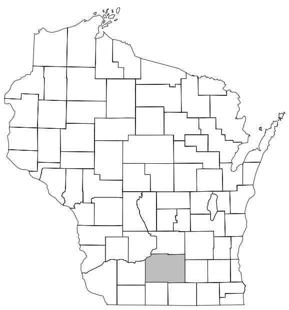
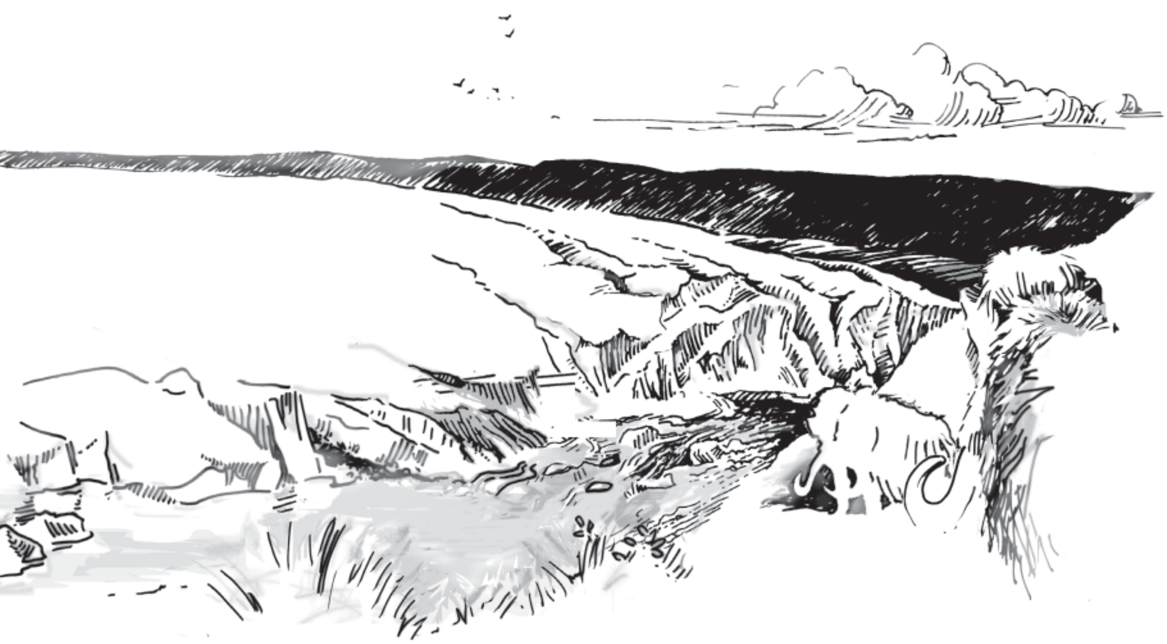


Pleistocene Geology of Dane County, Wisconsin

Lee Clayton
John W. Attig



Wisconsin Geological and Natural History Survey
Bulletin 95 ◆ 1997

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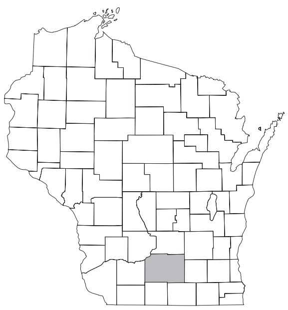

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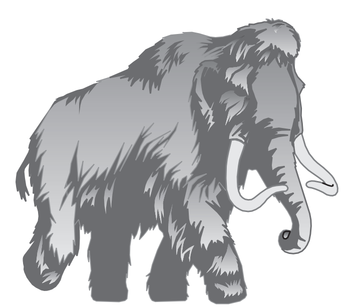
The Survey conducts earth-science surveys, field studies, and research. We provide objective scientific information about the geology, mineral resources, water resources, soil, climate, and biology of Wisconsin. We collect, interpret, disseminate, and archive natural resource information. We communicate 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 (INSIDE BACK POCKET)

PREFACE: A CENTENNIAL PERSPECTIVE

For more than a century, geologists have been studying the glacial deposits of Dane County. On the occasion of the centennial of the Wisconsin Geological and Natural History Survey (WGNHS), we take the opportunity to briefly review the history of glacial geology as viewed from and inspired by Dane County.

Geologists began traveling through the glaciated part of the Midwest during the early 1800s. They often noted boulders of granite and other rock that were not in place but were erratically scattered across the landscape. These erratics seemed to have originated far to the north, but how they came to the Midwest was a mystery.

Previously, geologists had noted similar erratics in northern Europe and thought Noah's Flood had washed them there. However, during the 18th century, polar explorers brought back observations of icebergs laden with rock debris, which inspired a refinement in the flood theory: The erratic debris of Europe was reinterpreted to be "drift" that had melted out of icebergs drifting on Noah's Flood.

The glacial theory began to replace the flood theory in the late 18th and early 19th centuries, when naturalists in Switzerland and Scandinavia recognized that the present-day glaciers carry material resembling drift and that the glaciers had once been much bigger. Although he was at first a skeptic, the Swiss zoologist and paleontologist Louis Agassiz became the most famous missionary for the idea that there had been glaciers on a continental scale. By 1840 many of Europe's leading geologists had been converted to the idea of an Ice Age. In 1847 Agassiz moved to Harvard University and for two decades promoted his theory in North America. The theory met some resistance.

One of the first geologists to write about Dane County, Wisconsin, was the Englishman George W. Featherstonhaugh (pronounced Frestonhaw). Traveling eastward from Mineral Point and Blue Mounds, he approached the future site of Madison on May 30, 1837. There, the landscape inspired him to make his much-quoted comment that this area was "one of the most exquisitely beautiful regions I have ever seen in any part of the world." Featherstonhaugh, writing a decade later, remained sympathetic to the idea that much of the surface debris of North America "was a result of the Noachic Deluge," but he failed to comment on the presence of this debris in Dane County (1847 [1970], v. 1, p. xvi, footnote 1; v. 2, p. 87, 336).

David Dale Owen (1852, p. 144-145), writing about the erratic boulders of Wisconsin, Iowa, and Minnesota, said

> The only explanation that is at all satisfactory in accounting for the transporting power which has brought these detached masses of granite rocks into their present position is floating ice—ice drifted by currents setting in from the north before the land emerged from the ocean, in the same manner as, at the present time, thousands of tons of rock are precipitated on the bed of the Atlantic Ocean from icebergs, which annually work their way from the north, and melt in southern latitudes.

Similarly, in 1862, J.D. Whitney stated that "drift currents" carried the drift to Wisconsin and that the Driftless Area escaped because it was an island in the ocean (Hall and Whitney, 1862, p. 99, 117).

However, the glacial theory soon triumphed over the flood theory. In 1873 T.C. Chamberlin joined the geological survey of 1873-82, a predecessor of the present WGNHS (Ostrom, 1988, p. 466-467; Bailey, 1981); the findings of the survey appear in the four-volume *Geology of Wisconsin*. In those volumes Chamberlin (1877, 1880, 1882, and 1883) described the glacial geology of Wisconsin in considerable detail, laying the foundation for our present understanding of

Pleistocene events in the region. These reports included a colored map called *General Map of the Quaternary Formations of Wisconsin,* at a scale of about 1:950,000 (plate 2, dated 1881).

Chamberlin went on to become the president of the University of Wisconsin, a member of its geology department, and later the head of the geology department at the University of Chicago. During much of this time he was also head of the glacial division of the U.S. Geological Survey, where he continued to promote the study of the Pleistocene glacial deposits in Wisconsin.

One of Chamberlin's employees at the U.S. Geological Survey, W.C. Alden, mapped the Pleistocene geology of the southeastern quarter of Wisconsin, including Dane County; judging by copies of field maps in WGNHS files, most of the field work was done between about 1899 and 1909. The resulting map (scale 1:250,000) and reports (Alden, 1905, 1918) are major landmarks in the history of Pleistocene studies in the Midwest.

One of the most influential Pleistocene geologists in the Midwest was Fredrik T. Thwaites. For his bachelor's thesis (1906), Thwaites mapped the geology of an area just southeast of Madison near Lakes Waubesa and Kegonsa, and during the summer of 1907, he was Alden's field assistant. For his master's thesis (1908), Thwaites mapped the geology of an area in southwestern Dane County near Middleton, Cross Plains, and Verona, "it being the district traversed by the field excursions of the elementary classes in geology" at the university. He devoted much of the rest of his life to the study of the Pleistocene geology of Wisconsin. Many Midwestern universities used his *Outline of Glacial Geology* (1946-63) as a textbook. Through the influence of Thwaites, Alden, and Chamberlin, the imprint of the Pleistocene glacier on Dane County has helped shape the science of Pleistocene and glacial geology, and it continues to do so.

The present program of Pleistocene county mapping at the WGNHS began when David M. Mickelson and M. Carol McCartney produced a field guide, including a geologic map, describing the glacial landscapes of Dane County (Mickelson and McCartney, 1979; Mickelson, 1983). Since then, the program has evolved, with the publication of reports and maps for 14 counties, and several more are in various stages of preparation. We have published all the county maps at a scale of 1:100,000.

In this bulletin we present a detailed look at the Pleistocene geology of Dane County and commemorate the centennial of the founding of the present state geological survey. Wisconsin had five separate, discontinuous geological surveys between 1853 and 1882, each separately established by the state legislature and later discontinued. The sixth and present survey, the Wisconsin Geological and Natural History Survey, was founded in 1897.

Recently, we also marked the centenary of the naming of the most recent glaciation. The name "Wisconsin Glaciation" originated in Dane County, but it is now used throughout North America and beyond. In 1894, Chamberlin named the "East Wisconsin stage," and in 1895 he shortened it to "Wisconsin stage," which is nearly equivalent to the Wisconsin Glaciation of this report (Thwaites, 1963, p. 72).

Pleistocene Geology of Dane County, Wisconsin

Lee Clayton and John W. Attig

ABSTRACT

Dane County, in southern Wisconsin, straddles the border between two geologic areas: the unglaciated area to the west and the glaciated area to the east.

Western Dane County is part of the Driftless Area. There, 300 m of nearly flat-lying lower Paleozoic dolomite, sandstone, and shale is exposed. Dolomite of Cambrian and Ordovician age makes up the tops of rounded plateaus, and sandstone of Cambrian and Ordovician age is present in the scarps surrounding the plateaus and on the lower valley sides. Ordovician shale makes up most of Blue Mounds on the western border of the county. Pleistocene lake sediment and meltwater-stream sediment underlie some valley bottoms. Most hillslopes are blanketed with about 1 m of red-tinged clayey Cenozoic sediment, which in turn is overlain by about 1 m of late Pleistocene silt (loess).

The Paleozoic units also are present in the central and eastern part of the county, but there they are generally overlain by as much as 100 m of Pleistocene sediment. Most of the sediment is part of the Horicon Member of the Holy Hill Formation, which is characterized by till consisting of gravelly, clayey, silty sand. At least the eastern part of the county was apparently glaciated many times, and some evidence indicates that glacial lakes extended into the valleys of southwestern Dane County, perhaps several times. However, abundant evidence is available for only the Wisconsin Glaciation. During the Brooklyn Phase, which was apparently an early phase of the Wisconsin Glaciation, a glacier advanced westward 5 km beyond Brooklyn. Later, during the Johnstown Phase of the Wisconsin Glaciation, the Green Bay Lobe of the Laurentide Ice Sheet reached Prairie du Sac, Cross Plains, Verona, and Brooklyn. Later, less extensive advances of the Green Bay Lobe reached Dane County during the Milton and Lake Mills Phases.

The outermost moraine formed during the Johnstown Phase is nearly continuous across the county, except for gaps where it crosses valleys. Two of the Lake Mills moraines are also nearly continuous, but the rest tend to be discontinuous. The outermost moraine and other medium-sized moraines that formed during later parts of the Johnstown Phase and during the Milton and Lake Mills Phases are sharp-crested ridges several meters high and several tens of meters wide. In addition, hundreds of small moraines are present in most of the glaciated parts of the county. They are no more than a few meters high and several meters to a few tens of meters wide, and they are generally in evenly spaced clusters.

An area 10 km wide eastward of the outermost moraine is characterized by hummocky till. Individual hummocks are low mounds generally no more than a few meters high but are up to 10 m high a few places. Generally, they are tens of meters wide. The hummocky topography is the result of the collapse of supraglacial till as the ice melted out from under it.

Drumlins are present in the eastern part of the county to within 10 km of the outermost moraine. They range from stubby drumlins that are as much as 400 m wide and 30 m high to spindly drumlins that are no more than 10 m wide and a few meters high; both types may be as long as 1 or 2 km. The spindly ones appear to have been fully streamlined at an unfrozen sliding glacial bed; the stubby ones are palimpsest forms that are incompletely streamlined and still retain part of the form of the pre-existing hills.

The topography of the Driftless Area, with its

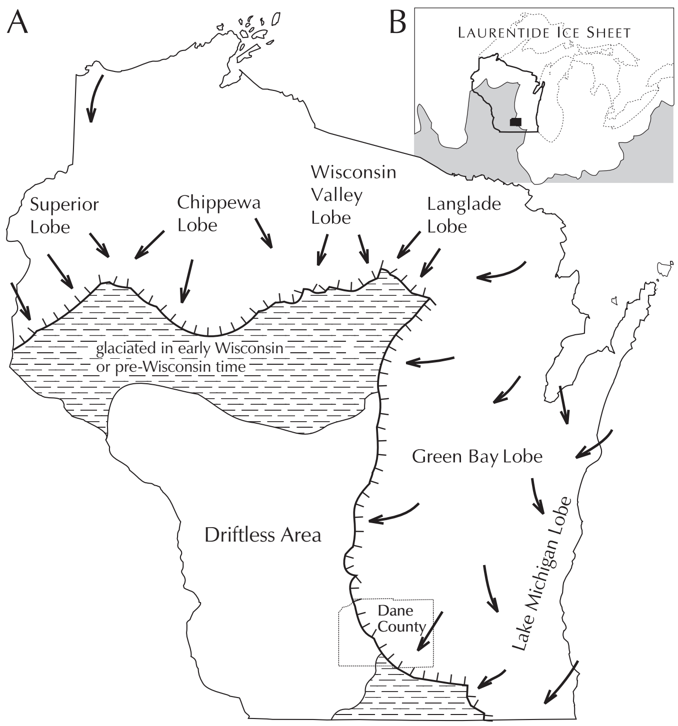


Figure 1. *Location of Dane County (**A**) in relation to the Laurentide Ice Sheet (**B**) and its lobes during the height of the Wisconsin Glaciation. Arrows show direction of ice flow; hachures indicate the edge of the ice sheet.*

sandstone scarps surrounding dolomite plateaus, can still be recognized in the glaciated area, especially where the preglacial relief was especially high or the till cover was too thin to completely obliterate the preglacial topography. This topography is still conspicuous in the hummocky-till zone, especially in the northwestern part of the county and in the Brooklyn till area, but also in many parts of the drumlin area.

Sand and gravel deposited by meltwater streams is present throughout the glaciated part of the county and adjacent parts of the Driftless Area. The sand and gravel is flat beyond the outermost Milton and Johnstown moraines, but generally it has hummocky collapse topography in other areas.

As the margin of the Green Bay Lobe retreated eastward, a complex series of dozens of glacial lakes formed between the glacier and the higher land to the southwest. Offshore sediment, most commonly sand but also silt and clay, accumulated in lowland areas. Beaches formed along the shores, but most were obliterated by hillslope processes associated with permafrost, which persisted until about 13,500 years ago.

INTRODUCTION

In this bulletin we describe the geology of the Pleistocene material in Dane County, Wisconsin, from the surface soil down to solid rock. Dane County occupies an area of 3,200 km^2 in the southern part of the state (fig. 1). At its center is Madison, which is the state capital, the home of the University of Wisconsin, and, for 100 years, the home of the Wisconsin Geological and Natural History Survey (WGNHS).

This report is based on field work conducted during the summers of 1994 and 1995. On plate 1 we attempt to show the surface geology as it was before modern earth-moving activities altered the landscape. For example, the moraine shown on plate 1 between Lake Wingra and Monona Bay is shown on a 1901 WGNHS map *(Hydrographic Map of Lake Monona, Dane Co., Wisconsin, and of the Adjacent Topography)* as a ridge up to 24 m high, but today little remains. Our geologic map is printed on a modern base map derived from the U.S. Geological Survey's topographic map of Dane County (scale 1:100,000). Figure 2 also shows many geographic names mentioned in this report.

Map contacts on plate 1 were drawn using U.S. Geological Survey quadrangle maps (7.5-minute series, topographic, scale 1:24,000) with 10- or 20-ft contour intervals as well as aerial photograph stereopairs (scale 1:20,000) taken in 1955 for the U.S. Department of Agriculture. A truck-mounted drill was used to gather subsurface information in a few areas, and additional lithologic information was derived from various sources, including Wisconsin Department of Natural Resources well constructor's reports, logs of borings by the Wisconsin Highway Commission (later called Wisconsin Department of Transportation), published geologic and soils maps (Whitson and others, 1917; Alden, 1918;

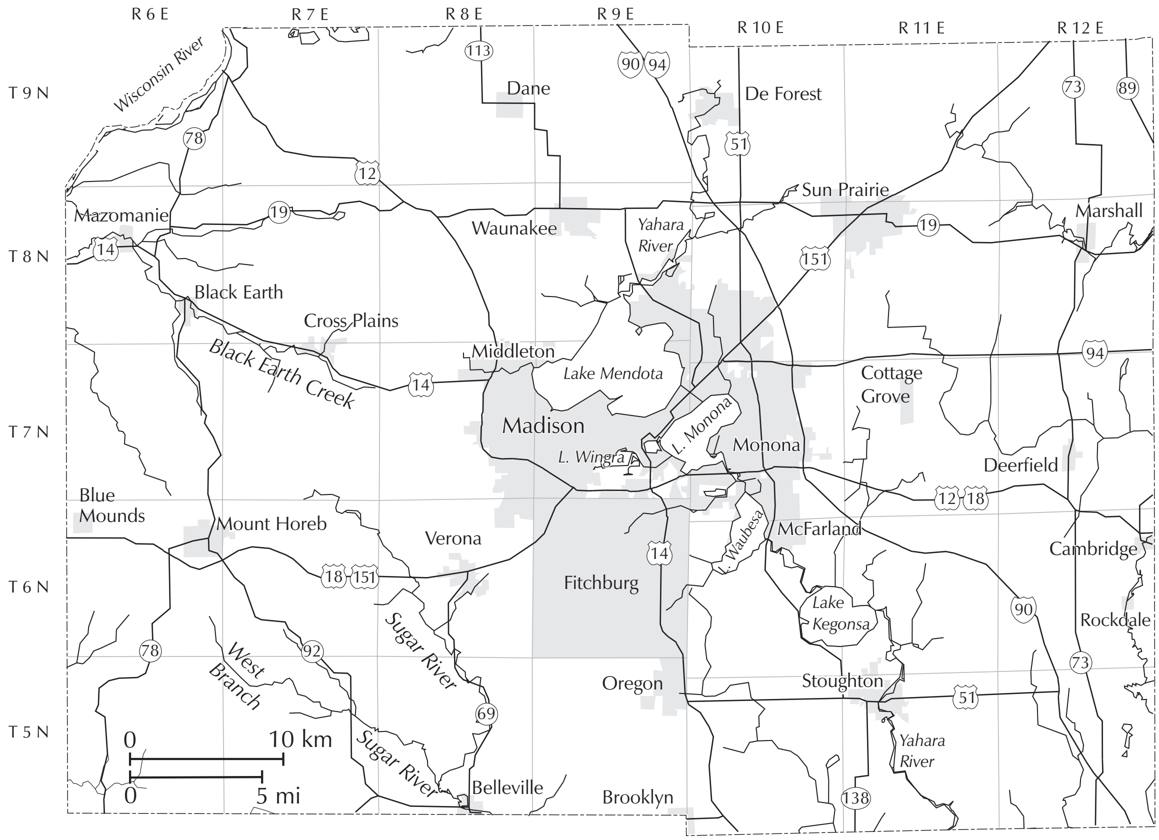


Figure 2. *Major geographic features of Dane County.*

Glocker and Patzer, 1978; Mickelson and Mc-Cartney, 1979), unpublished WGNHS Road Materials Investigation Reports and notes, and copies of field maps for Alden's 1918 report.

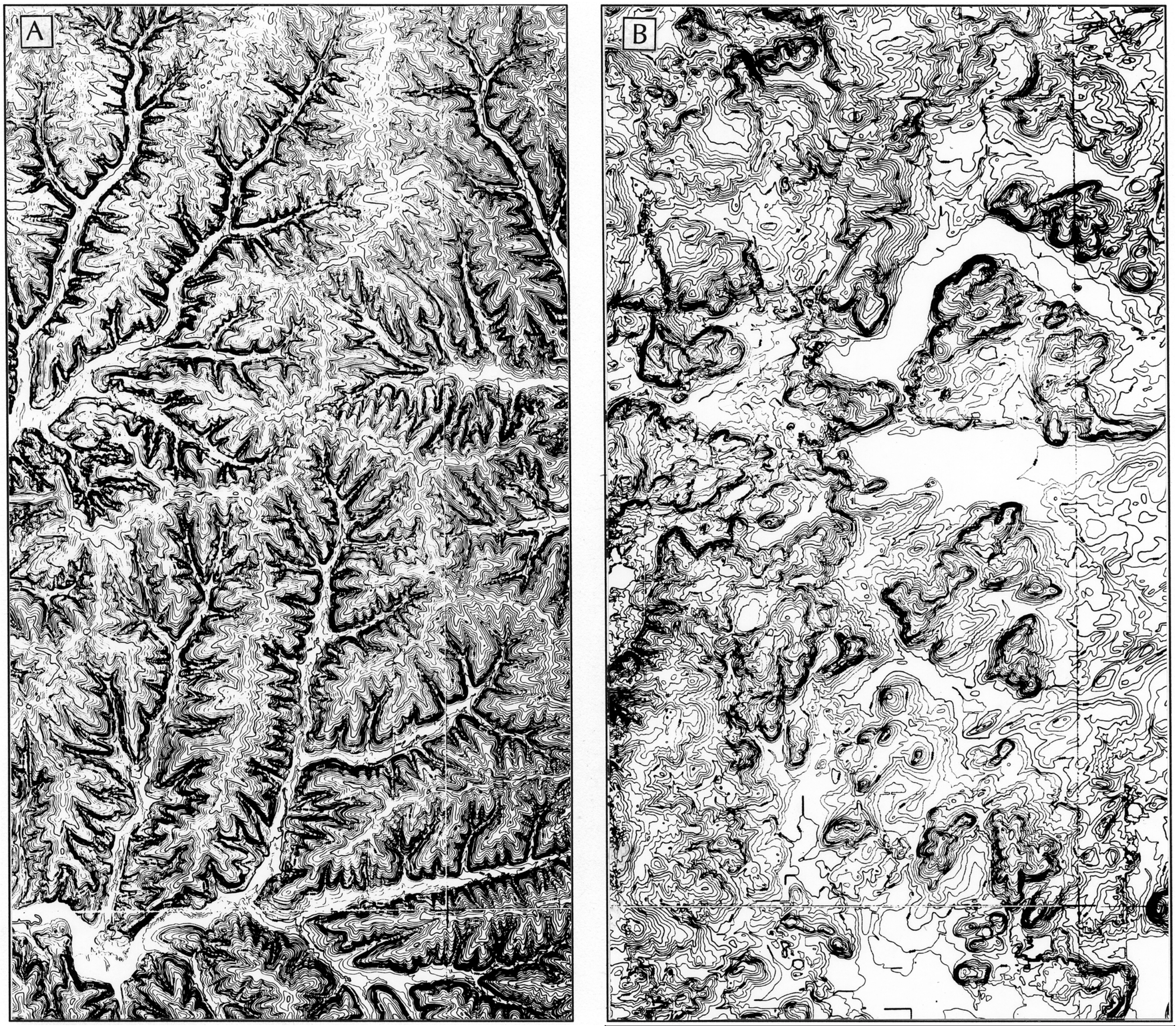
The colors used on plate 1 indicate the general environments of deposition of the mapped sediment. Yellow indicates windblown sediment, reds indicate various kinds of stream sediment, blues indicate offshore lake sediment, greens indicate glacial sediment, and gray indicates hillslope sediment. The general environment of deposition is also indicated by the first letter of the unit identifier: **w** for windblown sediment, **s** for stream sediment, **o** for offshore sediment, **g** for glacial sediment, and **h** for hillslope sediment. In addition, a variety of spot and line symbols shows different aspects of the geology on plate 1.

The 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 as far as 2.4 km north and south of the line of the cross section. In most places, subsurface information came from the lithologic logs given by water-well drillers in Wisconsin Department of Natural Resources well constructor's reports. The lithologic information in the well logs is variable in quality, and therefore the cross sections are schematic.

General description

Dane County straddles the boundary between the Driftless Area of southwestern Wisconsin and the area covered by the Laurentide Ice Sheet during the Wisconsin Glaciation (fig. 1). These two areas have distinctly different topography and geologic materials.

As in most nonglaciated areas, a branching network of streams and valleys dominates the topography of the Driftless Area in western Dane County (fig. 3A); valley bottoms are typically tens of meters below ridge crests. The Driftless Area consists of nearly flat-lying Paleozoic rock, commonly with dolomite on the uplands and poorly



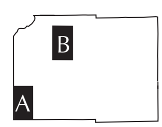


Figure 3. A. *Branching network of valleys characteristic of the Driftless Area of southwestern Dane County. Contours from U.S. Geological Survey's Daleyville, Mount Vernon, Blanchardville, and New Glarus Quadrangles (7.5-minute series, topographic, 1962); contour interval, 10 ft.* ***B.*** *Former network of valleys, northwest of Madison, highly modified during glaciation. Contours from U.S. Geological Survey's Springfield Corners, Waunakee, Middleton, and Madison West Quadrangles (7.5-minute series, topographic, 1983); contour interval, 10 ft. Scale 1:100,000.*

cemented sandstone in the valley sides. Pleistocene sediment is generally lacking, except for thin deposits of windblown and hillslope sediment on the uplands and valley sides and stream sediment in the valley bottoms.

The rest of Dane County originally had topography similar to that of the Driftless Area, but glaciers ground down the uplands, rounded off the corners of plateaus, and clogged valley bottoms with debris, creating lakes and ponds (fig. 3B). The resulting topography has less relief and is smoother than the preglacial topography. In addition, the Paleozoic rock in most of the glaciated area is covered by Pleistocene sediment characterized by fragments of rock derived from several hundred kilometers to the north-northeast.

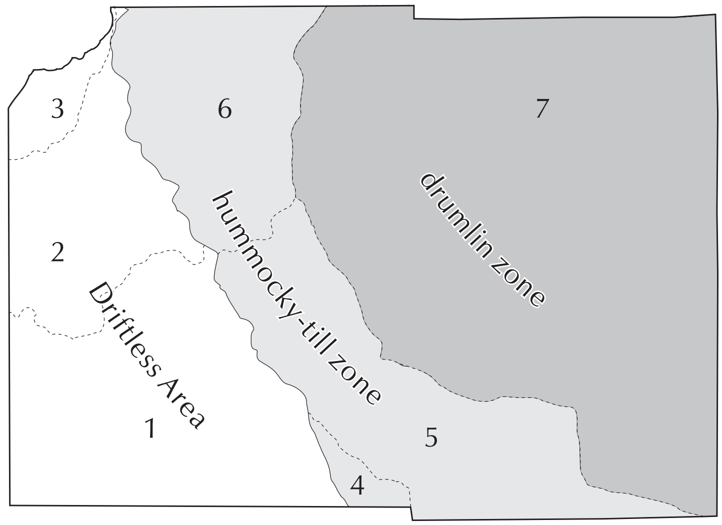


Figure 4. *Geologic regions of Dane County, based on characteristic landforms and geologic materials. A solid line marks the boundary between the Driftless Area (to the west) and the till-covered area (to the east); dashed lines mark the boundaries between numbered subdivisions described in the text.*

Figure 4 shows Dane County further subdivided into seven regions based on geologic materials and landforms. Regions 1, 2, and 3 are parts of the Driftless Area. Region 1 drains southward to the Rock River, and region 2 drains north to the Wisconsin River. They are separated by Military Ridge, which is a drainage divide that extends westward from Dane County nearly to the Mississippi River. Hillslopes in region 2 are considerably steeper than those in region 1. Glaciers probably reached the southeast corner of region 1 in Dane County, but little evidence of glaciation remains; its topography and geologic materials are like those of the rest of the Driftless Area. Region 3 is the bottomland of the Wisconsin River.

Region 4 is transitional between the Driftless Area to the west and the glaciated area to the east. The glacial sediment in this region is older than that at the surface in the area to the east. Where present, the glacial sediment is thinner than in the area to the east, and where it has been eroded from the steeper slopes, the ridges and valleys resemble those of the Driftless Area.

Regions 5, 6, and 7 were glaciated during the last part of the Wisconsin Glaciation. Region 5 has hummocky glacial topography; region 7 has abundant drumlins. (Our definitions for terms such as *hummock* and *drumlin* are given in later sections.) Just as region 2 has more rugged topography than region 1, region 6 had more rugged preglacial topography than region 5. For this reason, region 6 has more outcropping Paleozoic rock, at least around the edges of the uplands, than region 5, even though the Pleistocene material is about as thick in region 6 as in region 5 (plate 2; Olcott, 1973). As in region 4, this preglacial topography is dominant.

Acknowledgments

We thank D.M. Mickelson, A.K. Hansel, J.M. Robertson, R.M. Peters, Gary Werner, L.C. Pray, D.G. Althouse, and J.G. Mueller, who reviewed parts or all of the manuscript of this report or provided information to us, and the hundreds of landowners who allowed us access to their property. We thank Deborah Patterson and Michael Czechanski for production of the map and cross sections, Kathryn Barrett and Matthew Menne for assisting them, and Susan Hunt for the layout and production of the report.

PRE-PLEISTOCENE STRATIGRAPHY

Lower Paleozoic rock is at or near the surface in most of southwestern Dane County. In the rest of the county, it is generally buried under Pleistocene material, but rock outcrops are scattered throughout the glaciated area (plate 2; Cline, 1965; Olcott, 1973). Most of the Paleozoic rock is marine dolomite or sandstone (fig. 5).

The lowest Paleozoic unit consists of hundreds of meters of sandstone and shale of the Elk Mound Group (composed of, from oldest to youngest, the Mount Simon, Eau Claire, and Wonewoc Formations), which is underlain by Precambrian igneous and metamorphic rock. Only the upper part of the Elk Mound Group is exposed in northwestern Dane County, just above the level of the Wisconsin River.

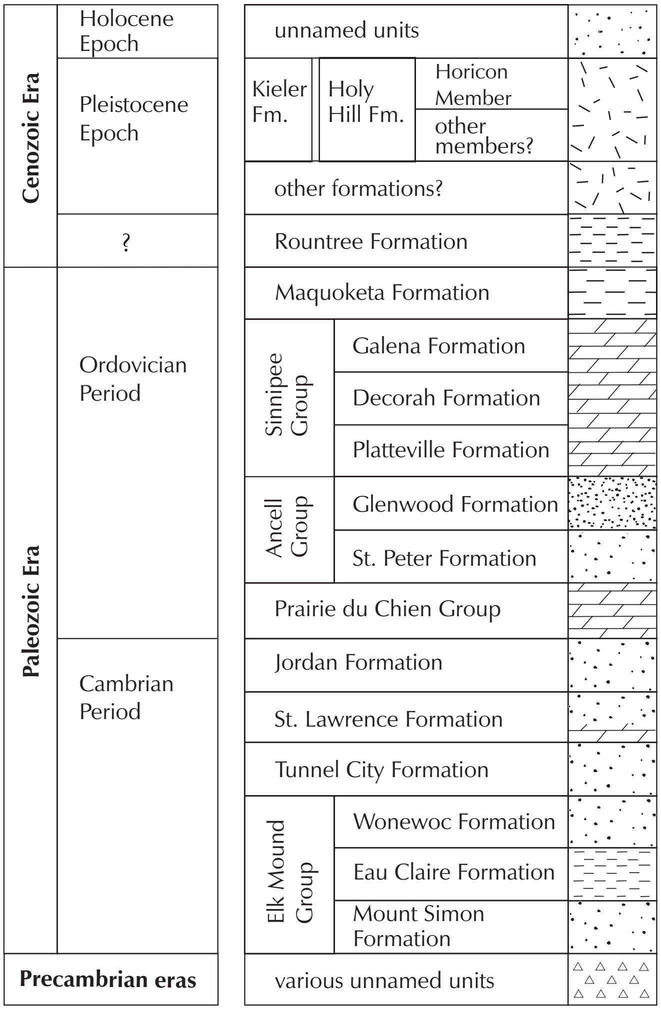


Figure 5. *Stratigraphic column of Dane County.*

Above the Elk Mound Group are the Tunnel City Formation (tens of meters of glauconitic sandstone) and the St. Lawrence Formation (several meters to tens of meters of sandstone, siltstone, and dolomite). They are exposed around the lower flanks of the highlands in the northwestern part of the county.

The youngest Cambrian rock exposed in the county is a few tens of meters of sandstone of the Jordan Formation, most commonly seen in the scarps (steep slopes) surrounding the Prairie du Chien plateaus in the northwest. It crops out from beneath Pleistocene sediment on the flanks of highlands in a few places in the eastern half of the county.

Overlying the Jordan is a variable thickness (as much as 60 m) of early Ordovician cherty dolomite of the Prairie du Chien Group. It is well exposed on plateau uplands in the northwestern part of the county and in scattered places throughout the glaciated part of the county.

Above the dolomite is a highly variable thickness (absent in some places and thicker than 60 m in others) of generally poorly cemented Ordovician sandstone of the Ancell Group. This group consists of a thin layer of sandstone of the Glenwood Formation, which overlies sandstone of the St. Peter Formation. The St. Peter sandstone is most commonly seen in or below the scarps surrounding the dolomite plateaus in the southwest.

Near Blue Mounds, the Ancell is overlain by as much as 95 m of Ordovician cherty dolomite of the Sinnipee Group (from oldest to youngest, the Platteville, Decorah, and Galena Formations). The Sinnipee dolomite is the upland rock on the plateaus in the southwest quarter of the county and is at or near the surface in some places in the eastern part of the county.

The youngest Paleozoic rock in the county is the 30 m of Ordovician shale of the Maquoketa Formation that makes up East Blue Mound, at the middle of the west border of the county. West Blue Mound, just across the border in Iowa County, contains 70 m of Maquoketa shale.

The Maquoketa on West Blue Mound is overlain by an unnamed formation consisting of chert with Silurian fossils (Hubbard, 1900). According to Thwaites (1960, p. 26), this caprock is about 25 m thick in a well on top of the mound and consists of “boulders of Niagara chert mixed with clay”; he also referred to it as “Niagara (all disintegrated)...chert” (WGNHS Geologic Log IW-15). It has also been called “surface” sand and gravel (WGNHS Geologic Log IW-106). The vague bedding observed in outcrops on the flat top of the mound dips at all angles, indicating that the caprock consists of moved boulders of chert rather than solid in-place chert. The unit does not crop out in Dane County, but lag boulders of the chert are found around East Blue Mound.

Overlying the Paleozoic rock is the Rountree Formation (Knox and others, 1990), which consists of a few meters of red-tinged clayey sediment draped across the hillslopes of southwestern Dane County and throughout the Driftless Area. It is present beneath much of the western edge of the Holy Hill Formation and for a few kilometers to the east, but farther east it is generally missing because of glacial erosion. The sediment in the Rountree Formation probably consists of Cenozoic hillslope material, but its likely age and origin are discussed in a later section of this report.

PLEISTOCENE STRATIGRAPHY

Pleistocene sediment ranges in thickness from 1 m or less across much of the southwestern part of Dane County to a few meters or tens of meters in much of the rest of the county to more than 100 m in the deepest preglacial valleys (plate 2; Olcott, 1973). There probably are scattered remnants of early and middle Pleistocene sediment in Dane County, but we know too little about them to assign them to named stratigraphic units. Most of the late Pleistocene glacial and associated deposits in the county are in the Holy Hill Formation. Contemporaneous with the Horicon is the thin Kieler Formation, both of which are overlain by unnamed Holocene units.

Unnamed early or middle Pleistocene units

Early and middle Pleistocene deposits probably underlie the late Pleistocene Holy Hill Formation, especially in deep preglacial valleys (plate 2; Olcott, 1972; Cline, 1965), but we know too little about them to speculate on their stratigraphic significance. Glacial sediment that is older than the Holy Hill exists to the south in Rock and Green Counties and in northern Illinois. Alden (1918, plate 3) thought it was deposited during the Illinois Glaciation and mapped it into Dane County as far north as Verona and as far west as the Sugar River. Most of this material has been eroded away, however, leaving little evidence for pre-Wisconsin glaciations in Dane County.

Alden (1918, p. 146) found no more than “scattered” pebbles, cobbles, and boulders of far-traveled rock at most places in Dane County southwest of the outermost Wisconsin moraine and east of the Sugar River. He saw glacial sediment (till) at only two places: “a little sandy till” in a gully 3 km west of Verona and “till 20 to 30 feet deep” in a gravel pit just northwest of Belleville. It is no longer exposed at either place. We saw pebbles of far-traveled igneous and metamorphic rock in deposits of debris eroded from adjacent hillslopes, but we did not identify any till in this part of Dane County.

Evidence that glaciers probably entered Dane County before the Wisconsin Glaciation is found just south of Dane County. At the Zweifel Road site 2.5 km southwest of the outermost Brooklyn moraine in Green County (j, fig. 6), we identified two distinctly different units in core samples (fig. 7) from a hole drilled on the ridge crest about 6 m south of a roadcut originally described by Bleuer (1971, appendix 1d). The upper 5.3 m (unit B) consists of two layers of sand and gravel interbedded with two layers of till; the till consists of clayey, gravelly, silty sand that has magnetic susceptibility (a measure of the amount of magnetic minerals such as magnetite present) of 1.7 to 2.9 x 10^{-3}. The lower 2.7 m (unit A), overlying dolomite, consists of more-variable gravelly, sandy, clayey silt that has magnetic susceptibility of 0.5 to 0.9 x 10^{-3} and joints stained black. Bleuer was uncertain of the identity of these stratigraphic units, as are we. Nor do we have any evidence of their age, although it seems likely this material was deposited during a pre-Wisconsin glaciation because it retains little or no glacial topography and it has been eroded from most of the area. If the glaciers reached this far west in Green County, they may have reached the Sugar River in Dane County as well.

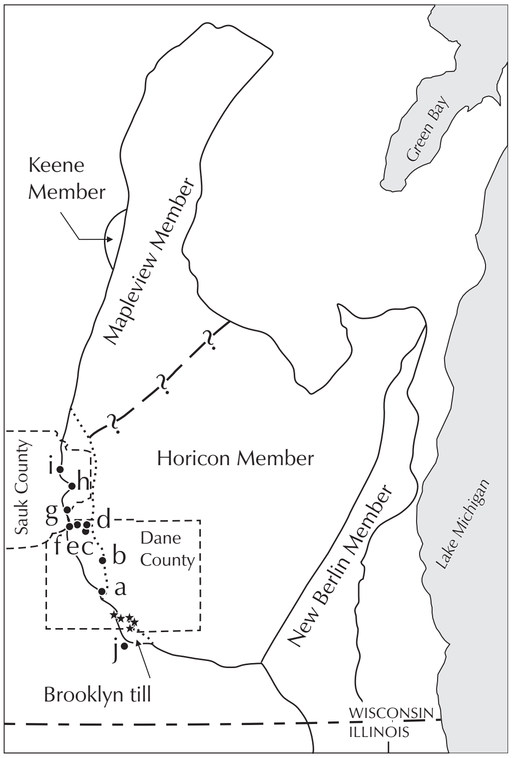


Figure 6. *Southeastern Wisconsin, showing location of till of the members of the Holy Hill Formation; they are not indicated where buried under younger till units close to Lake Michigan. The contact between the Mapleview and Horicon Members has not yet been determined (dashed line with question marks). Letters* ***a–i*** *indicate sites mentioned in the text where abundant dark igneous rock is found in the Horicon Member. The supposed eastern limit of fragments of dark igneous rock is indicated by the dotted line in northwestern Dane County. The dotted line in southern Dane County is the boundary between till of the Brooklyn and Johnstown Phases. Stars mark observations of abundant chert in Johnstown till and meltwater sediment. Letter* ***j*** *marks the Zweifel Road site.*

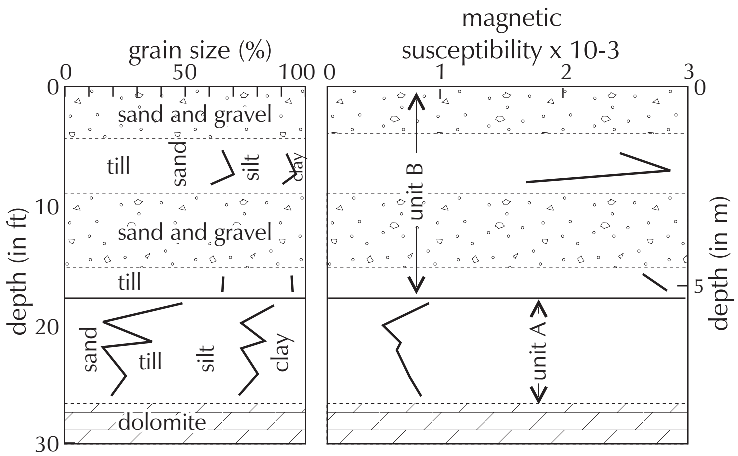


Figure 7. *Analyses of samples of till from a continuous split-spoon core at the Zweifel Road site, UTM coordinates 301,140 m E, 4,741,570 m N.*

Holy Hill Formation

The bulk of the Pleistocene sediment in Dane County is part of the Holy Hill Formation, which includes most of the brown sandy till in southeastern Wisconsin (fig. 6; Mickelson and Syverson, in press). Also included in the Holy Hill Formation are associated deposits of sand and gravel deposited by glacial meltwater streams and clay, silt, and sand deposited in glacial lakes.

The Holy Hill Formation includes two named stratigraphic subdivisions in the area: the Horicon Member, which extends eastward to the Kettle Moraine in Waukesha County, and the Mapleview Member, which is the lateral equivalent of the Horicon to the north (fig. 6). The Horicon is characterized by till that consists of brown gravelly, clayey, silty sand. Mapleview till is coarser, contains more quartz sand derived from Cambrian formations, and contains less dolomite derived from Ordovician formations than the Horicon till (Mickelson, 1986, p. 22; Attig and Muldoon, 1989, p. 9; Clayton, 1986, p. 7B8; Clayton, 1987, p. 3).

In Dane County, the Holy Hill till is typically reddish brown (5YR 5/4 on the Munsell scale), brown (7.5 YR 5/4), light reddish brown (5YR 6/4), or light brown (7.5 YR 6/4). The till is a homogeneous mixture that ranges from the finest clay up through boulders 2 m or more in diameter. On the basis of an analysis of 80 samples, the till commonly contains several percent gravel, and the finer-than-gravel fraction (finer than 2 mm) consists of 55 to 85 percent sand, 5 to 30 percent silt, 5 to 20 percent clay (fig. 8); the till of the hummocky area is slightly siltier than that of the drumlin area. These results are similar to those obtained by McCartney (1976), Oelkers (1995), and Rayne (1993), who analyzed several dozen samples from the Cottage Grove, Middleton, and Lake Waubesa areas in central Dane County. Magnetic susceptibility generally ranges from 0.6 to 1.0 x 10^{-3} (SI units). The hydraulic conductivity of till in Dane County has been analyzed by Rayne and others (1996).

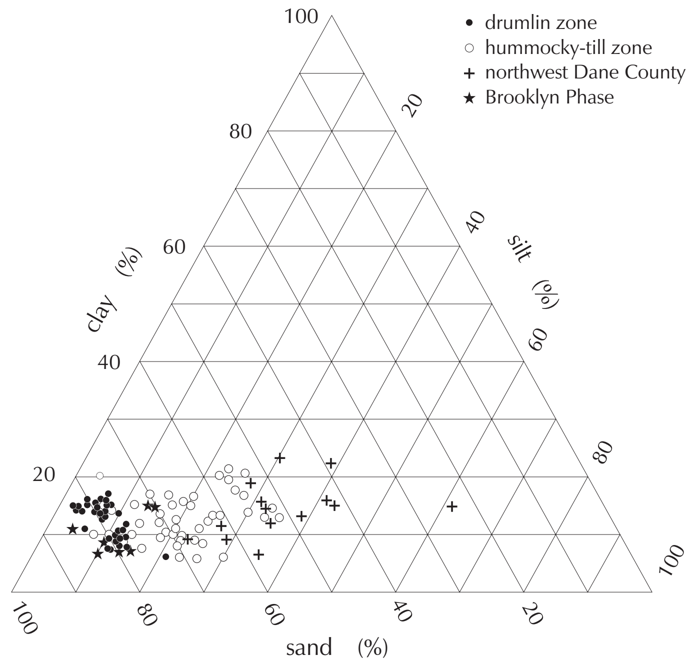


Figure 8. *Grain-size analyses of the finer-than-2-mm fraction from samples judged to be till of the Horicon Member of the Holy Hill Formation, including till deposited during the Brooklyn Phase and till (or till-like material) with abundant dark igneous rock in northwestern Dane County. Analyzed samples were collected from outcrops and drillholes scattered throughout the glaciated part of Dane County.*

Between 1919 and 1962, the WGNHS provided the state highway department with Road Materials Investigations Reports, which gave evaluations of potential road-building material near proposed highway construction projects. The field notes for these unpublished reports contain analyses of the rock types present in deposits of sand and gravel in the Holy Hill Formation at 220 sites throughout Dane County (WGNHS files); 50 or more pebbles were examined at each site, but the specific size range is unknown. According to these notes, dolomite is everywhere the most common pebble lithology, typically between 60 and 90 percent of the total, with slightly higher values in the northwestern and northeastern parts of the county and lower values in the south-central part. Chert is next in abundance, typically between 3 and 15 percent, with the highest values in the southeast quarter. Sandstone is between 1 and 10 percent, with the highest values just northwest and southeast of Madison. Mafic igneous rock is between 1 and 7 percent across the county. Felsic igneous rock is 1 to 6 percent, with the highest values southeast of Madison. Quartz and quartzite are 0 to 6 percent, with the highest values in the east-central part of the county. Because dozens of different summer employees (mostly geology students) made these analyses over a period of several decades, their consistency is suspect, and further analysis of this data may be unwarranted. However, quartzite pebbles are known to be abundant in the east-central part of the county, carried there from outcrops of the Waterloo quartzite in southwestern Dodge County (Buell, 1895), suggesting that the reports of slight areal differences for the other lithologies may also be reliable.

We observed another deviation from average Holy Hill till, which does not show up in the road-material data. In material from three drillholes east of Sauk City (c, d, and e, fig. 6), more than half the pebbles in till-like glacial debris consists of crumbly, coarse-grained, black igneous rock to depths of at least 15 m; on the basis of the most likely glacial flowpath down the Green Bay lowlands, this rock probably came from at least as far north as the east end of Lake Superior (fig. 9). The till-like material is somewhat darker and siltier (typically 30 to 40%, compared to 5 to 30%) and less sandy (40 to 60%, compared to 55 to 85%) than Holy Hill till in the rest of the county. It has higher magnetic susceptibility (typically 1.5 to 10 x 10^{-3}, compared to 0.5 to 1.0 x 10^{-3}). A magnet removed one-sixth of the very-coarse sand fraction from one sample with a susceptibility of 15 x 10^{-3}.

Similar material has been noted in a quarry just north of Middleton (b, fig. 6; Johnson and others, 1982) and in a house excavation just northwest of Verona (a, fig. 6; D.M. Mickelson, University of Wisconsin–Madison, Department of Geology and Geophysics, verbal communication, 1995). Lundqvist and others (1993) also found abundant pebbles and cobbles of black igneous rock in certain till layers and gravel bodies

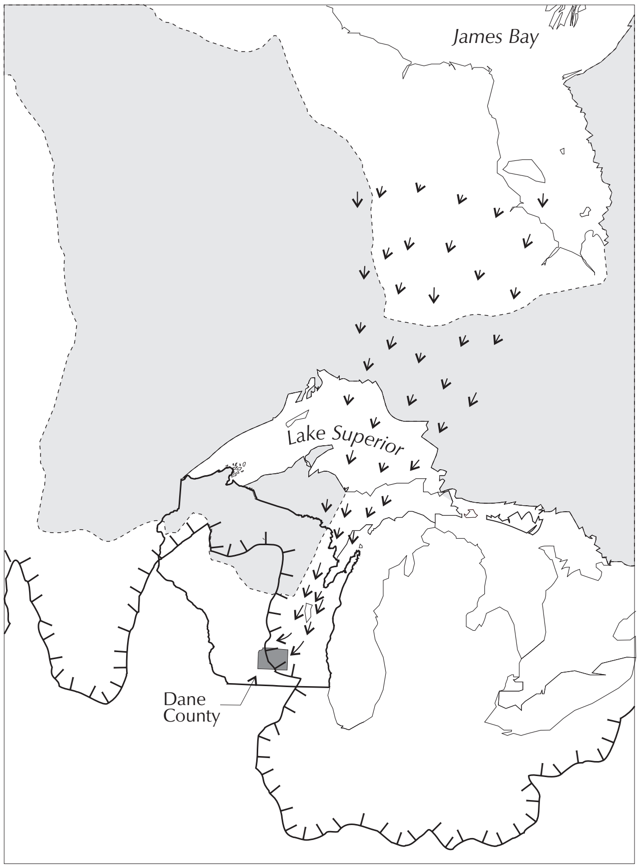


Figure 9. *The southern sector of the Laurentide Ice Sheet about 16,000 BP; its edge is the line with hachures. Arrows indicate the possible source of rock types carried by the glacier to Dane County; the direction of glacial movement is based on drumlins and similar directional indicators (Farrand and others, 1984; Lineback and others, 1983; Dyke and Prest, 1987). The shaded area is Precambrian rock; the unshaded area, Paleozoic and younger rock underlying the Pleistocene material.*

exposed in a gravel pit in the outermost Johnstown moraine across the river from Sauk City (f, fig. 6) and in three other pits in the moraine in eastern Sauk County (g, h, and i, fig. 6). Alden (1918, p. 221) said that five townships in eastern Sauk County (fig. 6) and adjacent Columbia and Adams Counties have till with exceptionally abundant "crystalline pebbles"—as much as 45 percent of the pebbles. He suggested that they probably came from knobs of Precambrian rock known to exist in Columbia, Green Lake, and Marquette Counties. However, on the basis of the orientation of drumlins and other flow indicators in the Green Bay lowland (Alden, 1918, plates 3 and 4), these knobs are too far north to be the source of these pebbles.

In contrast to the glacial material with abundant black igneous rock discussed in the previous paragraphs, glacial material to the southeast has abundant chert. The field notes for the Road Materials Investigations Reports indicate that the outermost Johnstown moraine and associated meltwater sediment in some places in south-central Dane County (stars, fig. 6) contain 15 to 40 percent chert pebbles, but only 0 to 6 percent mafic-rock pebbles.

These materials are all considered part of the Horicon Member of the Holy Hill Formation, even though they are atypical. We have no reason at this time to assign these materials to different stratigraphic units.

Although it was deposited before the till at the surface in the rest of Dane County, the till of the Brooklyn Phase in south-central Dane County (fig. 6; map units **gb** and **gp,** plate 1) is also part of the Horicon Member. On the basis of the analysis of seven till samples from one 5.5-m-deep drillhole, it has the same color, grain size, and magnetic susceptibility as till in the rest of the Horicon Formation (fig. 8).

Other late Pleistocene and Holocene units

A discontinuous layer of windblown silt (loess), about 1 m thick, overlies the Holy Hill Formation and older units where the Holy Hill is absent. Most of it was deposited during the last part of the Wisconsin Glaciation. In the Driftless Area it has been included in the Peoria Member of the Kieler Formation (Leigh and Knox, 1993).

Various Holocene dune-sand deposits, hillslope deposits, and nonglacial stream and lake deposits have been left unassigned to any formal stratigraphic unit.

GLACIAL SEDIMENT AND LANDFORMS

Glacial sediment (till) is indicated on plate 1 by greens and by **g** (for glacial) as a letter-symbol prefix. It was described in the section on Pleistocene stratigraphy. Here we discuss the origin of the various glacial sediments and landforms in Dane County.

The thickness of the Pleistocene sediment of Dane County is fairly well known (plate 2; Olcott, 1973); it is typically 5 to 20 m in the glaciated part of the county, but it is more than 100 m in some of the deep, preglacial valleys. The proportion of sediment that was deposited during the Wisconsin Glaciation is unknown, but it is probably large. Similarly, the till deposited during the Wisconsin Glaciation presumably includes several till sheets resulting from several separate episodes of advance and retreat of the ice margin, but we do not know the thickness of the last till sheet, or any of the others, because we have no lithologic information to distinguish them.

To illustrate, during the Brooklyn Phase of glaciation, the Green Bay Lobe advanced farther into the south-central part of the county than it ever did again; after that, the ice margin retreated out of the county; some time later the Johnstown readvance, which in this area was not quite as extensive as the Brooklyn advance, occurred. However, no lithologic differences are known for distinguishing this readvance; the interpretation that they are different till sheets is based on topographic evidence alone.

In one setting, however, the till-sheet thickness is known: In areas of map unit **gd** (plate 1), where dolomite is at the surface, the thickness of every till sheet is negligible. In other areas, the uppermost till sheet can be estimated to be at least as thick as the height of moraines and till hummocks. That is, the uppermost till sheet in Dane County ranges in thickness from 0 to probably more than 10 m.

Two general types of till can be distinguished in Dane County: supraglacial till of the hummocky zone and subglacial till of the drumlin zone (figs. 10 and 11). The supraglacial till tends to be less uniform and to contain more silt than the subglacial till.

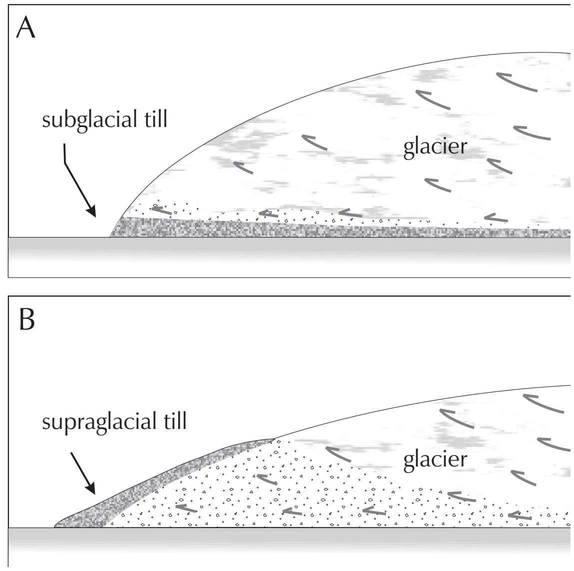


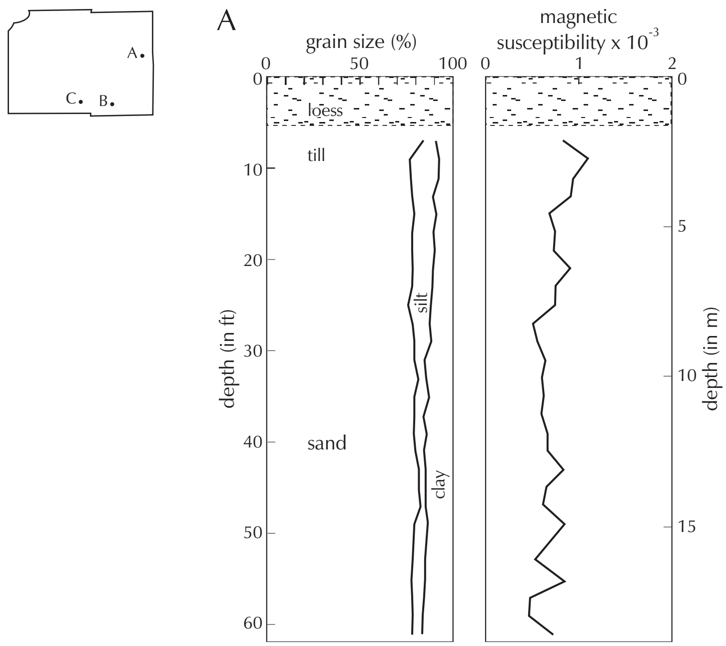
Figure 10. *Schematic cross sections of a glacier showing deposition of (**A**) subglacial till when the ice at the bottom of the glacier melts and releases the enclosed debris, and (**B**) supraglacial till when the ice at the upper surface of the glacier melts and releases enclosed debris. Half arrows show direction of glacier movement.*

Moraines

In this report, we consider an end moraine (for convenience, here shortened to moraine) to be a ridge oriented perpendicular to the ice-movement direction and composed of glacial debris deposited along the margin of an active glacier. This happens when the glacier margin has stabilized at one place for some time, following either a retreat or an advance of the margin, resulting in a thickening of the till sheet.

In the following discussion we group moraines according to size—small, medium, and large. On plate 1, small moraines are distinguished from medium-sized ones by different line symbols, but no large ones are present in Dane County.

Small moraines. We first noticed the small moraines on aerial photographs (fig. 12). They are too small to be shown by the 10-ft contours on existing topographic maps and are too small to be easily recognized on the ground. They are



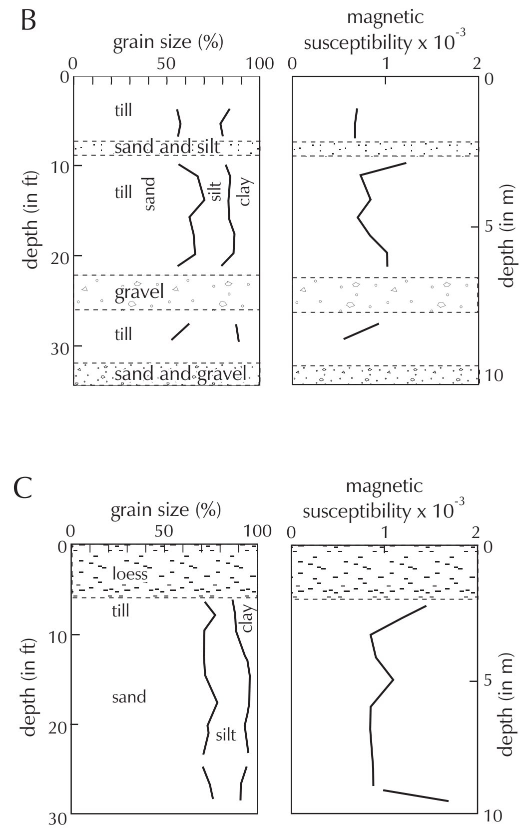


Figure 11. *Analyses of samples from continuous split-spoon cores of till from the drumlin zone (**A**) and the hummocky zone (**B, C**). **A.** 1 km south of Mud Lake, UTM coordinates 333,420 m E, 4,772,930 m N. **B.** 2 km southwest of Stoughton, UTM coordinates 317,710 m E, 4,750,870 m N. **C.** 3 km southwest of Oregon, UTM coordinates 302,510 m E, 4,753,100 m N.*

generally no more than a few meters high and several meters to a few tens of meters wide, and individual segments are commonly no more than a few hundred meters long. Many of these small moraines are clustered in sets of dozens of uniformly spaced ridges, in contrast to the medium-sized moraines, which tend to be isolated from each other (fig. 13).

The small moraines of Dane County may be similar in origin to the "minor moraines" or "washboard moraines" that are common in the region from Iowa to Alberta (Gwinn, 1951; Elson, 1968). These features formed at the margin of the wasting ice sheet, probably during brief stillstands or slight readvances of the margin, perhaps yearly.

The small moraines also resemble "push moraines," which form yearly during the winter readvance of many modern glaciers (see, for example, Price, 1970). The small moraines of Dane County and the washboard moraines tend to be about as wide as the inter-moraine areas and irregular in outline, as if they had undergone some collapse when underlying ice melted. In contrast, modern push moraines tend to be much narrower than the inter-moraine areas and have sharper outlines because they have undergone no collapse. If those in Dane County formed yearly, the margin of the Green Bay Lobe was wasting back at the rate of about 50 m/year.

In a few places, pairs of small moraines are closer to each other than they are to adjacent pairs (seen, for example, on aerial photographs of the NW¼ sec. 2, T8N, R9E, and the SE¼ sec. 34, T9N, R9E, 4 km east-northeast of Waunakee). The cause of this doubling is unknown, but each pair might have originally been a single ice-cored moraine that acquired a central trench when the core melted (fig. 14).

Medium-sized moraines. In contrast to the small moraines, those called medium-sized moraines on plate 1 can be recognized on topographic maps having 10-ft contour intervals. They are at least a few meters high.

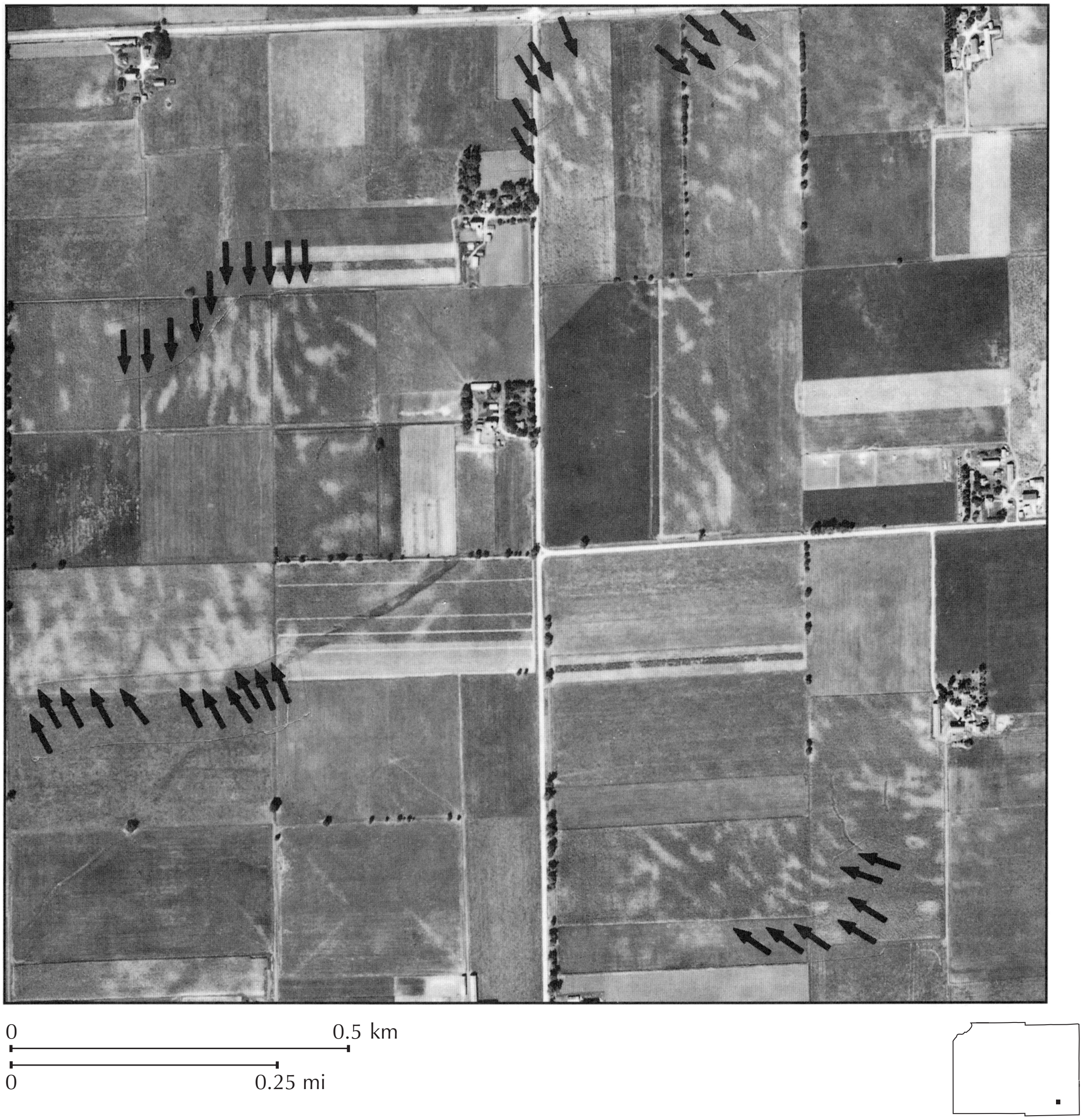


Figure 12. *Aerial photograph of small moraines (arrows), 4 km east of Stoughton. U.S. Department of Agriculture aerial photograph WU-6P-32. E½ sec. 11 and W½ sec. 12, T5N, R 11E.*

In the past, the medium-sized moraines that formed during the Lake Mills Phase of the Wisconsin Glaciation in the northeastern part of the county, were called the "Lake Mills moraines," using the plural form because more than one was recognized. In contrast, medium-sized moraines formed during the earlier Johnstown Phase and Milton Phase were called the "Johnstown moraine" and the "Milton moraine," using the singular form because only one moraine was recognized for each phase. We now recognize that several medium-sized and many small moraines were formed during each of these phases.

The medium-sized moraine that formed during the maximum advance of the Green Bay Lobe in Dane County is the outermost (southwesternmost) Johnstown moraine (fig. 13). It is typically 5 to 10 m high and 20 to 100 m wide. In many places it is a simple ridge, but in some

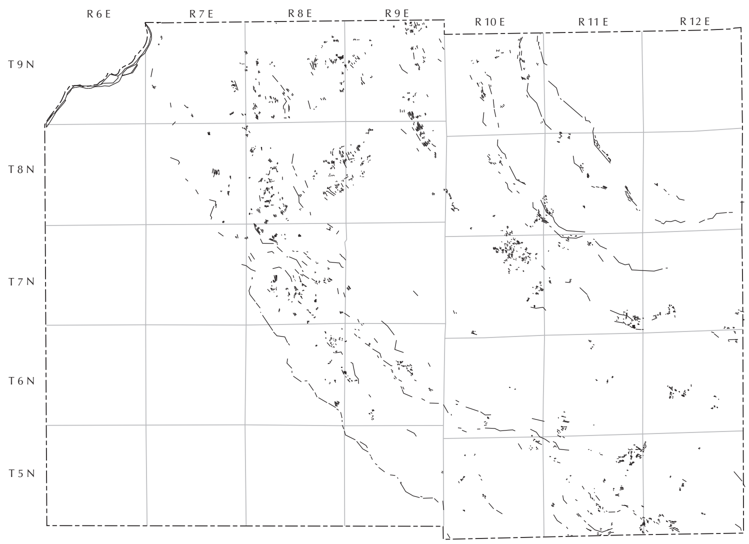


Figure 13. *Distribution of small moraines and medium-sized moraines in Dane County.*

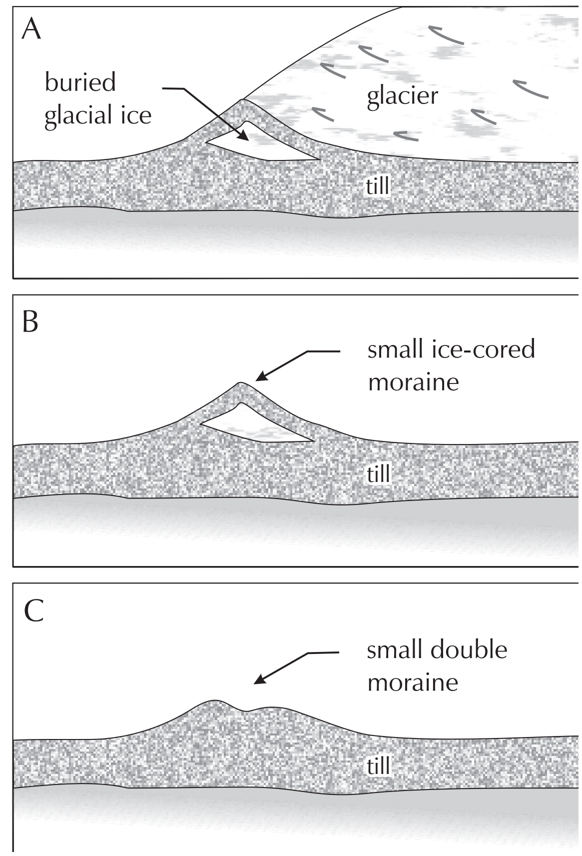


Figure 14. *Schematic cross sections showing the formation of a small double moraine (**C**) when its ice core (**B**) melts; the ice core may have resulted from the shearing of subglacial till over a stagnant mass of ice (**A**).*

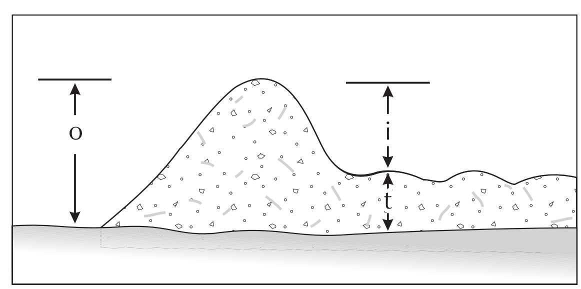


Figure 15. *Schematic section through outermost moraine of the Johnstown Phase. Thickness of the till sheet (**t**) estimated by subtracting the height of the ice-contact face (**i**) from the height of the other side of the moraine (**o**).*

places it is a hummocky ridge. This and other hummocky moraines in places merge with belts of hummocks that lack a ridge form and are here considered to be collapse topography (map unit **gk,** plate 1) rather than moraines.

Where neither side of the outermost Johnstown moraine has been buried by stream or lake sediment, the southwest flank is generally only a few meters taller than the northeast flank. This shows that the sediment in the moraine is much thicker than it is immediately northeast of the moraine (fig. 15), probably because the glacier margin stabilized at the moraine for a significant period.

A discrete moraine is lacking along parts of the maximum extent of the Green Bay Lobe. In the southern and west-central part of the county, it is missing in a few places, probably because no moraine formed. In the northwestern part of the county, it is also missing in some places, but generally because erosion removed it from steeper slopes and younger sediment buried it in low areas.

The outermost Johnstown moraine is generally a conspicuous landform, accentuated in places by a belt of trees on its crest, such as where Mineral Point Road crosses it 6 km west of Highway 12–14. There, its crest is 70 m east of the junction with Timber Lane (at the northwest corner of sec. 30, T7N, R8E); the moraine is about 10 m high and 100 m wide. Just southeast, Shady Oak Lane runs along the west edge of a similar segment of the moraine for 2 km southeast of its junction with Mid Town Road (through the middle of sec. 5, T6N, R6E).

One of the best places to view a moraine is in Prairie Moraine Parkway on Highway PB, 1 km south of Highway M, southeast of Verona (fig. 16). Much of the site is open grassland, allowing unobstructed views. In this area, the outermost Johnstown moraine is 10 to 20 m high and 80 m wide. The Ice Age National Scenic Trail will run along its narrow crest. Hummocky collapse topography is visible to the north of the moraine. To the south, we have seen no trace of glacial material on outcrops of the St. Peter sandstone. Far-traveled boulders of igneous and metamorphic rock have been seen no farther south than the foot of the south flank of the moraine, except in places where slopes to the south allowed meltwater or debris flows to carry boulders out beyond the foot of the moraine.

Most other medium-sized moraines shown on plate 1 are of similar size or smaller than the outermost Johnstown moraine, and many are more discontinuous.

In a few places in northeastern Dane County (plate 1; fig. 13), a solitary medium-sized moraine is part of a cluster of small moraines. These medium-sized moraines may represent longer periods of near stability, when the glacier stacked several small annual moraines on top of each other.

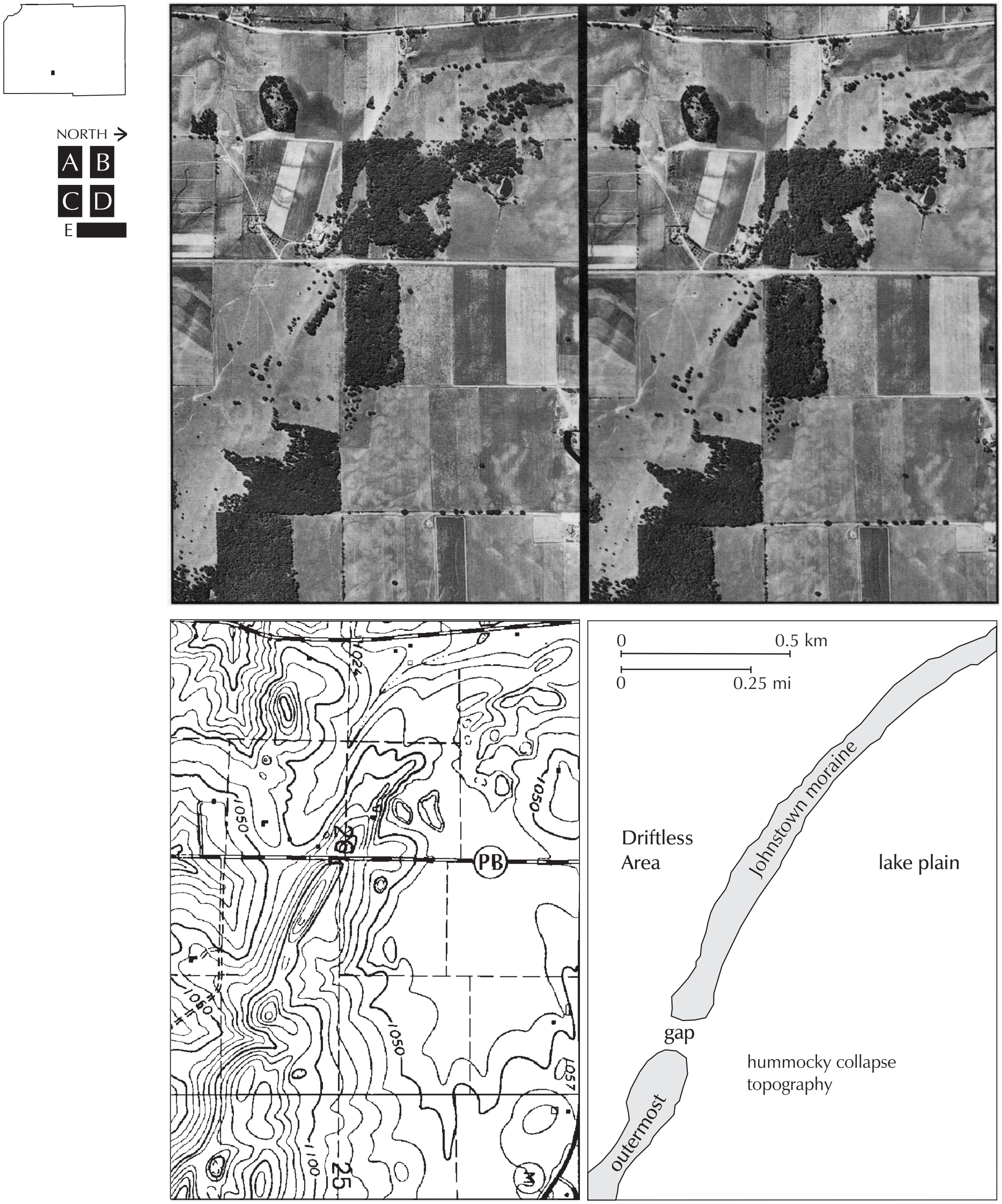
In general, the origin of these medium-sized moraines is clear. Where the glacial ice was moving forward at the same rate as ice at the margin was melting back, the margin stabilized. Debris in the glacier was carried forward to the margin and deposited there.

However, the details are unclear. The debris may be deposited on the moraine by the flowage of till and other debris off the top of the snout of the glacier (fig. 17A and B), as suggested by Attig (1993, p. 9-10) for a moraine in northern Wisconsin shaped much like the outermost Johnstown moraine in Dane County and perhaps the same age. Alternatively, a moraine might be composed of till that melted out from under the snout of the glacier (fig. 17C and D), as suggested by Lundqvist and others (1993) for the outermost Johnstown moraine at the northwest corner of Dane County and in adjacent Sauk County; this would indicate that at least the outermost edge of the glacier had a thawing bed.

Large moraines. The terms small and medium-sized used above imply the existence of large moraines in the region. The Hancock and Almond moraines, which are the outermost moraines formed during the maximum advance of the Green Bay Lobe to the north of Dane County, are typically broad hummocky ridges 10 to 20 m or more high and 0.5 to 1.0 km or more wide. No comparable large moraines exist in Dane County.

Wide vs. narrow moraines. Previous maps of the Pleistocene geology of southeast Wisconsin have shown much wider moraines than shown here on plate 1, perhaps at first because it was expedient to exaggerate their width so they would show up on small-scale maps. Alden (1918, plate 3), for example, showed his Johnstown moraine to be a few kilometers wide in parts of Dane County, including not only the narrow “marginal ridge” (Alden, 1918, p. 213), which is here considered to be the moraine, but also a vaguely defined belt of more hummocky topography, whose up-glacier edge is “very indefinite” or “poorly defined” (Alden, 1918, p. 211-213).

We do not consider most of Alden’s hummocky moraines to be moraines because they do not fit our definition of a moraine. They are not ridges. They do not correspond to a thickening of the till sheet. Many are parallel to the ice-movement direction or obliquely oriented rather than perpendicular to ice-movement direction. We interpret the hummocky topography to be collapse topography, which formed behind the stagnant-ice margin and well in front of the active-ice margin, not at the active-ice margin.



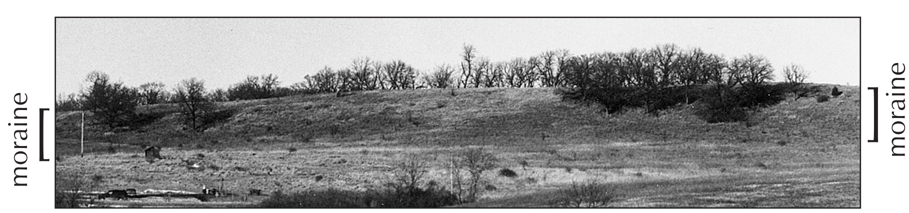


Figure 16. *The outermost Johnstown moraine in the Prairie Moraine Parkway, 2 km southeast of Verona. The gap in the moraine was cut by a meltwater stream.* ***A/B.*** *Stereoscopic pair U.S. Department of Agriculture aerial photographs WU-3P-41 and 42.* ***C.*** *Part of U.S. Geological Survey's Verona Quadrangle (7.5-minute series, topographic, 1962); contour interval, 10 ft.* ***D.*** *Sketch map of same area.* ***E.*** *View to north-northeast from Highway PB.*

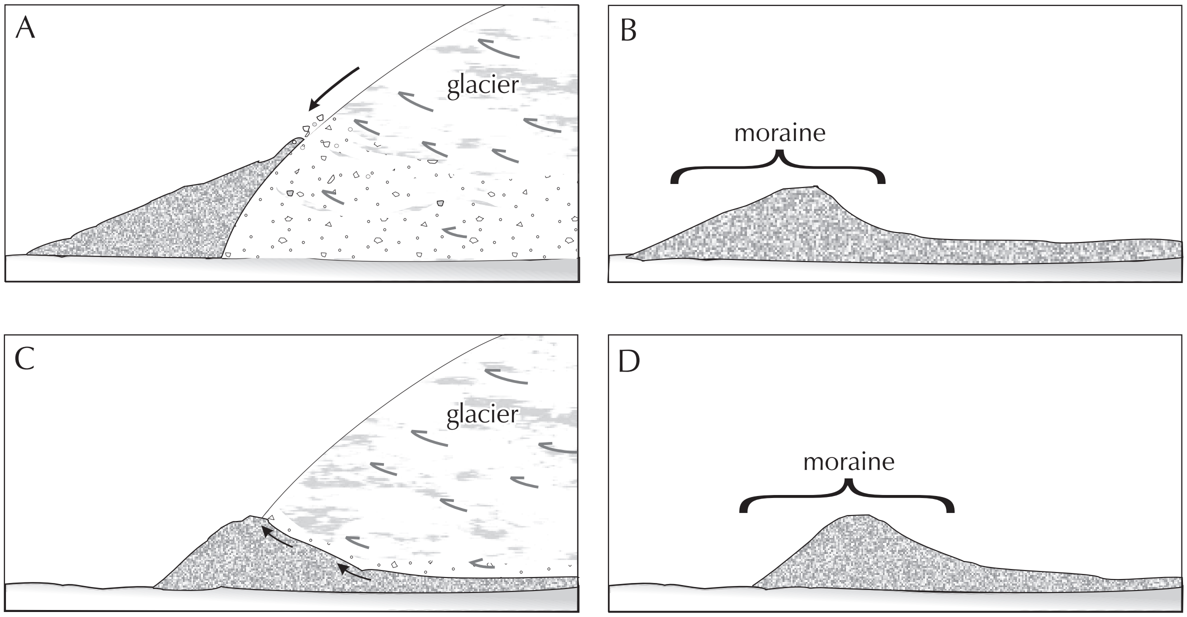


Figure 17. *Formation of a moraine (**B**) from supraglacial debris; debris in the ice melts out on the surface of the glacier, then flows and slides off the snout of the glacier (**A**). Formation of a moraine (**D**) from subglacial debris; debris in the ice melts out of the base of the glacier and is dragged forward to the snout (**C**). The half arrows show ice movement, and complete ones show debris movement. Dark gray areas represent subglacial and supraglacial debris.*

Hummocky collapse topography

On plate 1, we have divided the green area representing glacial sediment into two large regions. To the northeast is a zone of drumlins (shown by line symbols in map unit **gs**); to the southwest, a zone of hummocky topography about 10 km wide (map units **gh** and **gk**). This hummocky zone is part of a zone of hummocky collapse topography as wide as 50 km formed around much of the southern margin of the Laurentide Ice Sheet during the main part of the Wisconsin Glaciation.

The word *hummock* is used to describe a mound, knoll, or hillock that is approximately round in map view—that is, not an elongated ridge. The term has been used to describe the bumpy surface of some bogs as well as some kinds of volcanic, eolian, landslide, and glacial topography lacking a dendritic drainage pattern. The word *collapse* is used here to indicate a rather chaotic process that occurs when one layer of material is let down as the underlying layer of material is removed. We use it for the process occurring when glacial ice melts out from under a cover of till, stream sediment, or lake sediment. Not all hummocky topography is collapse topography, and not all collapse topography is hummocky.

Nearly all hummocks in the glaciated part of Dane County are collapse hummocks composed of supraglacial material. In areas shown as map unit **sc** on plate 1, this supraglacial material consists largely of meltwater-stream sediment. In areas shown as map units **gh** and **gk,** it is more likely to be supraglacial till, with associated supraglacial mass-movement deposits consisting of glacial debris that underwent some sorting.

In most of the hummocky area in Dane County, individual hummocks are low mounds no more than a few meters high and a few tens of meters wide (map unit **gh**). In a few places they are as high as 5 m or even 10 m and as wide as several tens of meters (map unit **gk**); a notable example is the band of hummocky topography oriented northeast-southwest in secs. 8, 18, and 19, T5N, R10E, between Brooklyn and Oregon in south-central Dane County (plate 1). The hummocks range from simple round mounds to doughnut-shaped mounds to irregular mounds with no preferred orientation (fig.18).

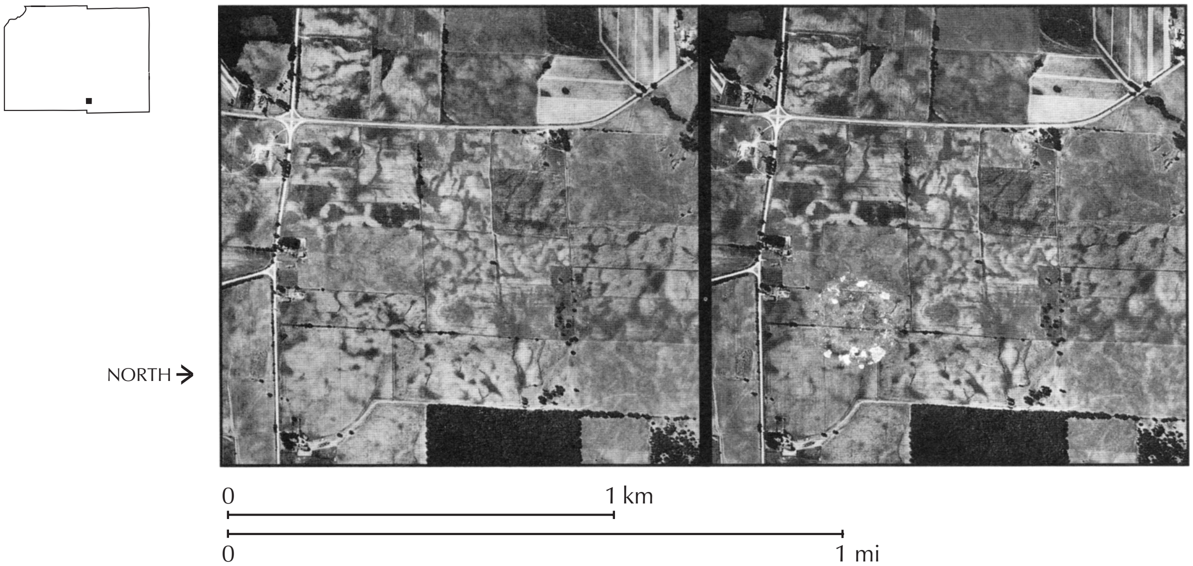


Figure 18. Aerial photograph stereopair showing hummocky Johnstown till, 3 km north of Brooklyn. White spots are tops of hummocks where soil erosion has exposed lighter subsoil. U.S. Department of Agriculture aerial photographs WU-2P-7 and 8. Sections 18 and 19, T5N, R10E, and secs. 24 and 25, T5N, R9E.

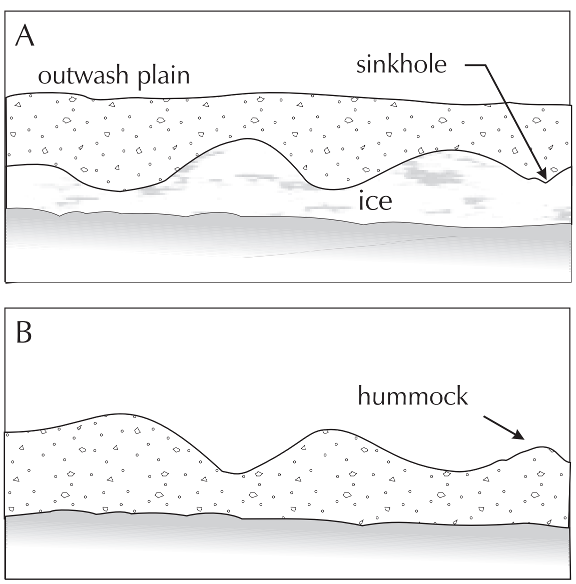


Figure 19. *Schematic cross sections showing how hummocks form.* ***A.*** *Material such as meltout till, lake sediment, or stream sediment (dotted area) is deposited on a stagnant mass of glacial ice.* ***B.*** *When the ice melts, the supraglacial material is let down (collapsed) onto solid ground (gray area), to form hummocky topography. Coarse-grained material is let almost straight down along faults; fine-grained material flows into lower areas.*

Once a mass of glacial ice has stagnated (stopped moving), it becomes pockmarked with depressions much like the sinkholes in limestone regions. Where this ice is covered with meltwater-stream sediment (fig. 19A), the resulting topography is similar to the original topography on the ice, but inverted—the ice sinkholes become hummocks (fig. 19B). In a similar way, supraglacial till is let down to produce hummocky-till topography.

When stream sediment collapses, it may be let down largely intact. The bedding may be preserved between widely spaced faults if it is permeable and well drained, preventing flowage. Similarly, when the sandy till in Dane County collapsed, it may have been let down without much flowage if it were well drained, as in the sandy-till hummocks of northern Wisconsin studied by Johnson and others (1995).

The stagnant glacial ice in the hummocky-till area was an irregular sheet of ice that became patchy as it eventually melted away. Stagnant glacial ice melted soonest under large supraglacial lakes and rivers and where the cover of insulating supraglacial debris was thinnest. Where it was thickest, the glacial ice probably melted when the permafrost beyond the glacier melted. For these reasons it is likely that much of the

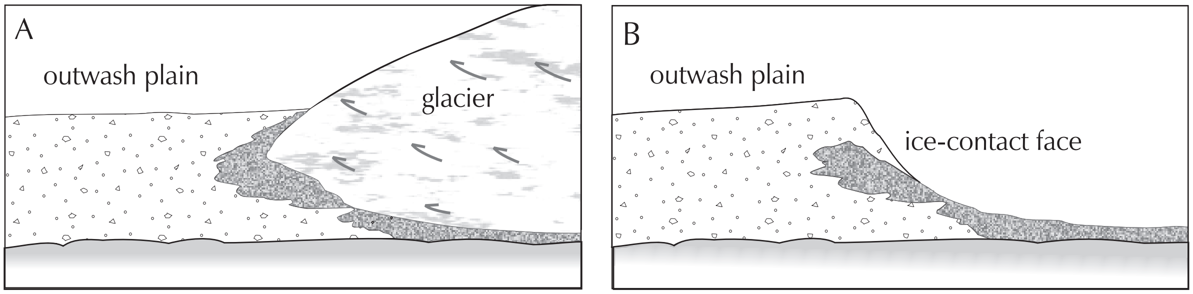


Figure 20. *Schematic cross section through snout of a glacier showing sand and gravel (dotted area) deposited on an outwash plain (**A**), leaving an ice-contact face when the glacier melts (**B**). Till (dark gray area) is shown between the outwash and the glacier.*

hummocky topography was formed and that much of the supraglacial debris was deposited hundreds or thousands of years after the main mass of the glacier had melted from the region.

Ice-contact faces

Ice-contact faces (shown on plate 1 with a line symbol) and moraines form at the margin of a glacier and mark the place the glacier margin stabilized for some time. An ice-contact face forms where a body of stream or lake sediment lies against the front of the glacier. The ice-contact face commonly consists of till partially overlain by collapsed stream or lake sediment (fig. 20). No moraine formed, or one formed but was later buried under the stream or lake sediment.

Four scarps around the headwaters of Roxbury and Halfway Prairie Creeks in northwestern Dane County are shown on plate 1 as ice-contact faces, but their origin is unclear. The most distinct one is 1.2 km east of Indian Lake; it is a steep slope several meters high, with flatter surfaces up-valley and down-valley from it. The others are less striking because of postglacial gullying and collapse due to the melting of buried masses of stagnant glacial ice. All are downstream from divide-crossing meltwater gorges that may be tunnel channels. Unlike the other ice-contact faces in the county, they face west, away from the direction of flow of the active glacier. If they are ice-contact faces, they formed against up-glacier sides of masses of stagnant glacial ice lying in the valleys to the west.

Subglacial-drag forms

If the base of a glacier is at the thawing point, it can move by sliding as well as by internal flow of the ice. Where a glacier slides on its bed, a variety of subglacial-drag forms can result.

Figure 21. *Photograph of scratch marks on dolomite where the glacier was sliding on its bed, revealed where overburden has been stripped away in a quarry north of Middleton, near center of sec. 35, T8N, R8E.*

The smallest visible drag marks are scratches (striations) formed where the glacier dragged sand grains embedded in its base across the rock surface (fig. 21). Others are grooves as large as 1 m wide, which form where the inscribing tools were pebbles, cobbles, boulders, or concentrations of finer debris. They can be seen in most quarries in the glaciated area where the overburden has been stripped off.

Another probable subglacial erosional form consists of vertical scarps, typically 1 or 2 m high, that apparently formed where the glacier plucked off the more susceptible edges of otherwise intact beds of dolomite (fig. 22). They have no apparent preferred orientation with respect to the direction of glacial movement. We have recognized the scarps on aerial photographs (fig.

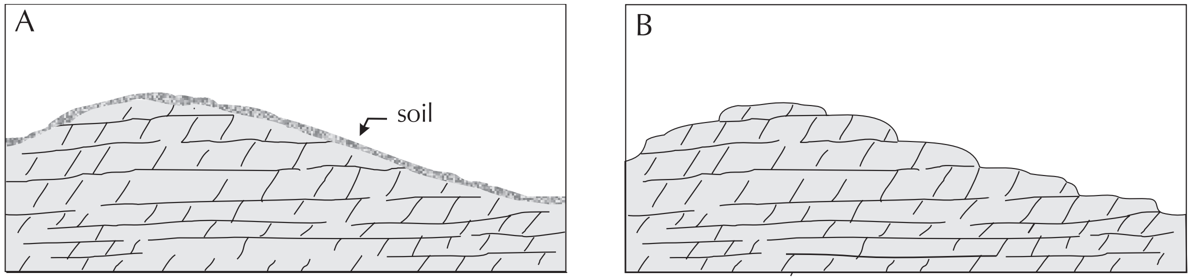


Figure 22. *Schematic cross sections through a hill of Sinnipee dolomite in Driftless Area (**A**) and in glaciated area (**B**), where subglacial plucking of loose blocks of dolomite has produced bedding-plane scarps, which are commonly vertical or even overhanging, no higher than a few meters, and subglacially striated, even under overhangs.*

23) in the areas where we mapped unit **gd** on plate 1, and in quarries where the overburden has been stripped away. We think they are subglacial erosion forms because they are common in the drumlin zone in the northeastern part of the county and are rare in the eastern part of the hummocky-till area, but are absent in the unglaciated area.

Subglacial scouring to produce bedding scarps, scratches, and grooves was most intense in the drumlin region. In the hummocky-till region, within 10 km of the east edge of the Driftless Area, evidence of scouring decreases westward. In many places nearest the Driftless Area, the red-tinged clayey sediment of the Rountree Formation is still preserved between the till and the dolomite, indicating little scouring.

Drumlins

The term *drumlin* is used here to mean a subglacial-drag form that is larger than those discussed in the previous paragraphs, or higher than roughly 1 m, and composed, at least at the surface, of till rather than other unlithified material or rock. Plate 1 shows drumlins with an arrow symbol marking their crests in the area of map unit **gs.**

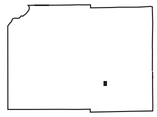
Drumlins in Dane County (fig. 24) are part of a larger field of drumlins formed by the Green Bay Lobe in several counties in the southern part of the Green Bay lowland (Alden, 1905, 1918). In Dane County, they have a wide range of size and shape (figs. 25–28). For purposes of discussion we have grouped them into two categories.

One group consists of stubby drumlins (figs. 25 and 26). These include most of the large and conspicuous drumlins that show up on the early topographic maps produced by plane-table methods, which Alden used, and on modern, large-scale (1:24,000) topographic maps produced by photogrammetric methods, used in later studies. Many of these drumlins are 0.2 to 0.4 km wide, 0.5 to 2 km long, and 10 to 30 m high, and they tend to be oval in outline in map view, with a length-to-width ratio between 2:1 and 10:1.

The other group consists of spindly drumlins (figs. 27 and 28). Many are inconspicuous on the ground and on topographic maps, but are conspicuous on aerial photographs. The smallest of these (too small to be shown individually on plate 1) are 10 m or less in width and a few meters or less in height, but the length of many is comparable to that of the stubby drumlins. The largest in this group in Dane County are about 100 m wide, 10 m high, and 3 km long. They tend to be ridges with a uniform width, rather than oval in outline; some have length-to-width ratios greater than 100:1.

There seems to be a continuous gradation between these two types, showing that they are a single series, resulting from the same processes. For this reason, we call them all drumlins here. Alden (1905, 1918) and Mickelson and McCartney (1979) have previously mapped the stubby forms and the largest of the spindly ones as drumlins.

The spindly drumlins have a much more streamlined appearance, with few irregularities in their cross profile; many stubby ones are more irregular—they are incompletely streamlined by subglacial remolding. Similarly, the spindly drumlins are uniform in orientation; they are



perfectly parallel to adjacent drumlins. In contrast, many stubby drumlins are misaligned with respect to adjacent drumlins, again showing that they were incompletely remolded.

For these reasons, we interpret the spindly drumlins to be equilibrium forms, fully molded and streamlined at the base of the sliding glacier. The stubby ones are probably pre-existing hills that were not fully streamlined. Some stubby drumlins of Dane County have a core of dolomite or sandstone, indicating they are partially streamlined preglacial hills. Whittecar (1976) and Stanford (1982) have shown that some drumlins east of Dane County in Waukesha County have cores consisting of erosional remnants of pre-existing meltwater-stream sediment, and the same is true in Dane County. Some stubby drumlins in Dane County may also be streamlined pre-existing glacial landforms, including re-streamlined older drumlins having slightly different orientations.

Because the drumlins formed at the base of a moving glacier, they must consist of subglacial till, at least near the surface. Some drumlins with cores of older material may have been covered with a sheet of till so thin that it would later be eroded from the steeper drumlin flanks.

As illustrated in figure 11A, most of the near-surface till of the drumlin area in eastern Dane County is uniform and therefore probably is subglacial till. This is in contrast with the variable material of the hummocky areas to the southwest that lack drumlins (fig. 11B and C); these areas are underlain by less uniform supraglacial till interbedded with resorted debris-flow deposits. Figure 11 shows that the till of the drumlin zone is slightly less silty than the hummocky till; the reasons for this are unknown (Oelkers, 1995, p. 48–49).

Several drumlins in northeastern Dane County have been breached by unexplained short gaps (not shown on plate 1). The gaps are

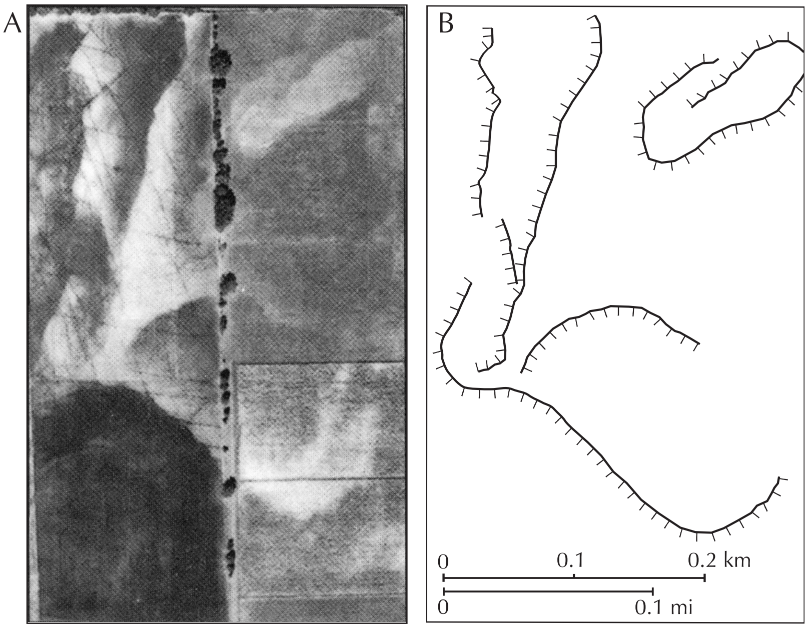


Figure 23. *Aerial photograph (**A**) and sketch map (**B**) showing bedding-plane scarps in areas where dolomite is at or nearly at the surface (white areas), 1.5 km west of Utica. Hachure marks point down the face of the scarp. Joint traces can also be seen where the dolomite is at the surface (oriented at various angles, especially north-northwest and west-northwest) as well as at field boundaries (east-west and north-south). The last direction of glacial movement was to the south-southwest, but nothing in this view shows that. U.S. Department of Agriculture aerial photograph WU-6P-28. S½ sec. 24, T6N, R11E.*

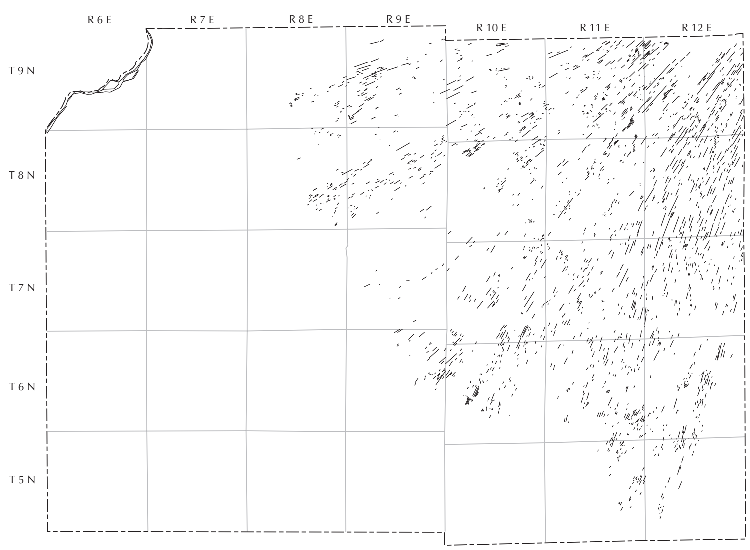


Figure 24. *Distribution of drumlins in Dane County. Lines mark the crests of drumlins and represent their true length.*

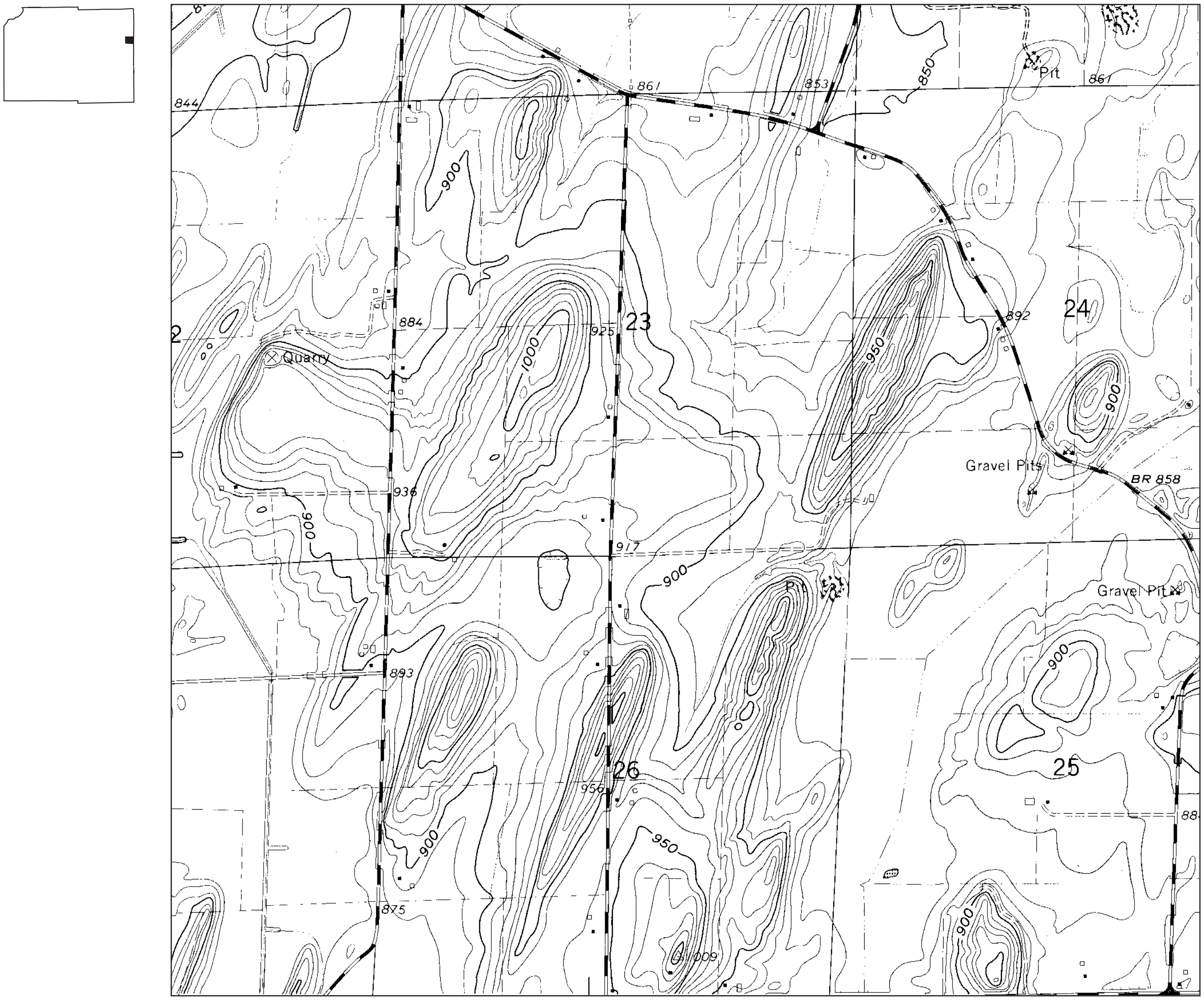


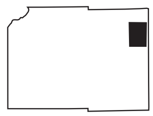
Figure 25. *Part of the U.S. Geological Survey's Marshall Quadrangle, Wisconsin (7.5-minute series, topographic,1962), showing typical large drumlins, 2 km southeast of Marshall; contour interval, 10 ft. Sections 13, 14, 15, 22, 23, 24, 25, 26, and 27, T8N, R12E.*

typically 50 to 80 m wide. They have the appearance of short segments of meltwater channels (figs. 28 and 29), but no indication of a channel can be seen on either side of the drumlin. Perhaps supraglacial meltwater streams cut them when the ice had melted off the crests of the drumlins, but before the glacial ice had melted in the lowlands between the drumlins.

The best place to view drumlins in Dane County is in the Deerfield-Marshall area. Most large hills in that area and along Glacial Drumlin State Trail and Highway 94 east of Cottage Grove are drumlins. They are particularly conspicuous from the air, especially when the sun is low enough for the drumlins to cast shadows. One of the best known drumlins is Observatory Hill on the University of Wisconsin campus in Madison.

Nondescript glacial topography

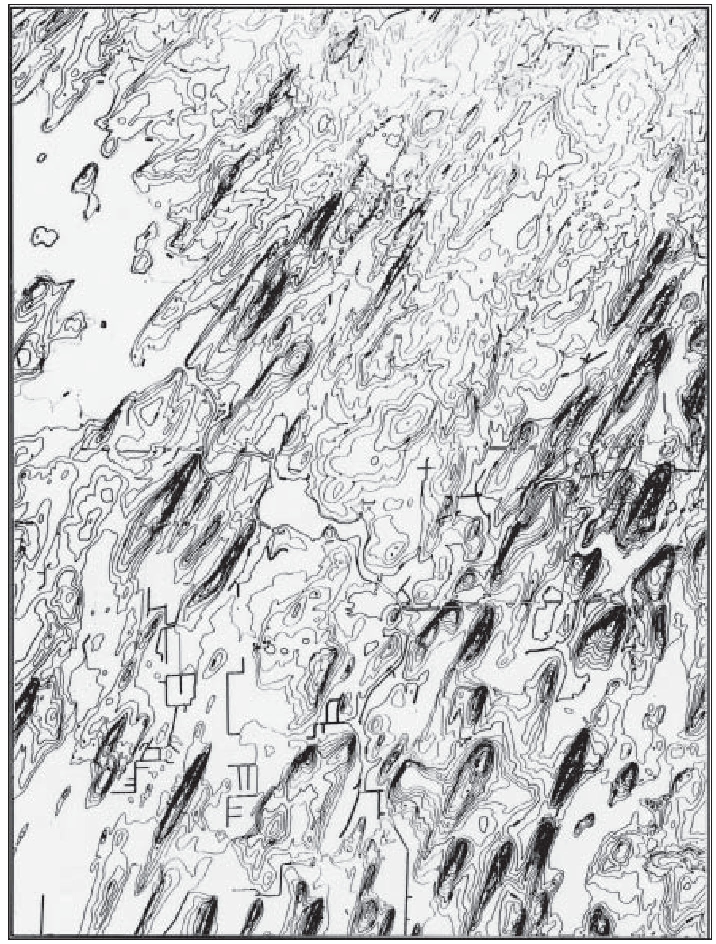
In parts of glaciated Dane County, conspicuous glacial landforms are lacking. Some places in the northeastern half of the county, mapped as unit **gs,** have till at the surface, yet have no discernible drumlins or moraines. Southwest of this are areas mapped as unit **gh**, where the hummocks



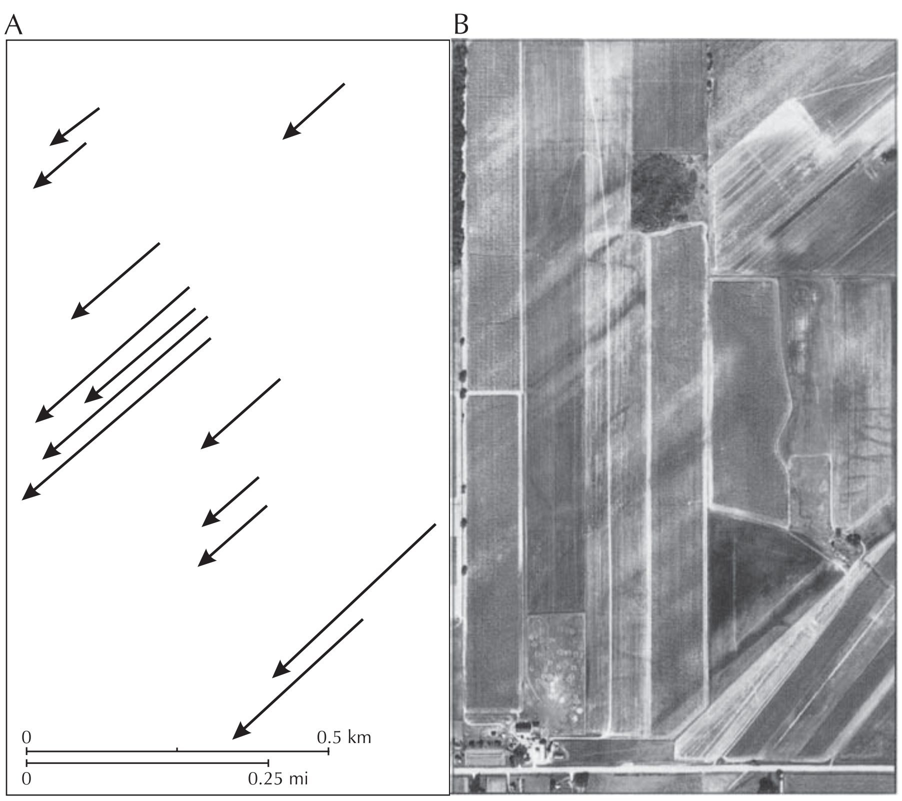
are too low to be noticeable. These are vaguely undulating areas with irregular low swells or billows that have no preferential orientation either parallel or perpendicular to the direction of ice movement. The height and width of these swells seem to vary erratically across the landscape.

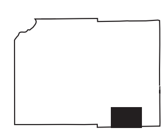
This topography is nondescript for several reasons. It is partly the result of the masking effect of the layer of loess that covers the till; in other areas, a thin layer of unmapped offshore sediment masks small glacial landforms. In addition, the details of the glacial topography have been obliterated by soil erosion and downhill sedimentation, especially by soil flowage immediately after glaciation. Soil erosion and sedimentation have again intensified in historic time as a result of cultivation and widespread cut and fill in urbanized areas.

These processes were especially significant in areas where the glacial topography never was dominant, that is, in areas where the underlying

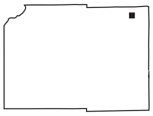


▲ ***Figure 26.*** *Large drumlins shown by 10-ft interval contours taken from U.S. Geological Survey's Marshall Quadrangle, Wisconsin (7.5-minute series, topographic, 1962). Scale 1:100,000.*





◀ ***Figure 27.*** *Aerial photograph (**B**) of drumlins (1 km east of East Bristol) that are too small to be recognized on the 7.5-minute topographic maps with 10-ft contour intervals. Sketch map (**A**) of the same area showing the more conspicuous drumlins. U.S. Department of Agriculture aerial photograph WU-6P-5. Section 1, T9N, R11E and sec. 6, T9N, R12E.*



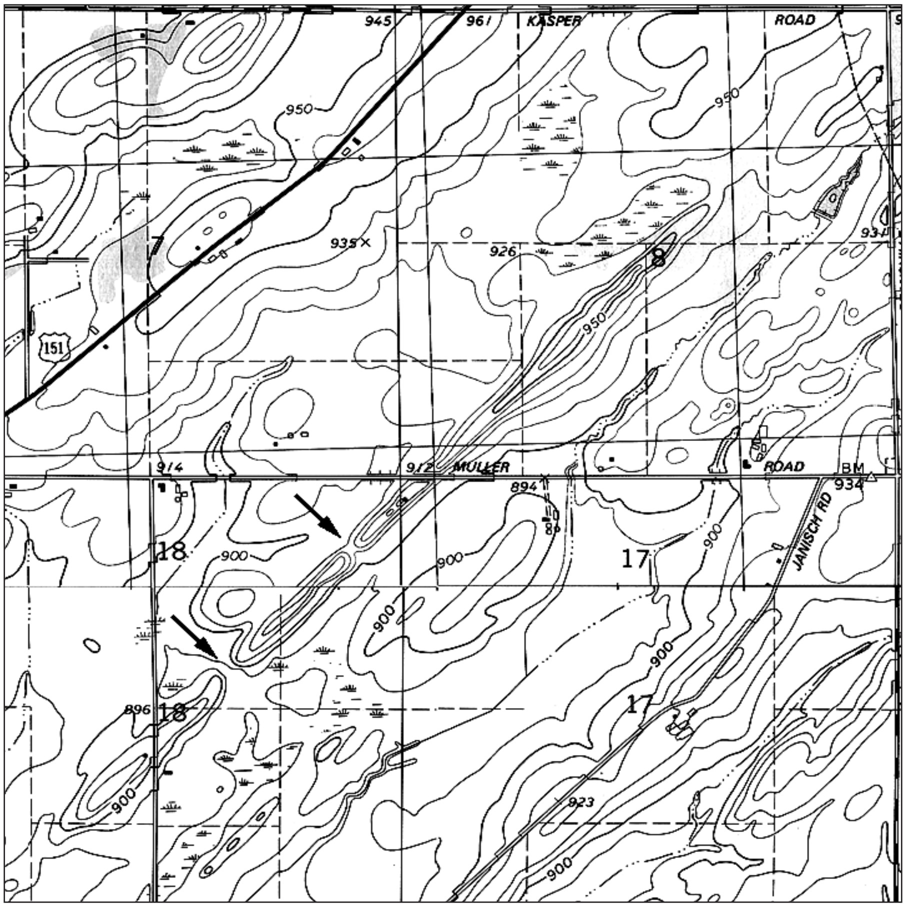


Figure 28. Part of U.S. Geological Survey's Columbus and Marshall Quadrangles, Wisconsin (7.5-minute series, topographic, 1980 and 1962), showing drumlin gaps (indicated by arrows); contour interval, 10 ft. Sections 7, 8, 17, and 18, T9N, R12E.

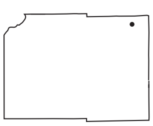


Figure 29. Photograph of the southernmost of the two drumlin gaps shown in figure 28. View to east-southeast.

topography was too rugged to be masked by the till of the last glacial advance. This is most obvious in northwestern Dane County. There, the topography of the Driftless Area continues eastward into the glaciated area with only slight modification by the cover of till.

Areas where the preexisting topography consisted of an earlier glacial landscape are more difficult to identify. However, because the preglacial topography is known to have been preserved in northwestern Dane County, it is likely that earlier glacial landscapes were preserved as well. Much of the present-day glacial topography of Dane County is probably a palimpsest or composite landscape consisting of landforms of the most recent glaciation draped over earlier glacial landforms that had not been completely destroyed by later glacial erosion or deposition.

Perhaps other areas are without significant postglacial modification and are without preglacial topography showing through, yet have nondescript topography because the glacier failed to produce distinctive landforms.

Ice Age National Scenic Trail

The Ice Age National Scenic Trail offers a good way to see glacial features described in this report. The Ice Age Trail is one of eight national scenic trails within the National Park system. The trail was established to protect and illustrate a landscape created during the most recent glaciation. When complete, it will cross 1,800 km of glacial topography, entirely within Wisconsin. One part will extend eastward from the Minnesota border to near Antigo, then southward through Dane County, and eastward to northwestern Walworth County; in most places, this part will be no more than several kilometers from the outermost position of the ice sheet during the height of the Wisconsin Glaciation. A shorter segment will extend from Walworth County northeastward onto the Door Peninsula; it will cross progressively younger glacial topography formed during the final phases of the Wisconsin Glaciation.

The trail enters Dane County at the west edge of the drumlin zone south of Lodi (fig. 30). It will then remain in the hummocky-till zone nearly to Cross Plains, where it will enter the Driftless Area for several kilometers and then return to the hummocky zone. Several kilometers southeast of Verona it will leave the hummocky zone and travel across the part of the Driftless Area that may have been glaciated in pre-Wisconsin time. It leaves the county 3 km east of Belleville.

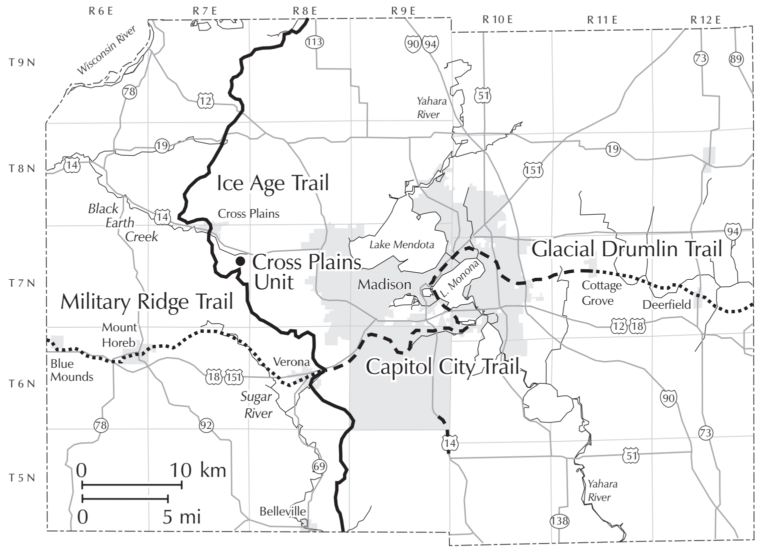


Figure 30. *Location of the section of the Ice Age National Scenic Trail that will pass through Dane County (22 km has been completed). Also shown are the Military Ridge State Trail (dotted), the proposed Capitol City State Trail (dashed), the Glacial Drumlin State Trail (dotted), and the Cross Plains Unit of the Ice Age National Scientific Reserve.*

On the east side of Verona the Ice Age Trail will cross the Military Ridge State Trail, which extends westward through the Driftless Area, passing south of Blue Mounds, on an old railroad grade (fig. 30). The Military Ridge Trail will be continued eastward through the middle of Madison to Cottage Grove (the proposed Capital City State Trail). In eastern Dane County, the Glacial Drumlin State Trail, also on an old railroad grade, extends from Cottage Grove eastward through Wisconsin's most conspicuous drumlin field, to Waukesha County, where it meets the Walworth-Door segment of the Ice Age Trail.

STREAM SEDIMENT AND LANDFORMS

Plate 1 shows stream deposits in shades of red. The sediment deposited by nonglacial streams is shown in brownish reds; that deposited by glacial-meltwater streams is shown in truer reds.

Meltwater-stream sediment

Sediment deposited by glacial-meltwater streams in Dane County is typically pebbly sand, slightly

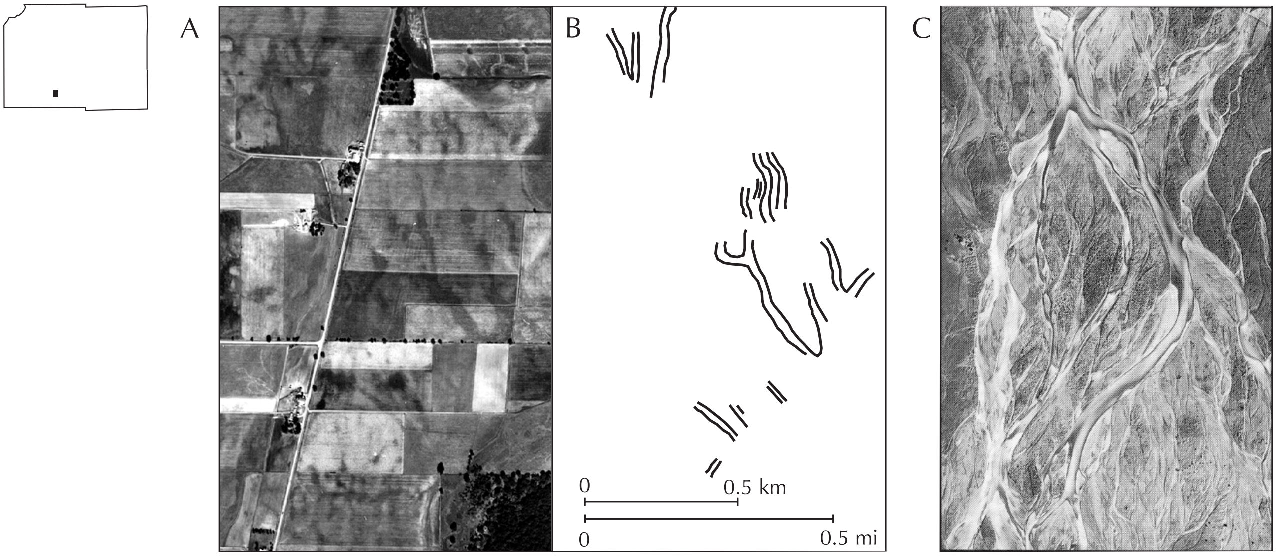


Figure 31. *Aerial photograph (**A**) of obscure braided-channel scars on outwash plain on the west side of the Sugar River, 1 km south of Paoli, and a sketch map (**B**) outlining some of the more conspicuous channels (U.S. Department of Agriculture aerial photograph WU-8P-37; secs. 10 and 15, T5N, R8E). For comparison, aerial photograph (**C**) of a modern braided river (Waiau River at north end of Culverden Plain, north Canterbury, New Zealand, Lands and Survey Department aerial photograph 1804/20, 26-8-50).*

pebbly sand, sandy gravel, or cobble gravel. As in the associated till, the pebbles and cobbles of the sediment are predominantly dolomite, with smaller amounts of a variety of igneous, metamorphic, and sedimentary rock types. Aikin (1993) has given a detailed description of meltwater-stream sediment in a gravel pit east of Stoughton. Where shown on plate 1, the stream sediment is generally more than a few meters thick and in some places is tens of meters thick.

Gravel pits in meltwater-stream sediment have been an important source of commercial aggregate in Dane County. Much gravel has been mined from the areas that we mapped as units **su** and **sc** on plate 1. The gravel pits are generally within a few hundred meters downstream from the point where the meltwater flowed out of the glacier, for example, on the west and south sides of the outermost moraines formed during the Johnstown and Milton Phases. Eskers were once a significant source of aggregate, but they have been largely mined out. Many gravel pits in the county are in areas that we have mapped as units beginning with the letter **g;** some of these are in meltwater-stream units too small to show at the scale of plate 1, but many are in gravel deposits underlying the uppermost till sheet, and were discovered by chance where the till cover was thin.

Uncollapsed. Uncollapsed meltwater-stream sediment was deposited in flat floodplains on solid ground rather than on glacial ice. It is shown by map unit **su** (or unit **so,** where covered by thin peat) on plate 1.

These floodplains, where near the front of the glacier, are commonly called outwash plains. In most of the glaciated part of the county, except west of the drainage divide north and south of Martinsville, these outwash plains are roughly equidimensional and are deltas at the edge of glacial-lake plains. Where the outwash plains are bordered by sandy lake plains, the contact between the two is distinct if it is marked by a delta slipface—a scarp between the outwash plain and the offshore plain (shown by line symbol on plate 1). If not, the contact between them was drawn on the map at the elevation of the lake outlet or at the downstream limit of braided channel scars on the outwash plain; examples of braided channels are shown in figure 31 and their distribution is indicated on plate 1 by arrowhead symbols. In the rest of the county, the

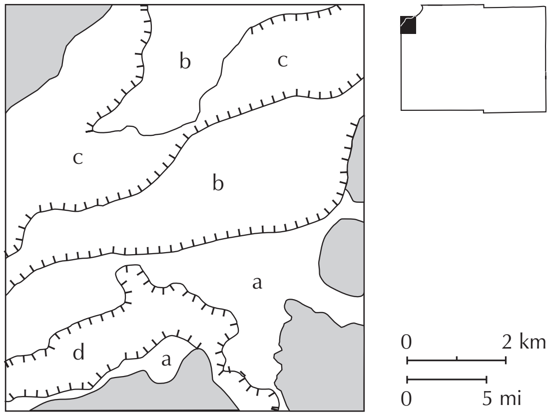


Figure 32. *Outwash terraces (**a, b, c,** and **d**) near Mazomanie. The hachure marks point down the face of the terrace scarps. Gray tones represent valley sides.*

outwash plains are elongated features in the bottoms of the valleys of the Sugar and Wisconsin Rivers and their tributaries, where they are terraces above the modern floodplain.

In the Mazomanie area, the outwash plains are at three terrace levels, separated from each other by stream cutbanks, which are shown by a line symbol on plate 1.

The highest Mazomanie terrace, at an elevation around 241 to 248 m (790 to 815 ft), extends westward from the valley wall and past the county border, in the form of a flat-topped ridge about 1 km wide (a, fig. 32). It may correlate with the outwash plain in front of the outer Johnstown moraine northwest of Prairie du Sac, although it seems a little too high, perhaps because Black Earth Creek spread a fan of meltwater-stream sediment out onto the Wisconsin River floodplain at this point (fig. 33).

The next terrace to the north of this ridge (b, fig. 32) is 17 to 21 m lower, at elevations of 224 to 227 m (735 to 745 ft). It correlates with an Elderon terrace in the Sauk City area, which formed at the end of the period during which great floods drained glacial Lake Wisconsin (fig. 21 of Clayton and Attig, 1990; Clayton and Attig, 1989). The steep terrace in the Black Earth valley (d**,** fig. 32) probably also was formed at this time.

The next terrace is 1 to 2 m lower (c, fig. 32). It probably also is an Elderon terrace.

We do not know why high-level terrace **a**

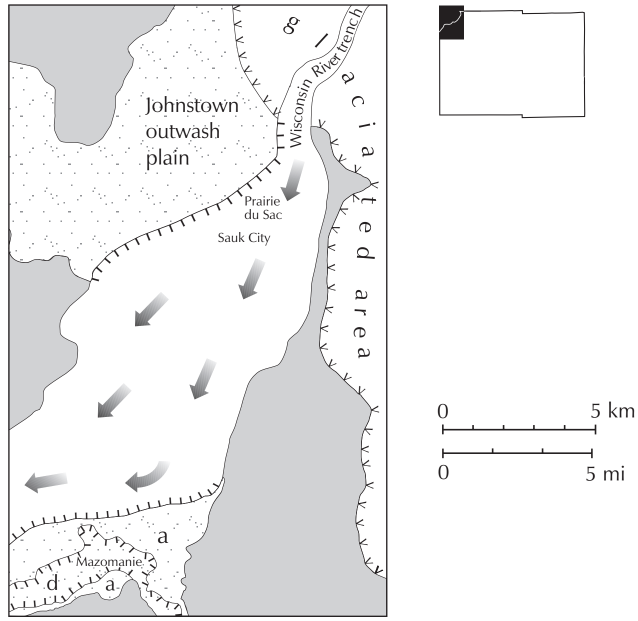


Figure 33. *Path of flood (arrows) down Wisconsin River trench to the north edge of terrace **a**. Gray tones represent valley sides.*

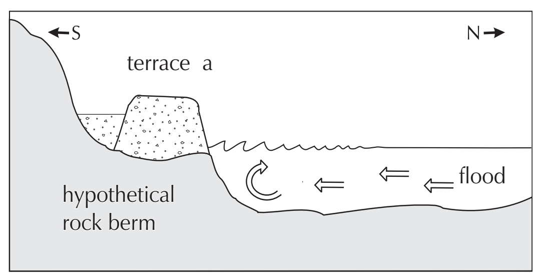


Figure 34. *Cross section showing the protection of terrace **a** by hypothetical rock berm.*

was preserved. The Johnstown outwash plain northwest of Prairie du Sac was preserved because it was out of reach of the Lake Wisconsin floods that came out of the rock-bound Wisconsin River trench northeast of Prairie du Sac (fig. 33). Below the mouth of the trench, the floods removed almost all traces of the high outwash terraces, except for terrace **a**. Terrace **a** should have received the full force of the floods coming down the valley against an outside bend where the valley turns westward. An obvious explanation is that terrace **a** was protected by a rock berm at its north cutbank (fig. 34), but no evidence for such a berm exists. Available well constructor's reports in WGNHS files show that

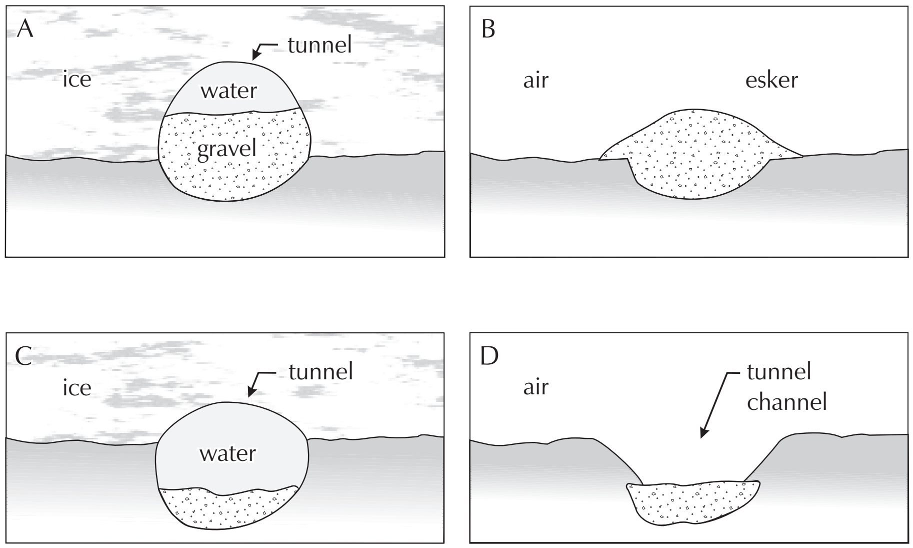


Figure 35. *Schematic cross sections of glacier perpendicular to direction of glacial flow, showing rivers flowing in tunnels at the base of a glacier. If the river is aggrading (**A**), an esker ridge results when the glacier melts (**B**); if the river is degrading (**C**), a tunnel channel remains when the ice melts (**D**).*

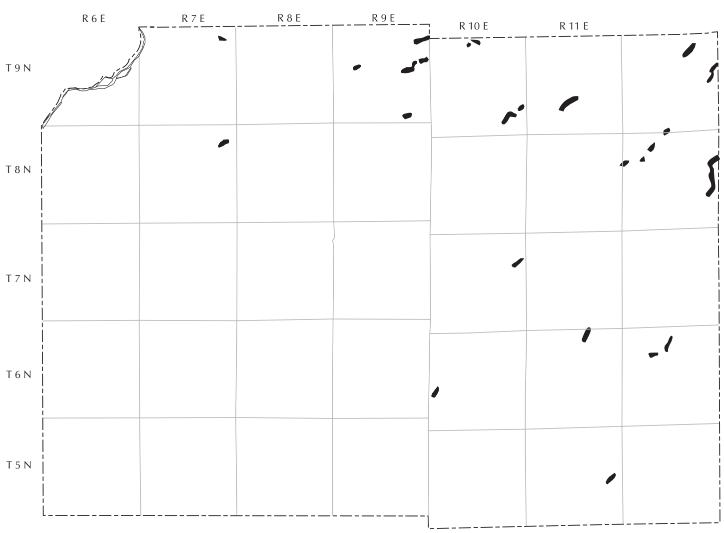


Figure 36. *Distribution of eskers in Dane County.*

the sand is several tens of meters thick in this area.

Collapsed. In places where the meltwater rivers deposited sediment on top of a mass of stagnant glacial ice, the sediment collapsed when the underlying ice melted, resulting in hummocky topography. The locations of hummocky collapsed stream sediment in Dane County are shown by map unit **sc** on plate 1. The sediment included in map unit **sc** is similar to that of adjacent areas of map unit **su**. The buried ice presumably melted when the permafrost of the region melted.

Eskers. A river flowing in a tunnel at the base of a glacier will form an esker ridge when the river is actively depositing sand and gravel on its bed (fig. 35A and B). Many eskers may have formed in Dane County during the most recent glaciation, but the smallest ones would probably be too small to be recognized today (fig. 36) because they were obliterated by postglacial erosion or were blanketed by windblown silt or by glacial sediment. We have recognized few eskers in hummocky till areas, perhaps because few formed there, but probably also because the supraglacial till of the hummocks has covered and hidden them. In gravel pits in northwestern Dane County and eastern Sauk County, Lundqvist and others (1993) identified several small esker bodies exposed in the pit walls that are without surface expression because they were buried in the till of a moraine.

Only the largest eskers have been shown on plate 1, and most of them are in the drumlin area in the northeast half of the county. They generally lie in the lowlands between drumlins, where they are roughly parallel to the long axes of the drumlins; a few eskers drape over the flanks of the drumlins.

Even the largest eskers in Dane County would be considered small if compared with eskers in other regions. The longest is southwest of Waterloo, next to the Maunesha River, at the east edge of Dane County; it is 7 km long but consists of several disconnected segments. Most eskers in the county are shorter than 2 km. They generally are meandering ridges about 10 m wide, but judging by the size of gravel pits in them, many deposits are about 20 m wide, and

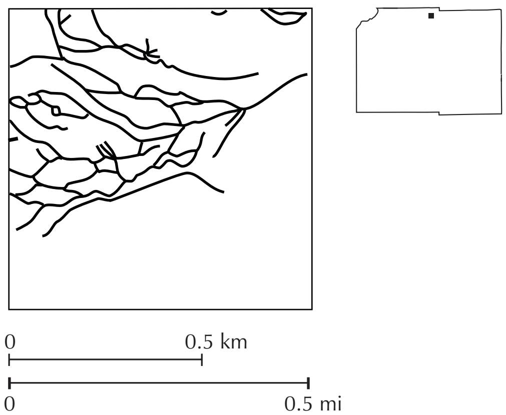


Figure 37. *Map of the esker complex 1 km northeast of Norway Grove. The lines mark the crests of eskers. Meltwater flow was to the west. Traced from U.S. Department of Agriculture aerial photograph WU-7P-156, taken in 1955. SE¼ sec. 14, T9N, R9E.*

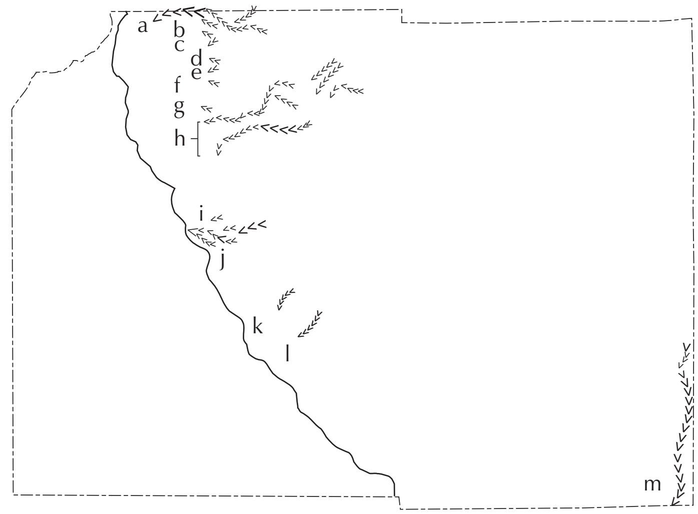


Figure 38. *Possible tunnel channels (shown by arrowheads) in Dane County, identified by letter (**a–m**) for discussion in the text. The solid line is the maximum extent of the Green Bay Lobe during the last part of the Wisconsin Glaciation.*

some are twice that. Most are 1 to 5 m high.

The bottoms of most of the gravel pits are a few meters below the level of the surrounding till plain. This shows that the esker bodies were entrenched into the bed of the glacier. Some eskers shown on plate 1 have been almost entirely mined out, leaving a meandering trench.

Most of the eskers in Dane County are simple sinuous ridges, with only an occasional braided reach or side branch. The conspicuous exception is the esker complex just northeast of Norway Grove in the north-central part of the county (south half of sec. 14, T9N, R9E). The complex is 1 km long and contains dozens of interconnected esker segments, as shown in figure 37. Individual segments are 3 to 30 m wide and most are no more than a few meters high. Most of the complex has been mined out since the aerial photographs upon which figure 37 is based were taken. Exposures show that the esker bodies are several meters thick and underlain by a thin, patchy layer of till. This till is underlain by a thicker body of fluvial sand and gravel, which is the focus of the gravel-mining operation.

Some exposures of the esker sediment in Dane County show gravelly sand, but much of it is sandy gravel, cobble gravel, and even boulder gravel. The stones have lithologies similar to those found in the surrounding till—mostly dolomite, with some siliceous, igneous, and metamorphic rock. Many esker deposits have been described in WGNHS Road Materials Investigation Reports.

Tunnel channels. A river flowing in a tunnel at the base of a glacier will form a tunnel channel rather than an esker when it is eroding its bed (fig. 35C and D). Tunnel channels have been identified northward from Dane County into northern Wisconsin, where they formed under the west edge of the Green Bay Lobe when it was near its maximum extent during the Wisconsin Glaciation. We have identified those tunnel channels with some confidence. No other identification seems possible because they were cut by rivers flowing uphill; they rise in elevation tens of meters in the downstream direction until they breach the outermost moraine, with a large fan of meltwater-river sediment at the mouth of each.

However, the supposed tunnel channels of Dane County (fig. 38) lack some of the characteristics needed for positive identification as tunnel channels, possibly because they were cut before the most recent glaciation, when much of the evidence was obliterated. None have the fan of stream sediment and breached moraine characteristic of the mouths of those farther north. None terminate at the outer edge of the outermost moraine as do those farther north. Few show evidence of being cut by rivers that flowed uphill. In addition, all of those in Dane County have rock walls, at least in part, but few of those to the north do. However, along with those to the north, the channels in Dane County cut through drainage divides where they cross from one valley to the next; only tunnel channels or lake spillways are likely to do this.

The tunnel channels in Dane County and those to the north are much wider than the nearby eskers, indicating that tunnel rivers discharged much more water than esker rivers. This may have occurred during huge intermittent floods resulting from the draining of subglacial lakes.

The most northern tunnel channel shown in figure 38 contains Mud Lake, Fish Lake, Crystal Lake, and Spring Creek. This sag is the size of many northern Wisconsin tunnel channels, about 1 km wide, and it originally was perhaps a few tens of meters deep. It was partly filled with collapsed meltwater-stream sediment after tunnel flow ceased, just as those to the north were. The sag originally was a pair of preglacial valleys connected at their heads by a saddle across a local preglacial drainage divide. The saddle may have been reshaped as a tunnel channel, or, alternatively, it may have been entrenched by water flow from a glacial lake east of the divide.

The six saddles through the preglacial drainage divide south of the Crystal Lake sag (b–g, fig. 38) could have been deepened by the outflow from glacial lakes east of the divide or by tunnel rivers during the Wisconsin Glaciation or earlier. The sixth (g, fig. 38) is a small rock gorge just southwest of St. Johns Cemetery; it is 50 m wide and 10 to 20 m deep and was obviously cut by meltwater flowing across the divide. We know of no evidence for a glacial lake associated with any of these six.

Continuing southward, a complex of possible tunnel channels contains, from west to east, Brandenburg Lake, Springfield Corners, Waunakee Marsh, and Sixmile Creek at the northwest edge of Waunakee (h, fig. 38). The northern of the two distributaries crosses the drainage divide between the Wisconsin River valley and the Yahara River valley through a small rock gorge about 30 m deep and 100 m wide just east of the junction of Whippoorwill Road and Highway 19. This complex is a series of preglacial valleys that were probably reshaped by tunnel-river erosion; lithologic logs in well constructor's reports in WGNHS files show that the valley bottom beneath the Pleistocene sediment near Springfield Corners is highly irregular, sloping both up-valley and down-valley, which is not easily explained except by subglacial river erosion (Mickelson, 1983, p. 35-36).

Farther south (i, fig. 38), another small rock gorge, 30 m deep and 100 m wide, crosses the drainage divide 2 km north of Black Earth Creek. It is now occupied by Rocky Dell Road. It, as well as other divide-crossing gorges, might have been cut by outflow from a glacial lake or glacier-tunnel river.

The largest of this series of possible tunnel channels is the Black Earth trench (j, fig. 38). It is 1 km wide and was 75 to 100 m deep before being partly refilled by meltwater sediment during the most recent glaciation. It crosses the preglacial drainage divide between the Wisconsin River valley and the Yahara River valley 6 km west of the present-day divide, which is at the outlet of glacial Lake Middleton. This outlet is only a few meters deep, indicating a very small amount of discharge from the lake; little of the depth of the trench is the result outflow from Lake Middleton. However, it could have been the outlet of earlier glacial lakes in the Sugar and Yahara River valleys. Alternatively, or additionally, a glacier-tunnel river may have eroded the Black Earth trench.

Two additional possible tunnel channels, on the southwest side of Madison, are rock-walled trenches cut through the divide between the Sugar River valley and the Yahara River valley (k and l, fig. 38).

The southeasternmost possible tunnel channel (m, fig. 38) is occupied by a segment of Koshkonong Creek and by Rice Lake. It continues southward to the east side of Edgerton in Rock County and southward across the Rock River. In most places it is partly buried by lake sediment or collapsed meltwater-stream sediment.

Nonglacial-stream sediment

Plate 1 shows nonglacial-stream sediment in browner shades of red than used for glacial-stream sediment. Modern stream sediment (map unit **sm**) has been deposited on the floodplains of present-day rivers. It typically consists of several meters of channel sediment composed of sand or gravelly sand. The characteristics of this material are determined by the nature of the material eroded from the upstream valley walls; for example, cherty cobble gravel is common in the steepest valleys of the Driftless Area. This channel sediment in turn is commonly overlain by dark, silty overbank sediment from a fraction of a meter to a few meters thick, which in places is overlain by thin and patchy peat. The water table is generally just below the floodplain surface. The channel sediment and the overbank sediment contain considerable organic material.

Premodern nonglacial-stream sediment (map unit **sp**) is found on fans or terraces upslope from the modern floodplains. We have observed this material in only a few places and cannot describe it in detail, but it resembles nearby modern stream sediment, typically consisting of sand, gravelly sand, or sandy gravel, depending on what was available upstream. The sediment typically has much less organic material than the modern stream sediment. The water table is generally well below the surface of the premodern material. For example, an auger hole showed more than 10 m of reddish-brown (5YR 5/4) sand underlying a low terrace along the West Branch of Sugar River (SW¼ NE¼ NE¼ sec. 13, T5N, R7E).

We used aerial photographs to distinguish modern and premodern material on plate 1. The modern surfaces show channel scars, but they have been obliterated on the premodern ones. The premodern stream sediment was probably deposited during the most recent glaciation, when hillslopes were exceptionally unstable. Plate 1 appears to show whole valley bottoms taken up by premodern-stream sediment, but in most places it is divided by a narrow strip of modern-stream sediment that cannot be shown at the scale of the map.

In many places along valley sides, soil-flow rubble and other hillslope deposits are interbedded with the stream sediment. They have not been mapped separately because of a scarcity of field information and because the hillslope deposits generally occupy areas that are too small to be shown at the scale of plate 1.

LAKE SEDIMENT AND LANDFORMS

Several different kinds of lake sediment can be distinguished in Dane County. Shore deposits consisting of sand and gravel in the form of beach ridges and beach terraces with wave-cut scarps have been recognized around the plains of glacial lakes in only a few places and around the plains of postglacial, premodern lake plains in many places; they are shown by a line symbol on plate 1. In addition, beaches are present along the shores of most present-day lakes, but these beaches are not shown on plate 1. The position of former shorelines of glacial lakes is also marked on plate 1 with the line symbol for delta slipfaces; these are mapped where the downstream edge of an outwash plain meets a lake plain at a recognizable scarp. The great bulk of lake sediment in Dane County, however, is offshore sediment deposited in deeper water beyond the beach zone of glacial lakes.

Offshore sediment of glacial lakes

Most of the sediment mapped as units **og, op,** and **oe** on plate 1 consists of offshore sediment of glacial lakes, and most of it apparently consists of sediment deposited by cold, turbid, and therefore dense lake-bottom currents. As a result, the sediment is coarsest in areas where the river changed to a bottom current as it entered the lake and finest where the bottom current came to rest.

In Dane County, the Holy Hill till consists largely of sand, with lesser amounts of clay, silt, and gravel; presumably, this is what was carried by the glacier and was accessible to the meltwater rivers. Typically, meltwater rivers deposited most of their coarse gravel as well as much of their fine gravel and some of their sand on an outwash plain before the meltwater reached the lake. If there were a sudden deepening of the water at the shore, most of fine gravel and much of the sand would be deposited at the delta slipface. The rest was free to be carried into the lake by the bottom current. However, few of the outwash deltas of Dane County had much of a slipface, so a large part of the sand was carried out into the lakes.

As a result, the sediment on the lake plains shown on plate 1 is zoned, with large areas of bottom-current sand in the shallows near the mouths of the meltwater rivers, with smaller amounts of silt farther out, and with clay farthest from the river mouths. Information was inadequate to map these zones separately, so they were mapped together in map units **og, op,** and **oe.** Where a delta slipface is not recognizable, the contact between river sand and lake sand on plate 1 was drawn at the elevation of the lake outlet or at the downstream limit of braided channel scars on the outwash plain.

The offshore silt and clay generally are horizontally bedded. Bedding is sharp because bottom dwellers have not stirred it, but in some of the material the bedding is almost too faint to recognize, perhaps because deposition was rapid. Bottom-current sand is generally horizontally bedded or cross-bedded. The offshore sediment ranges up to tens of meters in thickness.

Some lake plains in Dane County are slightly hummocky, for example, in most of the middle part of sec. 25, T6N, R12E, 1 km southeast of Rockdale. This may be collapse topography where the lake sediment was deposited on top of stagnant glacial ice, but on sandy lake plains it may be the result of wind erosion. In other places, it may be the result of the lake sediment compacting over underlying hummocky topography on collapsed till or meltwater-stream sediment.

Offshore sediment of postglacial, premodern lakes

In this report we use the term *glacial lake* to refer to a lake that received glacial meltwater and the term *postglacial lake* to refer to one that persisted after meltwater flow was cut off. We have made no attempt to evaluate the sediment in the bottoms of present-day lakes, but the sediment of postglacial lakes was observed in several places where lakes no longer exist. The offshore sediment of glacial lakes is typically sand, silt, or clay with distinct bedding and without organic material. The postglacial-lake sediment is clay or silt with abundant organic material, including mollusk shells and plant fragments. In places, biogenic lime is abundant enough to form white marl. Bedding is commonly indistinct because of stirring by bottom-dwelling organisms.

On plate 1, areas of glacial-lake and postglacial-lake sediment have been mapped together as units **og** and **op.** In many areas, peat overlies postglacial offshore clay or silt (map unit **op**), which in turn overlies glacial offshore sand, silt, or clay. In areas mapped as unit **og,** no attempt was made to distinguish areas with glacial-lake sediment from areas with postglacial-lake sediment at the surface because of inadequate information on the distribution of the postglacial-lake sediment.

However, the information we do have shows that postglacial lake sediment is widespread in map unit **og.** Surface outcrops of it were seen several places in Dane County, and it has been observed in samples from several drillholes. For example, core from a drillhole in the middle of the plain of glacial Lake Middleton showed nearly 7 m of black postglacial lake sediment at the surface (WGNHS Geologic Log DN-1421-F), and elsewhere on the lake plain Thwaites (1908, p. 80) reported that the "upper foot or two contains numerous small shells." Similarly, samples from a drillhole in the glacial-lake plain 5 km west of Albion showed 1 m of black postglacial lake clay overlying glacial-lake sand and silt. Logs of a series of Wisconsin Highway Commission borings through a small lake plain 5 km northeast of McFarland showed about 3 m of marsh peat over as much as 13 m of "sedimentary peat" made up of the "remains of aquatic plants" and "shells," with "minor amounts of sand, silt and clay" (located in the middle of the SE¼ sec. 30, T7N, R11E); 2.5 km to the south, in another lake basin, the organic material is 12 m thick (in the SW¼ NE¼ sec. 6, T6N, R11E). (Information about these two sites is from a copy of drillhole logs and a letter from R.F. Robinson to W.K. Summers, January 30, 1961, in WGNHS files.) Similarly, the logs of a set of Highway Commission borings showed as much as 6 m of organic silt and sand in the same basin 3 km northeast of the previous site (NW¼ NE¼ sec. 32, T7N, R11E). Logs of another set of Highway Commission borings show 14 m of peat and organic silt with shells in a lake plain 5 km northeast of Cottage Grove (the south edge of sec. 35, T8N, R11E).

Most of the bones of extinct mammals, such as mastodons, mammoths, and giant beaver, that have been found in eastern Dane County and adjacent Jefferson County (West and Dallman, 1980) came from the postglacial lake sediment described here. The recovery of mastodon bones at a site 3 km northwest of Deerfield has been described by Dallman (1968).

WINDBLOWN SEDIMENT AND LANDFORMS

Windblown sediment takes three forms in Dane County. Sand is generally moved as bedload, which drifts along the ground in high winds, with individual grains bouncing only short distances into the air. Silt is moved as suspended load, with particles carried high up into the air by eddies during dust storms. A third type is of unknown origin, but may be a mixture of the two.

Windblown sand was deposited in Dane County in small patches on outwash plains and lake plains where the underlying sand is well sorted and where it contains little clay, silt, or gravel. Patches of windblown sand that are big enough to be shown on plate 1 are present only on the outwash terraces north of Mazomanie, in the northwestern part of the county (map unit **w**). Dunes are present, but they are irregular in form and no more than a few meters high. Most of the sand was probably deposited during the drier middle part of postglacial time.

Windblown silt—or dust—was deposited over all of Dane County during the last part of the Wisconsin Glaciation, but was subsequently eroded from many areas. The dust deposits—or loess—are the foundation of the region's agriculture because most cultivated soils have developed in loess.

We judge the original thickness of the loess to have been about 1 m in most of the county. Today, on flat, stable terraces and uplands where little soil erosion has occurred, the loess commonly ranges from 0.5 to 1.5 m in thickness, but 1 m seems typical. The loess is thickest in slight swales on these flat surfaces because of erosion and redeposition by processes such as sheet wash. This redeposited loess is difficult to distinguish from primary loess.

Regional trends in loess thickness have been obscured by local variations, and we lack evidence for the erosional source of the dust across most of the county. However, loess thickness may be 2 m or more on level surfaces in the northwest corner of the county, within about 10 km of the Wisconsin River, according to Glocker and Patzer (1978, p. 64; areas of Seaton Series), presumably because much of the loess there was blown off the floodplain of the river when it was carrying silt-laden glacial meltwater.

On steep slopes, erosion has removed the loess, exposing the underlying material. The silt that accumulates as fans at the base of these slopes can be distinguished from loess by the presence of grains of sand or gravel eroded from the underlying material.

Loess is also absent from surfaces, such as modern floodplains, that have been geologically active since loess deposition ceased at the end of the Wisconsin Glaciation. Loess is absent from meltwater deposits consisting of well sorted sand because these deposits were subject to continual wind erosion during and after the period of loess deposition. However, gravelly outwash plains retained their loess cover because the gravel resisted wind erosion, providing a stable surface on which loess could accumulate.

Wind-eroded sand plains with sand dunes commonly are covered with about 1 m of silty sand rather than windblown silt in the interdune areas—for example, on the highest terrace just north of Mazomanie (the "loamy outwash" of Glocker and Patzer, 1978, p. 19-20). Its origin is unknown, but it may be blowdirt consisting of soil aggregates that were deposited in standing vegetation when the dunes were active.

HILLSLOPE SEDIMENT AND LANDFORMS

A variety of hillslope processes, including sheet wash, soil creep, and soil flowage, has helped shape the present topography in most parts of Dane County, and they are largely responsible for the landscape of the Driftless Area. These processes erode the hillslopes and transport the erosional debris to adjacent streams, which wash the debris out of the region.

Hillslope erosion has been active since the beginning of intensive agriculture during the last century (Knox, 1987), but it was probably even more active during glaciation, when permafrost was present. In permafrost areas, the surface soil thaws each summer and becomes waterlogged, which makes it unstable. This waterlogged soil easily flows, even on gentle slopes, and it is susceptible to other erosional processes as well.

No hillslope deposits have been separately mapped on plate 1, partly because most occupy areas too small to be shown at the scale of the map, but also because we have too little information on their distribution. In general, the hillslope deposits are thin on the gentle convex upland slopes (typically less than 1 m thick), they are absent on steep slopes, and they are thickest (typically a few meters thick) on the gentle concave slopes at the base of steep slopes.

Similarly, we have little information about the makeup of the hillslope deposits, especially the thick deposits at the base of steep slopes, because exposures of the material are rare in that position. In general, the hillslope deposits are made up of material derived from up the slope and are coarsest at the base of the steepest slopes; the postglacial material is typically finer grained than that deposited during times of glacial climate.

Hillslopes in the Driftless Area

In the following paragraphs, the highest areas are discussed first, followed by the dolomite plateaus (the prevalent landform of southwestern Dane County) and the Cambrian sandstone slopes nearer the Wisconsin River.

West Blue Mound, most of which is just west of the boundary between Dane and Iowa Counties, is the highest spot in southern Wisconsin, at an elevation of 524 m (1,719 ft), which is 300 m above the Wisconsin River at the northwest corner of the county. This flat-topped hill has survived erosion because of a resistant cap of chert about 30 m thick. East Blue Mound, which is 70 m lower, also has a flat top, probably because of a dolomite bed within the Maquoketa shale, but the mound has been preserved because it, too, once had a chert cap.

Fragments of the chert are found on most slopes directly downhill from both mounds. Some fragments just below the chert cap of the west mound are as large as 10 m across, but they gradually decrease in size in a down-slope direction. Some are still 2 m across at a distance of 1 km from the cap, at elevations as low as 340 m (1,100 ft).

Smith (1948) recognized evidence of permafrost throughout the region during the Wisconsin Glaciation, and he (p. 209-210) concluded that the large chert blocks on the slopes surrounding Blue Mounds reached their present positions by soil flowage (solifluction) during the Wisconsin Glaciation. He discounted the possibility that they were let down from a previously larger chert cap when the shale was eroded out from under its edges; however, that is a likely explanation, at least in part, for the chert blocks around the east mound, because no chert cap now exists or existed during recent glaciations. Chert blocks as large as 2 m are at elevations as low as 400 m (1,300 ft) around the east mound. About 40 m of shale has been eroded off its top since the last of its chert cap was eroded away.

From the base of Blue Mounds, the land slopes down to a Sinnipee plateau. In cross profile (fig. 39) these plateaus are evenly rounded domes up to several kilometers wide.

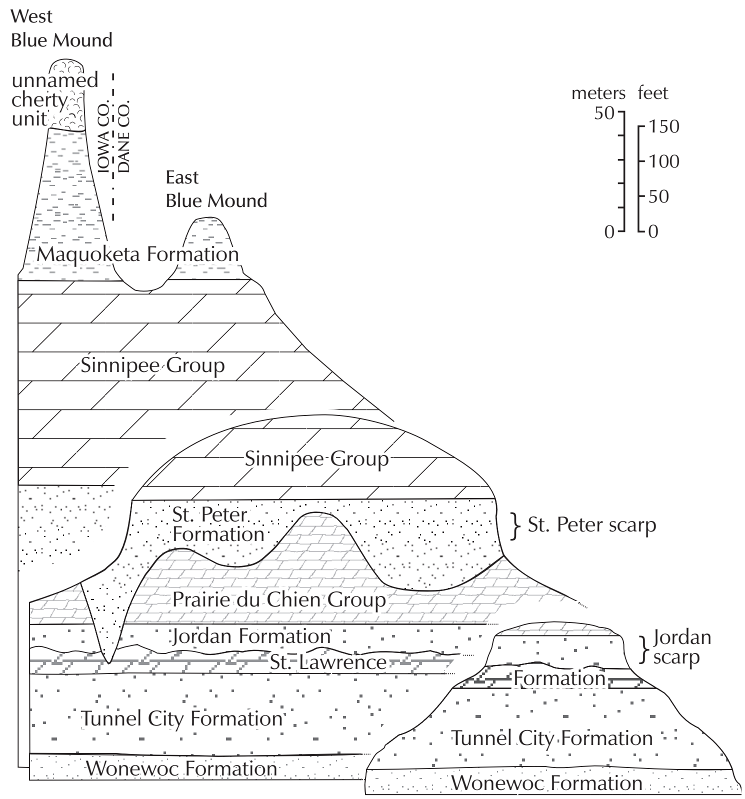
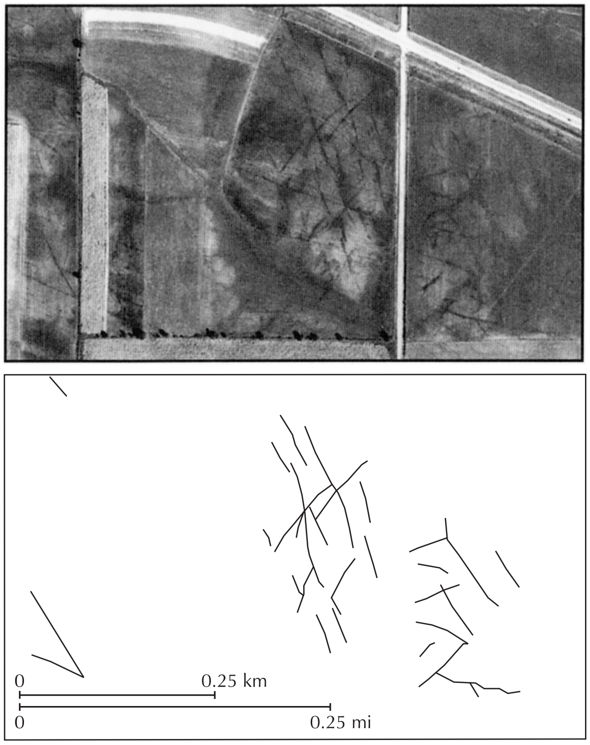


Figure 39. *Summary of the pre-Pleistocene stratigraphy of outcropping rock in Dane County, with a schematic topographic profile through the Driftless Area from roughly the west-central edge of the county (left) to its northwest corner (right). The back panel shows Blue Mounds; the middle panel shows a Sinnipee plateau; and the front panel shows a Prairie du Chien plateau. The vertical dimension is highly exaggerated.*

Typically, the flat middle parts of these uplands are blanketed with nearly 1 m of loess. Loess or reworked loess in transit on the flanks of the uplands thins to zero at the steep edge of the uplands. Between the loess and the Sinnipee dolomite is a layer of clay of the Rountree Formation.

The Rountree consists of a few meters of red-tinged clay and clayey sand containing chert fragments. It apparently is thickest and most continuous where it is on dolomite of the Prairie du Chien and the Sinnipee Groups, but it is found on other Paleozoic units as well. Rountree materials have been described in logs of Wisconsin Department of Transportation borings along Highway 18–151 on the crest of the Sinnipee plateau between Blue Mounds and Verona; the Rountree in this area is typically 1 to 2 m thick, but is as thick as 10 m in open weathered joints



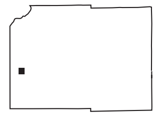


Figure 40. *Aerial photograph of joint traces on Sinnipee upland (Military Ridge), 1 km west of Mount Horeb; sketch map shows the most conspicuous ones. U.S. Department of Agriculture aerial photograph WU-9P-26. S½ sec. 10, T6N, R6E.*

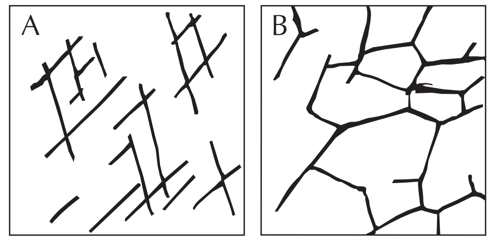


Figure 41. *Schematic maps showing difference in intersection patterns between fractures in the Sinnipee dolomite (**A**) that intersect and cross each other, and ice-wedge casts (**B**) that intersect but do not cross.*

and in sinkholes. It is thinner on steeper slopes, generally where the loess is also thin. The clay and clayey sand are characteristically colored various shades of red, especially reddish brown, but in some wet situations they are brightly multicolored, with various shades of red, yellow, green, purple, white, and black.

The Rountree clay and sand have been considered to be the "residuum" that is the insoluble material left during the weathering of the dolomite in the Prairie du Chien and Sinnipee Groups (see Glocker and Patzer, 1978, and Willman and others, 1989, for example). However, where well exposed, down-slope foliation can generally be seen, indicating that instead of in-place residuum, it is a mass-movement deposit.

For example, in a new excavation for the basement of a house at the edge of the Driftless Area on the west side of Verona, 2 m of red-tinged clay with chert fragments overlies 1 m of dolomite rubble, which overlies dolomite. The clay contains streaks and blocks of pale green (5G 7/2 on the Munsell scale) clay; the streaks have been drawn out parallel to the slope, indicating down-slope flowage.

Because the Rountree clay is characteristic of dolomite terrain, one of its ultimate sources must have been residuum consisting of the insoluble residue from the dolomite. Other material, such as loess, probably has been intermixed with the residuum by mass movement. In addition, Knox and others (1990, p. 66-67) and Frolking (1978) argued that much of the clay is the result of soil-forming processes.

Viewed from the air, the Sinnipee plateaus are conspicuously patterned by fracture traces (fig. 40). In cultivated fields, the traces are dark stripes 1 to 2 m wide and several hundred meters long. Sets of fracture traces run parallel to each other at spacings of meters or tens of meters, and sets of traces cross each other at various angles. They can be seen only on the nearly level crests of Sinnipee plateaus, but apparently can develop at any stratigraphic level within the Sinnipee that happens to be exposed on the plateau tops. None have been seen on the Prairie du Chien dolomite; this can be used to distinguish the Sinnipee and Prairie du Chien, even in the glaciated part of the county where the dolomite is at the surface (map unit **gd,** plate 1).

These traces appear to be the result of weathering along joints in the dolomite and subsequent in-filling of the resulting fissure by surface material, including Rountree clay and windblown silt. We have distinguished them from ice-wedge casts (described below) by their junctions: Joint traces cross each other; ice-wedge casts meet in T or Y junctions (fig. 41).

It is possible, however, that some and perhaps all the traces on the Sinnipee plateaus originated as joints that were later widened by ice wedges. Lateral movement of joint blocks is apparent on a small Sinnipee plateau 0.4 km northwest of the Primrose crossroad (fig. 42). There, the fracture traces are 5 to 10 m wide where blocks of dolomite have been forced apart, probably by ice wedging. If so, this may provide an explanation for the presence of joint traces on the Sinnipee and their absence on the Prairie du Chien dolomite: The Sinnipee may have bedding-plane joints that allow lateral movement and the Prairie du Chien may not, but we have no other evidence of this.

Another process affecting the landscape of the Sinnipee plateaus is the dissolving of the dolomite by groundwater, producing cavities, such as the Cave of the Mounds at the top of the Sinnipee Group on the south side of East Blue Mound. The roofs of some cavities have collapsed, producing a few scattered small sinkholes on the surface of the Sinnipee plateaus (Palmquist, 1965, p. 132-135).

The St. Peter scarp surrounds the Sinnipee plateaus. The plateaus are commonly level enough to be cultivated to their edge, or at least are pastured, and the St. Peter scarp is too steep for cultivation and is generally wooded (fig. 43). St. Peter sandstone is at the surface in the upper part of the scarp, without a cover of loess or Rountree clay; its lower slope is covered with flow debris, including sandstone and dolomite rubble, overlain by more recent reworked loess and Rountree clay that was washed down from

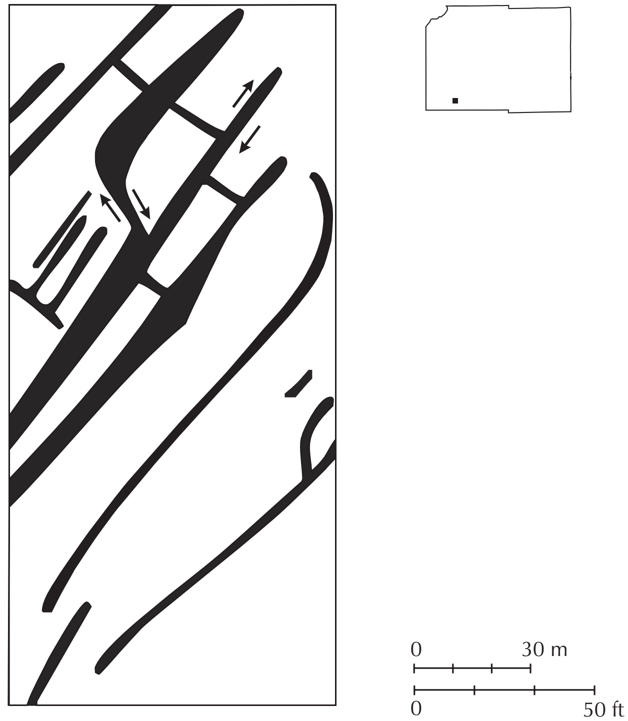


Figure 42. *Sketch map of joints in dolomite that spread apart as much as 5 to 10 m, perhaps because they once held ice wedges, 0.4 km northwest of Primrose. Traced from U.S. Department of Agriculture aerial photograph WU-4P-29. W½ SE¼ SE¼ sec. 16, T5N, R7E. The arrows show relative slippage between blocks.*

the plateau above (Hole, 1976, p. 57-58, figs. 7-10). The St. Peter scarp is typically 10 to 20 m high, but it is discontinuous (plate 1); it is absent in places, possibly where the St. Peter sandstone is thin or absent.

Each of the three major widespread stratigraphic scarps in the region—the St. Peter, Jordan, and Wonewoc scarps—is composed of soft sandstone capped by harder material. In Sauk County, the Wonewoc scarp is capped by the well cemented Ironton sandstone, and the Jordan scarp is capped by well cemented sandstone called “clinkstone” (Thwaites, 1960, p. 26; Clayton and Attig, 1990, p. 14-15 and 25). Habermann and Dury (1974) stated that the St. Peter scarp (as well as the Jordan scarp) in Dane County is capped by a resistant “duricrust,” and Thwaites (1960, p. 26) thought that the St. Peter scarp is held up by Glenwood sandstone cemented with iron oxide just above the St. Peter Formation.

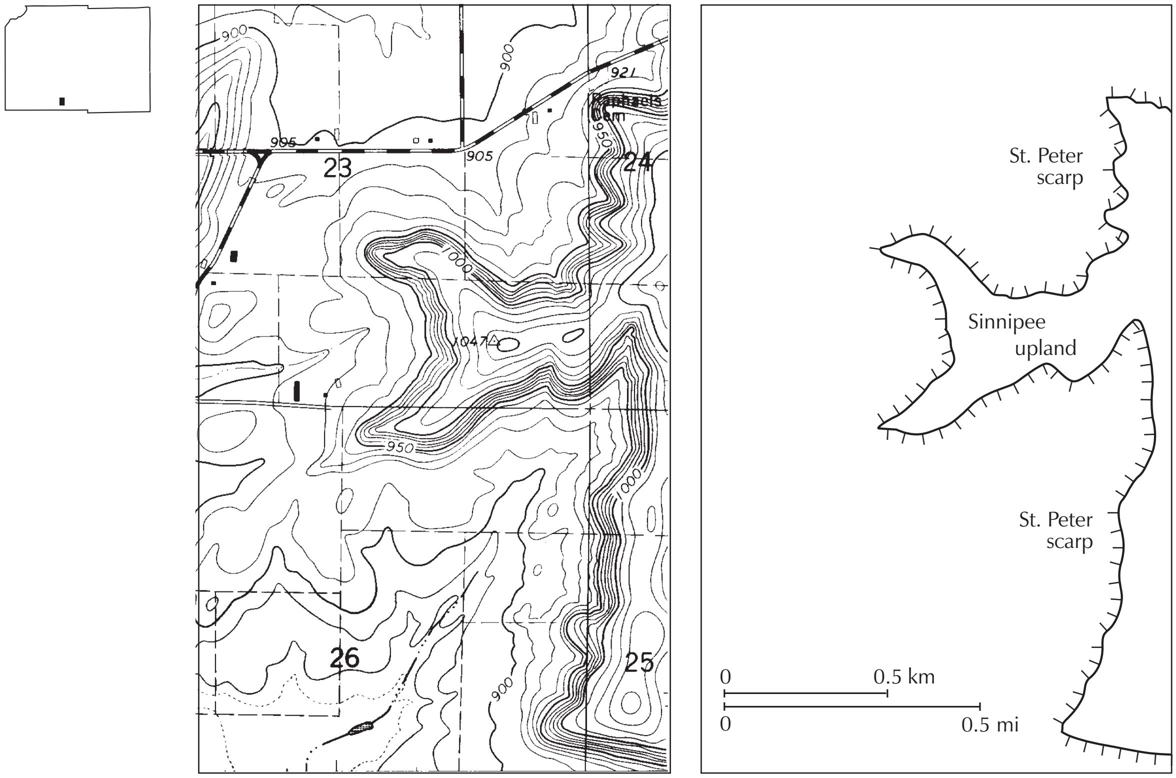


Figure 43. *Part of U.S. Geological Survey's Verona Quadrangle, Wisconsin (7.5-minute series, topographic, 1962), showing St. Peter scarp at edge of a small Sinnipee plateau, 2 km south of Basco. Sections 23, 24, 25, and 26, T5N, R8E.*

Down-slope from the St. Peter scarp are the plateaus formed of dolomite in the Prairie du Chien Group (fig. 39). They have the shape of a smoothly rounded shield in cross profile, but they are not as big as the Sinnipee plateaus; they are generally no more than 1 km wide. They are blanketed by thin loess overlying thin red-tinged clay and sand of the Rountree Formation. The Jordan scarp is similar to the St. Peter scarp; it is a steep sandstone slope covered with trees. Below the scarp is a slight bench in the St. Lawrence Formation, followed by a steeper irregular slope on the Tunnel City Formation down to the Wisconsin River bottomlands.

Hillslopes in the glaciated area

In the Driftless Area, hillslope processes shaped the present landscape; in most of the rest of the county, glacial processes were dominant. But even in the glaciated area, hillslope processes—preglacial as well as postglacial—have left their mark.

The preglacial landscape of the glaciated part of Dane County was probably much like that of the Driftless Area today. The topography on the surface of the Paleozoic rock underlying the Pleistocene sediment is approximately equivalent to the preglacial topography there, but considerable glacial and meltwater erosion must have occurred in some areas, especially along the line of basins now occupied by the Four Lakes of Madison, on the southwest side of the drumlin zone. Topographic maps of the surface on the Paleozoic rock underlying the Pleistocene sediment in Dane County have been constructed by Alden (1918, plate 2), Cline (1965), and Olcott (1972). The maps show major valleys, but they have inadequate detail to show the St. Peter and Jordan scarps.

However, in many parts of the glaciated area, the scarps appear to have been only slightly modified and are still easily recognized where they have only a thin cover of till, as in the area of the Brooklyn till (region 4, fig. 4);

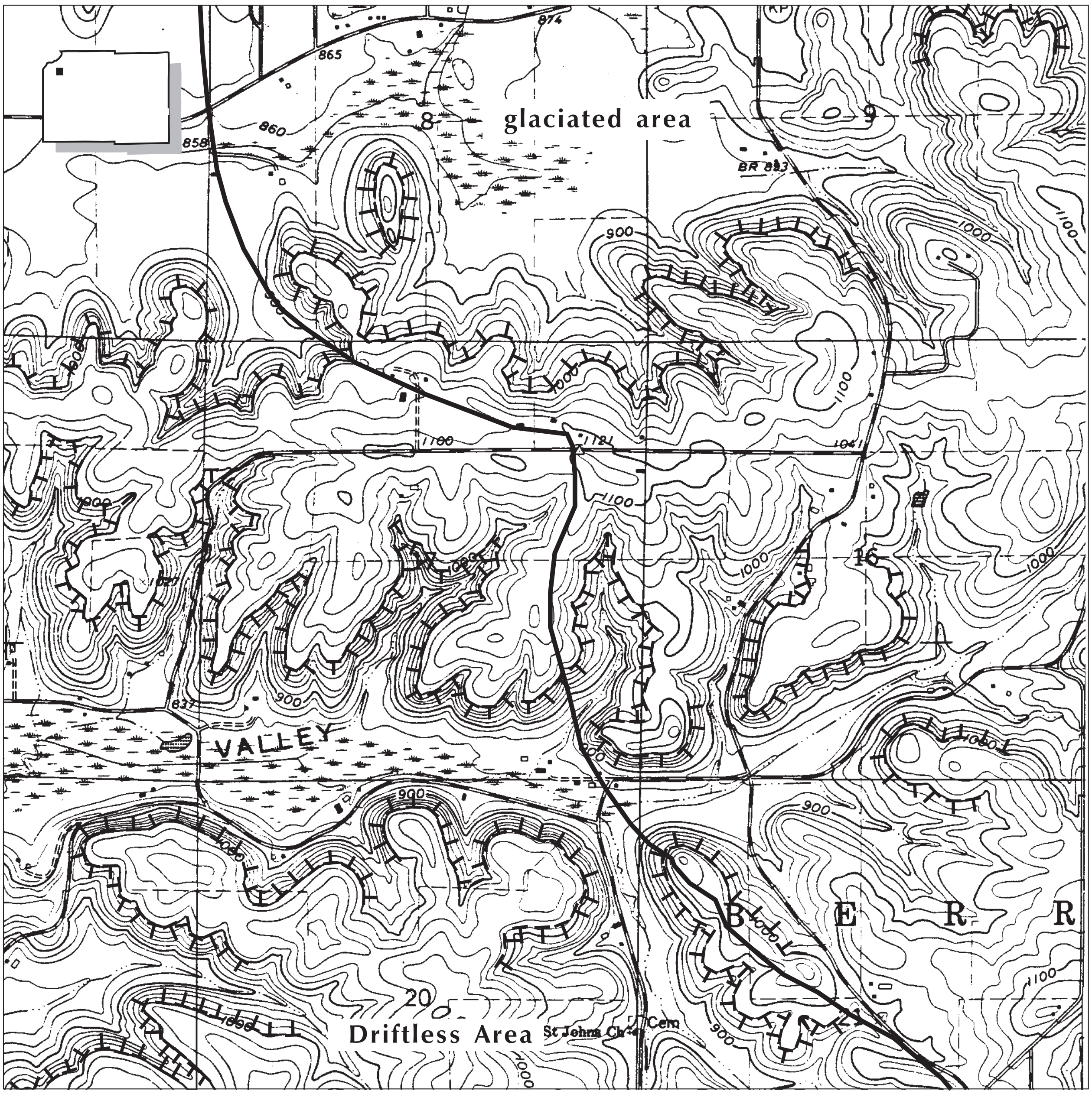
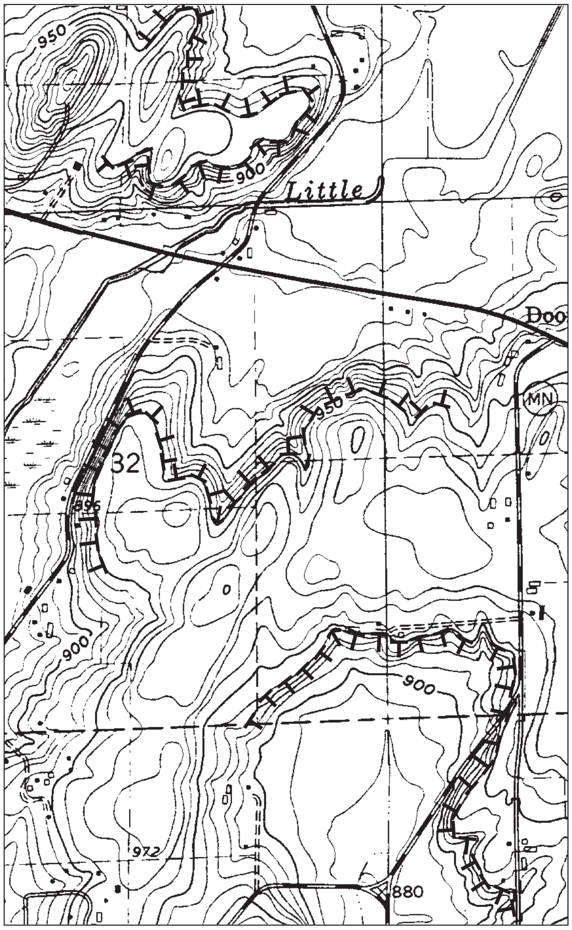


Figure 44. *Part of U.S. Geological Survey's Black Earth Quadrangle, Wisconsin (7.5-minute series, topographic, 1962), showing the Jordan scarp (dashed lines), 6 km northeast of Black Earth, where it has been only slightly modified by glaciation (to the right of the wide solid line); contour interval, 20 ft. Sections 7, 8, 9, 16, 17, 18, 19, 20, and 21, T8N, R7E.*

where the preglacial topography was especially rugged, as in the northwestern part of the county (region 6, fig. 4; fig. 44); and, to a lesser extent, in the other hummocky-till areas (region 5, fig. 4). In addition, some scarps have been exhumed by postglacial slope processes that have completely removed the thin cover of till, especially in the Brooklyn till area. Even in the drumlin area in the northeastern part of the county, the preglacial St. Peter scarp can still be recognized in many places (fig. 45), as can the Jordan scarp in the north-central area. During the Wisconsin Glaciation, as well as earlier ones, the ground in front of the glacier was permanently frozen to great depths (Attig and Clayton, 1992). During the summers, the snow and surface soil thawed but the underlying permafrost prevented water from infiltrating. The resulting morass was par-



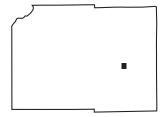


Figure 45. *Part of U.S. Geological Survey's Cottage Grove Quadrangle, Wisconsin (7.5-minute series, topographic, 1962), showing the St. Peter scarp (dashed lines), 5 km south of Cottage Grove in eastern Dane County; contour interval, 10 ft. Sections 4 and 5, T6N, R11E, and secs. 28, 29, 32, and 33, T7N, R5E.*

ticularly susceptible to soil flowage, and for that reason the freshly created landforms left behind by the wasting glacier were quickly degraded (fig. 46). The permafrost may have persisted for 1,000 years or more after the glacier finally wasted out of the county. As a result, all glacial and associated landforms have a run-down, degraded appearance; they lack the fresh, sharp outlines of landforms at the edge of present-day glaciers. In contrast, landforms that originated after the permafrost melted (the lower Lake Middleton beaches, described later, for example) are fairly well preserved.

Erosion on the steepest slopes has removed all traces of glacial topography (and, in many areas, all till). For example, in the area of figure 44, the outermost Johnstown moraine is preserved only on the Prairie du Chien plateaus, but has been eroded from the Jordan scarp, has been buried under stream sediment, or has been washed out of the valley by meltwater. These eroded areas are shown by map unit **ge** on plate 1.

GEOLOGIC HISTORY

Little is known about the several billion of years of Precambrian history in Dane County, but during the Cambrian and Ordovician Periods (fig. 5) lime, quartz sand, and mud were deposited and later lithified to form the cherty dolomite, sandstone, and shale that characterize the Driftless Area and underlie the Pleistocene material in the rest of the county. Deposition of lime, sand, and mud continued through the Silurian and Devonian Periods and probably until nearly the end of the Paleozoic Era, but, except for the Silurian chert blocks at East Blue Mound, none of that material has been preserved in Dane County.

We have little direct evidence of what happened in Dane County during the next quarter billion years, except that much of the Paleozoic rock was eroded away. Toward the end of this long episode of net erosion, the preglacial landscape had assumed nearly its present form. During the Ice Age, the part of this erosional surface in eastern and northern Dane County was altered through erosion by glaciers and by meltwater and has subsequently been protected from erosion by a blanket of glacial and meltwater sediment. In contrast, the long erosional episode on this surface continues uninterrupted in the Driftless Area today.

Figure 47 summarizes the late Cenozoic history of Dane County.

Subdivisions of glaciations have been called substages (an event term rather than a time-stratigraphic term), advances, intervals, stades, or

Figure 46. *Stereographic pair of aerial photographs showing a drumlin, 1 km northwest of Waterloo, with inactive gullies on both sides, probably cut while permafrost still was present. U.S. Department of Agriculture aerial photographs WU-5P-21 and 22. West side of sec. 6, T8N, R13E.*

phases, among others. We generally call them phases (an event term rather than a diachronic term). Figure 48 shows how we typically name them. The fictitious "Ajax Phase" begins and ends at the places of greatest glacier-margin retreat (fig. 48A). ("Ajax Advance" is inappropriate because the margin was advancing during only the first, more poorly known, part of the phase.) However, if a great deal is known about a retreat interval, it may need a name; in figure 48B, the "Acme Interval" is the name for nonglacial events between glacial phases. Figure 48C shows that a named phase may involve ice-margin stability without a preceding retreat. Figure 48D shows that a named phase may include smaller subphases.

Recognition of glacial lakes

We have recognized dozens of glacial lakes in the county; in this report we discuss only some of the larger or more interesting glacial lakes. One of the surest kinds of evidence for the former existence of a lake is offshore sediment. In this setting, most horizontally laminated, nonorganic silt and clay can be interpreted as offshore sediment of a glacial lake. Offshore sand and stream-deposited sand are more difficult to distinguish, but, as mentioned previously, in some places they have been distinguished by the presence of braided channel scars on the stream sediment and their lack on the offshore sediment. In other places, we have interpreted sand to be offshore sediment because of its association with laminated silt and clay.

However, the distribution of offshore sediment, as shown on plate 1, commonly gives a minimum idea of the former extent and level of a lake because offshore sediment was deposited in only the deepest parts of the lake basin; many of the low-lying areas shown as till on plate 1 were submerged, but have at most only a thin and patchy cover of lake sediment. The extent and level of a glacial lake have been interpreted using a variety of other kinds of evidence. For example, beaches and shore terraces are present in some places, but they are too poorly preserved to provide much evidence in most of Dane County. In a few places where an outwash plain has filled one side of a lake basin, the lake level has been determined by the elevation of a scarp interpreted to be a delta slipface. The lake level can also be determined by finding the lowest point on the rim of the basin; if an outlet channel is present at that point, the lake level was the level of the bottom of the channel plus the likely depth of water in a channel of that size.

Once an elevation is known and adjustments were made for any topographic changes since that time, the former shore of the lake can be determined by following that elevation contour around the lake basin. If the lake were no more than a few kilometers wide, the biggest topographic adjustment needed is the reestablishment of the now-missing side of the basin where the glacier stood. For our glacial-lake reconstructions, we used ice-margin positions in figure 49, which were determined from the locations of moraines (fig. 13) and similar features. This procedure was used for most glacial lakes in Dane County, but for the largest, glacial Lakes Yahara and Scuppernong, we also had to consider topo-

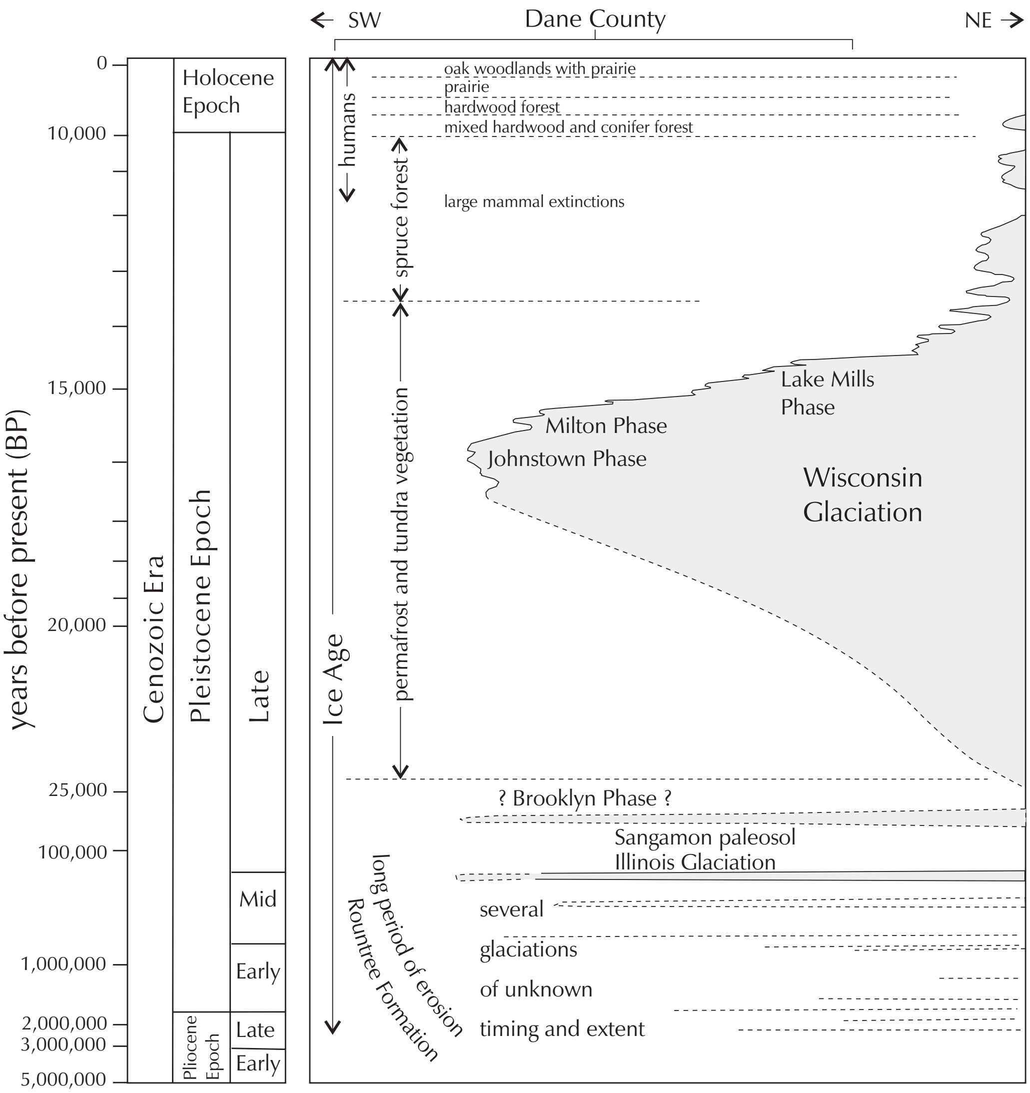


Figure 47. *Schematic representation of geologic events in Dane County, emphasizing the last—or main—episode of the Wisconsin Glaciation. The left-hand box shows the terminology for the eras and epochs of geologic time. The vertical axis of both boxes shows time. The horizontal axis of the right-hand box shows the distance from southwest to northeast across Dane County and farther, with distance greatly compressed, to northeastern Wisconsin, at the right-hand edge of the diagram. The gray tone indicates the presence of the glacier. The line represents the position of the margin of the glacier at any given time. The glacial events are enclosed by a solid line where their timing or extent is fairly well known compared to earlier events; dashed lines are used where timing or extent is unknown. The earlier glaciations are shown as single lines because the time scale is so compressed there. The time scale is irregular; the scale is expanded at times of most interest in this report.*

graphic changes caused by the rebound of the Earth's crust when the weight of the glacier was removed; this is discussed in a later section.

Early glaciations

The Ice Age began about 2,500,000 years ago, during the last part of the Pliocene Epoch (fig. 47). Several times through the middle part of the Pleistocene Epoch, the global climate underwent major fluctuations, and, during cold periods, ice sheets covered much of North America and other parts of the world. During several of these pre-Wisconsin glaciations, the ice sheet reached what is now the state of Wisconsin, and once extended 590 km south of Dane County into southern Illinois (Willman and Frye, 1970). Although there is little direct evidence for it, the

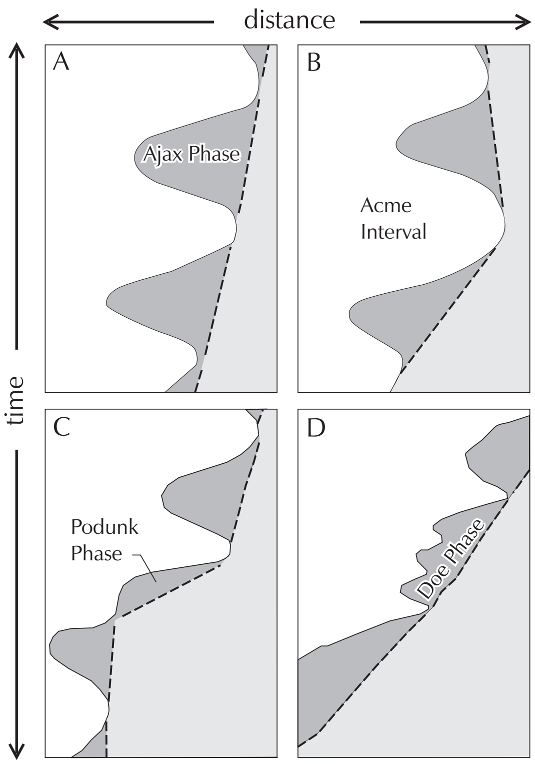


Figure 48. *Time-distance diagrams showing how phases of glaciation have been named. The solid line marks the position of the edge of the glacier, with the glacier moving from right to left. Light gray represents the glaciation being considered, such as the Wisconsin Glaciation; dark gray represents phases of the main glaciation.*

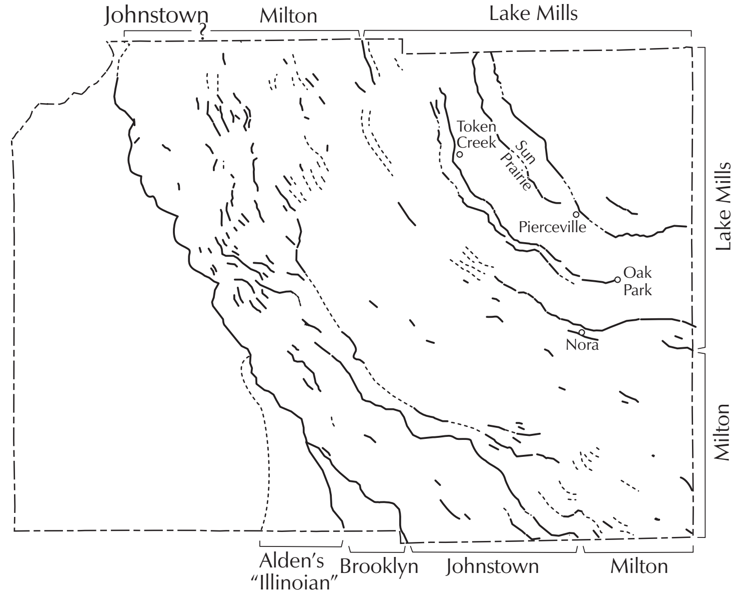


Figure 49. *Map of Dane County showing the maximum extent of the glacier during named phases and unnamed subphases of glaciation. Solid lines show fairly certain ice margins; dashed lines show speculative ice margins in areas of little information between more-certain margins, or they show trends of segments of small moraines.*

ice sheet probably reached the eastern part of Dane County during at least a few of these early glaciations.

The last of these pre-Wisconsin glaciations is called the Illinois Glaciation, which has been well documented in Illinois (Willman and Frye, 1970; Lineback, 1979). The Illinois ice sheet must have covered eastern Wisconsin to reach Illinois. It seems likely that it reached at least eastern Dane County, but evidence is buried under later glacial deposits, except possibly in the Belleville and Verona area of south-central Dane County (fig. 49) and in adjacent Rock and Green Counties, where Alden (1918) and Bleuer (1971) observed scattered occurrences of glacial material that might have been deposited during the Illinois Glaciation.

Lakes in Sugar River valley. Glacial lakes were dammed in the Sugar River valley during some of these late pre-Wisconsin glaciations. Except for northwestern Dane County, which drains to the Wisconsin River, drainage was generally to the south-southeast, into the valleys of the Sugar River and other rivers tributary to the Rock River, a tributary of the Mississippi. Every time a glacier flowed west into the mouths of these valleys, lakes formed. This probably happened many times during earlier glaciations, but little is known about most of these lakes because the evidence is buried under deposits of the most recent glaciation or has been eroded away. However, there is some evidence that lakes spread into the Sugar River and Pecatonica River valleys of southwestern Dane County during the earlier glaciations.

Alden (1918, p. 146) proposed that a glacial lake existed in the upper part of the Sugar River valley when the "Illinoian" glacier stood at its maximum extent (fig. 50). He stated that it stood at an elevation of 320 to 335 m (1,050 to 1,100 ft), the elevation of the lowest point on the drainage divide between the Sugar valley and the Pecatonica valley to the south (a, fig. 50); modern topographic maps show the low point at 329 to 332 m (1,080 to 1,090 ft), but no chan-

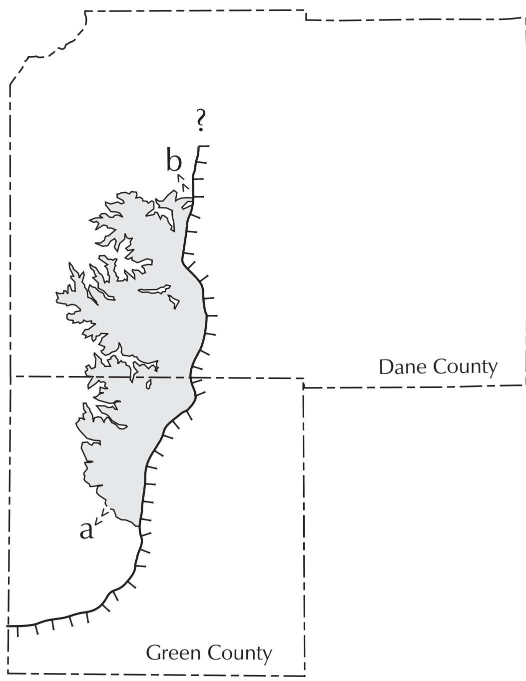


Figure 50. *Alden's glacial lake in the Sugar River valley (gray area). The hachured line marks maximum extent of the ice during the Illinois Glaciation according to Alden, except in the area north of Verona, where it has been extrapolated northward through the area glaciated later. Letters indicate a possible southern outlet to Pecatonica valley (**a**) and a possible northern outlet to Black Earth River valley (**b**). The lake margin was traced from topographic maps of the present land surface except for the part that was later glaciated; for that area, Olcott's (1972) map was used. No adjustment was made for crustal rebound.*

nel form can be seen there. (However, on Alden's plate 3, the shore is shown at the 1,000-ft contour.)

No evidence from Dane County supports the existence of such a lake, and it is unlikely to have existed in the form suggested by Alden. His "Illinoian" ice margin is probably not a single ice margin, but more likely is a composite of different margins at different times. In any case, the location of any pre-Wisconsin ice margin is unknown north of Verona, where any evidence that existed has been buried beneath till deposited during the Wisconsin Glaciation. If the pre-Wisconsin ice margin were a few kilometers east of the westernmost margin during the Wisconsin Glaciation, the outlet probably would have been to the north down the Black Earth trench (b, fig. 50), whose bottom is between 259 and 274 m (850 and 900 ft) (Olcott, 1972).

West of Belleville, Alden (1918, p. 144, plate 3) found "scattered crystalline pebbles foreign to the area," which he interpreted to be from "ice blocks floating on lakes." These observations are now hard to verify because of the gravel that has been trucked into the Driftless Area from gravel pits in the glaciated area. After Alden's time, nearly every rural road was graveled, and snowplows probably scattered gravel out into adjacent ditches and fields in places where Alden made most of these original observations. In addition, gravel from the glaciated area was sometimes used as agricultural lime, which is another possible source of far-traveled lithologies in the Driftless Area. In more recent years, glacial boulders used for decorative landscaping have commonly been trucked at least as far as the western border of the county.

During excavation for the Highway 18–151 bypass southwest of Verona (NE corner of SE¼ SW¼ sec. 21, T6N, R8E), several meters of sand and gravel were exposed in a hilltop at an elevation of about 305 m (1,000 ft). The pebbles and cobbles consist largely of local rock types: chert, sandstone, and dolomite. Rare pebbles of igneous and metamorphic rock are present on the face of the outcrop, but none were observed in place in the sand and gravel deposit. The deposit is about 0.5 km beyond Alden's "Illinoian" ice margin and 1 km beyond the Wisconsin ice margin. It could not have been deposited by meltwater rivers during the Wisconsin Glaciation because it is 20 m above the highest Wisconsin outwash plain, and it is probably not meltwater river sediment of any age because it has too few pebbles of far-traveled rock. It is more likely a shoreline deposit, but its relationship to any of Alden's lakes in the Sugar River valley is unknown.

Alden (1918, p. 148-149) thought this lake in the Sugar River valley spilled southward into another lake in the Pecatonica River valley, at an elevation of about 305 m (1,000 ft). This is the elevation of the lowest possible outlet in northeastern Jo Daviess County, Illinois; modern topographic maps show it to be between 302 and 305 m (990 and 1,000 ft). On the basis of present-day land elevations, this lake would have extended into Pecatonica tributary valleys in the southwest corner of the county, but we found no evidence for this.

Lake Broadhead. Leighton and Brophy (1966) identified a clearly defined spillway across the divide between the Sugar River and Pecatonica River valleys, 4 km southwest of Juda in southeastern Green County (a, fig. 51). It is 0.2 km wide, and its present bottom is between 280 and 283 m (920 and 930 ft), but judging from the form of the cutbanks, water may have stood near 290 m (950 ft) when it was cut. The spillway was the outlet of a lake in the Sugar River valley named Lake Broadhead by Leighton and Brophy (1966).

Assuming topography like today's, Lake Broadhead was dammed by glacial ice extending at least as far west as the southwest corner of Rock County; otherwise, the lake would have spilled south at that point instead of west through the Juda outlet (b, fig. 51). Similarly, the ice must have extended at least as far west as Fitchburg in central Dane County or the lake would have extended into the Yahara River valley and spilled into the Black Earth trench. No known ice margin matches these requirements.

Aside from the Juda outlet channel, we know of no direct evidence for the existence of Lake Broadhead. However, there is considerable evidence south of Dane County for lakes like Lake Broadhead (see, for example, Palmquist, 1965; Whittecar, 1979; Leighton and Brophy, 1966). In Dane County, well constructor's reports in WGNHS files show 10 to 20 m of "clay" beneath about 10 m of sand and gravel deposited by meltwater streams in the Sugar River

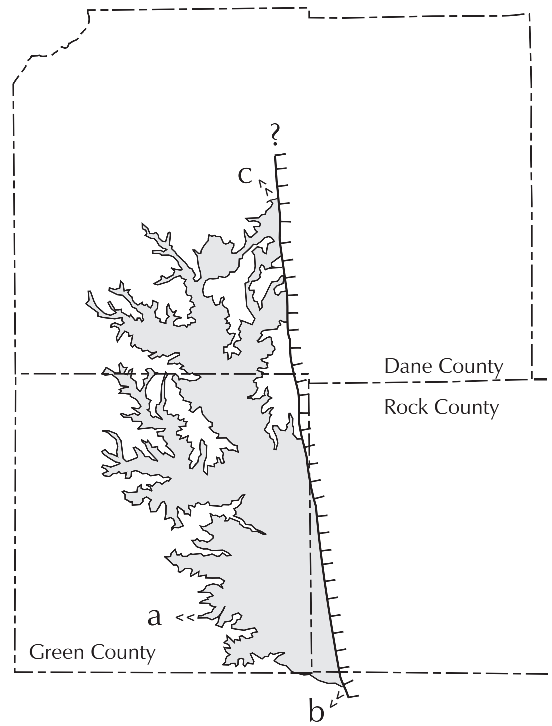


Figure 51. *Glacial Lake Broadhead (gray area). The glacier margin (line with hachure marks) must have been at least this far west, otherwise the lake would have drained north (**c**) or south (**b**) rather than west (**a**) through the Juda outlet. The lake margin was traced from topographic maps of the present land surface except for the part that was later glaciated; for that area, Olcott's (1972) map was used. No adjustment was made for crustal rebound.*

valley between Verona and Belleville. The "clay" is between elevations of about 238 and 262 m (780 and 860 ft). It may have been deposited in Lake Broadhead or in other similar glacial lakes.

Brooklyn Phase of the Wisconsin Glaciation

The Brooklyn Phase is the first Pleistocene event that is well documented in Dane County. The till deposited during the Brooklyn Phase was mapped as units **gb** and **gp** on plate 1. Its distribution in Green, Rock, and Dane Counties is shown in figure 52.

The exact timing of the Brooklyn Phase has long been debated (Alden, 1918, p. 185-186; Mickelson, 1983, p. 13). The Brooklyn till is probably significantly older than the Johnstown till because Brooklyn till has undergone more erosion. The Brooklyn till has been completely eroded from much of the area shown in figure

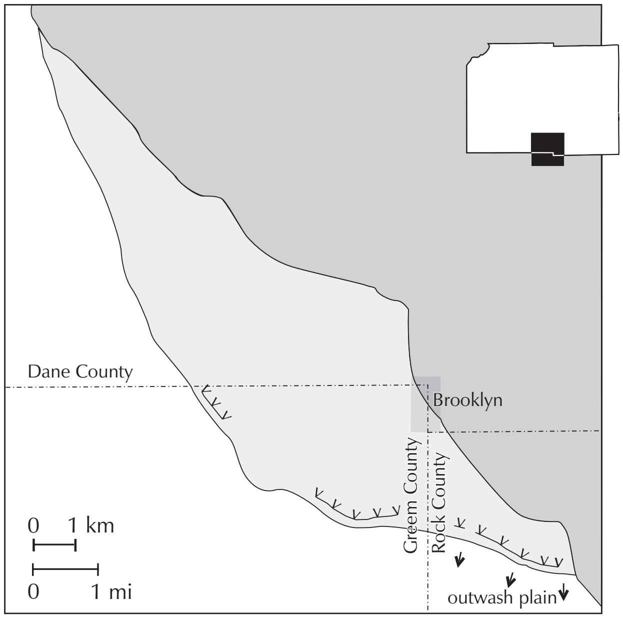


Figure 52. *Distribution of the Brooklyn till (light gray); to the northeast it is buried under Johnstown till (dark gray). Brooklyn moraines are shown by lines with attached arrowheads. Arrows with stems indicate direction of meltwater flow on outwash plain.*

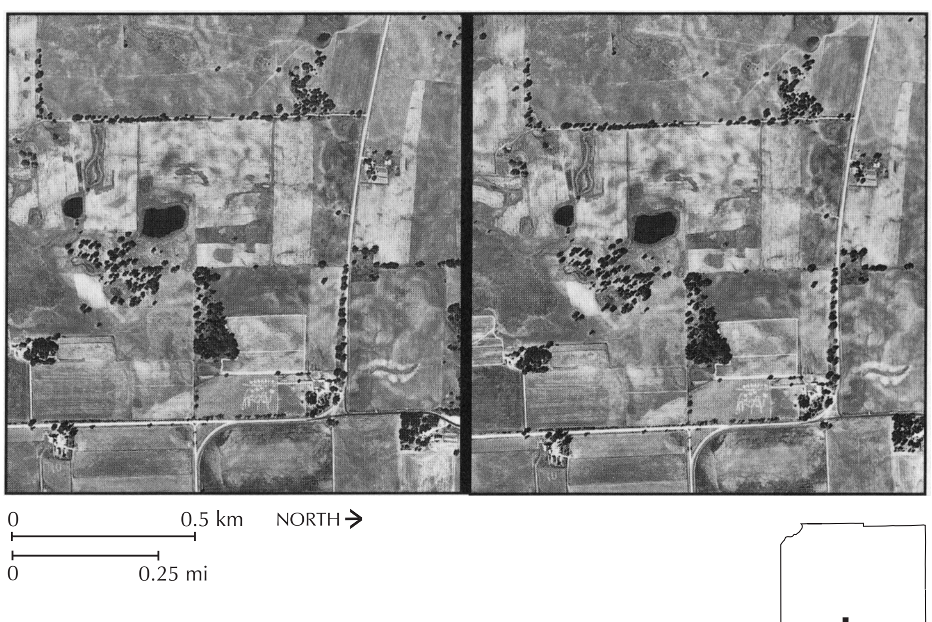


Figure 53. *Stereoscopic pair of aerial photographs of hummocky Brooklyn till, 6 km southwest of Oregon. U.S. Department of Agriculture aerial photographs WU-7P-124 and 125. Section 20, T5N, R9E.*

52, exposing the underlying rock. For example, 9.6 km west-northwest of the village of Brooklyn, the St. Peter scarp is fully exposed (plate 1). The same scarp just to the northeast has been obscured where covered by Johnstown till. Furthermore, Glocker and Patzer (1978, p. 151) reported a paleosol developed on the Brooklyn till and beneath loess deposited during the last part of the Wisconsin Glaciation (including the Johnstown Phase); this paleosol is absent on the Johnstown till, indicating it is significantly younger than the Brooklyn till.

On the other hand, the Brooklyn till cannot be a great deal older than the Johnstown till because its glacial topography is well preserved in some areas. Hummocky collapse topography on Brooklyn till (map unit **gp,** plate 1) is nearly as fresh looking as that on the Johnstown till (compare fig. 18 with fig. 53), and Brooklyn moraines (fig. 53) are nearly as fresh looking as Johnstown moraines. In addition, the channels of braided meltwater streams on the outwash plain south of the Brooklyn moraine in northwest Rock County (fig. 52) resemble those on Johnstown outwash plains.

Furthermore, if the areas of map unit **sc** on the Johnstown outwash plain really are collapse depressions as shown on plate 1 rather than wind-eroded depressions, for example, the Brooklyn glacial ice was still present when the Johnstown outwash was deposited; therefore, the interval between the Brooklyn Phase and the Johnstown Phase could not have been long. Alternatively, the collapse depression possibly resulted from buried ice from an unknown glacial phase between the Johnstown and Brooklyn Phases.

And finally, in Illinois, the Sangamon paleosol is developed on till of the Illinois Glaciation and on older materials (Willman and Frye, 1970). None of the soils on the Brooklyn till seems as well developed as the Sangamon paleosol, indicating that the Brooklyn till was deposited after the Illinois Glaciation, unless the Sangamon paleosol has been completely eroded away.

Outwash-dammed lakes. If one river aggrades its bed faster than another where they join, the first will dam a lake in the valley of the other. During the Brooklyn and Johnstown Phases of the Wisconsin Glaciation, the large meltwater rivers crossing the Driftless Area may have carried enough sand and gravel to cause them to aggrade their beds more rapidly than tributaries that received little or no meltwater. As a result, lakes might have been dammed in the tributaries of the Sugar and Wisconsin Rivers.

The size of these lakes is unknown because the lake basins have since been filled; the lake sediment has been buried by postglacial stream sediment, and as a result, the configurations of the lake bottoms at the time are unknown, although some may have been a few kilometers long. Two exceptions in Dane County, with basins that remain unfilled, were the lakes in Marsh Valley and Dunlap Creek valley north of Black Earth. Both were dammed by aggradation up to the high terrace level (about 247 m). If the high terrace had escaped subsequent entrenchment, today the basins would hold lakes 4 km long.

However, many nonglacial tributaries were heavily laden with bedload as the result of rapid hillslope erosion when permafrost was present, causing them to aggrade as fast as the meltwater rivers. In places, the nonglacial stream sediment of map unit **sp** (plate 1) stands above adjacent meltwater-stream sediment (map unit **su**), such as it does on the south side of Cross Plains, where plate 1 shows map unit **sp** separated from the lower-lying map unit **su** by a cutbank.

Johnstown Phase of the Wisconsin Glaciation

Little is known about the interval between the Brooklyn and Johnstown Phases, but probably the ice sheet had wasted back out of the county and perhaps out of the state (fig. 47). It again readvanced to Dane County. On the basis of the chronology of Mickelson and others (1983) and Clayton and others (1992), the Green Bay Lobe reached its maximum extent in Dane County probably between about 18,000 and 14,000 BP (figs. 47, 49, and 54). This episode of glacial advance, stability, and retreat is the Johnstown Phase of the Wisconsin Glaciation. The name Johnstown was apparently first used in roughly this sense by Alden (1918, p. 132, 209), who named it for the villages of Johnstown and Johnstown Center in Rock County, near the outermost Johnstown moraine.

At the maximum extent of the Green Bay Lobe during the Johnstown Phase, shown in figure 54, braided meltwater rivers flowing from the edge of the glacier were heavily laden with a suspended load of silt and clay and a bedload of sand and gravel. The silt and clay were carried out of the county or deposited in the basins of glacial lakes, and the sand and gravel formed outwash plains extending down the Sugar and Wisconsin Rivers and their tributaries, as shown in figure 54. The divide between meltwater flowing south to the Sugar and north to the Wis-

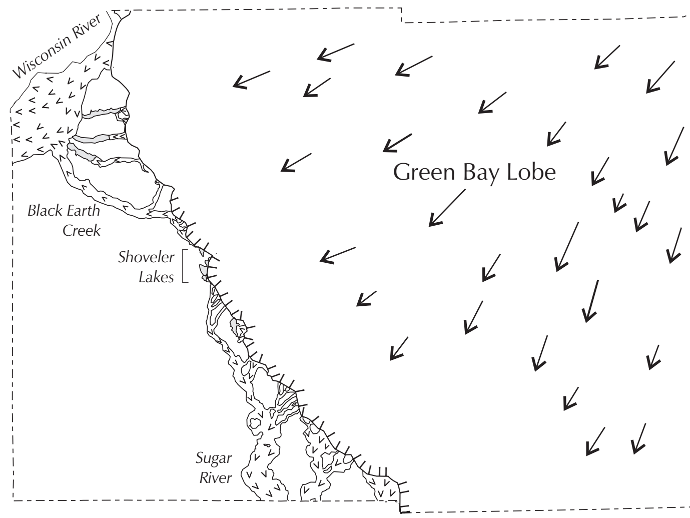


Figure 54. *Dane County during the middle part of the Johnstown Phase when the Green Bay Lobe had reached its maximum extent. The glacier movement directions are indicated by large arrows. The terminus of the glacier is indicated by the line with hachures. Direction of meltwater flow is indicated by arrowheads.*

consin was 1 km south of Mineral Point Road.

A nearly continuous moraine formed along the glacier margin when it stood at its maximum extent during the Johnstown Phase. However, the moraine was later eroded from the steeper slopes in the northwest part of the county (map unit **ge**, plate 1). Later, general ice-margin retreat from the maximum position was interrupted by brief pauses or minor readvances of the ice margin, forming the smaller, more discontinuous moraines shown on plate 1 between the outermost Johnstown moraine and the outermost moraine of the succeeding Milton Phase.

The arrows in figure 54 show the direction of glacial movement, as indicated by drumlin orientations. The drumlins were probably molded to a considerable extent during the Johnstown Phase because at least the larger drumlins are parallel to likely Johnstown flow lines, which should have been perpendicular to the ice margin where they intersected it. However, in a few places in northeast Dane County, the smallest drumlins are perpendicular to nearby moraines rather than the more distant Johnstown moraine, suggesting that the smaller drumlins formed later and closer to the ice margin than the larger ones.

The drumlins are present to within about 10 km of the maximum extent of the glacier (plate 1); within the drumlin zone the glacier was probably sliding on a bed that was just at the freezing point. To the southwest, in the hummocky-till zone, drumlins are lacking; small drumlins may be hidden under an obscuring blanket of supraglacial till and other supraglacial debris. Alternatively, drumlins never formed there because the glacier was not sliding but was frozen to its bed.

The frozen-bed zone may never have been 10 km wide, however. A hummocky zone 10-km wide could have been produced by a narrower frozen-bed zone moving northeast across the area as the ice-margin wasted back. Subglacial drag marks are visible in places where the overburden has been stripped off the dolomite in at least the northeast half of the hummocky zone, indicating the glacier had been sliding on a thawed bed at least part of the time it stood there. However, Rountree clay is commonly present on dolomite and under till in the outermost 1 km of the hummocky zone, indicating little erosion, perhaps because a frozen bed that wide existed most of the time the ice stood at the outermost moraine. But if the outermost Johnstown moraine in northwestern Dane County and eastern Sauk County really is composed of subglacial till, as argued by Lundqvist and others (1993), the outermost edge of the bed was unfrozen when the glacier was at its maximum extent.

The cause of the abundant hummocky supraglacial debris was probably the frozen bed of the snout of the glacier. More actively moving ice was sheared up over less rapidly moving ice, and subglacial debris, when frozen to the bed, was dragged up into the glacier, where it accumulated on the glacier as its surface melted down. Because the supraglacial debris insulated the underlying glacier, a layer of stagnant glacial ice was preserved. This layer of ice was of irregular thickness, but on the basis of an analogy with modern debris-covered glaciers, it was at least several tens of meters thick in many areas. This ice persisted for hundreds or thousands of years, much of it probably until the climate warmed enough for the permafrost, along with the buried glacial ice, to melt about 13,000 or 14,000 BP (Attig and Clayton, 1992). As this stagnant glacial ice melted, the supraglacial debris collapsed to produce the hummocky topography characteristic of glaciated area southwest of the drumlin area.

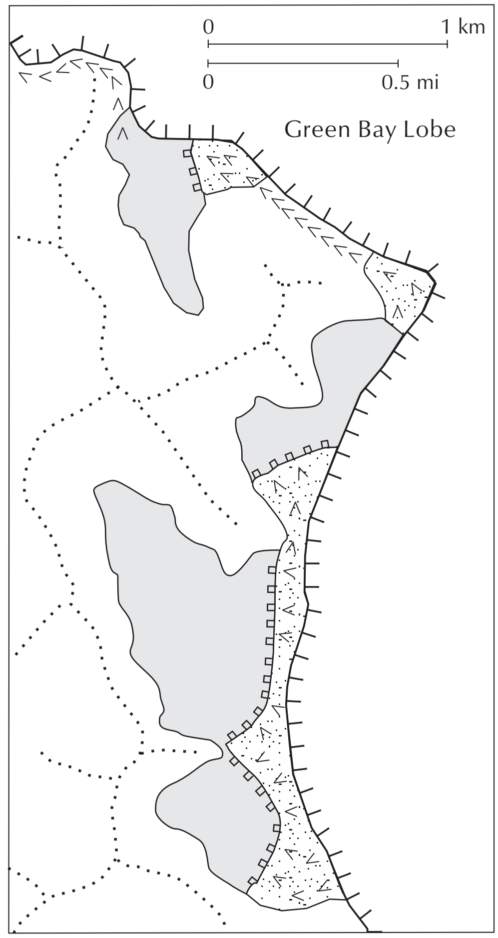
The Shoveler lakes. During the Johnstown Phase, a series of small glacial lakes formed at the east edge of the Driftless Area where Old Sauk Road and Mineral Point Road now cross

Timber Lane west of Madison (fig. 55). (The intermittent pond northwest of the junction of Timber Lane and Mineral Point Road has been labeled "Shoveler Sink" by the U.S. Fish and Wildlife Service, hence our designation "Shoveler lakes.")

Each of these lakes occupied the head of a small preglacial valley that was dammed by the glacier and by glacial debris. The glacial meltwater deposited an outwash delta in each, and each in turn spilled northward into the next lake across the rock spurs separating the basins. The lowest of these lakes spilled through a channel across the drainage divide shown in the northwest corner of figure 55 and in the center of figure 56; from there, the water cascaded down into the Black Earth trench.

"Wilkie Gorge" is a small rock gorge, 0.5 km long, that has been cut into the south wall of the Black Earth trench at the east end of the divide-crossing channel mentioned in the previous paragraph (fig. 56). Black (1974, p. 72-92) stated that the north half of the gorge was cut by glacial meltwater flowing north along the edge of the glacier and then plunging down through a tunnel under the glacier. It is also possible that the north half was formed by meltwater flow out from under the glacier or that it was cut by ice-marginal drainage as the ice margin began to retreat. It may also have formed largely during postglacial time, eroded by the same gully-forming processes that eroded dozens of other gullies in the walls of the Black Earth trench. More likely, its origin was complex: It may have begun as a small preglacial valley that was deepened during glaciation, perhaps by meltwater flowing in under, out from under, or along the margin of the glacier, followed by postglacial erosion.

The gorge is within the Cross Plains Unit, one of nine units of the Ice Age National Scientific Reserve (fig. 30), all of which are in Wisconsin. The reserve is the only part of the National Park System focusing on continental glaciation.



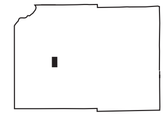


Figure 55. *The Shoveler lakes (gray areas) during the height of the Johnstown Phase, when the Green Bay Lobe was at its maximum extent, with outwash plains (dotted area) and delta slipfaces (line with square hachures). Arrowheads indicate the direction of meltwater flow; dotted lines in the Driftless Area are drainage divides.*

The Cross Plains Unit, which is not yet in operation, will likely highlight the gorge as well as the contrasting topography of the Driftless Area and the glaciated region, the Black Earth trench, the outermost Johnstown moraine, the divide-crossing channel, and the glacial Shoveler lakes and their outwash deltas.

Today, Shoveler Sink drains through a sinkhole on its northeast side (Thwaites, 1908, p. 94). K.R. Bradbury (Wisconsin Geological and Natural History Survey, verbal communication, 1995) suggested this sinkhole and another just north of it may have originally been pits eroded by springs fed by meltwater from a cave beginning to the east under the glacier.

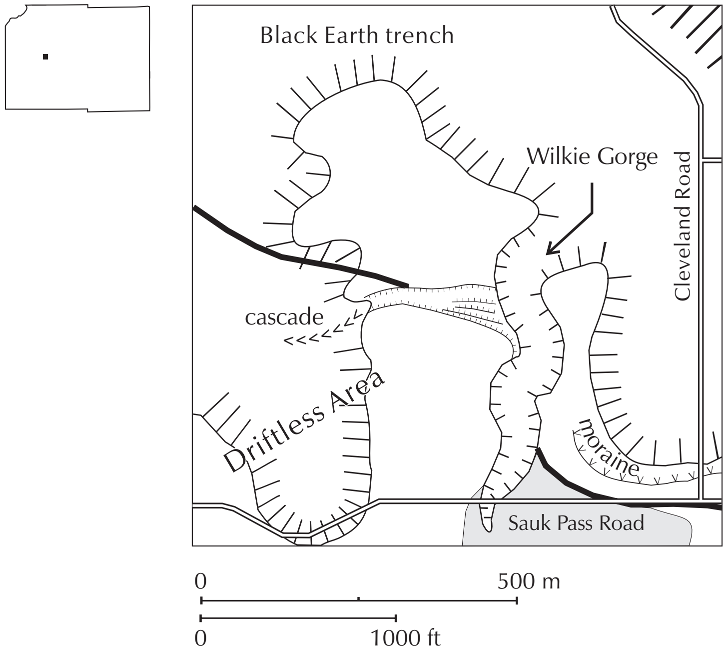


Figure 56. *"Wilkie Gorge" on the south side of the Black Earth trench. The line with long hachure marks is the edge of the upland and adjacent steep slopes. The lines with short hachures in the middle of the map mark the sides of a meltwater channel. The heavy dark line is the southwestern extent of the Green Bay Lobe. The gray area is the bed of the northernmost of the Shoveler Lakes shown in figure 55. Meltwater from the Shoveler Lakes flowed northward along the margin of the glacier through a channel now occupied by the middle reach of the gorge; it then flowed west through the channel shown in the middle of the map and cascaded down into the Black Earth trench. Later, the water might have flowed down through a channel under the glacier and into the Black Earth trench (north part of the gorge). The area shown is approximately the E½ NW¼ and W½ NE¼ sec. 13, T7N, R7E.*

A similar glacial lake existed 4 km to the southeast, near what is now the junction of Highway PD and Nine Mound Road. Several gravel pits in the outwash delta in this area have exposed 10 to 15 m of sediment, which coarsens rapidly eastward from sand to cobble and boulder gravel deposited near the ice margin.

Milton Phase of the Wisconsin Glaciation

The margin of the ice sheet must have stabilized at the position shown in figure 54 for a considerable time during the Johnstown Phase because the moraine is larger and more continuous than most others in the county and it is more consistently bordered by glacial-lake and stream deposits. The ice then melted back some unknown distance, with a few minor periods of stability when the lesser Johnstown moraines formed. The next major event was the Milton Phase (fig. 47), when the ice margin melted back or readvanced to the position shown in figure 57, then stabilized at that position, and again began to melt back. The main Milton period of stabilization might have been comparable to that of the Johnstown Phase because the moraine and outwash plains formed during that interval are similar in size.

The name Milton was first applied to this glacial episode by Alden (1918, p. 133, 259). The outer Milton moraine passes through Milton Township and near the city of Milton in Rock County.

Meltwater from the glacier drained to the northwest to the Wisconsin River, as it did during the Johnstown Phase, but much of the Sugar River drainage shifted southeastward to the newly uncovered valley of Badfish Creek. Figure 57 shows three small glacial lakes spilling southeast into a lake in the lower Badfish valley, which represents an early stage of Lake Yahara–Scuppernong (discussed later).

The Milton glacier margin of figure 57 is probably the continuation of Alden's Milton ice margin in the Milton area, but exact correlations will have to be established by more detailed work between the two areas. The maximum Milton ice margin shown with a solid line in figure 49 could be drawn with some confidence because of the nearly continuous series of outwash plains (map unit **su,** plate 1), but beyond that to the northwest the line is discontinuous because the ice-margin position there is uncertain. Our best guess is that the Milton Phase of Dane County is equivalent to at least part of the Elderon Phase north of the Baraboo Hills (Clayton and Attig, 1990, p. 39).

Thwaites (1908, p. 67, 81) used the name "Pheasant Branch Substage" for a minor episode of ice-margin stabilization during which an outwash plain or delta formed on the east side of glacial Lake Middleton; a similar outwash plain or delta formed in the southern part of what is now the city of Stoughton. We have tentatively associated both with an ice margin drawn in figure 49 through a series of disconnected moraines 2 or 3 km east of the Milton ice margin and just west of the east edge of the hummocky-till zone (plate 1).

Toward the end of the Milton Phase, the regime of the glacier changed and it no longer produced hummocky-till topography because it no longer produced much supraglacial till. Perhaps the climate warmed enough to largely eliminate the frozen-bed zone. The supraglacial debris was no more than about 1 m thick in many areas; otherwise, the very small drumlins would have been obliterated.

Lake Middleton. As the margin of the ice sheet melted eastward during the last part of the Wisconsin Glaciation, a lake came into existence atop the drainage divide between the Black Earth valley and the Yahara valley, on the west side of what is now the city of Middleton (figs. 58 and 59). This lake was named Lake Middleton and first studied by Thwaites (1908, p. 72-87; see also Alden, 1918, p. 266).

Just before the lake formed, the ice margin stood at the east edge of the outwash terrace at the head of the Black Earth trench (NW¼ sec. 10, T7N, R8E; figs. 58 and 59). The lake existed at least until after the ice margin retreated eastward 3 km to the east edge of the outwash plain in the middle of what is now the city of Middleton. An outlet was cut through the outwash terrace in the Black Earth trench, and water level stabilized between 283 and 287 m (930 and 940 ft), which is the elevation of the outlet to the west into the Black Earth trench, the main high beach, and the brink of the delta slipface, which is a few meters high.

Finally, the supply of sand and gravel was cut off as the ice margin melted off the east side

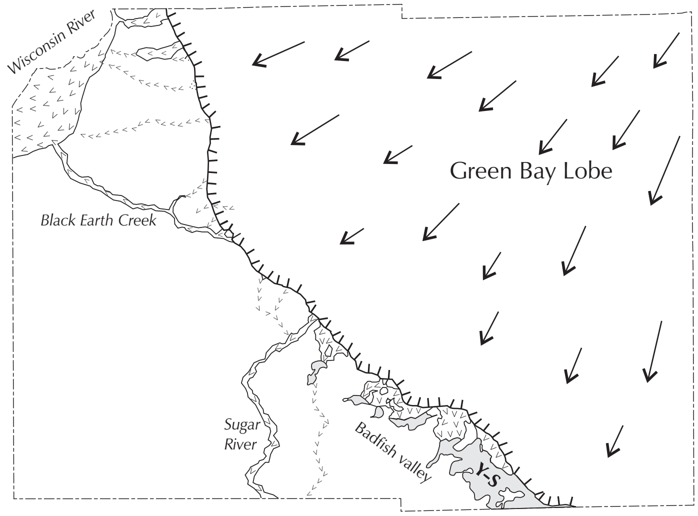


Figure 57. *Dane County during the height of the Milton Phase. Lake Yahara–Scuppernong (Y–S) has appeared in the Badfish River valley. Symbols as in figures 54 and 55.*

of the outwash plain, forming a narrow lake—the initial stage of Lake Mendota—between the outwash plain and the ice (fig. 58). This incipient Lake Mendota had to spill westward into Lake Middleton until the ice margin melted far enough eastward to uncover a lower southern outlet from Lake Mendota. The lowest available drainage route was westward across the outwash plain, where discharge from Lake Mendota must have cut an outlet channel to Lake Middleton (along the route of, but in the opposite direction of, the future Pheasant Branch). When the ice melted enough for Lake Mendota to spill to the south, its level dropped below its western outlet, and meltwater flow into Lake Middleton ceased.

However, Lake Middleton continued to exist as a nonglacial lake about 13 m deep. The center of the basin today is about 6 m below the bottom of the west outlet, and an additional 7 m of postglacial sediment lies below the center, as shown in figure 59. To the east the lake was held in by the outwash plain. Apparently, the meltwater flowing westward across the outwash plain from Lake Mendota failed to cut very deeply into the outwash plain; otherwise, Lake Middleton would have emptied eastward when Mendota's flow shifted to the south.

The three levels of beaches of Lake Middleton are separated from each other by no more than a few meters, indicating that its postglacial

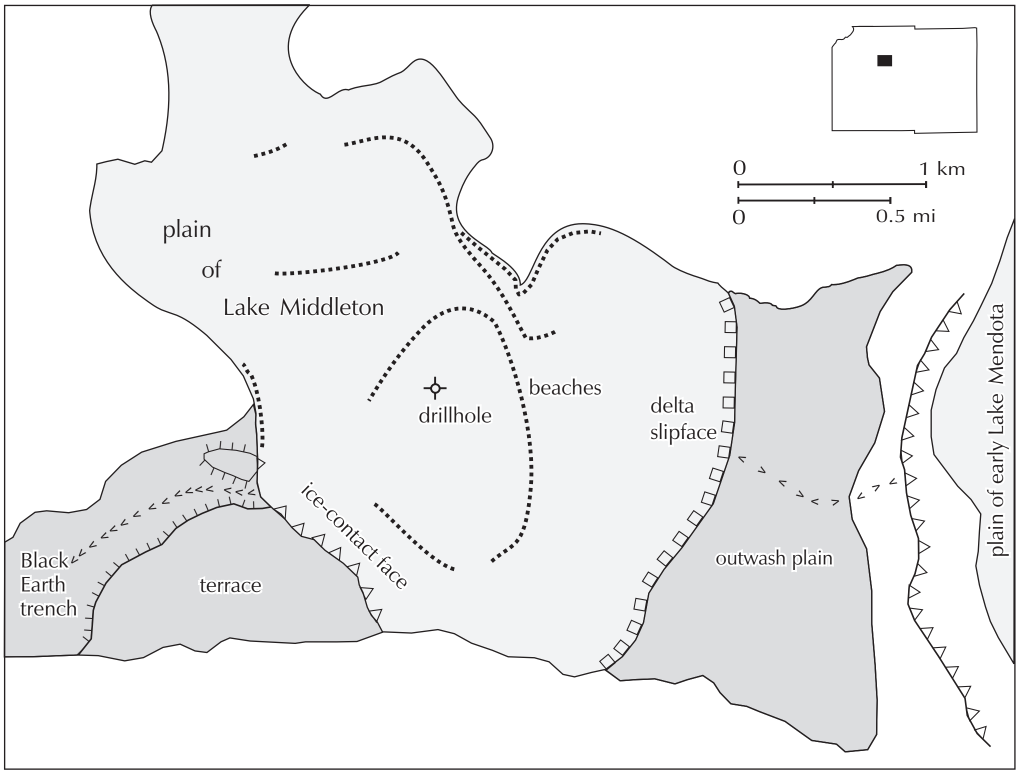


Figure 58. *Lake Middleton plain. The light gray area indicates lake plain. The dark gray areas are meltwater-stream deposits. The western (Black Earth) outlet of Lake Middleton (shown with a string of arrowheads) was used when the glacier margin was at the ice-contact face (line with triangles) between Lake Middleton and Lake Mendota. Later, Lake Mendota drained westward through its Pheasant Branch outlet into Lake Middleton. Still later, Lake Middleton drained eastward through its Pheasant Branch outlet into Lake Mendota when the glacier had wasted back far enough to open Lake Mendota outlets to the south. Dotted lines represent beaches.*

outlet was downcut in stages. The beaches of Lake Middleton (fig. 58) are much better preserved than those of glacial lakes in the region, which also indicates that the lake persisted into postglacial time. In addition, some beaches are below the level of the western outlet, indicating that they formed after meltwater flow through the western outlet ceased.

Thwaites (1908, p. 83) recognized evidence that Lake Middleton persisted long after meltwater flow into the lake had ceased: "...shell bearing clays and the freshness of the beaches the like of which no ice-dammed lake has left." Material from a WGNHS drillhole (Geologic Log DN-1421-F) in the middle of the lake plain showed 7 m of postglacial-lake sediment consisting mostly of organic black mud with plant fragments.

Some time later, after the 7 m of organic mud was deposited in the lake, Pheasant Branch, flowing in the early Mendota spillway but in the reverse direction, entrenched its channel enough to completely drain Lake Middleton. The stages of downcutting indicated by the beaches may be related to those indicated by the terraces in Pheasant Branch trench described by Thwaites (1908, p. 76-78, 83-85). A fan of sand around the mouth of this trench overlies a paleosol containing tamarack wood radiocarbon dated at 11,560 ± 350 BP, showing that much of the trench was cut after that date (Thwaites, 1908, p. 86; Alden, 1918, p. 266; date W-2015 from Black, 1976, p. 97). Lake Middleton did not persist into modern times; the original land survey of 1833 shows a marsh, not a lake.

Lithologic logs in well constructor's reports in WGNHS files indicate more than 100 m of Pleistocene sediment beneath the Lake Middleton plain, but the thickness of Lake Middleton sediment is unknown. Material from a WGNHS

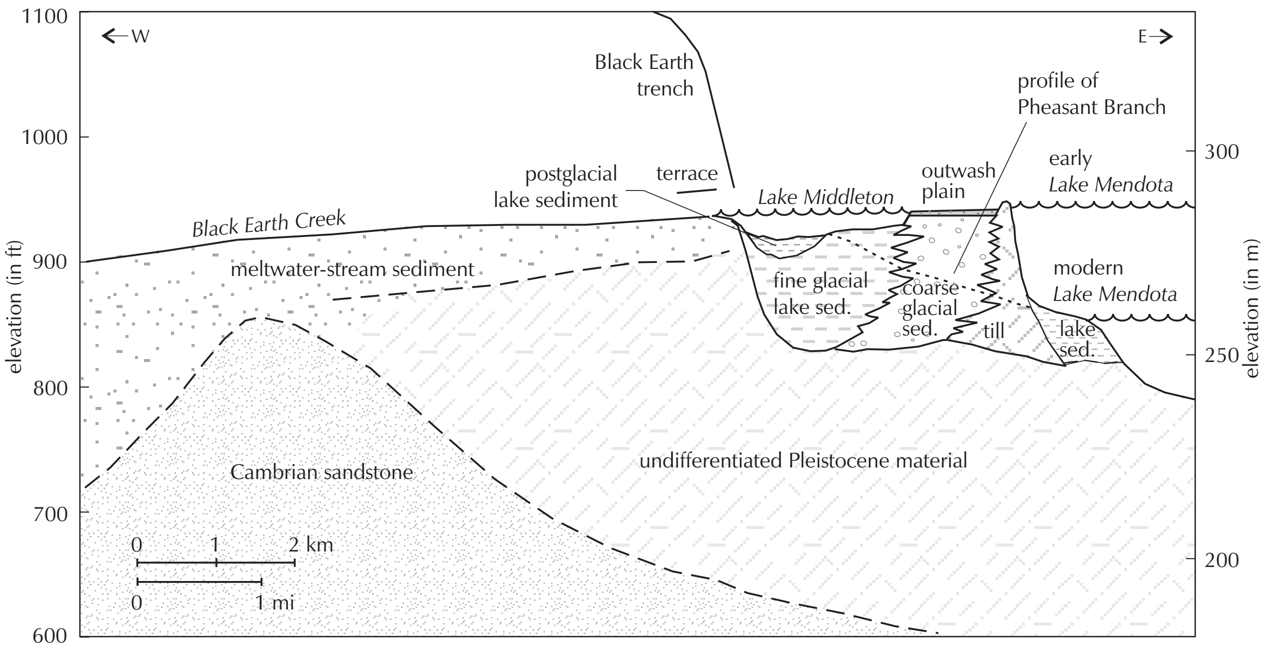


Figure 59. *Schematic cross section up the Black Earth trench through the basin of Lake Middleton to Lake Mendota.*

drillhole showed more than 21 m of gray inorganic mud deposited in the middle of glacial lake Middleton underlying the 7 m of postglacial lake sediment mentioned previously (WGNHS Geologic Log DN-1421-F). Alden (1918, p. 226) reported wood and peat at depths of 16 to 30 m in wells, suggesting that Lake Middleton sediment is no thicker than that, and Thwaites (1908, p. 136) stated that about 18 m of sediment overlies wood and other organic material.

The early Four Lakes. As mentioned previously, Lake Middleton at first spilled westward, but then drainage shifted to the east into Lake Mendota. Through the period when the ice margin retreated from the Middleton outwash plain, a continually shifting series of lakes south of Lake Middleton was dammed between the retreating ice front and the upland on the west side of the Yahara River valley (fig. 60).

When the glacier first melted back off the upland, many small glacial lakes formed between the glacier and the upland (fig. 60A). As the ice margin continued to retreat to the northeast, they coalesced into larger lakes that were the early stages of the Four Lakes in the Yahara River valley (fig. 60B, C).

The sequence of lakes described in the following paragraphs is based on a reconstruction of the ice margins as the Green Bay Lobe wasted northeastward. If the ice margins were as shown in figure 60, and if the topography were as shown on modern topographic maps, the lakes must have been approximately as in figure 60. This reconstruction is corroborated by the presence of spillway channels at appropriate places—at the low points across the drainage divides around the lakes.

Early glacial Lake Mendota spilled westward to Lake Middleton and the Black Earth Creek as long as no outlet was available to the south at a lower elevation than the west outlet of Lake Middleton (fig. 60A, B); the bottom of the west outlet is between the 283- and 287-m (930- and 940-ft) contours. (Present-day Lake Mendota is at an elevation of 259 m [849 ft].) The first available outlet to the south into early glacial Lake Monona–Waubesa was a saddle with a bottom between the 274- and 277-m (900- and 910-ft) contours, located at what is now one city block east of West High School, near the corner of Allen Street and Chadbourne Avenue in west Madison. However, no channel form is visible there now, suggesting that it was a strait between two lakes at one level.

Before glacial Lake Mendota became joined to glacial Lake Monona–Waubesa (fig. 60B),

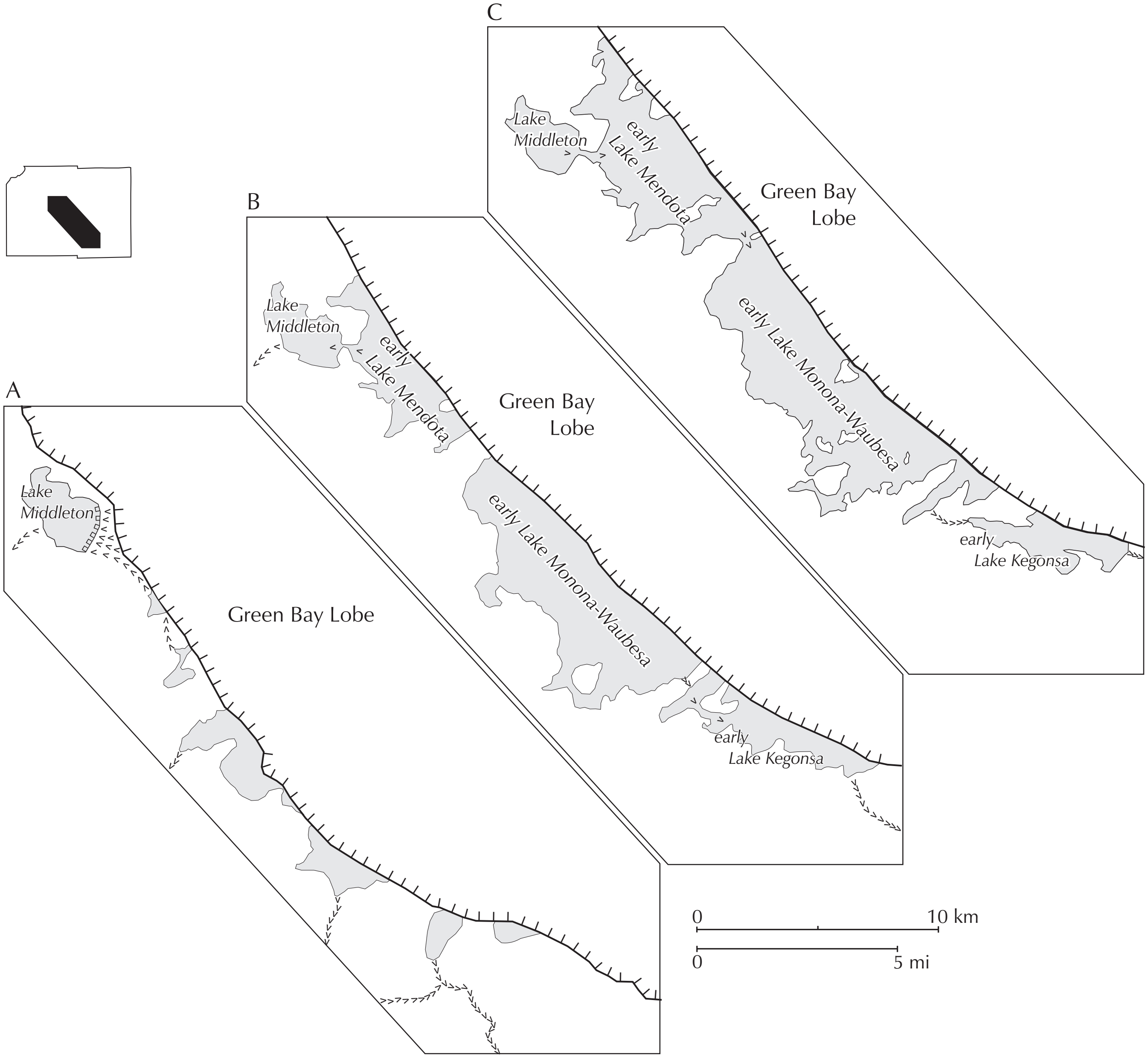


__Figure 60.__ Early versions of the Four Lakes (Mendota, Monona, Waubesa, and Kegonsa) that were created as the margin of the Green Bay Lobe melted back off the southwest side of the Yahara valley. This reconstruction is based in part on correlation of the segments of ice margins shown in figure 49. __A.__ The ice margin had recently melted back off the drainage divide between the Yahara valley to the northeast and the Sugar and Black Earth valleys to the southwest, forming a number of small glacial lakes between the divide and the glacier; the ice margin shown here extends from the ice-contact face on the east edge of the outwash plain on the east side of Lake Middleton to the ice-contact face through the middle of Stoughton. As the ice margin melted back to the northeast, the small glacial lakes coalesced to form early versions of the Four Lakes. __B.__ At first, early Lake Mendota and Lake Middleton drained west down the Black Earth River, and early Lakes Monona–Waubesa and Kegonsa emptied into Lake Yahara–Scuppernong in the Badfish valley, just beyond the southeast edge of the map. __C.__ Later, drainage from Lake Middleton and early Lake Mendota also shifted to the southeast. Symbols as in figures 54 and 55.

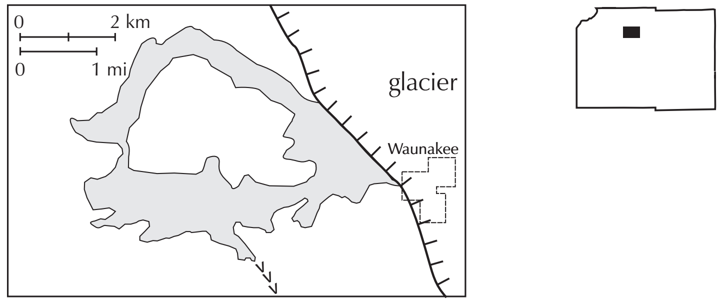


Figure 61. *Glacial Lake Waunakee. Symbols as in figures 54 and 55.*

Lake Monona–Waubesa probably spilled to the southeast into glacial Lake Kegonsa through a clearly defined channel 2 km south of modern Lake Waubesa (N½ NE¼ sec. 20, T6N, R10E). Its present bottom is between the 283- and 287-m (930- and 940-ft) contours, near the level of the west outlet of Lake Middleton. Early Lake Kegonsa may have spilled southeast into Lake Yahara–Scuppernong (discussed below) by way of a saddle between the 274- and 277-m (900- and 910-ft) contours 2 km south of modern Lake Kegonsa (fig. 60B).

Further retreat of the ice margin allowed Lake Monona–Waubesa to expand southeastward and spill through a slightly lower outlet, another well defined channel south of modern Lake Waubesa (NE¼ SE¼ SE¼ sec. 20, T6N, R10E; fig. 60C). The bottom of the channel is between the 280- and 283-m (920- and 930-ft) contours, below the west outlet of Lake Middleton; if the strait between Lake Monona–Waubesa and Lake Mendota (at West High School) was open at this time, as shown in figure 60C, water from Lake Middleton, Lake Mendota, and Lake Monona–Waubesa flowed this way into early Lake Kegonsa. About the same time, a well defined outlet channel with its present bottom between 271 and 274 m (890 and 900 ft) was uncovered just southeast of Lake Kegonsa (SW¼ SW¼ sec. 29, T6N, R11E). It emptied into Lake Yahara–Scuppernong.

Lake Waunakee. As the margin of the glacier melted back to the Waunakee area, a lake formed in the lowland occupied by Waunakee Marsh and adjacent areas. Early high-level outlets to the west and south are obscure, but when the glacier margin reached the east end of what is now Waunakee Marsh, the water level dropped to a distinct outlet channel shown in figure 61, on the northeast side of Kingsley Cemetery, at an elevation of about 287 m (940 ft). (Waunakee Marsh today is at an elevation of about 280 m [920 ft].) Once the glacier margin melted back through Waunakee, lower outlets were opened to the southeast, into an early version of Lake Mendota.

The lakes in the valley of Badfish Creek. A series of glacial lakes occupied the valley of Badfish Creek in southern and southeastern Dane County during the Milton Phase of the Wisconsin Glaciation. The westernmost lake occupied two basins between what are now Oak Hall and Oregon (fig. 62). It initially spilled southwestward through stagnant ice that was covered with meltwater-stream sand and gravel (map unit **sc,** plate 1) near modern Lake Harriett and then through the outermost Johnstown moraine, at an elevation of roughly 296 m (970 ft). Once the glacier had wasted back to near the northeast edge of the basin, an eastern outlet was uncovered on the north side of Oregon, and lake level dropped to near 290 m (950 ft); the bottom of the outlet is between the 287- and 290-m (940- and 950-ft) contours.

This lake spilled into another shallow lake east of Oregon (fig. 62), which was at an elevation of about 283 m (930 ft). It spilled eastward through a sandstone gorge now occupied by the Oregon Branch of Badfish Creek.

The lake east of Oregon spilled in turn into a lake that filled the main part of the Badfish valley and the lower Yahara valley (fig. 62) and extended southeastward as far as Milton in Rock County. Its outlet was where the Rock River breached the outermost Johnstown moraine a few kilometers northwest of Janesville.

These lakes were no more than a few meters deep. They were bordered on their northeast sides by outwash plains that are 1 to 2 km wide (fig. 62; plate 1). Meltwater rivers flowed from

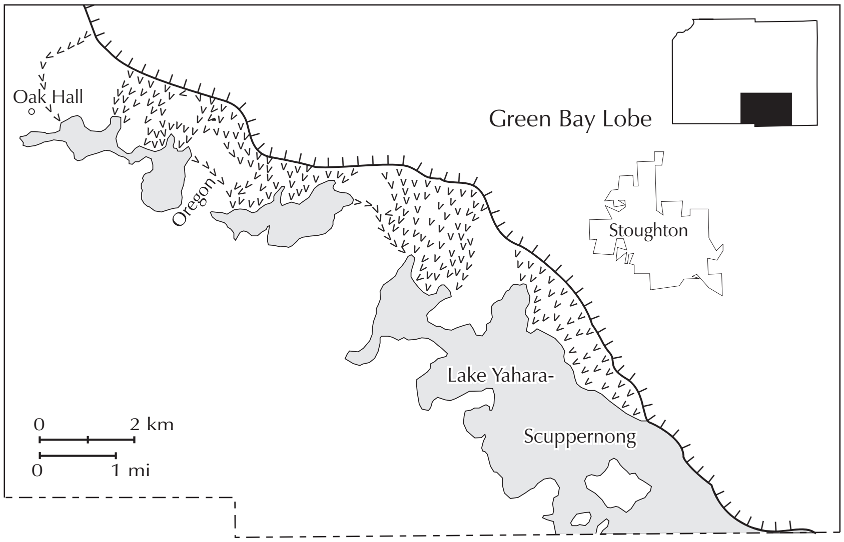


Figure 62. *Glacial lakes in the Badfish valley. Symbols as in figures 54 and 55.*

the glacier, across the outwash plains, and to the lakes during the Milton Phase of glaciation. The lake plain and the outwash plain are separated by a distinct scarp a few meters high, shown on plate 1 as a delta slipface north of present-day Bass Lake. The elevation of the brink of the scarp is about 273 m (895 ft), marking the elevation of the lake that filled the main part of the Badfish valley, about 7 m above the present elevation of Bass Lake.

Lakes Yahara and Scuppernong. The main lake in the valley of Badfish Creek, just discussed, was an early stage of a glacial lake that existed in the Yahara River and Rock River valleys in Dane, Rock, Jefferson, Walworth, and Waukesha Counties. During early and high-level stages, this was a single lake, here called Lake Yahara–Scuppernong. During later and lower-level stages of this lake, it split into two separate lakes, Lake Yahara in the Yahara River valley, named by Mickelson (1983, p. 18), and Lake Scuppernong in the main Rock River valley, named by Clayton (in press).

The earliest stage of Lake Yahara–Scuppernong occurred as meltwater spilled across the low point in the outermost Johnstown moraine, at an elevation of about 274 m (900 ft). This was at the future site of a gorge of the Rock River, 5 km northwest of Janesville in Rock County (fig. 63). At first, the lake was small, with only a small outlet river that had little erosional ability. As the glacier wasted back, the lake and its spillway river increased in size, and the river in erosional ability. However, as the outlet river eroded its bed, lake level dropped, and the outlet trench lengthened, which tended to retard erosion.

As the ice wasted back from the outermost Milton moraine, the Janesville outlet continued to downcut, and the level of Lake Yahara–Scuppernong continued to drop. Two levels are shown ending at ice-contact faces in figure 63. The higher one is marked by a delta (map unit **su,** plate 1) on the south side of the ice-contact face extending east-west through the city of Stoughton. Parts of this delta (map unit **sc**) were deposited on ice and have collapsed, obliterating any delta slipface that may have been present, but we estimate that the water level at that time was 268 m (880 ft) (fig. 64). A second delta, 2 km north of Stoughton, is outlined on plate 1 with symbols for an ice-contact face on its north side and a delta slipface on its south side. We estimate that the lake elevation was 267 m (875 ft) when this delta formed.

Until now, our maps showing glacial lakes have been constructed ignoring the effect of the rebound of the Earth's crust when the weight of the glacier was removed. However, Lakes Yahara and Scuppernong were big enough that we had to consider the topographic changes caused by the rebound when drawing the remaining two lake maps.

For the lowest Scuppernong water plane shown in figure 63, we used a crustal tilt of 0.13 m/km to the south-southwest, which is the same as used in the reconstruction of the eastern part of Lake Scuppernong in Waukesha County (Clayton, in press); the second lowest is shown slightly steeper. This value of tilt was the result of trial and error tempered by a rough extrapolation from the amount of tilt in an area just to the northwest around glacial Lake Wisconsin; there, a slightly earlier, and therefore steeper, shoreline had an estimated tilt of about 0.2 m/km (Clayton and Attig, 1989). For geophysical reasons, tilt of this order of magnitude is likely in this region (Larsen, 1987; Clark and others, 1990), and this amount of tilt is generally in harmony with the known geology in Dane and Waukesha Counties. Therefore, a tilt of 0.13 m/km seems a reasonable estimate, but our reconstruction should be considered only a first approximation of the extent of Lakes Yahara and Scuppernong.

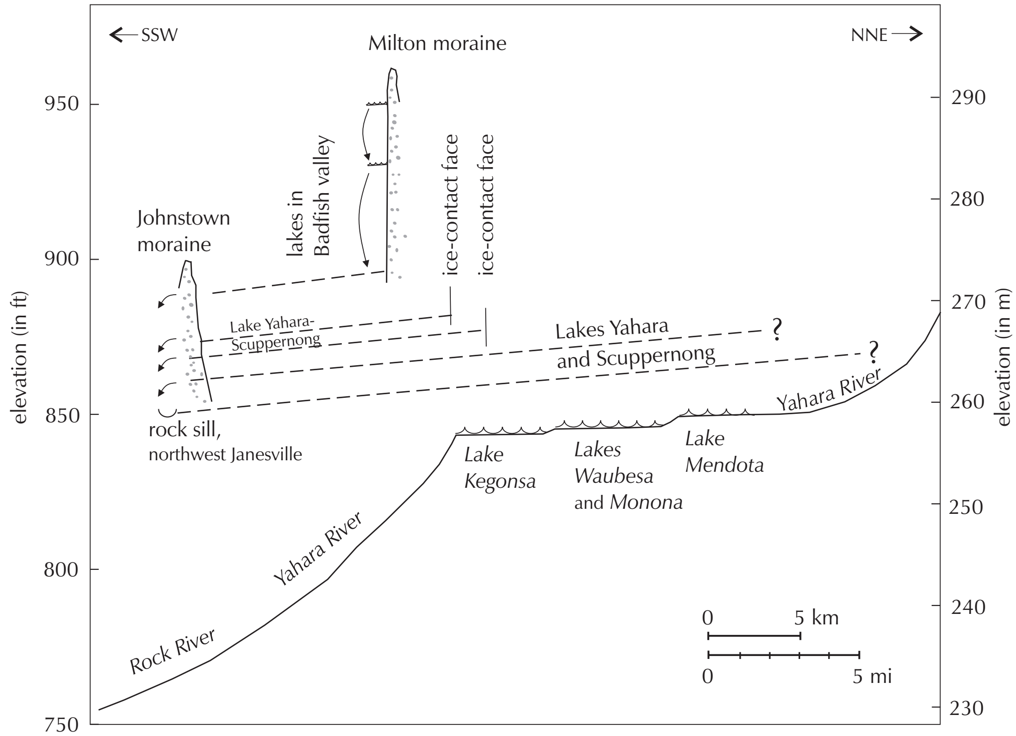


Figure 63. Schematic profile showing the water planes of glacial lakes in eastern Dane County and northern Rock County. Profile was drawn south-southwest in the direction of probable crustal rebound, with an estimated tilt of 0.13 m/km for the lowest glacial-lake water plane. A wave pattern indicates modern lake (solid line) and glacial-lake (dashed lines) water planes. Arrows indicate direction of lake outflow (those spilling south through the outermost Johnstown moraine are various stages of Lakes Yahara and Scuppernong).

The second lowest water plane shown in figures 63 and 65 is based on vague shore terraces at several places around the Madison lakes, such as a shore terrace at about 266 m (872 ft) on Turville Point in Turville Park on the south side of Lake Monona. The lowest water plane shown in figures 63 and 66 is based on similar evidence noted by Mickelson (1983, p. 20-21) and on well preserved beaches in southwestern Waukesha County (Clayton, in press). We speculate that the level of this lowest water plane was maintained by a dolomite sill at an elevation of about 260 m (850 ft) in Riverside Park in the Rock River gorge on the northwest side of Janesville (fig. 63).

As the outlet northwest of Janesville eroded and the water level dropped, the separation of Lake Yahara from Lake Scuppernong became more distinct. At the time of the lowest water plane shown in figure 63, the two lakes were connected by two narrow straits, one now occupied by the Yahara River in and south of

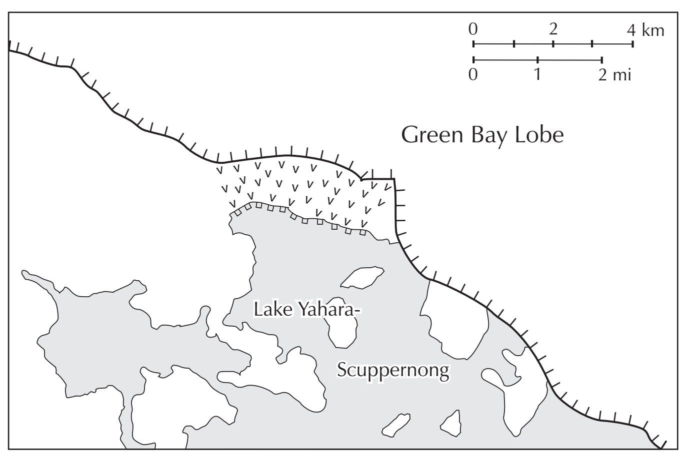
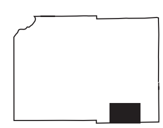


Figure 64. Lake Yahara–Scuppernong when the glacier stood at the ice-contact face in Stoughton. Symbols as in figures 54 and 55.



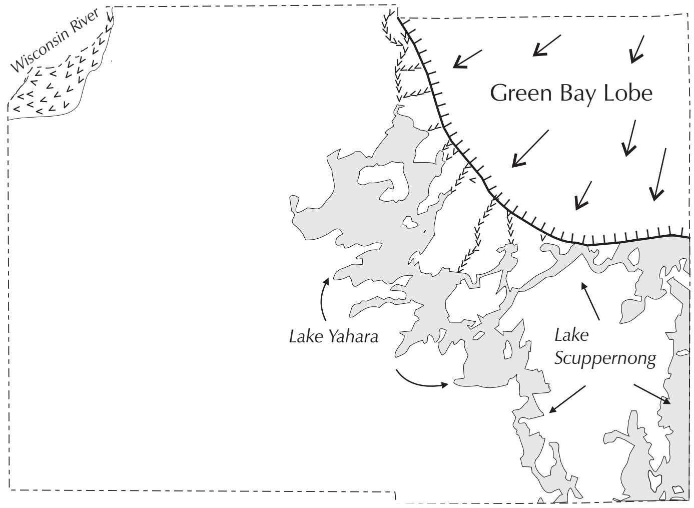


Figure 65. *Dane County during part of the Lake Mills Phase, when the ice margin stood at the moraine near Oak Park. Lake Yahara and Lake Scuppernong are connected by two narrow straits. Symbols as in figures 54 and 55.*

Stoughton (fig. 66) and the other, by a marsh 3 km southeast of Cottage Grove.

The northern extent of neither of these two water planes is known, but the glacier may have been in the northern part of the basin, in northeastern Dane County, as suggested by the question marks in figure 63. Alternatively, it may have wasted back entirely out of the county, as suggested in figure 66, or even out of the basin.

Lakes Yahara and Scuppernong persisted as long as the Janesville sill restricted outflow to the south. They were glacial lakes that received glacial meltwater as long as the Green Bay Lobe still terminated within the Rock River drainage basin. Once the glacier margin had wasted back north across the drainage divide and into the Lake Winnebago basin, Lakes Yahara and Scuppernong, if they still existed, no longer received meltwater—they had become postglacial lakes. The change from glacial-lake to postglacial-lake conditions is marked by the change from inorganic to organic sediment deposited in many of the sedimentation basins in Dane and Jefferson Counties.

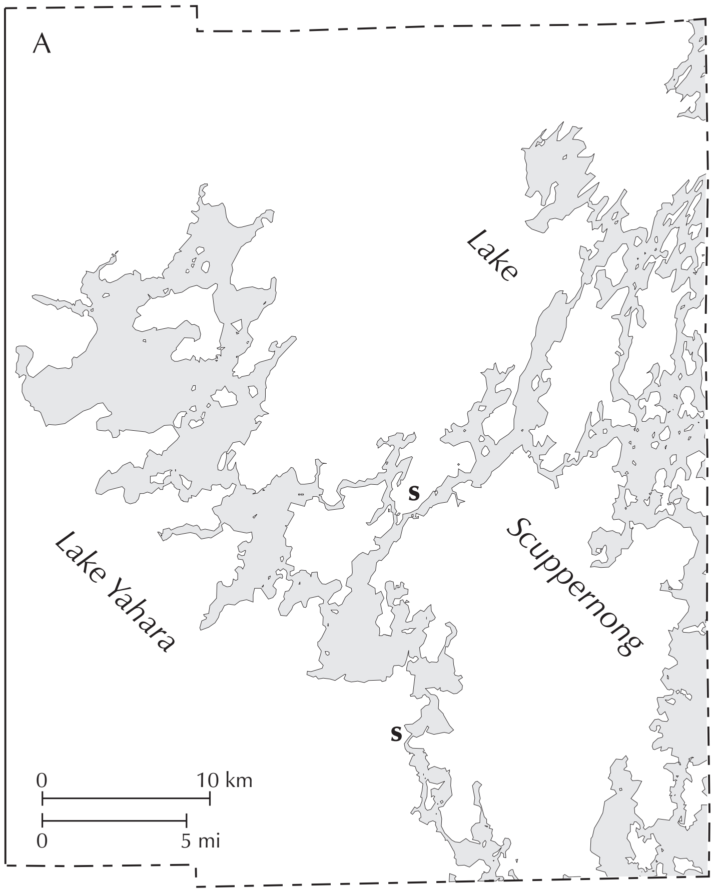
Ice-wedge polygons have been observed in the Scuppernong basin (P.M. Colgan, University of Wisconsin–Madison, Department of Geology and Geophysics, verbal communication, 1995), indicating that at least parts of it were dry land as early as about 13,500 BP, when the last permafrost melted from the region (Attig and Clayton, 1992). This indicates that the Janesville sill was eroding so rapidly that Lake Scuppernong (as well as Lake Yahara) ceased to exist as a separate continuous lake while the Green Bay Lobe still terminated in the Rock River drainage basin.

Lake Mills Phase of the Wisconsin Glaciation

The Lake Mills Phase was merely a continuation of events begun during the last part of the Milton Phase. We are treating them as separate phases here because the names are well established (Alden, 1918, p. 277) and because the cluster of Milton subphases seems to have been separated from the cluster of Lake Mills subphases by a period when the ice margin continuously wasted back without major interruption.

The Green Bay Lobe produced a series of small moraines as it wasted back northeast out of the county. They are variably spaced, but 50 m apart might be considered a representative spacing. If one small moraine formed each year, as suggested previously, and if the ice margin were wasting back at a steady rate, about 1,000 years would have been required for the ice margin to retreat from the edge of the hummocky-till zone to the northeastern corner of the county. Extra time might also have been required for the glacier margin to advance to the position of the Lake Mills medium-sized moraines, and some time would have been needed for the margin to stabilize long enough to form the medium-sized moraines. If the chronology shown in figure 47 is correct, there was not quite enough time for all this to happen, but its details are uncertain enough that the yearly formation of the small moraines cannot be ruled out.

The medium-sized moraines represent periods of stability in the glacier margin, if not periods of advance. The first of the known medium-sized Lake Mills moraines formed near Nora in



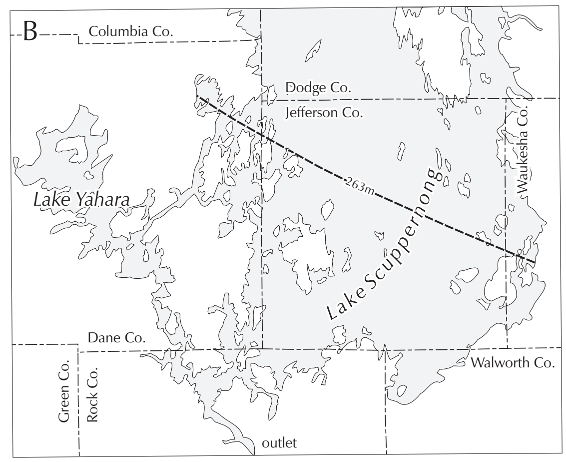


Figure 66. *Extent of Lake Yahara and Lake Scuppernong at the lowest water plane shown on figure 63, assuming a crustal tilt of 0.13 m/km to the south–southwest and assuming that the glacier had wasted out of the region. The straits between the two lakes, south of Stoughton and southeast of Cottage Grove, are indicated by the letter S. The small map (**B**) was manually traced from the contours (10-ft interval) of U.S. Geological Survey (7.5-minute series, topographic) maps (Clayton, in press). The large map (**A**) was derived from a digital terrain model provided to Dane County Land Records by Ayers and Associates, a product of their Digital Orthophoto Project. Symbols as in figures 54 and 55.*

east-central Dane County (fig. 49; plate 1). The next, which is paired with another in places, is at Oak Park and Token Creek. Sun Prairie is between segments of the next one. Pierceville is just southwest of the next one.

These moraines have been traced northward through Columbia and Marquette Counties by P.M. Colgan (University of Wisconsin–Madison, Department of Geology and Geophysics, verbal communication, 1995), who has shown that the medium-sized Lake Mills moraines correlate with moraines east of the Elderon moraines north of the Baraboo Hills. The great floods down the Wisconsin River from the catastrophic draining of glacial Lake Wisconsin occurred during the last part of the Elderon Phase (Clayton and Attig, 1989), therefore before the Lake Mills Phase and during the last part of the Milton Phase.

As the glacier melted back, glacial Lakes Yahara and Scuppernong expanded northeastward to fill the valleys of the Yahara and Rock Rivers. The exact relationship between the position of the glacier margin and the height of the lakes is uncertain. However, most of the patches of flat, uncollapsed meltwater-stream sediment (map unit **su,** plate 1) deposited during the Milton and Lake Mills Phases have ice-contact faces on their northeast side. Most have a steep slope that is probably a delta slipface on their southwest sides, although only the most conspicuous are shown that way on plate 1. This suggests that a specific glacier margin correlates with a specific lake height. For example, figure 65 shows the glacier standing at the moraine at Oak Park and the lake standing at the lowest level shown in figure 63.

Postglacial time

A radiocarbon date of 13,120±130 BP (Wis-431) was obtained for a spruce log in postglacial lake sediment 3 km northwest of Deerfield (West and Dallman, 1980, p. 27). This indicates that the glacier must have melted out of east-central Dane County by at least that time, perhaps considerably earlier. It may have been out of the Rock River basin by roughly 14,000 BP, as suggested by Mickelson and others (1983) and Clayton and others (1992). If Lakes Yahara and Scuppernong still existed, they were no longer glacial lakes. If the outlet near Janesville had been eroded deeply enough, Lakes Yahara and Scuppernong no longer existed. They were gradually replaced by separate smaller lakes in the remaining deeper basins as the outlet was downcut.

When the Rock River had reached its present stage at Janesville, the configuration of the lakes and rivers of Dane County was much like that of today, except that many lakes were larger, and many of the smaller lakes existed in areas that today are peat land (map unit **op,** plate 1) and also in some areas that today are dry lake plains (map unit **og**). The lakes of Dane County shrunk because their outlets were downcut, because sediment was deposited where rivers entered the lakes, and because peat accumulated along shores not subject to wave erosion.

A variety of evidence indicates that Dane County had a cold climate during the Wisconsin Glaciation. Fossils, including pollen in sediment deposited in lakes and ponds, indicate a treeless tundra with low shrubs and grasses. Trees may have been present in protected places, especially during the warmer episodes, but widespread spruce forest did not appear until about 13,500 BP. No samples of wood have yielded radiocarbon dates between about 26,000 and 13,500 BP, but after that time trees were abundant in Wisconsin, according to radiocarbon dates (Attig and Clayton, 1992, 1990).

The central North American tundra, although much colder, must have resembled an African grassland, with dozens of species of now-extinct large mammals, the largest of which was the mammoth. Many species, most notably the mastodon, apparently survived until the climate warmed enough for the tundra vegetation to be replaced by spruce forest. Bones of mastodon, mammoth, and giant beaver have been found in offshore sediment at several locations in the Lake Scuppernong basin (Dallman, 1968; West and Dallman, 1980).

Humans were able to move south out of northwestern North America apparently when the west edge of the Laurentide Ice Sheet melted back from the east edge of the Cordilleran Ice Sheet in Alberta. They arrived in central North America about 11,500 BP, shortly before most species of large mammals became extinct.

Around 10,500 BP (Winkler, 1985), the climate warmed and became more stable and more like the modern climate, even though the ice sheet was still large enough to reach the south side of the Lake Superior basin. At that time the spruce forest was replaced by a mixed hardwood and coniferous forest, which was in turn replaced by a hardwood forest in southern Wisconsin. During the middle Holocene, the climate was somewhat drier than today, with prairie vegetation, much of which was replaced by oak woodlands with patches of prairie during the last part of the Holocene (fig. 47). Only minor climatic changes have occurred in the past few thousand years, during the last part of the Holocene.

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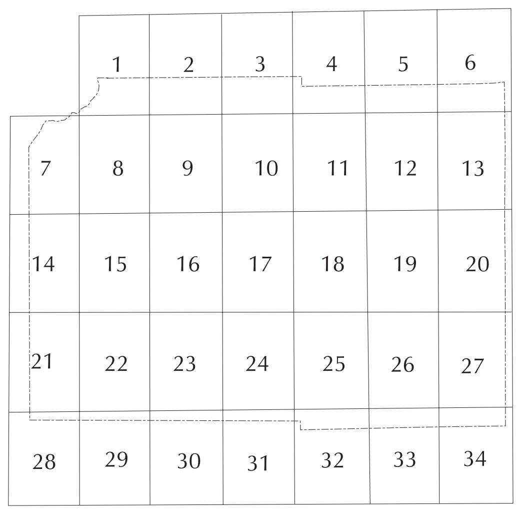
Dane County
location diagram

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



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2 Lodi-1975
3 Arlington-1984
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5 North Bristol-1980
6 Columbus-1980
7 Mazomanie-1962
8 Black Earth-1962 (82 PR)
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