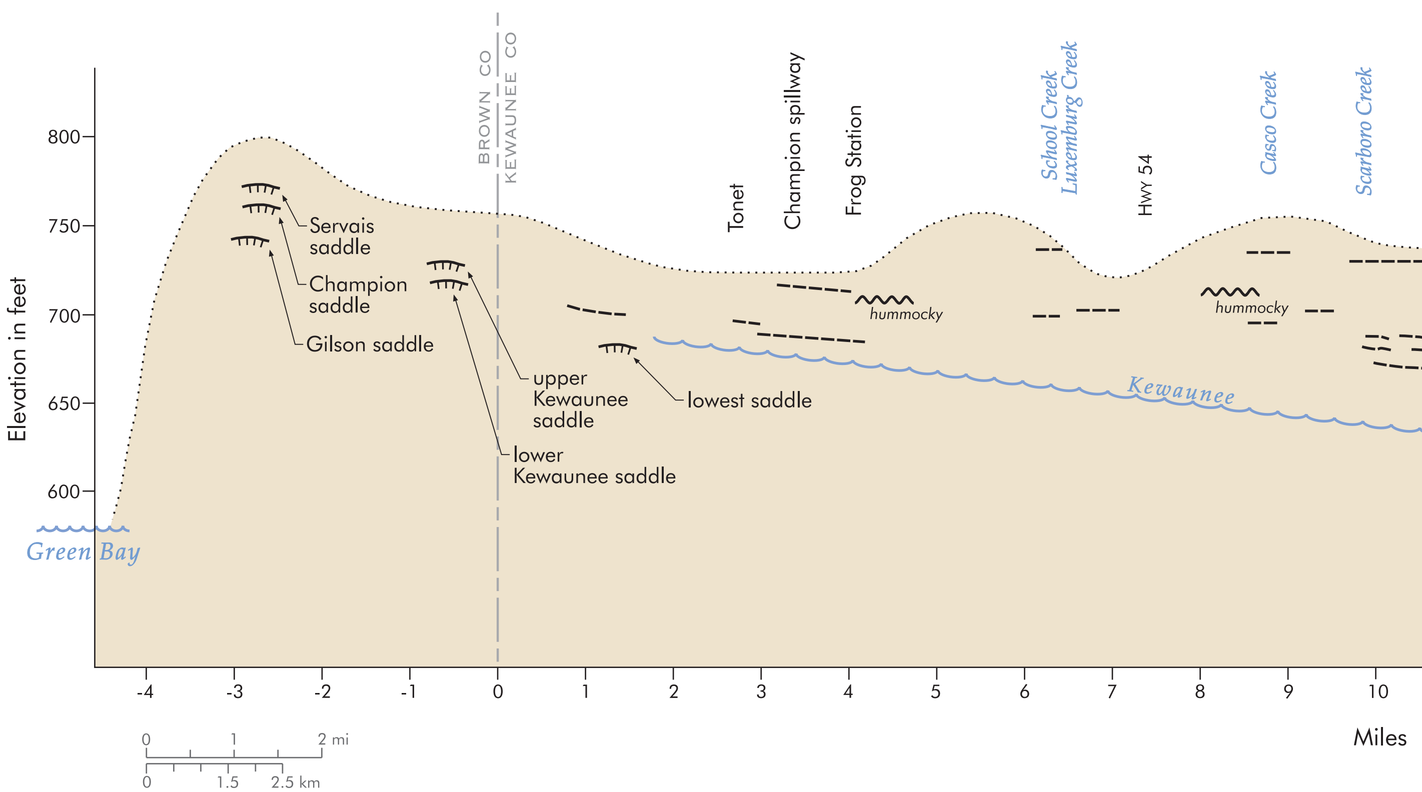


then diverted south into the Krok and East Twin spillways (figs. 19 and 21A). The East Twin either emptied into the spillway now occupied by the West Twin River near Larrabee or emptied directly into Lake Michigan next to the West Twin River at the city of Two Rivers, south of the area shown in figure 19. (The Neshota River's name changes to West Twin River between Denmark and Larrabee.)

Water from the Kewaunee spillway was diverted into the Krok spillway whenever the lower Kewaunee was blocked by the glacier just downstream from the junction of the two, south of the village of Casco (point A in figs. 18C, 19, and 22). Water from the uppermost Kewaunee spillway flowed into a small lake at the junction with the Krok spillway and then into the Krok. The southern half of that lake is now occupied by the Lipsky Swamp; the northern half, by a sand plain between Scarboro Creek and Little Scarboro Creek. The north end of the sand plain is at the same elevation, 730 ft (220 m), as an outwash fan (delta) on the north side of the Kewaunee River. The fan slopes down from an elevation of 770 ft (230 m) at Casco, where water discharged from large subglacial tunnels now marked by a complex of eskers occupying a linear depression, beginning 2.5 mi (4 km) southwest of Namur in Door County (figs. 18C and 19). The subglacial tunnels north of Casco must have been the source of the sand and gravel that nearly filled the Kewaunee trench in the junction area (fig. 19). Glacial Lake Oshkosh discharge could not have carried much bedload because much of the upper Kewaunee trench was occupied by a small lake at the time (fig. 18C).

The position of the edge of the glacier when the Krok spillway was active can be determined with some confidence. The glacier could have been no farther east than the prominent bend in the Kewaunee spillway 1 mi

Figure 22. Vertical profile of the Kewaunee spillway. Comb-like symbol is the present-day saddle, at the present-day drainage divide. Depending on the depth of postglacial fill, the actual bottom of the spillway was somewhat lower. Horizontal dashed lines are fluvial terraces or lake planes. The dotted line is the approximate level of the upland on either side of the spillway. The wavy line marks the lowest extent of glacial hummocks down in the palimpsest parts of the spillway.

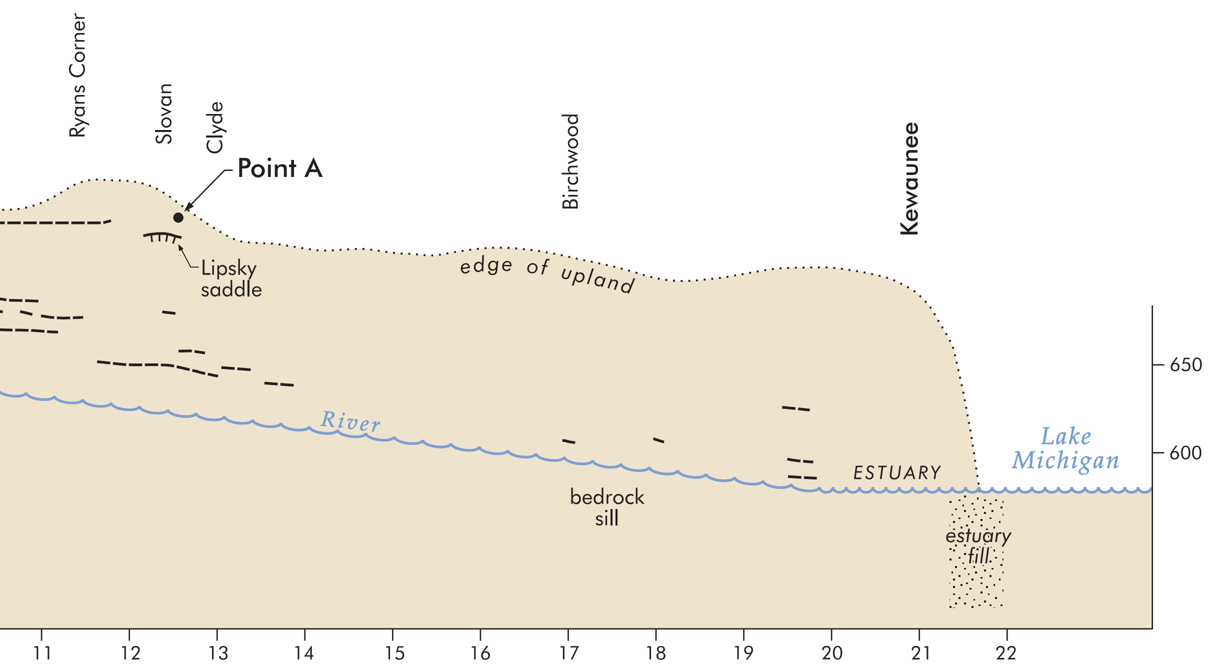


(1.5 km) southwest of Slovan (point A in figs. 18C, 19, and 22); otherwise, the water would have spilled down the lower Kewaunee trench into the Lake Michigan lowland below an elevation of 730 ft (223 m) in the junction area. At the same time, the water level in glacial Lake Oshkosh must have been no higher than 770 ft (235 m), or it would have used the Neshota spillway instead of the Kewaunee. Only the highest Kewaunee outlet south of Servais Road and south of Champion (fig. 19) is high enough to have spilled into the lake at Lipsky swamp, and by the time the lower ones were used, the Lipsky lake no longer existed because the Kewaunee spillway had dropped below that level when the glacier wasted eastward from point A (figs. 18C, 19, and 22).

The lowest saddle at the head of the Kewaunee spillway is between 680 and 690 ft (207 and 210 m). Glacial Lake Oshkosh continued at that level until the glacial margin had receded northward 15 mi (24 km) to the next lower two saddles across the peninsula, one between 650 and 660 ft (198 and 201 m) and the other between 630 and 640 ft (192 and 195 m) elevation at the west end of Gardner Swamp (fig. 19). These were the last used outlets from glacial Lake Oshkosh.

The lowest outlet from the Gardner basin is to the north to Lake Michigan, between 610 and 620 ft (186 and 189 m), 0.5 mi (0.8 km) south of Little Sturgeon Bay. No channel form can be seen here; perhaps Lake Michigan was at the same level as the lake in Gardner basin, and the saddle south of Little Sturgeon Bay was a strait rather than a river. Lake Michigan finally merged with glacial Lake Oshkosh, which then became Green Bay.

The Ahnapee River occupies a shallow valley that probably carried water from an earlier version of glacial Lake Oshkosh at some time before the Two Rivers till was deposited. The saddle



between the head of the Ahnapee River and the Gardner Swamp (fig. 19) is about 20 ft (6 m) higher than the nearby Little Sturgeon saddle, and there are no unmodified spillway cutbanks bordering the bottomland or other indication of discharge from glacial Lake Oshkosh after the last glacial recession from the area. However, the bottomland is bordered by irregular steep slopes, indicating that this may be a palimpsest spillway.

Evidence from elsewhere in the Lake Michigan basin shows that after glacial Lake Oshkosh merged with Lake Michigan, water levels continued to fluctuate. According to Goldthwait (1907), the beach that is approximately 20 ft (6 m) above present lake level south and north of Algoma is correlative with the Nipissing shoreline formed in Middle Holocene time, and he identified another several feet higher that may be the most recent Pleistocene beach.


Nast Brothers' Quarry

W.O. Hotchkiss, 1914

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