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Geology of Sauk County, Wisconsin

Lee Clayton and John W. Attig

Wisconsin Geological and Natural History Survey

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With a section about the Precambrian geology by B.A. Brown and an appendix naming the Rountree Formation by James C. Knox, David S. Leigh, and Tod A. Frolking

A description and discussion of Precambrian and Paleozoic material in the eastern part of the Driftless Area and Pleistocene material deposited along the west side of the Green Bay Lobe of the Laurentide Ice Sheet.

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ABSTRACT

Sauk County consists of three geologically and topographically distinct areas: the Baraboo Hills, in the east-central part of the county; the southern, western, and northern parts of the county, which are a typical part of the Driftless Area; and the glaciated eastern part of the county.

Precambrian rock of the Baraboo Hills includes metamorphosed rhyolite, granite, and diorite around the outer flanks of the Baraboo Hills, overlain by a thick sequence of quartzite of the Baraboo Formation, which is overlain by phyllite of the Seeley Formation, dolomite and iron ore of the Freedom Formation, the "Dake quartzite," and the "Rowley Creek slate." These units, which are more than 1.5 km thick, have been folded into the complex, doubly plunging Baraboo Syncline.

The Paleozoic sequence of the Driftless Area consists of about 275 m of nearly flat-lying sedimentary units, including (from bottom to top) quartzose sand and sandstone of the Mount Simon Formation; sandstone, shale, siltstone, and dolomite of the Eau Claire Formation; quartzose sand and sandstone of the Wonewoc Formation; glauconitic and quartzose sand and sandstone of the Tunnel City Formation; siltstone and dolomite of the St. Lawrence Formation; and quartzose sand and sandstone of the Jordan Formation, all of which were deposited during the Cambrian Period. These are overlain by dolomite of the Oneota Formation, which is unconformably overlain by the quartzose sand and sandstone of the St. Peter Formation, both of which were deposited during the Ordovician Period. In addition, the quartzose sandstone and conglomeratic sandstone of the Parfreys Glen Formation (named in this report) occur where any of these Cambrian and Ordovician units lap onto the Baraboo quartzite. Small outcrops of sand and gravel of the Windrow Formation (Mesozoic or Cenozoic) have been reported at one spot on the Baraboo Hills. Yellowish-red sandy clay and clayey sand of the Cenozoic Rountree Formation (named in this report) generally occur on top of the Oneota and St. Peter Formations.

Most of the remainder of Cenozoic material was deposited during the Wisconsin Glaciation and is included in the Big Flats and Horicon Formations. Till occurs in the moraine in eastern Sauk County formed during the Johnstown Phase of glaciation at the west edge of the Green Bay Lobe, as well as in younger and smaller moraines to the east of the Johnstown moraine. Offshore sand, silt, and clay deposited in glacial Lake Wisconsin and several other glacial lakes occur in valley bottoms throughout northern Sauk County. Meltwater-stream sediment occurs in broad fans west of the Johnstown moraine as well as along the Wisconsin River trench. The sandstone gorges of the Wisconsin Dells were probably cut during floods resulting from the drainage of the glacial Lake Wisconsin.

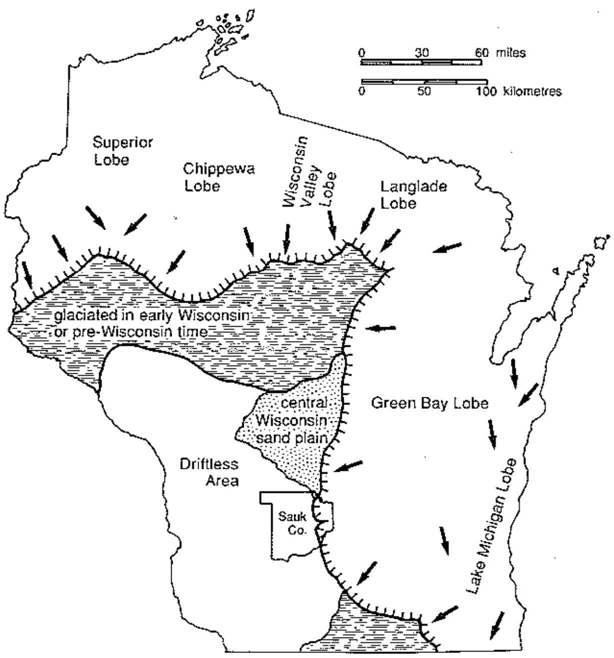

Figure 1. *Location of Sauk County in Wisconsin. Also shown are areas covered by ice during the last part of the Wisconsin Glaciation (north and east of line with hatch marks) and earlier (horizontal dashes). Arrows indicate ice-movement directions.*

INTRODUCTION

This report is a description of the geology of Sauk County in south-central Wisconsin (fig. 1). We have emphasized the material from a depth of about 1.5 m to a few hundred metres. The surface soil to a depth of 1.5 m has been described in detail by Gundlach (1980).

General setting

Northern, western, and southern Sauk County is part of the Driftless Area (figs. 1 and 2). There, the narrow uplands are underlain by several metres of Cenozoic clay, which is generally underlain by several metres of Ordovician dolomite. The valleys are about 100 m deep in much of this area. Their steep sides consist of nearly flat-lying Cambrian sand and sandstone. Valley bottoms are underlain by several metres to tens of metres of Pleistocene sediment overlying Cambrian sand and sandstone. Precambrian igneous and metamorphic rock is typically about 100 m below valley bottoms in this part of the county.

In central Sauk County, the South Range of the Baraboo Hills (fig. 2) rises as much as 250 m above the surrounding land. (The Baraboo Hills have also been called the Baraboo Bluffs and Baraboo Range.) The Baraboo Hills consist of roughly 1.5 km of Precambrian quartzite in the form of a complex doubly plunging syncline -- the Baraboo Syncline. The South Range consists of steeply dipping quartzite of the south limb of the syncline; the smaller, narrower, more discontinuous North Range consists of nearly vertical quartzite of the north limb. Precambrian igneous rock crops out in a few places around the outer flanks of the syncline. The top of the South Range is a flat erosional surface, probably formed during the Paleozoic Era. Paleozoic rock similar to that surrounding the Baraboo Hills occurs within the basin in the middle of the syncline.

Eastern Sauk County was probably glaciated several times, but nearly all the glacial material exposed at the surface was deposited during the last part of the Wisconsin Glaciation, when the Green Bay Lobe of the Laurentide Ice Sheet advanced as far west as Devils Lake. The western extent of this advance is marked by the Johnstown moraine (fig. 2). East of the moraine, glacial, stream, and lake sediment, which consists primarily of sand, is thicker than 100 m in some lowland areas; on the eastern part of the Baraboo Hills, the glacial sediment is generally only a few metres to tens of metres thick. Except where the moraine crosses the Baraboo Hills, it is flanked to the west by an apron of outwash sand. North of the South Range, glacial Lake Wisconsin occupied the area east of the Johnstown moraine, and glacial Lake Wisconsin and glacial Lake Baraboo occupied the valleys west of the moraine (Clayton and Attig, 1989). South of the South Range, glacial Lake Merrimac occurred east of the moraine, and Lake Black Hawk and Stones Pocket Lake were dammed by the aggrading outwash plain west of the moraine. The outwash extends down the Wisconsin River in the form of broad terraces.

Sources of information

This report is based on fieldwork completed during the summer of 1988. Map contacts on plate 1 were drawn using aerial photograph stereopairs (scale 1:20,000) taken in 1968 for the

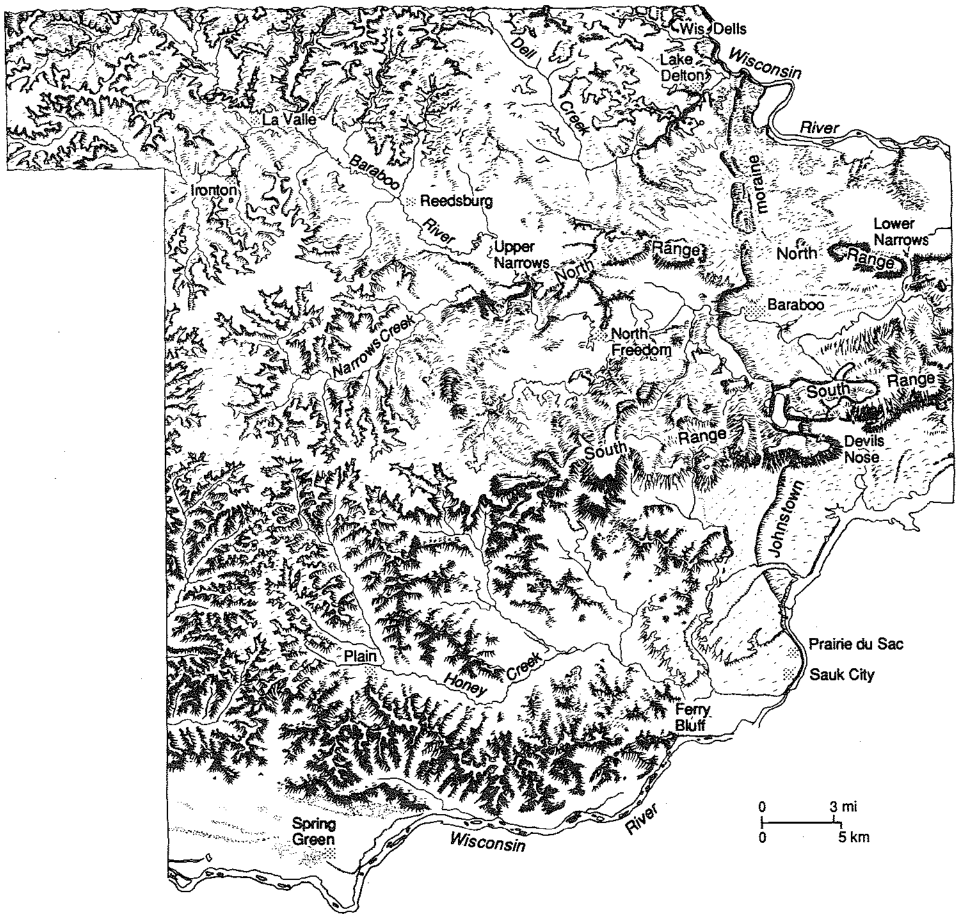

Figure 2. *Landscape of Sauk County (the North Range and South Range make up the Baraboo Hills).*

U.S. Department of Agriculture and U.S. Geological Survey quadrangle maps (7.5-minute series, topographic, scale 1:24,000) with 10-ft or 20-ft contour intervals. Additional lithologic information was derived from the following sources: soil maps (scale 1:20,000) (Gundlach, 1980), Department of Natural Resources Well Constructor's Reports, Wisconsin Geological and Natural History Survey (WGNHS) Geologic Logs, WGNHS Road Materials Investigation Reports, various geologic field notes in WGNHS files, and mineral-exploration drillhole logs in WGNHS files.

Sauk County has been studied by a large number of geologists during the past several decades (see the review by Dalziel and Dott, 1970); several of their reports contained maps. These maps (areas shown in fig. 3), most of which are at a scale of about 1:63,000, cover two-thirds of the county. The maps have greatly influenced our understanding of the geology, but in most places we have remapped the contacts.

Map reliability

The reliability of the geologic contacts shown on plate 1 is partly dependent on our sources of information. The aerial photographs that we used were taken when leaves were on the trees, which masked the contacts in some areas. The topographic maps that we used are somewhat variable in quality, which is also partly dependent on tree cover. The soil maps used are probably most reliable in cultivated areas. Reliability of our contacts is also partly dependent on the quality and quantity of previous geologic maps in different parts of the county.

Map reliability is also related to the amount of fieldwork we did in different areas, which was primarily determined by road access. In addition,

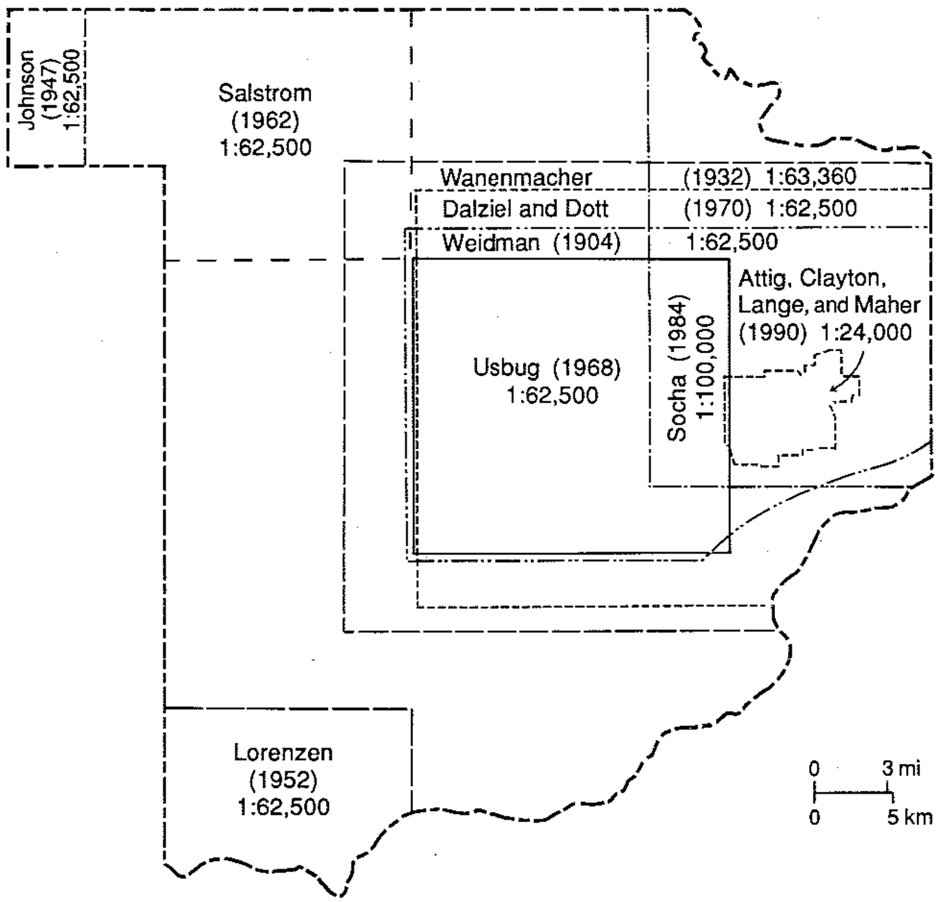

Figure 3. *Previous geologic mapping in Sauk County.*

the abundance of outcrops in different parts of the county is variable. Contacts are generally shown much more precisely where the slopes are steep than where they are gentle. Some contacts were easier to pick than others because of the abundance of outcrops or the presence of a topographic bench; for example, the tops of the Jordan and Wonewoc Formations are drawn more precisely than the tops of the St. Lawrence and Tunnel City Formations.

The width of some units has been exaggerated on plate 1 where they are too narrow to show at true scale.

Cross sections

The cross sections shown on plate 2 have been drawn through the middle of the north and south halves of each township. However, they are not intended to show the material exactly at that position; they are generalized representations of material as far as 1.5 miles north and south of the line of the cross section. Only the drillholes from which we obtained useful geologic information are shown on the cross sections.

Land locations

In this report, general locations are based on the public-land survey (section, township, range), but more precise locations are given using Universal Transverse Mercator (UTM) coordinates. UTM grid lines appear on plate 1 of this report, on all U.S. Geological Survey topographic maps published at a scale of 1:100,000, and on all U.S. Geological Survey topographic maps published at a scale of 1:24,000 after 1974. In addition, UTM grid tick marks occur on all U.S. Geological Survey topographic maps published at a scale of 1:24,000 between 1957 and 1974. All UTM coordinates given here are based on North American Datum 1927 (NAD 27).

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We thank the following people who reviewed the manuscript of this report, discussed various aspects of the geology with us, provided useful information, or helped with the identification of stratigraphic units: B.A. Brown, R.H. Dott, Jr., T.J. Evans, J.C. Knox, K.I. Lange, I.D. Lippelt, K.M. Massie-Ferch, M.G. Mudrey, Jr., M.E. Ostrom, R.M. Peters, and Robert Pody.

PRECAMBRIAN HISTORY

B.A. Brown

The Baraboo Hills, in central and eastern Sauk County, contain the southernmost extensive exposures of Precambrian rock in Wisconsin. The Baraboo Hills have been studied by geologists for more than a century; a summary of early work is given by Dalziel and Dott (1970).

The Proterozoic quartzite, granite, diorite, and rhyolite of the Baraboo Hills are the only Precambrian rock exposed at the surface in Sauk County, and only a few wells in the county are known to reach Precambrian rock away from the Baraboo Hills (plate 2). Two wells in Sauk City (WGNHS Geologic Logs SK-8 and SK-10) penetrated "granite" at a depth of 160 m, and a well near Wisconsin Dells is reported by Thwaites (1931) to have encountered "granitic gneiss" underlying "quartzite" and "basalt" at 137 m, but no samples are available. Samples from the Sauk City wells are weathered and have not been radiometrically dated but are probably part of the northeast-trending belt of 1,760-million-year-old granite and rhyolite that underlie the Baraboo quartzite and much of south-central Wisconsin (Smith, 1978). Granite is also reported in a well (WGNHS Geologic Log SK-198) 4 km north of Prairie du Sac and in a well at Spring Green (WGNHS Geologic Log SK-18); igneous or metamorphic rock is reported in a well in Dutch Hollow, 5 km northwest of the village of La Valle (NW1/4 sec. 18, T13N, R3E; unpublished log in WGNHS files).

Irving (1877) and Van Hise (1893) made observations about the geologic structure of the Baraboo area and produced a cross section showing the Baraboo Hills as the north-dipping limb of a major anticline. Weidman (1904) published the first detailed map of the Baraboo area and drew cross sections showing the quartzite of the North and South Ranges as limbs of the doubly plunging Baraboo Syncline.

Weidman (1904) also provided a good description of the Baraboo quartzite and the underlying rhyolite, and his report still stands as the best detailed description of the overlying slate and iron-bearing rock. Most of the Precambrian units overlying the Baraboo quartzite in the central area of the syncline do not crop out and are known only from early mining and drilling records.

Weidman (1904) subdivided the Precambrian metasedimentary rock into four lithostratigraphic units: conglomerate at the base of the Baraboo Formation; the Baraboo Formation, consisting of quartzite; the Seeley Formation, consisting predominantly of phyllite; and the Freedom Formation, consisting of iron-bearing marble, iron-bearing argillite, and chert (figs. 4 and 5). The existence of younger Precambrian units was suggested by Van Hise and Leith (1911). On the basis of logs from exploration drilling for iron ore in the eastern part of the Baraboo Syncline, Leith (1935) proposed two additional formations overlying the Freedom -- the "Dake quartzite" and the "Rowley Creek slate" -- but none of the samples or drill logs have been preserved.

The Baraboo quartzite and to a lesser extent the underlying rhyolite and overlying Cambrian Parfreys Glen Formation are extremely resistant to erosion and are topographically expressed as the Baraboo Hills. All materials younger than the Baraboo quartzite are much less resistant and form the lowlands on both sides of the North and South Ranges of the Baraboo Hills.

Rhyolite

The oldest rock exposed at the surface in Sauk County is the slightly metamorphosed rhyolite at the Lower Narrows, Devils Nose, and Denzer (map unit **Pr**, plate 1), which underlies the quartzite of the Baraboo Formation. The largest rhyolite exposures occur on either side of the Lower Narrows of the Baraboo River (sec. 20 to 23, T12N, R7E). Smaller exposures also occur at the base of Devils Nose (NE1/4 NE1/4 sec. 32, T11N, R7E) and northeast of the community of Denzer (SW1/4 NE1/4 SE1/4 sec. 11, T10N, R5E). In the South Range, the rhyolite is best exposed near Caledonia Church in Columbia County (sec. 3, T11N, R8E).

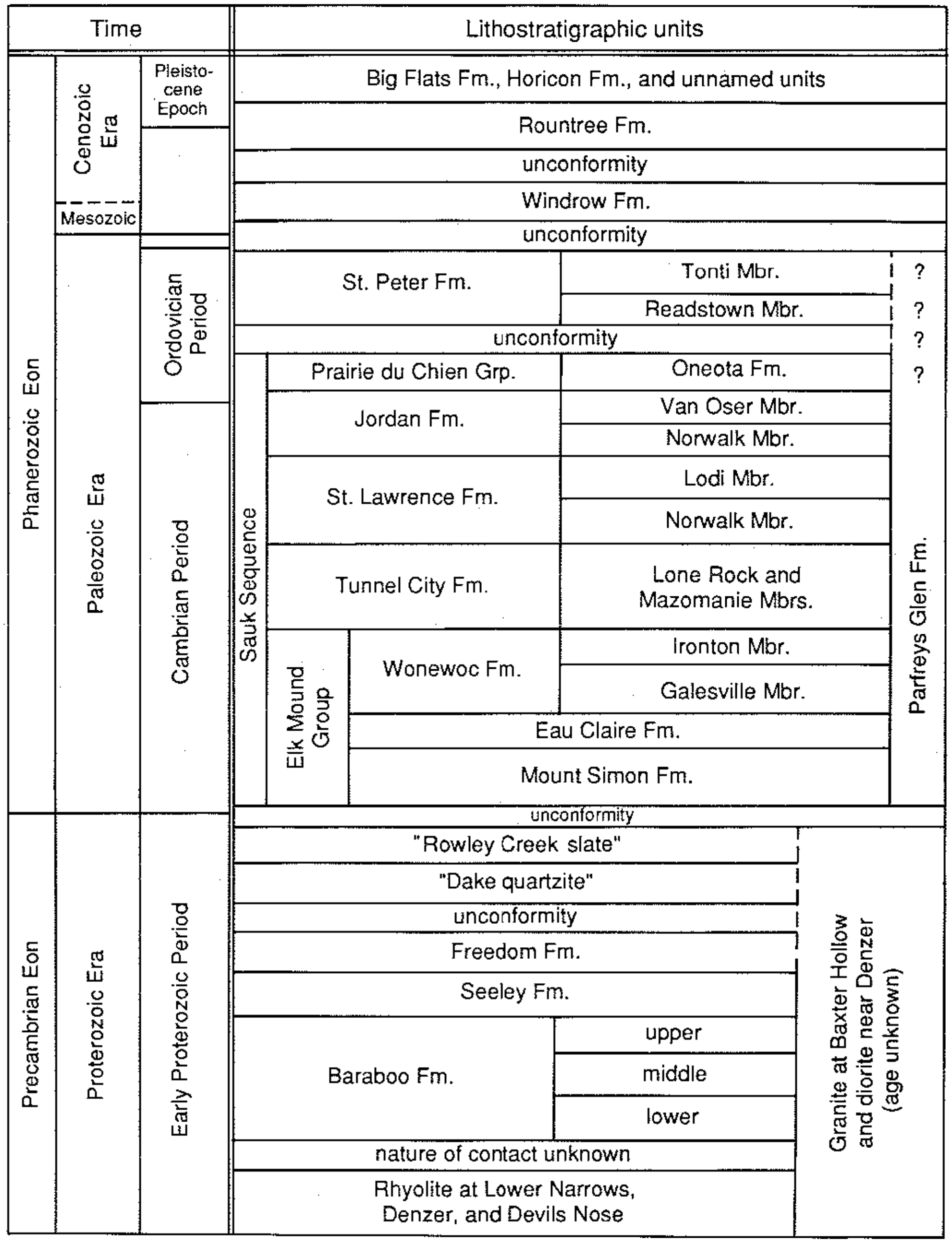


Figure 4. *Lithostratigraphic units in Sauk County, showing relative position and age.*

The rhyolite was mapped by Weidman (1904); rhyolite petrography and field relationships were described in detail by Stark (1930, 1932). Smith (1983) discussed the chemistry and tectonic setting of the rhyolite. The fine-grained varieties consist of a groundmass of feldspar, quartz, sericite, and opaque minerals with scattered phenocrysts of quartz and feldspar. Coarse-grained varieties include clast-supported and matrix-supported rock with clasts up to 0.1 m in diameter. The rhyolite ranges from red to dark gray to black.

The rhyolite is probably at least several hundred metres thick at the Lower Narrows. The lower contact of the rhyolite has not been seen.

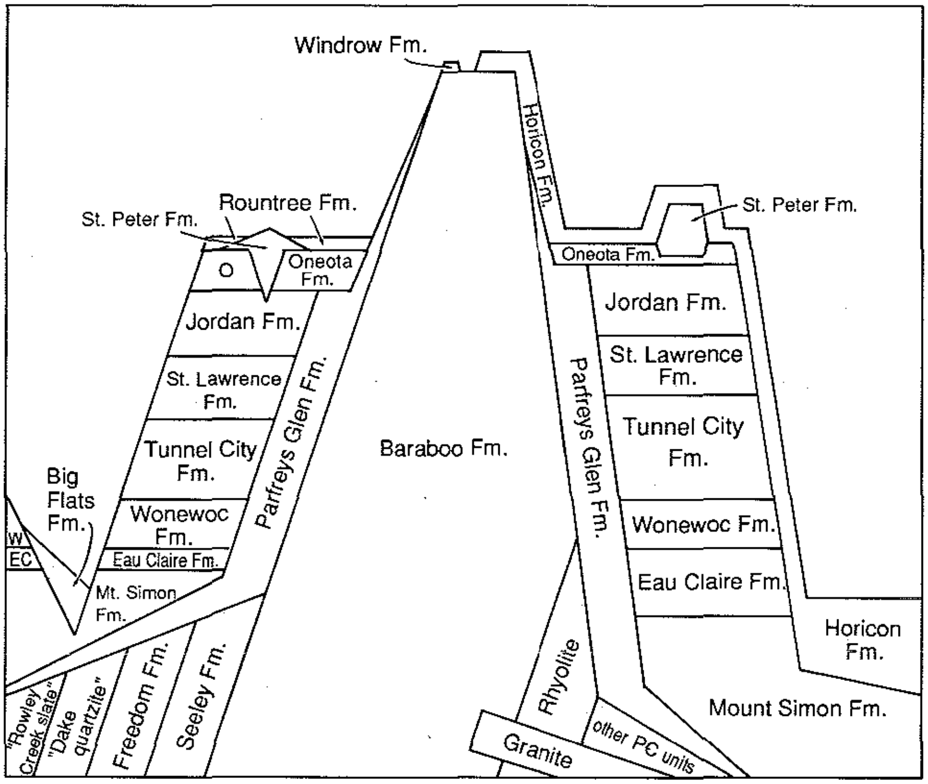


Figure 5. *Lithostratigraphic units in Sauk County, showing geometric relationships between the units (not true scale).*

The rhyolite is variable in character. It includes unbedded but flow-foliated rock that probably originated as lava flows and fine-grained and coarse-grained tuffaceous rock. Some fine-grained tuff has well developed welded texture visible in thin section, indicating deposition as ash flows (nuee ardente). Nonwelded varieties are commonly bedded, indicating reworking and subaqueous deposition. Coarse, matrix-poor varieties associated with flows probably originated by autobrecciation of the flows. Matrix-supported varieties containing scattered clasts up to 0.1 m may be lahars or mud-flow deposits.

Smith (1983) analyzed the Baraboo rhyolite and reported a close chemical affinity with petrographically similar rock in the Fox River valley and in the subsurface of southern Wisconsin. Van Schmus (1978) reported a U-Pb zircon age of 1,760 million years for the Fox Valley rhyolite; Rb-Sr dating of this rhyolite yielded an age of 1,640 ± 40 million years (Dott and Dalziel, 1972), an age now associated with a regional thermal event that disturbed Rb-Sr systems throughout much of northern Wisconsin, Michigan, and southern Ontario (Sims and Peterman, 1980).

Diorite and granite

Intrusive igneous rock is exposed at three places on the south limb of the Baraboo Syncline. Diorite occurs in two places near Denzer, and granite crops out in Baxter Hollow.

The diorite near Denzer (Weidman, 1904; Stark, 1932) is exposed in a knob in the middle of SE1/4 sec. 9, T10N, R5E, and boulders of diorite occur on the valley bottom in the NE1/4 NW1/4 and NW1/4 NE1/4 sec. 10, T10N, R5E (map unit Pd, plate 1). This material is medium-grained, gray to red quartz diorite or granodiorite that originally consisted of quartz, plagioclase, hornblende, biotite, perthitic alkali feldspar, and accessory apatite and iron oxides. The plagioclase has been altered to saussurite, and the biotite has been altered to chlorite. Smith (1983) concluded that the Denzer diorite was chemically similar to and possibly was derived from tholeiitic-basalt magma like that forming the dikes that cut the rhyolite exposed at Marcellon, 50 km to the northeast in Columbia County. The relationships at Marcellon indicate that the diorite at Denzer is younger than the rhyolite, but no known evidence indicates that it intruded the quartzite.

The granite at Baxter Hollow is exposed along Otter Creek and in a roadcut (map unit Ꝑg, plate 1; SW1/4 sec. 33, T11N, R6E; Weidman, 1904, p. 19); this granite was penetrated by engineering drillholes on the east side of the hollow (WGNHS Geologic Logs SK-306, 307, 310, and 311) and just east of the hollow (SK-304, 309, and 312). The granite is generally fine grained and pink to red, but it ranges widely in texture and mineralogy (Gates, 1942). Dominant minerals are intergrown potassium feldspar and quartz, with some plagioclase, biotite and chlorite, and accessory zircon and apatite. The chemistry of the Baxter Hollow granite is similar to that of a 1,760-million-year-old dike cutting rhyolite at Observatory Hill in Marquette County.

The intrusive nature of the Baxter Hollow granite has been debated. Gates (1942) concluded that the granite was intrusive, but Dalziel and Dott (1970) expressed doubt on the basis of the existence of a sheared zone between the granite and quartzite at Baxter Hollow. On the basis of study of drill core at Baxter Hollow, Greenberg (1986) and Petro (1983) concluded that the granite is intrusive into the Baraboo quartzite. The "shear zone" remains enigmatic, but it may represent tectonic movement after intrusion.

The Baxter Hollow granite has not been dated by the U-Pb method. Dott and Dalziel (1972) reported three Rb-Sr ages ranging from 1,530 ±120 to 1,590 ±140 million years. These ages span the 1,500 million year age of the Wolf River batholith and the 1,640 million year regional thermal event; they cannot be used to date the Baxter Hollow granite in relation to these regional events. Establishing the Baxter Hollow granite's age would be significant because it is the only igneous rock known to intrude quartzite in the Baraboo area.

Baraboo Formation

The Baraboo Formation was never formally named, but the term Baraboo quartzite has probably been used since Irving (1877, p. 504-519) described the "Baraboo quartzite ranges" (here called the Baraboo Hills) in detail. The name Baraboo Formation is here applied only to quartzite of the Baraboo Hills in Sauk and Columbia Counties and not to similar quartzite elsewhere in southern Wisconsin. On plates 1 and 2, the distribution of the Baraboo Formation is indicated by map unit **Ꝑb**.

The Baraboo quartzite consists primarily of subrounded to angular quartz grains that are commonly very fine to fine sand in size and are generally no coarser than 2 cm (Dalziel and Dott, 1970). The total exposed thickness of quartzite is about 1.5 km. The quartzite commonly contains 10 to 15 percent (maximum 30%) matrix (detrital grains smaller than 0.3 mm) consisting of quartz, pyrophyllite, kaolin-group minerals, hematite, and muscovite (Henry, 1975). The quartzite ranges from white to dark gray, commonly with a pink, red, or purple tinge.

The rock is a true quartzite that has undergone low-grade metamorphism and partial or complete recrystallization. It was cemented by quartz overgrowths and by a small amount of hematite, which caused the red hues. In most places the rock fractures across the original grains, but in a few places at the Precambrian-Cambrian unconformity and on the land surface on top of the South Range, weathering has caused it to disaggregate along original grain boundaries.

Henry (1975) described the petrography and sedimentary structures of the Baraboo Formation on the basis of an examination of stratigraphic sections at the Upper Narrows, the Lower Narrows, Devils Lake, Baxter Hollow, and at the Highway 12 cuts in the South Range. He subdivided the formation into three units primarily on the basis of sedimentary structures and grain size.

The quartzite of the lower unit consists of fine to very coarse sand with abundant poorly sorted pebbly beds and lenses up to 0.6 m thick. It is predominantly gray but ranges to pinkish gray. The pebbles are composed of milky vein quartz, with smaller amounts of hematitic chert, hematitic argillite, and siltstone. Henry (1975) identified no rhyolite pebbles in the quartzite. He did suggest, however, that the presence of embayed quartz and chert lacking iron oxides in the pebbles indicates partial derivation from siliceous volcanic rock, such as the underlying rhyolite, which is characterized by embayed quartz phenocrysts in a chert-like devitrified groundmass. The sand has high-angle cross-bedding in sets 10 to 20 cm thick interlayered with pebbly beds in the lower part of the unit. The pebbly beds decrease in abundance and thickness upward until high-angle cross-bedding with abundant pebbles becomes dominant near the top of the unit. No clayey beds are present. The unit is from 60 to 200 m thick and is best exposed on the west side of the Lower Narrows.

The middle unit of the Baraboo Formation (Henry, 1975) is quartzite with abundant phyllite beds up 0.3 m thick. The quartzite consists of very fine to fine sand with low-angle cross-bedding and thin pebbly layers, commonly one pebble thick. Henry (1975) reported an abrupt change from gray to pink in the lower unit to brick red in the lower few tens of metres of the middle unit. This change is attributed to an increase of sand-sized hematitic chert. The sets of low-angle cross-bedding are grouped in co-sets that are 1 to 20 sets thick. Individual sets range from 8 to 30 cm thick. Solitary sets of high-angle cross-bedding are interlayered with sets of low-angle cross-bedding. The middle unit is 400 to 500 m thick, and the contact with the lower unit of the formation is abrupt. It is well exposed in the Upper Narrows (Rock Springs Gorge, formerly Ablemans Gorge); Van Hise Rock, next to the road through the gorge, contains a good example of a phyllite bed in this unit (fig. 6).

The upper unit of the Baraboo Formation (Henry, 1975) is pink to purplish-red quartzite with abundant phyllite beds up to 2 m thick. The quartzite consists of very fine to fine sand with high-angle cross-bedding generally 10 to 20 cm thick but thickening to 90 cm near the top of the unit. Ripple marks are common, as is distorted and overturned bedding. The lower contact of the upper unit is gradational and is marked by the transition to predominantly high-angle cross-bedding. The upper unit is exposed in the Highway 12 cuts near Skillet Creek south of Baraboo. The upper unit is about 750 m thick.

Seeley Formation

No modern description is available for the Seeley Formation, which has not been available for direct study since iron mining stopped in the 1920s. No

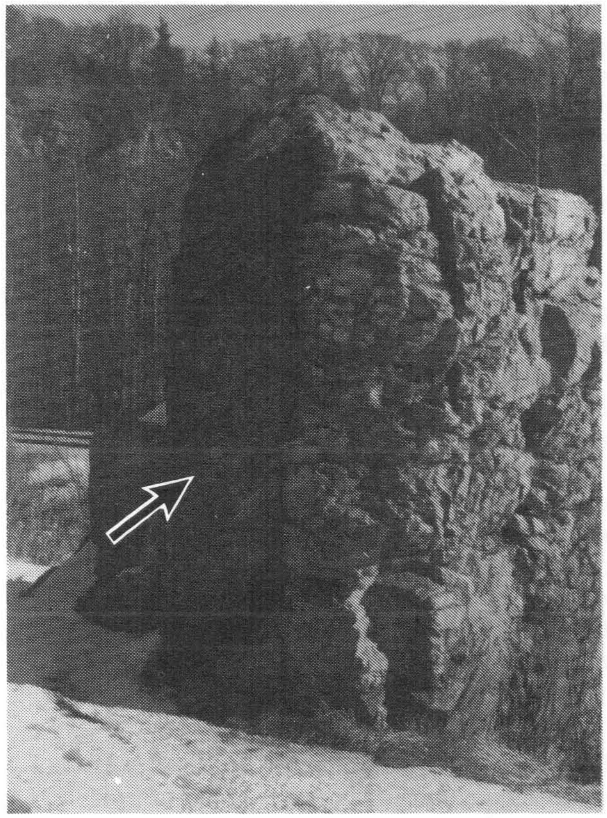


Figure 6. *Van Hise Rock, 1 km north of the village of Rock Springs (UTM coordinates 264,260mE, 4,819,060mN). Phyllite bed is shown by the arrow on left. View is looking east.*

outcrops of the formation are known. The Seeley Formation was named by Weidman (1904, p. 46-51) for Seeley Creek in central Sauk County. No type section was designated. It occurs in the subsurface for a distance of about 8 km southwest of the village of North Freedom (Weidman, 1904, plates 1, 12, and 13; Schmidt, 1951), where it is overlain by the Freedom Formation or by tens of metres of Cambrian and Pleistocene sediment, and it probably occurs elsewhere between the North and South Ranges (unit Ꝑf on plate 2; Leith, 1935, fig. 216).

Weidman (1904) described the Seeley as uniform gray slate with bedding defined by slight differences in color and grain size. Henry (1975) analyzed a sample in the University of Wisconsin-Madison collections and reported chlorite, muscovite, and quartz. Samples that fit Weidman's description of the Seeley were collected from a core dump at the Cahoon Mine (NW1/4 sec. 11, T11N, R6E; plate 1). They are gray to green, depending on chlorite content, and show laminated bedding several millimetres thick and a well developed tectonic cleavage at a high angle to the bedding (Geiger, 1986). The grain size of these samples is that of a fine-grained phyllite rather than that of a true slate.

Weidman (1904, p. 50) estimated that the Seeley Formation is between 150 and 300 m thick. The Seeley Formation is probably transitional with the Baraboo Formation because of the abundance of thick beds of phyllite in the top of the Baraboo and because Leith (1935) reported lenses and beds of quartzite up to 8 m thick in the lower part of the Seeley Formation observed in mine workings. An example of this transition can be seen in cuts along Highway 12 on the north side of the South Range (NW1/4 sec. 15, T11N, R6E); the cuts expose phyllite beds near the top of the Baraboo Formation.

Freedom Formation

Like the Seeley Formation, the Freedom Formation is known only from descriptions of iron mines and iron-exploration cores made early in this century. No outcrops of the Freedom Formation are known, although a cross section by Weidman (1904, plate 15) shows it exposed in a railroad cut at the Illinois Mine. The Freedom Formation was named by Weidman (1904, p. 51-89) for the township of Freedom (T11N, R5E). No type section was designated. It is known in the subsurface for a distance of about 9 km southwest of the village of North Freedom (unit **Ꝑf** on plate 2; Weidman, 1904, plates 1, 12, and 13; Schmidt, 1951), where it is generally overlain by tens of metres of Cambrian and Pleistocene sediment, and it probably occurs elsewhere between the North Range and South Range (Leith, 1935, fig. 216).

Weidman (1904, p. 79) and Schmidt (1951, p. 15) estimated that the Freedom Formation is about 300 m thick. The interbedded phyllite in the lower part indicates that the contact with the Seeley Formation is gradational.

Weidman (1904, p. 51-79) suggested that the formation could be divided into two members of about the same thickness. The lower unit consists of hard and soft hematite, layered hematite and chert, granular hematite and chert, and mixed chert and carbonate with quartz, clay minerals, and iron silicates. The upper part of the formation consists largely of dolomite.

The iron ore in the Freedom Formation consists of hard and soft hematite formed from alteration of iron silicate and carbonate. Weidman (1904, p. 75) and Schmidt (1951, p. 21) gave detailed descriptions of the ore from early drilling records. Schmidt (1951, p. 14) noted that the iron-bearing rock ranges from 60 to 160 m thick over short distances, indicating abrupt facies changes or hydrothermal alteration.

Iron ore was first discovered in the North Freedom area in 1887, and weathered ore was mined intermittently for paint pigment. Higher-grade ore was discovered in 1900, and 600,000 Mg (megagrams) of ore was produced between 1903 and 1925 from the Sauk Mine (sec. 10, T11N, R5E) and Illinois Mine (sec. 16, T11N, R5E) near La Rue, and the Cahoon Mine (sec. 11, T11N, R6E) south of the city of Baraboo. Iron production ceased because of the cost of pumping the large volume of water (up to 0.4 m^3/s) needed to keep the workings dry. A large amount of oxidized ore still remains underground, but because of changed technology and cost of extraction, they are not of economic interest today.

"Dake quartzite"

Leith (1935, p. 329-330) reported two additional Precambrian formations overlying the Freedom Formation: the "Dake quartzite" and the "Rowley Creek slate." According to Leith, these formations were identified using logs of holes drilled during exploration for iron ore and descriptions of the logs in an unpublished report by C.L. Dake; most of the drillhole cores had been destroyed by 1935. The logs and the report are no longer available, and our knowledge of these two formations is from the brief descriptions given by Leith.

Leith named the Dake quartzite after C.L. Dake, based on the descriptions of 42 drillholes, all of which went through the quartzite to the underlying Freedom Formation. According to Leith's (1935) figure 216, this quartzite occurs in the middle of the Baraboo Syncline near the city of Baraboo and for several kilometres eastward. It consists of quartzite, much of it conglomeratic, like the lower member of the Baraboo Formation. The lower part contains iron-oxide cement derived from the Freedom Formation. Leith (1935) reported that the unit is up the 65 m thick, and he gave evidence that there is an angular unconformity between it and the Freedom Formation.

Leith suggested that pebbly quartzite exposed on the south bank of the Baraboo River southwest of the village of West Baraboo (UTM coordinates 275,530mE, 4,816,560mN; too small to be shown on plate 1) and on a ridge 2 km east of the city of Baraboo (northern part of sec. 32, T12N, R7E; map unit **Ꝑk**, plate 1) might be Dake quartzite. Much debate has surrounded these exposures, principally because no drilling has since confirmed the relationships suggested by Leith. Schmidt (1951) suggested that they may be part of the lower Baraboo Formation brought up by faulting. Geophysical maps (Hinze, 1957) do not indicate a fault of necessary magnitude here. The Dake problem cannot be resolved with presently available information.

"Rowley Creek slate"

Like the Dake quartzite, the "Rowley Creek slate" was named by Leith (1935, p. 329-330) and was based on drillhole logs that are no longer available; eight drillholes went through the slate to the underlying Dake quartzite. No outcrop of the formation is known. Leith named the formation after Rowley Creek, on the county line east of the city of Baraboo. According to Leith's (1935) figure 216, the slate occurs in two small areas in the middle of the Baraboo Syncline east of the city of Baraboo. It apparently is similar to the Seeley Formation. According to Leith, the formation is up to 45 m thick.

Precambrian structure

The Baraboo Hills are well known to structural geologists from the early work of R.D. Irving, C.R. Van Hise, C.K. Leith, and coworkers, who described and classified rock cleavage in the quartzite and phyllite (Dalziel and Dott, 1970). Van Hise Rock (fig. 6), along Highway 136 north of the village of Rock Springs, was named as a memorial to Van Hise and his work. The rock consists of a bed of phyllite between two quartzite beds in the Baraboo Formation. It illustrates the refraction of a spaced fracture cleavage from the quartzite into a penetrative cleavage in the phyllite bed. This phenomenon can be seen in the South Range as well, in cuts along Highway 12 (NW1/4 sec. 15, T11N, R6E).

Using an analysis of mesoscopic structures and a study of quartz petrofabrics, Dalziel and Stierwalt (1975) concluded that the structures and quartz fabric could have formed in a single progressive deformational process, the folding of the Baraboo Syncline (fig. 7). Jank and Cambray (1986) identified quartz pressure solution and phyllosilicate content as important controls for the

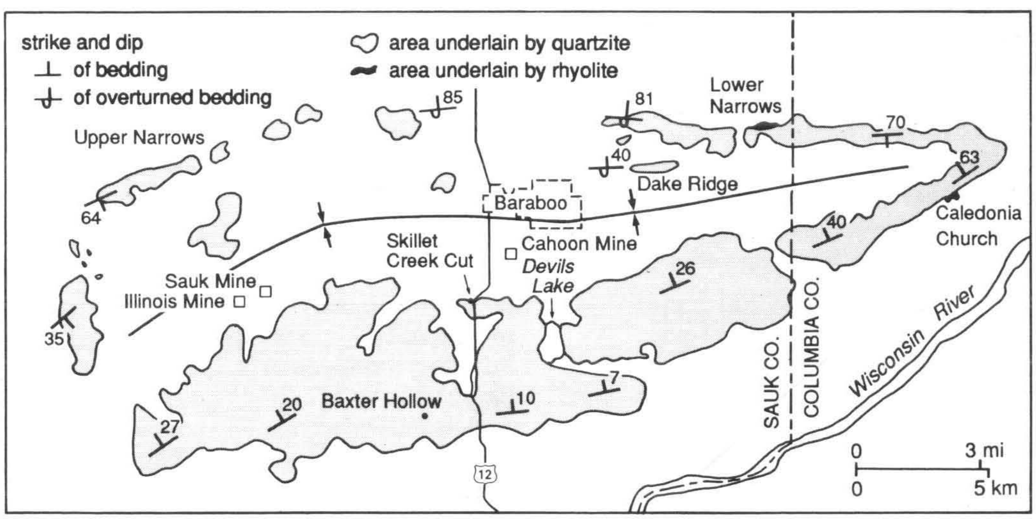


Figure 7. *Map of the Baraboo Syncline, showing iron mines and the surface occurrence of Precambrian rock; syncline axis and strike and dip of bedding from Dalziel and Stierwalt (1975).*

development of cleavage in the quartzite. Hempton and others (1986) reexamined the mesoscopic structures and structural interpretations of Dalziel and Dott (1970) and Dalziel and Stierwalt (1975). They concluded that some late crenulation cleavages in the phyllite (those with asymmetry suggesting an opposite sense of shear to that which caused the folding of the syncline) could be attributed to down-dip strain related to a reopening or unfolding of the syncline. They attributed this unfolding to regional stress related to development of the Midcontinent Rift and the Grenville Orogeny about 1,000 million years ago.

Although the Baraboo Hills have been a classic locality for studying cleavage and flexural folding, continually evolving concepts of tectonics and deformational processes make this area a valuable laboratory for modern structural studies. Structural studies have been conducted here for nearly a century, but the structure of the Baraboo Syncline is not known in detail. Much work remains to be done to document the role of faulting and such problems as the nature and significance of the Dake quartzite.

Tectonic setting of the Precambrian rock

The Precambrian rock in Sauk County is the result of an important but poorly understood stage in the development of the North American continent. Dott (1983) coined the informal term "Baraboo interval" for the period of time (approximately 1,450 to 1,750 million years ago) when the quartzite of the Baraboo and Barron Formations of Wisconsin and the quartzite of the Sioux Formation of Minnesota and South Dakota were deposited. Dott (1983) and Anderson and Ludvigson (1986) have suggested that the sediment deposited during the Baraboo interval was deformed by an orogeny that added new continental crust along the tectonic suture in northern Illinois about 1,630 million years ago. Southward vergence of structures in the rock of the Baraboo interval in Wisconsin does not support this, and to date no orogenic igneous rock younger than the Penokean Orogeny (a worldwide episode of crustal formation that occurred about 1,850 million years ago) has been identified in the region.

Greenberg and Brown (1984) redefined the Baraboo interval as a period of anorogenic tectonic activity that followed the Penokean Orogeny and ended with the emplacement of the Wolf River batholith (1,480 million years ago). This period included anorogenic granite magmatism and extrusion of rhyolite (1,760 million years ago) as well as sedimentation of the Baraboo-type sedimentary rock. Greenberg and Brown (1984) concluded that a number of isolated exposures of quartzite and related rock in central and northern Wisconsin probably also formed during the Baraboo interval. Taken together, this rock constitutes an important tectonic and stratigraphic package similar to those formed on other continents in the Early Proterozoic.

EARLY PALEOZOIC HISTORY

Introduction

During the Paleozoic Era, sediment was deposited in Sauk County along the crest of the Wisconsin Arch, a southern extension of the Wisconsin Dome into southern Wisconsin. Most of the Paleozoic formations in the county are part of the Sauk Sequence, named by Sloss and others (1949, p. 111) for exposures in Sauk County (fig. 4). One of seven major lithostratigraphic units overlying Precambrian rock on the North American craton, the Sauk Sequence is bounded on the bottom by the widespread Precambrian-Cambrian unconformity and on the top by a major unconformity between the Prairie du Chien Group and the St. Peter Formation, both of which are Ordovician. This sequence in Sauk County consists largely of nearly flat-lying marine sand and sandstone, with nonmarine sediment in a coastal zone around the Wisconsin Arch and dolomite at the top of the sequence. In Sauk County, the sequence is probably as thick as 275 m.

The lowest Cambrian stratigraphic unit in Sauk County is a layer of conglomeratic sandstone that is variable in thickness but is typically several metres or tens of metres thick. It occurs throughout much of the county, including the sides of the Baraboo Hills, where it is included in the newly named Parfreys Glen Formation, which is chronologically equivalent to the other Paleozoic formations in the area.

Outside the Baraboo Hills, the next overlying unit is the Elk Mound Group, which here is as thick as 150 m and consists primarily of quartz sand and sandstone. In west-central Wisconsin, the Mount Simon (lower Elk Mound) and Wonewoc (upper Elk Mound) Formations are separated by a unit containing finer-grained, more dolomitic, more fossiliferous, and more glauconitic sandstone -- the Eau Claire Formation. In southeastern Sauk County, a similar unit, several tens of metres thick, occurs in the subsurface, about 50 m below the top of the group; in northeastern Sauk County, a somewhat similar unit, only a few metres thick, occurs about 20 m below the top of the group. The Eau Claire Formation has not been recognized elsewhere in the county. The identification of the Eau Claire Formation in Sauk County is based largely on lithologic similarity and stratigraphic position rather than on direct tracing from the type area.

Overlying the Elk Mound Group is the Tunnel City Formation. In western Sauk County this unit is characterized by glauconitic and dolomitic sand and sandstone; eastward on the Wisconsin Arch, it becomes less glauconitic, especially in the middle part of the formation. It is generally about 35 m thick.

The overlying St. Lawrence Formation is about 15 m thick. It is largely very fine-grained sandstone and siltstone, but a few metres of dolomite occurs at the base in some places. The St. Lawrence is overlain by the Jordan Formation, which consists of about 15 m of quartz sandstone.

The highest Paleozoic unit in much of western Sauk County is the Oneota Formation of the Prairie du Chien Group. It generally consists of several metres of Ordovician dolomite capping the highest ridges. The Cambrian-Ordovician boundary has been considered to be near the Jordan-Oneota contact (Ostrom, 1967).

The St. Peter Formation in Sauk County consists of small, isolated bodies of Ordovician quartz sandstone no more than a few tens of metres thick, commonly overlying a few metres of clayey, silty, or sandy rubble. The unconformity below the St. Peter Formation extends no lower than the top of the Jordan Formation in most places.

The stratigraphic terminology used for these Paleozoic units has gradually evolved since geologists first visited the area in the middle of the nineteenth century. The unconformity between the Cambrian and Precambrian rock was established in the early 1870s (Irving, 1877, p. 504). Until the early part of the twentieth century, the Cambrian material was all considered part of the "Potsdam formation" (named for Potsdam County, New York), and what we now consider to be the Oneota dolomite was included in the "Lower Magnesian formation" (see, for example, Weidman, 1904).

The Potsdam and Lower Magnesian in Sauk County were mapped in 1907 by W.C. Alden (unpublished field maps in WGNHS files) and were shown on the geologic map of Wisconsin by Hotchkiss and Thwaites (1911). Alden's field maps for his report on the Pleistocene geology of southeastern Wisconsin show that the dolomite in the base of the St. Lawrence Formation was also mapped (Alden, 1918, p. 71-77).

E.O. Ulrich of the U.S. Geological Survey spent a few days in Sauk County most summers between 1913 and 1924, generally accompanied by local geologists, frequently including F.T. Thwaites (field notes in WGNHS files). Ulrich's correlations (summarized by Ulrich, 1924) were often in conflict with those of Thwaites and other geologists. Ulrich believed a major unconformity existed at the base of his "Ozarkian system," which he thought existed above the Cambrian System. The units he included in the middle and lower part of his Ozarkian system are actually the same units as in the upper part of the Cambrian System (Wanenmacher and others, 1934).

Thwaites' field notes from Sauk County indicate an interest in the Paleozoic stratigraphy from 1907, when he was Alden's field assistant, through at least the 1930s. Many of the detailed stratigraphic relationships in southern Wisconsin were worked out by Thwaites and Twenhofel between 1916 and 1921, when they mapped the Sparta and Tomah 15-minute quadrangles (northwest of Sauk County) for the U.S. Geological Survey. Their map and report were later refused publication because of stratigraphic disagreements with Ulrich, but they are available as a WGNHS open-file report (Thwaites and others, 1922). Their stratigraphy was summarized by Twenhofel and Thwaites (1919). The culmination of the stratigraphic work of this period in Sauk County and adjacent areas was Wanenmacher's

(1932) dissertation on the Paleozoic rock of the Baraboo region, the guide book for the Kansas Geological Society's field trip through the upper Mississippi valley (Trowbridge, 1935), and a paper on the Cambrian strata of Wisconsin by Twenhofel and others (1935).

M.E. Ostrom studied the Cambrian stratigraphy of southwestern Wisconsin during the 1960s. Some of the stratigraphic units had previously been defined by biostratigraphic criteria. Ostrom redefined these units on a lithostratigraphic basis and established the stratigraphic terminology now generally used (Ostrom, 1966, 1967).

Surface expression

We recognized the Paleozoic formations primarily by their lithologic appearances as seen in outcrops. However, only a minute proportion of the surface of Sauk County consists of outcrop. In the areas between outcrops, the formations are delineated by their general surface expression, as seen in the field and on topographic maps and aerial photographs.

The Paleozoic formations of Sauk County have a characteristic topography consisting of a series of abrupt or gradual benches; figure 8 shows the topography typically seen in northern Sauk County. The Mount Simon Formation in northeastern Sauk County forms gently undulating lowlands, except in the area of the Wisconsin Dells, where it forms near-vertical walls of gorges. The Eau Claire Formation in northeastern Sauk County forms a low, rounded bench. The lower part of the Wonewoc Formation (Galesville Member) in northern Sauk County typically is gently undulating, but the upper part (especially the Ironton Member) is steep and in many places forms a near-vertical cliff. In northern Sauk County, the Ironton bench at the top of the Wonewoc Formation is a conspicuous landform, but it is inconspicuous between the North and South Ranges and much of the southern part of the county. The shaley zone near the base of the Tunnel City Formation in northern Sauk County forms a flat area behind the brink of the Ironton bench. In general, the Tunnel City Formation forms rolling topography, with the Mazomanie Member rather hummocky in places. In parts of northwestern Sauk County, the Mazomanie forms a distinct bench. A rounded bench generally occurs at the bottom of the St. Lawrence Formation around the base of the Jordan escarpment, but the bench is less conspicuous in parts of southern Sauk County, especially in Bear Creek valley.

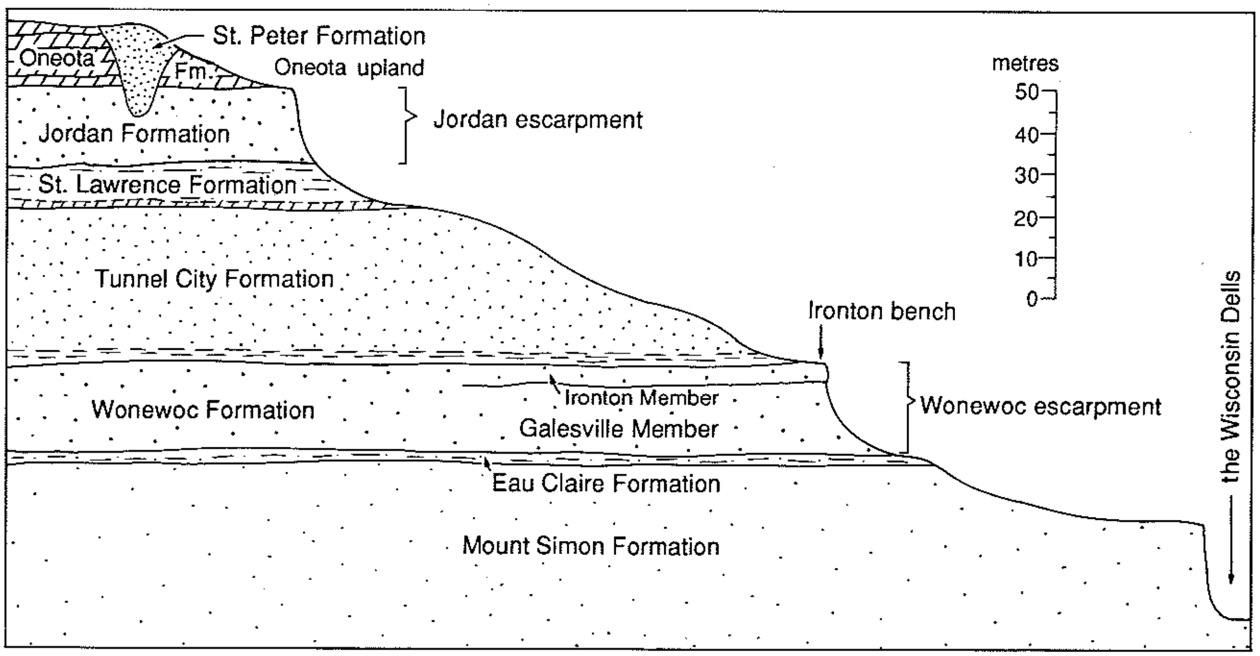


Figure 8. *Topographic profile across Paleozoic formations in northern Sauk County.*

The Jordan escarpment is a steep, wooded slope throughout Sauk County, commonly with a cliff at the top. The Oneota Formation forms uplands, which are flatter in the northern part of the county and more rounded, with steeper slopes near the edge of the uplands in the southern part. The St. Peter Formation has no distinctive topography to differentiate it from the Oneota in most of the county, but the St. Peter of Pine Bluff, between the North and South Ranges at the east edge of the county, forms a steep-sided, flat-topped hill. The topography of the Parfreys Glen Formation is much like that of the Baraboo Formation. In most areas it forms broad, rounded slopes on the flanks of the Baraboo Hills.

As seen in map view, the Paleozoic formations tend to have distinctive geometries (plate 1). The contacts between the Mount Simon and Eau Claire Formations and between the Wonewoc and Tunnel City Formations generally form a series of semicircular scallops (convex downslope), 0.1 to 0.2 km across, but near the village of La Valle they are somewhat larger and more lobate. The contact between the Tunnel City and St. Lawrence Formations closely parallels the contact between the St. Lawrence and Jordan Formations in many areas, but in northwestern Sauk County the Tunnel City contact forms a series of small semicircular scallops (convex downslope; fig. 9a) that are independent of the scallops in the Jordan contact. The surface occurrence of the Jordan Formation is uniformly about 50 m wide throughout the county. In most parts of the county, the Jordan-Oneota contact forms a series of lobate scallops that are convex downslope and are 0.1 to 0.5 km across (fig. 9b), but in a few places they are concave downslope (fig. 9c). These differences in contact patterns are probably caused by unknown lithologic differences.

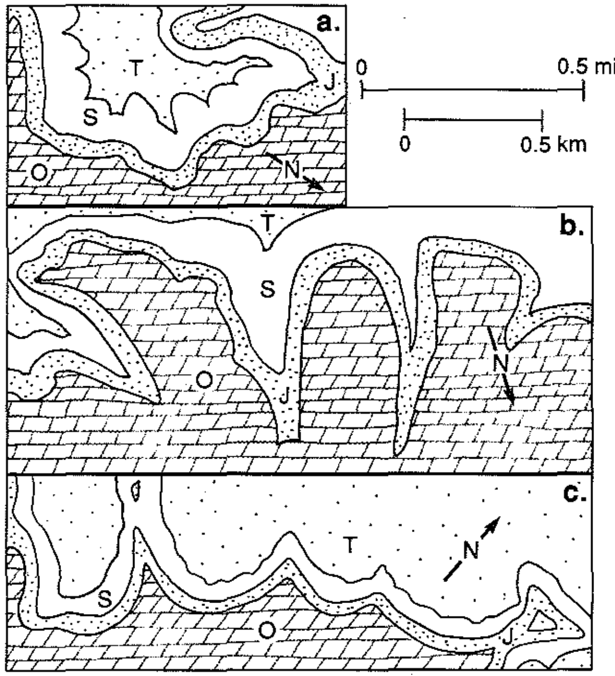


Figure 9. Patterns of surface occurrence of the Oneota (O), Jordan (J), St. Lawrence (S), and Tunnel City (T) Formations. a: sec. 23, T13N, R2E. b: sec. 30, T13N, R2E. c: sec. 18, T12N, R3E.

Cementation

Much of the sandstone of the Parfreys Glen Formation and a thin bed of sandstone at the top of the Jordan Formation are so thoroughly cemented with quartz that fractures pass through rather than around grains; the dolomite of the Oneota Formation is also generally well cemented. The Jordan and St. Lawrence Formations and the Ironton Member of the Wonewoc Formation tend to be moderately well cemented, but much of the rest of the Paleozoic sandstone or sand of Sauk County ranges from poorly cemented to uncemented. Some is so soft it can be excavated with a hand shovel.

Cementation varies laterally within the Paleozoic formations. The stratigraphy of southern Juneau County and northern Sauk County is better known than that of southern Sauk County because the sandstone is better cemented, and therefore outcrops are more abundant to the north. Ridges of well cemented sandstone occur along east-west faults and fracture zones in southern Juneau County (Clayton, in press) and at a few places in northern Sauk County -- an example occurs where the Baraboo River valley abruptly narrows because it crosses the La Valle Fault (discussed in the later section about structural geology). The Cambrian formations in southern Sauk County are generally poorly cemented and exposed, but in a few places they are well cemented, producing isolated sandstone cliffs, such as at Pillar and Tower Rocks south of Leland and Denzer.

The position of some sandstone cliffs is more the result of Pleistocene erosional history than of lithology. For example, cliffs occur at the north edge of the Wisconsin River valley bottom, where glacial meltwater rivers oversteepened the valley wall, and at the Wisconsin Dells, where glacial meltwater torrents eroded deep gorges. There the sandstone appears well cemented, but much of the cementation is case-hardening caused by evaporation of mineralized pore water at the cliff surface and perhaps also by biologic precipitation in areas where microorganisms live a few millimetres behind the cliff face.

Unit descriptions

The following descriptions of Paleozoic units are intended to apply to the units seen in Sauk County; generally, we do not discuss the characteristics of these units in other areas. Descriptions are primarily based on our field and laboratory observations, but in several places we have quoted other geologists' observations. Lithologic descriptions are primarily based on binocular microscopic observations of samples collected at outcrop, generally 10 to 40 samples for each unit. Grain size was estimated using an ocular micrometer with disaggregated samples. Color determinations were based on Munsell color charts, using dry samples from fresh outcrops. Color names are from the Munsell soil-color charts.

Elk Mound Group

The Elk Mound Group was named by Ostrom (1966, 1967) after Elk Mound in Dunn County, west-central Wisconsin, 180 km to the northwest of Sauk County. In that area, the group consists of (from bottom to top) the Mount Simon, Eau Claire, and Wonewoc Formations. It replaced the older name "Dresbach group," which was inappropriate because of possible confusion with the term Dresbachian Stage. (The upper member of the Wonewoc was generally excluded from the Dresbach, and in earlier usage the Mount Simon or both the Mount Simon and Eau Claire were also excluded.)

Later sections of this report contain discussions of criteria used to differentiate the Mount Simon, Eau Claire, and Wonewoc Formations in outcrops in northeastern Sauk County and in well logs in southeastern Sauk County. On plate 1, the Wonewoc and Eau Claire Formations have been differentiated from the Mount Simon Formation in the northeastern part of the county; in addition, the upper part of the Wonewoc Formation is shown at the surface in parts of the county where the lower units are lacking. In much of the county, however, the Elk Mound Group is known only from logs of drillholes in which the three formations cannot be differentiated, as shown on the cross sections of plate 2; the following discussion deals with the Elk Mound in these areas.

Next to the Baraboo Hills the Elk Mound Group is up to several tens of metres thick. In other parts of Sauk County, subsurface information is scarce, but the Elk Mound is probably 150 to 200 m thick (plate 2).

The Elk Mound Group is most commonly described in WGNHS geologic logs as consisting primarily of medium sand, with considerable coarse and fine sand. It is coarsest north of the Baraboo Hills, and pebbles of Precambrian rock generally occur near the base of the unit. The sand grains are described in geologic logs as being subrounded; samples from wells are described as very pale brown, white, pale yellow, or gray.

Sandstone cores from wells in the Elk Mound Group near Dutch Hollow Lake northwest of La Valle (geologic logs furnished by the Harza Engineering Company; in the WGNHS exploration-records files) are described as consisting almost entirely of quartz grains. Lithification is variable, but much of it is only slightly cemented (some can be crumbled by hand), generally with silica. WGNHS geologic logs from other parts of the county indicate that some silica cement is generally present, and some dolomitic cement occurs, especially south of the Baraboo Hills and between the North and South Ranges.

Mount Simon Formation

Ulrich named the Mount Simon Formation of the Elk Mound Group for a hill in the city of Eau Claire, in western Wisconsin, 160 km northwest of Sauk County (Walcott, 1914, p. 354). The Mount Simon Formation has been identified in southern Wisconsin, Illinois, Indiana, Kentucky, Ohio, Minnesota, and Iowa.

Opinion has varied through the years about the position of the top of the Mount Simon Formation in Sauk County. Recognition of the top of the Mount Simon is dependent on the recognition of the Eau Claire Formation; a discussion of this stratigraphic problem is included in the next section of this report. No more than the upper quarter of the Mount Simon is exposed at the surface in Sauk County, including the sandstone gorges of the Wisconsin Dells (map unit **Ꞓm** on plate 1). The rest of the unit is known only from drillholes. North of the Baraboo Hills the Mount Simon is roughly 150 m thick; south of the Baraboo Hills it probably ranges from 0 to more than 60 m (plate 2).

In the Wisconsin Dells area, the upper part of the Mount Simon Formation is well exposed in vertical cliffs along the walls of the Wisconsin River gorge and tributary gorges. Away from the gorge walls, it is generally not exposed. Where exposed at the Dells, it consists largely of medium and fine sand (based on 35 samples from two sections). In WGNHS geologic logs from throughout the county, the Mount Simon is generally described as consisting primarily of medium sand, with considerable coarse sand and a smaller amount of fine sand. The coarser grains especially have undergone considerable rounding and consist largely of quartz. Fossils are absent.

The bedding in the Mount Simon sandstone in the Wisconsin Dells has been described by Fielder (1985), who, however, considered it to be part of the Wonewoc Formation. Cross-bedding dominates most outcrops. The cross-bedding is commonly high angled, trough shaped, and large scale; the larger sets are typically 1 to 2 m thick. Large-scale cross-bedding is especially conspicuous on the walls of the Wisconsin River gorge.

The sandstone of the Wisconsin Dells gorges is typically very pale brown in fresh outcrop. Lichens are generally uncommon on outcrops, and a conspicuous green layer of algae occurs a few millimetres below the surface of outcrops, as in the Galesville Member. Although it appears well cemented in cliff faces, it is commonly soft and friable beneath the case-hardened surface. Maximum thickness of the Mount Simon Formation at the surface in northeast corner of the county is about 30 m.

A variety of opinion has been expressed about the environment of deposition of the Mount Simon sandstone at the Wisconsin Dells. Some have considered it to be marine because the Mount Simon sandstone of western Wisconsin contains fossils, and others have considered it to be nonmarine because of the lack of fossils in the Wisconsin Dells area. Fielder (1985; summarized by Dott and others, 1986) studied the bedding types in the sandstone near the city of Wisconsin Dells (although he considered it to be part of the Wonewoc Formation) and interpreted much of it to be of eolian origin, partly because of the presence of adhesion ripples and adhesion-ripple bedding.

Eau Claire Formation

The type section of the Eau Claire Formation of the Elk Mound Group is in the city of Eau Claire in western Wisconsin (Walcott, 1914, p. 354). The formation has been identified in southern Wisconsin, Illinois, Indiana, Minnesota, and Iowa. The formation thins eastward onto the Wisconsin Arch, and its recognition is difficult in south-central Wisconsin. It has been tentatively recognized in outcrop in the northeastern part of Sauk County, where it is too thin to be shown on plate 1 and has therefore been included in the same map unit as the Wonewoc Formation. The Eau Claire Formation has also been recognized from samples taken from drillholes in the southeastern part of the county. Elsewhere in the county it is absent or is either too thin or too similar to the Mount Simon and Wonewoc Formations to be recognized in drillhole samples.

Northeastern Sauk County

We examined several outcrops in northeastern Sauk and adjacent Juneau County and analyzed 30 samples from three outcrops in northeastern Sauk County. The unit that we call the Eau Claire Formation consists of a few metres of sandstone composed of very fine to coarse sand with some siltstone layers that are typically no more than a few millimetres thick. The coarser grains, which are primarily quartz, have undergone considerable rounding. The sandstone typically has thin, flaggy bedding, but very thin bedding is not obvious, apparently because of bioturbation. We found no identifiable fossils, but poorly preserved fossil fragments are present. Some rip-up clasts are also present. The sandstone is commonly reddish brown, but colors range from reddish yellow to red. Dark reddish-brown layers are common; they consist of sandstone with iron-oxide cement, are no more than a few centimetres thick, and cut across bedding. We did not observe the top of the unit, but it is probably 1 to 3 m thick in many parts of northeastern Sauk County. The lower contact appears gradational.

This unit, where exposed in northeastern Sauk County, can easily be distinguished from the underlying Mount Simon Formation and the overlying Galesville Member. It is redder and browner than either of those units, has more iron-oxide cement, is generally more indurated, is less well sorted, has more coarse sand and more silt, and is more bioturbated.

The unit generally occurs at the rounded brink of a topographic bench and is poorly exposed. We have seen the unit at the following locations in Sauk County: shallow ditch cuts on the north side of Trout Road at UTM coordinates 271,860mE, 4,832,530mN and 272,270mE, 4,832,500mN (3 km southwest of the city of Wisconsin Dells), a small roadcut on the north side of Highway P at 266,250mE, 4,830,230mN (8 km west of Lake Delton), the top of the cuts for the Highway 90/94 exchange in the NE1/4 sec. 8, T13N, R6E (west edge of the city of Wisconsin Dells), and the top of the cut for Highway 90/94 at 273,280mE, 4,835,320mN (3 km northwest of Wisconsin Dells). The contact between this unit (included in map unit **Cw** on plate 1) and the Mount Simon Formation has been mapped by following the topographic bench between these outcrops. In the Wisconsin Dells, this unit probably occurs at the covered interval 10 to 13 m above the base of Fielder's (1985) section below the Highway 90/94 overpass at the Mirror Lake gorge southwest of Lake Delton (in the NE1/4 sec. 29, T13N, R6E; at the contact of facies 2 and 3 at the right end of fig. 9 of Dott and others, 1986).

This unit has been recognized in southeastern Juneau County (Clayton, in press), where the topographic bench was also used to trace it between scattered exposures. Clayton correlated this unit with the "shaley zone" at the base of the "upper cliff section" identified throughout southwestern Juneau County by G.O. Raasch (1927 and 1928 field notes in WGNHS files). The shaley zone there is 1 to 3 m thick. Twenhofel and others (1935, p. 1730) considered the upper cliff section to be the Galesville Member.

Clayton (in press) considered Raasch's shaley zone to be the Eau Claire Formation because Ostrom (1987, p. 185) and Ostrom and Davis (1970, p. 57) identified it as Eau Claire at Sheep Pasture Bluff in southern Juneau County. Ostrom's identification was based on outcrop and subsurface correlations from more typical Eau Claire lithologies in western Wisconsin (Ostrom, 1962). Berg and others (1956, fig. 1 and 2) agreed that a very thin Eau Claire exists at about this stratigraphic position in southern Juneau County. Similarly, Emrich (1966, p. 8-10) agreed that the top of the Eau Claire Formation occurs at about this position in southern Juneau County. However, the unit considered to be the Eau Claire Formation in northeastern Sauk County differs from typical Eau Claire in western Wisconsin; the Sauk County unit contains more coarse sand and iron-oxide cement and less dolomite and glauconite, and is redder and much thinner.

If this unit is, in fact, part of the Eau Claire Formation, the sandstone in the Wisconsin Dells gorges (except in the high bluffs at Mirror Lake) is part of the Mount Simon Formation (plates 1 and 2). This differs from previous interpretations. Twenhofel and others (1935, plate 151; Trowbridge, 1935, p. 135) considered all the sandstone exposed in the Wisconsin Dells gorges to be part of the Eau Claire Formation. They recognized that their Eau Claire was lithologically nearly identical to the underlying and overlying units, but they considered it to be Eau Claire because they thought it chronologically equivalent to the Eau Claire of western Wisconsin. In contrast, Dott and others (1986) considered the sandstone at the Dells to be part of the Wonewoc Formation because they recognized no Eau Claire in the area. They concluded that the eolian sandstone in the Wonewoc Formation is thicker here than the more typical marine sandstone in the Wonewoc Formation farther west. Robert Pody's assignments (written communication, 1983) agreed with ours, except that he considered our Eau Claire Formation to be the uppermost bed of the Mount Simon Formation.

Southeastern Sauk County

The Eau Claire Formation has been identified in the subsurface in WGNHS geologic logs from southeastern Sauk County (cross sections 9N, 10S, and 10N of plate 2). Several logs indicate that the Eau Claire is between about 50 and 100 m thick in this area (WGNHS Geologic Logs SK-1, 2, 3, 5, 8, 9, 10, 11, 26, 55, 168, 176, 195, and 229). The formation here generally consists of dolomitic sandstone composed of quartzose, very fine to medium sand with considerable dolomitic siltstone, dolomitic shale, and sandy dolomite. Glauconite and fossil fragments are present in many samples. The shale and dolomite beds are as thick as 20 m in several wells.

We refer to this stratigraphic interval as the Eau Claire Formation because it is roughly in the middle of the Elk Mound Group and because it lithologically resembles the Eau Claire of western Wisconsin. Ostrom (1962) and R.M. Peters (WGNHS, verbal communication) consider at least the upper part of this interval to be the Eau Claire because they have correlated it in well logs to the better known Eau Claire Formation of southwestern Wisconsin. Because the Eau Claire contains fossils, it is considered to be a marine deposit.

Wonewoc Formation

The Wonewoc Formation of the Elk Mound Group was named after the village of Wonewoc in southwestern Juneau County, on the northwest border of Sauk County (Ostrom, 1966, p. 4-8, 59-60; 1967). This formation is included in map unit Ꞓw on plate 1. The lower member, the Galesville, contains quartz sand and sandstone much like that in the Mount Simon Formation. The upper member, the Ironton, contains bioturbated, red-stained sandstone somewhat like that of the Eau Claire Formation in the northeastern part of the county.

Galesville Member

The Galesville Member was named for the city of Galesville in western Wisconsin, 100 km northwest of Sauk County (Trowbridge and Atwater, 1934, p. 45). The Galesville has been identified in southern Wisconsin, Michigan, Illinois, Indiana, Minnesota, and Iowa. Identification of the bottom of the Galesville Member depends on the identification of the Eau Claire Formation. If our identification is correct, the Galesville Member is typically 15 to 20 m thick in northern Sauk County and about 50 m thick in the southeastern part of the county. Where the Galesville crops out in Sauk County, it generally consists of medium sand with considerable fine sand. WGNHS geologic logs indicate that considerable coarse sand is also present in the subsurface samples. On the basis of laboratory analysis of 50 samples in the Baraboo area, Dalziel and Dott (1970, table 8) found that the Galesville typically consists of fine sand north and south of the Baraboo Hills and fine to medium sand between the North and South Ranges; on the basis of laboratory analysis of 20 samples from northern Sauk County, Ostrom (1971) found that the Galesville is generally fine to medium sand. The coarser grains especially are well rounded, and consist almost entirely of quartz. Fossils are generally absent, but burrows are present in places, especially near the top of the member.

Fielder (1985) studied the bedding in the Galesville Member in the Wisconsin Dells area (facies 3 in fig. 9 of Dott and others, 1986). There, it consists of horizontal planar bedding with intervals of high-angled trough-shaped cross-bedding with sets generally thinner than 0.3 m. Scattered small channel fills are also present. Stenzel (1983) found similar bedding in the Galesville in northwestern Sauk County.

In fresh outcrop, Galesville sandstone is generally white. The sand is poorly lithified, but near-vertical outcrops are fairly abundant, even though the unit occurs low in the landscape in most parts of the county.

In contrast to most other sandstone in the county (except Mount Simon sandstone), lichens are largely absent on outcrops, and a conspicuous green layer of live algae occurs a few millimetres below the surface. The algae have been identified by E. Imre Friedmann (Florida State University, verbal communication) as cryptoendolithic cyanobacteria (blue-green algae), which have previously been reported from hot deserts of the Middle East and North America and cold deserts of the Arctic and Antarctic (Nienow and others, 1988, p. 271). Because the Galesville and Mount Simon contain a large proportion of translucent quartz and a small proportion of nutrients that support lichens and other organisms that shade the surface, light penetrates deeply enough for algae growth.

In Sauk County, the Galesville Member is most likely to be confused with the Mount Simon Formation. Where the position of the intervening Eau Claire Formation is unknown, the Galesville and Mount Simon can sometimes be differentiated by the overall whiter color, the greater proportion of white quartz grains, the smaller-scale cross-bedding, and the more abundant planar bedding of the Galesville Member. The sandstone at the top of the Galesville is conspicuously flaggy in some areas, but lower outcrops have a smooth, uniform look; in contrast, bedding planes and joints are much more conspicuous on outcrops of Mount Simon sandstone in the Wisconsin Dells. Some Galesville sandstone resembles some Jordan sandstone, but the bottom of the Jordan occurs 50 to 65 m above the top of the Galesville.

Ostrom (1987, p. 185) and Asthana (1969) indicated that more abundant feldspar in the Mount Simon Formation can be used to distinguish it from the Galesville in southern Juneau County. Odom (1975) suggested that feldspar content in the Galesville and Mount Simon in western Wisconsin is controlled largely by grain size -- feldspar is generally present only in very fine sand and finer material. However, in northeastern Sauk County, the two units have about the same grain sizes.

Fielder (1985, p. 144-147) believed the sandstone that we include in the Galesville Member in the Wisconsin Dells to be of shallow marine origin, but Dott and others (1986, p. 354-355; facies 3 of fig. 9) suggested a fluvial and eolian origin. Stenzel (1983, p. 170-173) preferred a fluvial interpretation for most of the Galesville sandstone in northwestern Sauk County. Anstett (1977, p. 71) pointed out that burrows indicate a marine origin for at least the upper part of the member in Sauk County.

Ironton Member

The Ironton Member was first mentioned in print by Thwaites (1923, p. 550) and was more formally named by Ulrich (1924, p. 93-94). The Ironton was considered to be the lowermost member of the "Franconia formation" (here called the Tunnel City Formation), but it was transferred to the Wonewoc Formation by Ostrom (1966, 1967). A stratigraphic interval nearly the same as that of the Ironton Member was named the "Woodhill member" by Berg (1954), but that name was soon abandoned in favor of Ironton. The type section of the Ironton Member is at the north edge of the village of Ironton in northwestern Sauk County (where the member is 3 to 4 m thick), either in a now-vegetated roadcut at UTM coordinates 730,950mE, 4,825,560mN (Ostrom, 1966, p. 61-62) or a natural cliff next to Highway 58 at 731,080mE, 4,825,900mN (Salstrom, 1962, section 25). The cliff is here considered to be the type section because it is now better exposed; according to Salstrom (1962), it is "Ulrich's original type section." Because these are small isolated outcrops, the type section of Berg's Woodhill member in southwestern Juneau County might have been a better Ironton type section; however, Berg's section is now considered a reference section of the Ironton Member (Clayton, in press; Ostrom, 1966, p. 57-58). The Ironton is most conspicuously developed in northern Sauk County, southern Juneau County, northeastern Vernon County, and Monroe County, although the unit has been identified in other parts of southwestern Wisconsin and in Illinois, Indiana, Minnesota, and Iowa.

Various geologists have placed the top and bottom boundaries of the Ironton at slightly different levels; as a result, they disagree about which lithologies should be considered characteristic of the Ironton. In northern Sauk County, we consider the Ironton to have the following characteristics. It consists of fine to medium sand. The Ironton is commonly considered to be coarser than the Galesville, but the difference is not conspicuous in northern Sauk County (Myers, 1981, p. 83). The Ironton sandstone is commonly considered to be more poorly sorted than the Galesville sandstone, but the difference is slight in northern Sauk County. The sand grains are primarily quartz and appear to be more angular than those of the Galesville, which may be a result of quartz overgrowths. The Ironton sandstone is generally slightly fossiliferous. It commonly has a frothy-looking porosity, probably due to the solution of fragments of fossils. Bioturbation has obliterated the bedding in many places. The sand grains are commonly coated with iron oxide, giving a brown, yellowish-brown, or reddish-brown color to fresh outcrops, especially near the top. The unit is well cemented with silica, and much of the unit is nonglauconitic, noncalcareous, and nondolomitic.

The Ironton Member in northern Sauk County is commonly well exposed in a vertical cliff a few metres high on the face of a conspicuous bench.

Near the top of the cliff in many places is a bed of reddish-brown, dolomitic, glauconitic, poorly sorted, bioturbated, fine to coarse sandstone, roughly 1 m thick. It is a characteristic part of the Ironton bench in this area, and therefore it has commonly been included in the Ironton. Salstrom (1962, section 25), for example, included it in the Woodhill (Ironton) at the Ironton type section. However, it has abundant glauconite like the overlying Tunnel City Formation and has often been considered part of it. Ostrom (1966, p. 61), for example, considered it to be the Birkmose Member of the Tunnel City at the Ironton reference section at the north edge of the village of Ironton.

Similarly, the position of the base of the Ironton Member is commonly obscure, and some geologists place the base higher or lower than others. In some areas the Ironton seems to be gradational with the underlying Galesville, with no obvious stratigraphic break through a zone several metres thick. In other areas, there is an obvious sharp basal contact, commonly corresponding to a scour horizon. Depending on which lithologic characteristic was thought to be most important -- grain size, fossils, bioturbation, or color, for example -- the reported thickness of the Ironton at a given outcrop might vary from geologist to geologist by a factor of two or more. As we have identified it, the Ironton Member is generally a few metres thick in northern Sauk County and less than 1 m thick in southern Sauk County. The Ironton and Galesville are not usually differentiated in drillholes.

Because of the fossils, which are discussed by Twenhofel and others (1935, p. 1703-1704), the Ironton is generally considered to be marine.

According to G.F. Hanson (WGNHS field notes, 1956), a small copper mine or prospect was opened in about 1875 in the NE1/4 SE1/4 sec. 1, T12N, R4E, in the valley of Copper Creek, 3 km northeast of Reedsburg. Malachite and iron-oxide stained sandstone were reported by Hanson at the site, which is near the stratigraphic horizon of the Ironton Member.

Tunnel City Formation

The Tunnel City Group was named for Tunnel City in Monroe County in west-central Wisconsin, 50 km northwest of Sauk County (Ostrom, 1966, 1967). We treat the Tunnel City as a formation (map unit Ꞓt on plate 1) because it is the practical mapping unit in this region -- its subdivisions could not be successfully mapped. The Tunnel City was named to replace the older name, "Franconia formation," which could be confused with the term Franconian Stage. This unit has been recognized in southern Wisconsin, Michigan, Illinois, Indiana, Minnesota, and Iowa. The Tunnel City Formation has two main subdivisions, the glauconitic Lone Rock Member and nearly nonglauconitic Mazomanie Member (Odom, 1978a). The Lone Rock Member makes up all of the Tunnel City Formation in southwestern and southeastern Wisconsin; in much of south-central Wisconsin, the Mazomanie Member is a wedge in the middle of the Lone Rock Member; and along the crest of the Wisconsin Arch, the Tunnel City Formation consists largely of the Mazomanie Member, in places overlain by a thin Lone Rock Member (Ostrom, 1966, figs. 11 and 12).

The type section of the Lone Rock Member is south of the village of Lone Rock, in the Wisconsin River bluff between UTM coordinates 727,400mE, 4,782,900mN and 727,800mE, 4,782,700mN, just west of the southwest corner of Sauk County (Ostrom, 1966, 1967; Ostrom, however, named it a formation). The Mazomanie Member was named by Ulrich (1920, p. 74), but the name was not widely used until revived by Berg (1954). Berg implied that the type section is at Ferry Bluff in southeastern Sauk County, north of the Wisconsin River near the village of Mazomanie, because the Mazomanie Formation is best exposed there and because this section was mentioned by Ulrich in his original description (probably at UTM coordinates 271,600mE, 4,790,700mN; also described by Twenhofel and others, 1935, p. 1724). Odom (1978b, p. 121), however, considered School House Bluff at the southeast edge of the village of Mazomanie to be the type section (also described by Ostrom, 1978a). We consider the Ferry Bluff section to be the type section.

The Tunnel City Formation in Sauk County is typically between 30 and 45 m thick (plate 2). It is largely sandstone and sand, much of which consists of fine sand, with some very fine sand and a smaller amount of medium sand. The Tunnel City is coarsest at its base, just above the top of the Wonewoc Formation. Detrital grains are composed primarily of quartz, with some feldspar. The Lone Rock Member contains a few percent to a few tens of percent glauconite; the Mazomanie Member generally contains no more than a trace. The detrital grains typically appear rather angular. Dolomitic sandstone, and rarely, sandy dolomite beds occur, especially near the base of the formation; the dolomite grains are commonly medium sand to coarse sand in size. Rip-up clasts are present. Planar bedding and cross-bedding are present, with trough-shaped sets typically a few tens of centimetres thick. The formation is slightly fossiliferous, and burrows are generally present.

The Lone Rock Member generally is olive to light olive gray; the Mazomanie Member is commonly pale brown in fresh outcrop. Most of the formation is poorly lithified or unlithified. Natural outcrops are rare in most places, although natural cliffs (generally the Mazomanie Member) are present in some parts of southern Sauk County, especially in bluffs northwest of the village of Prairie du Sac, between the village of Spring Green and Loddes Mill, and in the Denzer and Black Hawk area. Where exposed in roadcuts, the unit has an irregular, lumpy outcrop appearance. Many parts of the formation have calcareous or dolomitic cement.

Previous geologic reports have used a variety of other member names in the Tunnel City Formation. The Mazomanie Member is approximately equivalent to the "Yellow Sandstone" of Twenhofel and Thwaites (1919) and the "Hudson member" of Twenhofel and others (1935). Twenhofel and Thwaites (1919) referred to the Lone Rock Member, from bottom to top, as the "Basal Beds" (which included the Ironton), "Micaceous Shale," "Lower Greensand," and "Upper Greensand." Twenhofel and others (1935) changed the Basal Beds, Micaceous Shale, and Lower Greensand to the "Goodenough member," and they changed the Upper Greensand to the "Bad Axe member." Berg (1954) changed the Basal Beds above the Ironton to the "Birkmose member," the Micaceous Shale to the "Tomah member," and the Lower Greensand and Upper Greensand to the "Reno member." His Birkmose member in Sauk County is generally less than 1 m thick. In northern Sauk County, the Birkmose can probably be differentiated from the Reno member by being coarser and by the presence of the intervening few metres of Tomah "shale," which is thin-bedded, nearly nonglauconitic, quartzose sandstone composed of very fine to fine sand, with thin partings of micaceous shale, underlying the topographic bench above the Ironton-Birkmose cliff.

The Mazomanie Member makes up most of the formation in eastern Sauk County, but it is largely replaced by the Lone Rock Member in the western part of the county. The contact with the underlying Wonewoc Formation is generally sharp and easily recognized. The Tunnel City Formation is readily distinguished from most exposed parts of the Elk Mound Group in Sauk County by its finer grain size and more angular grains; however, the bottom few metres of the Tunnel City (Berg's Birkmose member) in some places is similar to the Elk Mound in this respect. The Lone Rock Member is distinguished from most of the Elk Mound by its glauconite. The Mazomanie Member is easily distinguished from most of the outcropping Elk Mound Group by its browner outcrop color and more irregular outcrop appearance.

The presence of sparse fossils throughout the Tunnel City Formation indicates that it was deposited in a marine environment (Dalziel and Dott, 1970). Sauk County during the Cambrian Period, with the Baraboo Hills rising above sea level, is shown in figure 10.

St. Lawrence Formation

The St. Lawrence Formation was named for St. Lawrence in southeastern Minnesota, 300 km northwest of Sauk County (Winchell, 1874). It has been identified in southern Wisconsin, Minnesota, Illinois, Michigan, and Iowa. St. Lawrence nomenclature has changed considerably since it was first named (Nelson, 1956, fig. 2). At this time, the formation, which is about 10 m thick, is commonly considered to have two subdivisions: the lower Black Earth Member (dolomite) and the upper Lodi Member (siltstone). In the past, the St. Lawrence interval was often lumped together with part or all of the overlying Jordan interval and called the "Trempealeau formation" (or group). When this was done, the Trempealeau was generally subdivided into three members (or formations): the "St. Lawrence member" (equivalent to the present Black Earth Member), the "Lodi member," and the "Norwalk member" or

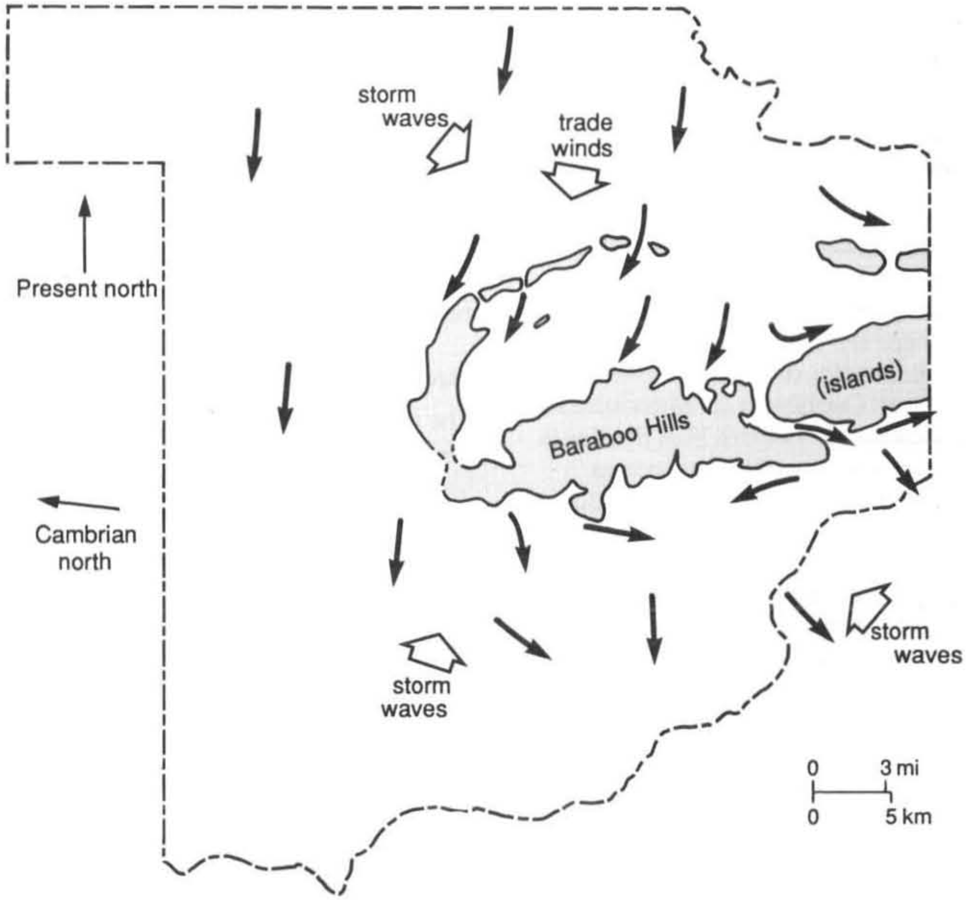


Figure 10. *Sauk County during the Cambrian, when the lower part of the Tunnel City Formation was being deposited, showing probable ocean currents (small arrows), wind, and waves around the Baraboo Hills, which were then islands. The area was then at about 10° south latitude and was rotated about 90° counterclockwise relative to present orientation. Modified from Dalziel and Dott (1974, fig. 3).*

"Jordan member." (The Norwalk is now considered to be a member of the Jordan Formation.) The term Trempealeau formation is no longer used because of possible confusion with the term Trempealeauan Stage. The Black Earth Member was also occasionally referred to as the "Mendota member" (Nelson, 1956, p. 167). In addition, some material under the Black Earth Member has sometimes been included in the St. Lawrence (or Trempealeau) Formation; glauconitic sandstone (commonly with rip-up clasts) is now generally included in the Tunnel City Formation, but nonglauconitic siltstone has been considered to be either an additional member (Arcadia) of the St. Lawrence Formation or part of the Lodi Member, which is thought to interfinger with the Black Earth (Nelson, 1956).

The Black Earth Member was named by Ulrich (1916, p. 477) after the village of Black Earth in Dane County, 10 km southeast of Sauk County. We have seen the Black Earth dolomite in only a few places in the county and therefore cannot adequately characterize it in this area. The Black Earth dolomite occurs on the topographic bench at or near the base of the St. Lawrence Formation. The Black Earth Member apparently interfingers with the Lodi Member; dolomite and siltstone are interbedded with each other in some sections (Wanenmacher, 1932; Boebel, 1950; Nelson, 1956). The Black Earth dolomite is apparently absent in some northern parts of the county and thickens to no more than a few metres in the southern part. The dolomite contains varying amounts of quartzose and glauconitic silt and very fine sand.

It is commonly described as being shades of gray or brown, with purple stains in some places. Fossil algal structures occur in some exposures (for example, at the "old Wood's Quarry" [Dalziel and Dott, 1970, p. 46, 123], in the SW1/4 sec. 10, T11N, R6E, 3 km southwest of the city of Baraboo).

The Lodi Member was named by Thwaites (1923, p. 547). According to Thwaites (verbal communication to Junemann, 1951, p. 4), the type section is either near the village of Lodi, 10 km southeast of Sauk County, or at Loddes Mill Bluff, in southeastern Sauk County, at UTM coordinates 272,200mE, 4,793,300mN. Loddes Mill Bluff was considered to be an appropriate type section because until recently it was labeled Lodi Mill Bluff on U.S. Geological Survey topographic maps. According to Junemann (1951), the Loddes Mill section was preferred because it is a better exposure. The Lodi Member has been recognized throughout southern Wisconsin and in Iowa, Michigan, and Minnesota.

The bulk of the St. Lawrence Formation (map unit **Ꞓs** on plate 1) consists of the Lodi Member. The top and bottom of the Lodi Member are poorly exposed, and they were observed together in only a few places. However, we have the impression that the unit is typically about 10 m thick in Sauk County (plate 2). The Lodi Member consists primarily of siltstone that is pale yellow (2.5Y 7/4 on the Munsell scale) in fresh outcrop. It has uniform planar bedding no more than a few centimetres thick, commonly with small bedding-plane irregularities, including animal trails. The grains are probably primarily quartz and feldspar. In a few places the unit is stained with various shades of red. In addition, gray shale and beds of sandstone composed of very fine sand are present. The siltstone is commonly dolomitic and has evidence of bioturbation on bedding planes. Rip-up clasts are locally present. Well preserved fossils occur in some places; as a result, the Lodi is considered to be marine.

Although the siltstone is hard, it rarely occurs in natural outcrop. It is usually seen in roadcuts and in borrow pits. The Lodi Member occurs on gentle slopes below the Jordan cliff and above the Black Earth bench.

The Lodi Member is easily distinguished from the underlying Black Earth Member because it is siltstone rather than dolomite. It is easily distinguished from the Tunnel City Formation because the characteristic pale yellow of the siltstone is seldom seen in the Tunnel City and because the Tunnel City has little siltstone, is much more irregularly bedded, and commonly contains glauconite.

We rarely observed the base of the St. Lawrence Formation in Sauk County, but it appears to be abrupt.

Jordan Formation

The Jordan Formation was named for Jordan in southeast Minnesota, 300 km northwest of Sauk County (Winchell, 1872). It has been identified in southern Wisconsin, Minnesota, Iowa, and Illinois. Jordan nomenclature has changed through the years (Nelson, 1956, fig. 2; Odom and Ostrom, 1978). It is now generally considered to have two major subdivisions: the lower part is the Norwalk Member and the upper part is the Van Oser Member. In the past, the Norwalk has occasionally been excluded from the Jordan, with the name Jordan being restricted to the Van Oser. The Norwalk Member was named for the village of Norwalk in Monroe County in west-central Wisconsin, 35 km northwest of Sauk County, and the Van Oser Member was named for Van Oser Creek in southeastern Minnesota, 300 km northwest of Sauk County.

In addition, the Sunset Point Member (previously called Madison member) occurs near the top of the Jordan Formation in Dane County, but it has not been identified in Sauk County; in the past it was often considered a separate formation overlying the Jordan Formation. The Coon Valley Member has been considered the uppermost member of the Jordan, overlying the Van Oser and Sunset Members (Odom and Ostrom, 1978), but we have included Coon Valley lithologies in the Oneota Formation.

In Sauk County, we have been unable to consistently distinguish the Norwalk and Van Oser Members; we mapped them together as the Jordan Formation (unit **Ꞓj** on plates 1 and 2), which consists of about 20 m of quartzose sandstone. Regionally, the two members are distinguished by grain size: the Norwalk contains fine sand, with some very fine and medium sand, and the Van Oser contains medium sand, with some fine and coarse sand. In addition to quartz grains, the Norwalk Member contains considerable feldspar (Odom and Ostrom, 1978). The contact between the two members appears abrupt in many places.

Scattered thin beds of greenish-gray shale occur at various levels in the formation in a few places. The Jordan sandstone generally is nonglauconitic and is commonly noncalcareous and nondolomitic. Evidence of bioturbation is present in some places, and the Jordan is therefore considered to be marine. The sandstone has both planar and cross-bedding.

In some fresh outcrops, the sandstone is white, but in most it has been stained with various shades of brown. Much of the sandstone is moderately well cemented and forms a cliff around the Oneota uplands, but some parts are poorly cemented. The brink of the cliff is held up by about 1 m of sandstone that is so well cemented by silica that it breaks across the sand grains. In the geologic literature of the region, this material has often been called clinkstone. It is here considered to mark the top of the formation.

The top of the Jordan Formation is well exposed, but the bottom was seen in only a few places. Where seen in Sauk County, the contact with the underlying Lodi Member is abrupt. The Jordan is generally easily distinguished from the Lodi, which consists of siltstone rather than sandstone. The Jordan sandstone resembles Mazomanie sandstone. In Sauk County the Mazomanie has a more irregular outcrop appearance, generally has a trace of glauconite, has more conspicuous cross-bedding, and is more burrowed. Where the Lodi is unexposed, the Lodi-Jordan contact has been drawn at the base of the steep slope surrounding the Oneota uplands (plate 1).

Oneota Formation

The Oneota Formation of the Prairie du Chien Group was named after the Oneota River, now called the Upper Iowa River, in northeastern Iowa, 120 km west of Sauk County (McGee, 1891, p. 331-332). The formation has been recognized in southern Wisconsin, Michigan, Illinois, Iowa, and Minnesota.

In Sauk County, the Oneota Formation generally consists of several metres of hard dolomite with grain sizes in the very fine-sand to medium-sand grades. Some quartz sand is present near the base. The dolomite generally ranges from very pale brown to light brownish gray on fresh outcrop. White chert nodules and beds occur at various levels. Oolitic dolomite and chert are commonly present near the base of the unit, and fossil algal structures are common (Adams, 1978). Cavities filled with red clay can often be seen on quarry walls.

The contact with the underlying Jordan Formation is abrupt and marks a distinct change in lithology from nonalgal, noncherty, nonoolitic sandstone to algal, cherty, oolitic dolomite. Although the lower Oneota does contain some sandy beds, they are unlikely to be confused with Jordan sandstone in Sauk County. Elsewhere in the region, members have been designated to include the sandy beds at the base of the Oneota, including the Hickory Ridge Member (Raasch, 1952, p. 87-88), Stockton Hill Member (Davis, 1970, p. 38-39), and the Coon Valley Member (Odom and Ostrom, 1978, p. 26-27). Although the Coon Valley was defined as the upper member of the Jordan Formation, we have included Coon Valley lithologies in the Oneota Formation.

The Oneota Formation occupies high plateaus in western Sauk County. In the northwestern part of the county, the Oneota commonly thins and ends somewhere behind the plateau brink; map unit **Oo** includes many areas where the clay of the Rountree Formation rests directly on the Jordan Formation. In the southwestern part of the county, the Oneota maintains a considerable thickness almost to the plateau brink. The lowermost several metres of the unit is exposed in roadcuts through the plateau edges and in several dozen quarries, most of which occur near the edge of plateaus. The highest parts of the formation were seldom observed because they are covered in most places with clay of the Rountree Formation (and in some places with sand or sandstone of the St. Peter Formation). The Oneota Formation is probably no more than about 25 m thick in Sauk County (plate 2).

St. Peter Formation

The St. Peter Formation of the Ancell Group was named for the St. Peter River (now called the Minnesota River) in southern Minnesota, 270 km northwest of Sauk County (Owen, 1847, p. 169-

170). The formation occurs in southern Wisconsin, Minnesota, Illinois, Iowa, Michigan, Indiana, Kentucky, Missouri, Nebraska, Kansas, Arkansas, and Oklahoma (Mai and Dott, 1985). In Sauk County (map unit **Os** on plate 1), the formation has two recognizable subdivisions -- the lower Readstown Member and the upper Tonti Member.

The Readstown Member was named for the village of Readstown in southwestern Wisconsin, 45 km west of Sauk County (Ostrom, 1967) and is equivalent to the Kress Member of the St. Peter Formation in Illinois. In Sauk County, material thought to belong to the Readstown Member consists of a few metres of breccia composed of pebbles, cobbles, and boulders of sandstone resembling that in the overlying Tonti Member. The matrix consists of sand, silt, and clay. Bedding is irregular and erratic, in places dipping at high angles, indicating mass movement or collapse. Fracture-block mosaics were seen in several outcrops, indicating that the sandstone moved a short distance after deposition and was then fractured, and small faults commonly cut across the bedding. Shiny slickensided surfaces coated with dark-red iron oxides are common at most outcrops. The sandstone is commonly white, but the many parts of the breccia have been irregularly stained a variety of colors, some bright. Bands of nearly black ironstone a few centimetres thick are common; they cut across bedding and through boulders.

Readstown breccia has been observed at several dozen places in Sauk County, but nowhere are the occurrences known to be large enough to map at the scale of plate 1. Most occur near the edge of the Oneota uplands, on the lowermost Oneota dolomite or on the uppermost Jordan sandstone. The best exposure we saw in Sauk County is a roadcut where the Ela Valley Road crosses the edge of the Oneota plateau, 6 km southwest of Loganville, at UTM coordinates 737,870mE, 4,807,980mN.

The Readstown breccia and ironstone in Sauk County were first described in a discussion of Cambrian iron ore in southern Wisconsin by Strong (1882, p. 53-56). He listed eight iron-ore prospects in the county, with analyses indicating as much as 59 percent iron. His locations are imprecise, but they all seem to be at the edge of the Oneota upland, with the exception of the Ironton Mine, and they are all probably in the Readstown Member.

The Ironton Mine is 1.5 km southeast of the village of Ironton, on the east side of the valley of Furnace Creek (named for the blast furnace that was once there), at UTM coordinates 731,850mE, 4,823,350mN. It is an open pit about 75 m across. The mine was worked from about 1850 to the 1880s or 1890s (Cole, 1918, p. 33, 89-91, 543-543). According to Strong (1882, fig. 8, p. 54), it produced about 10,000 Mg of iron up to 1873, and the ore is in a body of breccia or conglomerate composed of irregular blocks of sandstone with no signs of stratification. The pit is near the level of the contact between the Jordan and St. Lawrence Formations, but the material here presumably is in the Readstown Member; if so, the unconformity beneath the Readstown is stratigraphically lower than usual.

The sub-Readstown unconformity was recognized more than a century ago (Strong, 1882, p. 82; Thwaites, 1961). Its position ranges from near the base of the Oneota Formation to more than 20 m above the base in much of Sauk County, but it may be 15 m below the base at the Ironton Mine.

The material in the Readstown Member has been interpreted several ways (Dury and Knox, 1971; Flint, 1956; Grether, 1977; Habermann, 1978; Hart, 1963; Thwaites, 1961): a residual deposit or a subaerial deposit developed from residuum before the Tonti Member was deposited, a karst collapse deposit formed before or after the Tonti sandstone was deposited, and a duricrust formed during the middle part of Cenozoic Era.

The Tonti Member was named for Tonti Canyon in northern Illinois, 220 km southeast of Sauk County (Templeton and Willman, 1963, p. 45-46). The Tonti Member makes up most of the St. Peter Formation. In Sauk County the Tonti consists of several metres of fine to medium sand composed largely of quartz; it is noncalcareous, nondolomitic, and nonglauconitic. The grains, especially the coarser ones, tend to be rounded, but in many places the grains are covered with faceted quartz overgrowths, producing a conspicuously sparkly outcrop surface. The sandstone generally ranges from very pale brown to yellowish red in fresh outcrop. Where observed in outcrop, the sandstone is hard because of silica cement.

We saw boulders of Tonti sandstone on many parts of the Oneota upland. Most are probably lag from former Tonti occurrences, but some may mark unrecognized occurrences of in-place Tonti.

Outcrops of probable in-place Tonti sandstone were seen in only a few places. Natural outcrops occur in and adjacent to the NE1/4 NE1/4 SE1/4 sec. 2, T10N, R4E, 5 km northwest of Leland, where several metres of sandstone rests on Baraboo quartzite, 15 to 25 m above the base of the Oneota Formation along Highway PF, 0.5 km to the southeast.

Sandstone occurs in a roadcut near the junction of Ela Valley Road and Friendship Drive at UTM coordinates 737,820mE, 4,808,630mN, 5 km southwest of Loganville. It is about 10 m above the base of the Oneota Formation in the area, indicating that it is part of the St. Peter rather than the Jordan Formation.

St. Peter sandstone is exposed around the east, south, and west edges of Pine Bluff in SE1/4 sec. 25, T12N, R7E, 9 km east of Baraboo. The tallest outcrops occur on the southwest side of the bluff. According to J.M. Wanenmacher (1931 field notes in WGNHS files), 25 m of St. Peter sandstone occurs here, and the base of the Oneota Formation around the north end of the bluff is about 40 m below the top of the St. Peter outcrop.

Stanley A. Tyler (unpublished WGNHS Road Materials Investigation Report 1028, p. 135) reported outcrops of St. Peter sandstone on a small knob on the Oneota plateau in the SE1/4 NE1/4 NW1/4 sec. 22, T9N, R4E. The sandstone there is about 20 m above the base of the Oneota Formation.

Large outcrops of Tonti sandstone occur 3 km west of Sauk County, on an east-west ridge in the SE1/4 NE1/4 sec. 22, T13N, R1E. In addition, nearly in-place masses of Tonti sandstone were seen at some of the Readstown sites mentioned above.

Parfreys Glen Formation (new)

The Parfreys Glen Formation is here named for Parfreys Glen, a small valley on the south flank of the Baraboo Hills, 8 km southeast of the city of Baraboo (the type section is discussed in a later paragraph). The Parfreys Glen Formation consists largely of sandstone, but it is conspicuously

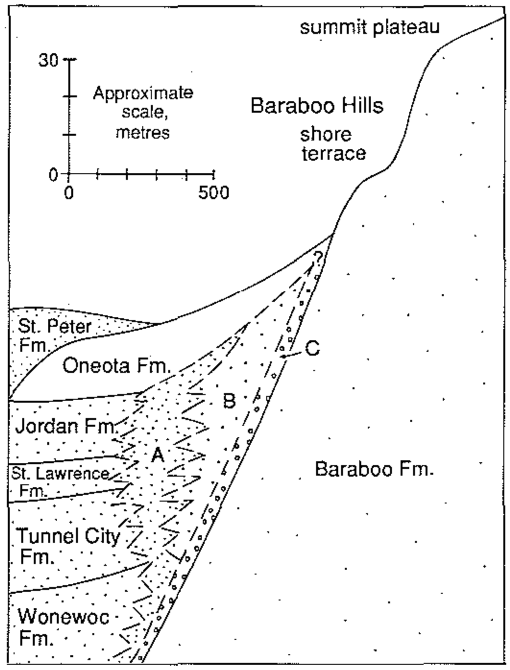


Figure 11. *Relationships (diagrammatic and generalized) between the sandstone (A), conglomeratic sandstone (B), and talus conglomerate (C) of the Parfreys Glen Formation and the adjacent formations.*

conglomeratic in many areas (fig. 11). The formation is nearly the same as the "undifferentiated quartzite conglomerate and conglomeratic sandstone facies" of Dalziel and Dott (1970, plate 1), but the Parfreys Glen also includes some sandstone with little or no conglomerate. The sandstone contains very fine to very coarse sand that is primarily quartz and is generally noncalcareous and nondolomitic. Most is nonglauconitic. The grains are generally not well rounded. Burrows of marine organisms are present in some areas. Color is variable, ranging from white through various shades of brown, gray, and yellow in fresh outcrop.

Most parts of the formation are very hard, with abundant quartz cement, causing the rock to break through the grains, but some parts are fairly soft. The conglomerate consists of pebbles, cobbles, and boulders (some several metres across) derived from nearby cliffs of Baraboo quartzite. The coarsest conglomerate next to the cliffs (fig. 11C) consists of angular fragments of quartz, but the conglomeratic sandstone, which is most widespread above the level of the Wonewoc Formation (fig. 11B), contains rounded fragments. The conglomerate has been described in detail by Dalziel and Dott (1970, p. 54-58, plate 6) and Dott (1974).

The surface occurrence of the Parfreys Glen Formation is a band as wide as 2 km on both sides of the North and South Ranges of the Baraboo Hills (unit Ꞓp, plates 1 and 2). It is generally no more than a few tens of metres thick (plate 2). At the stratigraphic level of the Wonewoc Formation, the Parfreys Glen Formation extends outward only a few tens of metres from the Baraboo quartzite but it extends outward hundreds of metres at the level of the Tunnel City, St. Lawrence, and Jordan Formations, and it appears to be narrower again or absent at the level of the Oneota Formation (fig. 11; plate 2). At the level of the Tunnel City Formation and the lower part of the St. Lawrence Formation, the Parfreys Glen Formation apparently is wider on the north side of the North Range and on the south side of the South Range than between the two ranges. The Parfreys Glen Formation may also include material at and above the stratigraphic level of the St. Peter Formation; small outcrops of conglomerate have been found at Paleozoic shore bluffs nearly as high as the crest of the Baraboo Hills (discussed in next section). Conglomerate is commonly reported in the logs of wells that penetrate through the Mount Simon Formation to the Precambrian rock; the Parfreys Glen Formation is here considered also to include conglomerate at the level of the Mount Simon and Eau Claire Formations (plate 2). The present intent is to restrict the formation to the area of the Baraboo Hills, but in the future it may become appropriate to extend it beyond this area.

The presence of pebbles of Baraboo quartzite is not in itself an infallible criterion for recognition of the Parfreys Glen Formation; parts of it lack quartzite pebbles, and quartzite pebbles are present in parts of the Wonewoc, Tunnel City, St. Lawrence, Jordan, and St. Peter Formations, especially south of the Baraboo Hills (Dalziel and Dott, 1970, p. 54-58). In many places, the pebbles in combination with the quartzite-like cementation can be used to distinguish the Parfreys Glen Formation from the other Cambrian formations. However, we generally mapped it (plate 1) where the Wonewoc, Tunnel City, St. Lawrence, and Jordan Formations become unrecognizable next to the Baraboo Hills. Through most of the county, these formations maintain a consistent sequence of distinctive lithologic types, each with a characteristic topography. Near the Baraboo Hills, the lithology and topography of each formation changes so that the formations are no longer separately distinguishable -- this is considered to be the boundary with the Parfreys Glen Formation. The Parfreys Glen Formation generally has rounded topography much like that of the Baraboo quartzite, lacking the stratigraphic benches that are characteristic of the Paleozoic sequence away from the Baraboo Hills or having small local benches that cannot be correlated with those away from the hills.

Irving (1877, p. 536-539) suggested that the material we include in the Parfreys Glen Formation (he called it "older sandstone") might lie unconformably below material we include in the Wonewoc and Tunnel City Formations (his "newer sandstone") and in the St. Lawrence, Jordan, and Oneota Formations. Alden (1918, p. 77-78) was inclined to agree with this interpretation. A major unconformity exists under the Parfreys Glen Formation, but scattered fossils indicate that at least part of the sandstone and conglomeratic sandstone in the Parfreys Glen Formation is chronologically equivalent to the Tunnel City, St. Lawrence, and Jordan Formations. Raasch (1935, fig. 225, p. 410, 413), for example, considered sandstone of the Parfreys Glen Formation at "Alps Farm" on the east side of the Devils Lake gorge to be the age equivalent of the Jordan sandstone. In addition, Wanenmacher and others (1934) and Raasch (1935, p. 408), among others, apparently saw outcrop relationships indicating that at least part of the Parfreys Glen Formation is interbedded with the Tunnel City, St. Lawrence, and Jordan Formations. Dalziel and Dott (1970, plate 1, map unit Ꞓu) were the first to map the material here considered to be the Parfreys Glen Formation; they referred to it as an undifferentiated conglomeratic facies chronologically equivalent to the Wonewoc, Tunnel City, St. Lawrence, and Jordan Formations.

Nevertheless, outcrops are inadequate in most places to demonstrate interfingering of the Parfreys Glen Formation with the other Cambrian formations. The coarser conglomerate is generally in the form of angular talus lying against a cliff of Baraboo quartzite, and the smaller rounded fragments have been washed away from the cliff face and interbedded with the sandstone. It is likely that the talus is considerably older than the adjacent sandstone.

The causes of these lithologic and topographic differences between the Parfreys Glen Formation and the other Cambrian formations are unclear. It is obvious that conglomerate is present in the Parfreys Glen Formation because it was derived from the nearby Baraboo Hills. Perhaps other characteristics of the Parfreys Glen Formation are also the result of its local source. Ostrom (1966, p. 72-73) argued that the disaggregation of the quartzite at the La Rue Quarry (discussed below) suggests a source for the local Cambrian sandstone. Wanenmacher and others (1934, p. 29-30) and Dalziel and Dott (1970, p. 43, 44, 128), however, argued that the quartz and heavy minerals are petrologically different from those in the Baraboo quartzite, indicating a more distant source.

The Parfreys Glen Formation is well exposed in a few places. A section described by Dalziel and Dott (1970, p. 139-142, fig. 40; see also Dott and Byers, 1980, p. 50-51, fig. 25) is here designated the type section. It is in Parfreys Glen, a Wisconsin Department of Natural Resources Natural Area in the SE1/4 NE1/4 sec. 22, T11N, R7E, 8 km southeast of Baraboo. About 30 m of Parfreys Glen sandstone is exposed along the canyon walls. Layers of rounded pebbles, cobbles, and boulders, with a maximum diameter of about 1 m, are interbedded with the sandstone, which dips southward several degrees off the Baraboo Hills.

Another good exposure, which has been described by Dalziel and Dott (1970, p. 131, fig. 35), is at UTM coordinates 261,370mE, 4,805,550mN, on the north side of Hemlock Draw, in a Nature Conservancy preserve 3 km north of Leland. About 50 m of sandstone and conglomerate can be seen dipping gently southward off the south flank of the Baraboo Hills. Boulders that are several metres across are present in a few places. The Parfreys Glen Formation here crops out at the level of the Wonewoc through Jordan Formations. The Wonewoc Formation outcrops on the south side of Hemlock Draw (plate 1), indicating that the Parfreys Glen Formation is no more than about 0.3 km wide between the Baraboo and Wonewoc Formations, but it is about 1 km wide at higher levels.

Dalziel and Dott (1970, p. 124-127) and Ostrom (1966, p. 72-73; 1978b) described an exposure that is on private property in the northeast part of the La Rue Quarry, in the SE1/4 NW1/4 NW1/4 sec. 22, T11N, R5E, 5 km southwest of North Freedom. A few tens of metres of Parfreys Glen sandstone lies on several metres of Parfreys Glen talus breccia dipping northward at about 30° off the Baraboo quartzite. The talus boulders are as large as 3 m.

Exhumed Paleozoic landforms on the Baraboo Hills

During the Middle Cambrian Epoch, before the Elk Mound Group was deposited, the South Range of the Baraboo Hills stood up more than 300 m above the surrounding plain. In the Late Cambrian, when the last of the Elk Mound Group was deposited, the South Range was half buried. In the Early Ordovician Epoch, when the Oneota Formation was deposited, the top of the North Range was buried. During the Middle Ordovician, downcutting of at least 30 m occurred in a few places, perhaps reexposing parts of the North Range. During the Late Ordovician, when the Sinnipee Group was deposited, the South Range was buried. By the Silurian Period, the top of the Baraboo Hills had been buried by perhaps 100 m of sediment. Later, the Baraboo Hills began to be exhumed; they have been partly reexposed down to the top of the Elk Mound Group in many areas, but only down to the level of the Oneota Formation at the west end.

Some of the landforms now seen on the exhumed Baraboo Hills have been preserved since the Paleozoic. They have been preserved because they were covered by Paleozoic rock through much of that time, but also because the Baraboo quartzite is so resistant to erosion that they have been only slightly modified since they were exhumed. Four general kinds of landforms have been preserved: valleys, plateaus, scarps, and terraces.

The largest valleys in the South Range still contain Parfreys Glen Formation, indicating that their overall shape has changed little since their burial during the Late Cambrian. Examples include Skillet Creek valley, Baxter Hollow, Pine Creek valley, and Herritz Hollow, all of which are in the South Range west of Devils Lake. To a considerable degree, Devils Lake gorge, which cuts through the South Range (discussed later), has also been preserved since the Paleozoic, but it was considerably modified by later erosional processes. Similarly, the Upper and Lower Narrows of the Baraboo River, where the river cuts through the North Range, may also have existed in the Paleozoic, but there is no Paleozoic rock there to prove this.

Flat summit plateaus were described by Thwaites (1935, p. 395, 401-402; 1958, p. 140-141, 145-147; 1960, p. 36-38). The plateaus occur throughout the highest part of the South Range and are shown on plate 1 with a horizontal dashed pattern. Many are roughly 1 km across; the edges of the plateaus are at an elevation of about 430 m (1,410 ft), and their middles are about 10 to 20 m higher. The plateaus consist of Baraboo quartzite overlain by a few metres of yellowish-brown silt and clay with pebbles, cobbles, and boulders of quartzite. This material is probably wind-blown silt with pedogenic clay that has been mixed with frost-shattered fragments of the underlying quartzite as a result of cryoturbation during glacial episodes.

The summit plateaus on the South Range are flanked by steep scarps (figs. 11 and 12). They occur between elevations of about 395 and 430 m (1,300 and 1,410 ft). The bases of the scarps, at an elevation of 395 m (1,300 ft), are marked by terraces that are tens of metres wide, especially on the north or northwest sides of the plateaus. The terraces are indicated on plate 1 by a heavy dashed line. The scarps and the terraces have been described by Thwaites (1935, p. 401; 1958, p. 147-148; 1960, p. 38-39), who also described small deposits of conglomerate, presumably part of the Parfreys Glen Formation, on the scarps and the terraces.

Because of the close association of the terraces with the scarps, Thwaites argued that they are the same age, and he convincingly argued that they were formed by marine wave erosion. We know of no likely alternative explanation. The terraces occur at the same elevation throughout the South Range, and they cut across the steeply dipping Baraboo quartzite, indicating that they are not structural benches. The position of the terraces and scarps around the rim of the valleys indicates that the terraces and scarps formed after the valleys; the erosion that produced the conglomerate of the Parfreys Glen Formation in the valleys should have destroyed any earlier terraces. Because Thwaites thought that the Oneota Formation occurs up to the level of the terrace on the west end of the Baraboo Hills, he suggested that the terrace and scarp formed during the time the Oneota dolomite was deposited. However, we show the Oneota and St. Peter Formations below the level of the terrace on plate 1 (and in fig. 11), and all known outcrops of the Oneota and St. Peter are well below that level. Except for small patches of conglomerate on the terrace (mentioned in the section about the Parfreys Glen

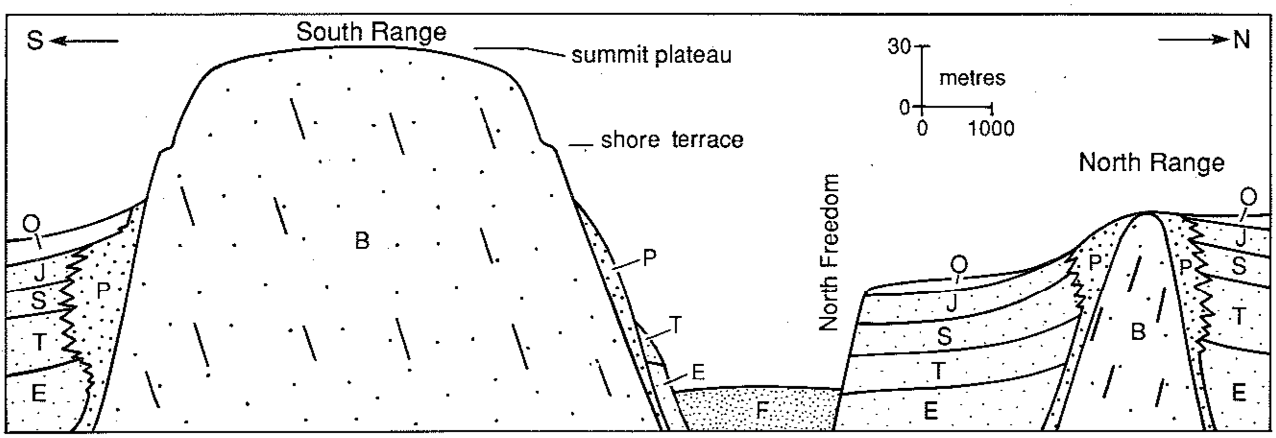


Figure 12. *North-south cross section through the village of North Freedom, showing relationships between the Paleozoic formations and the North and South Ranges of the Baraboo Hills. B: Baraboo Formation; E: Elk Mound Group; T: Tunnel City Formation; S: St. Lawrence Formation; J: Jordan Formation; O: Oneota Formation; P: Parfreys Glen Formation; F: Big Flats Formation.*

Formation), no Paleozoic rock occurs at the level of the terraces and scarps in Sauk County. As a result, it is not possible to date the terraces by tracing their erosion products into formations of known age.

Similarly, Thwaites suggested the summit plateaus were cut by wave action just before the Platteville dolomite (Ordovician) was deposited or when the earliest part of it was deposited across the top of the South Range because they are at about the stratigraphic position of the base of the Platteville Formation, projected into the area from the Blue Mounds, 40 km to the south. We agree that the plateaus are probably younger than the valleys because the plateaus would not have retained their shape if they had formed earlier. If the plateaus were cut by subaerial processes after the valleys formed, this must have happened when the valleys were filled with post-valley sediment or rock -- perhaps of the Parfreys Glen Formation. If the plateaus were cut by wave action after the valleys formed, it must have happened during sea-level change because the plateaus are not flat enough to have formed at a single sea level.

It is less clear whether the plateaus formed before or after the terraces and scarps; however, if the plateaus were cut by subaerial processes and if they formed after the terraces and scarps, these things must have happened when the scarps were buried under post-scarp sediment or rock. If the plateaus were cut by waves, this must have happened before the much fresher-looking shore scarps and terraces were cut -- the plateaus do not seem flat enough to have been cut by waves after the scarps and terraces were cut, unless they were cut during changing sea level.

Wanenmacher (1932, p. 75-76) and Raasch (1958) identified other, less conspicuous shore terraces and scarps at lower elevations on the Baraboo Hills.

Structure of Paleozoic rock

Sauk County is on the crest and west flank of the Wisconsin Arch, a broad, open fold between the Wisconsin Dome to the north, the Michigan Basin to the east, and Forest City Basin to the west (Heyl and others, 1959, fig. 12). In Sauk County the Paleozoic formations dip southward generally 1 to 2 m/km, but this general trend is interrupted by a number of smaller structures, some of which are discussed in the following paragraphs and shown in figures 13 and 14.

The Plum Valley Anticline in the northwestern corner of the county was mapped by Johnson (1947, p. 53). Its axis trends northeast-southwest for several kilometres, and its amplitude is at least 10 m (figs. 13 and 14). Sandstone in the upper part of the Wonewoc Formation can be seen in outcrop to dip several degrees to the southeast in the middle of sec. 4, T13N, R2E. All the Paleozoic formations have been folded, but the amplitude seems slightly greater in the Wonewoc Formation than in the Jordan (figs. 13 and 14; plates 1 and 2).

The La Valle Fault, near the village of La Valle, is at least 15 km long (fig. 13, plate 1). It trends east-west and is slightly curved. The south side is downthrown; the Ironton bench at the top of the Wonewoc Formation is about 10 m higher north of the fault than south. We did not observe the actual fault plane; it is possible that this feature is actually a steep monocline. The contact between the Tunnel City and St. Lawrence Formations seems to be unaffected by the fault.

About 1 km east of Denzer, a syncline of obscure form involves all the Paleozoic formations up through the Oneota (figs. 14 and 15). Dips of 25° to the east-northeast occur along the southwest side of the hill in the middle part of sec. 14, T10N, R5E; Dalziel and Dott (1970, plate 1) noted steep dips east of the hill. The base of the Oneota is about 30 m lower on the south end of the hill than on surrounding hills and about 14 m lower on the south end than on the north end of the hill. Smaller-scale structures in the quarry on the south end of the hill have been described by Dalziel and Dott (1970, p. 135-136); these appear to be penecontemporaneous with the deposition.

Wanenmacher and others (1934, p. 3-4) and Dalziel and Dott (1970, p. 52) recognized an anticlinal structure whose axis is oval in outline and corresponds to the crest of the Baraboo Hills; they measured dips of several degrees away from both sides of the North and South Ranges. For example, an asymmetrical anticline that involves all the Paleozoic formations up through the Oneota occurs 3 km north of the village of North Freedom (figs. 12 and 14). There, the base of the Oneota Formation is at an elevation of about 350 m (1,150 feet) on the north side of the North Range and

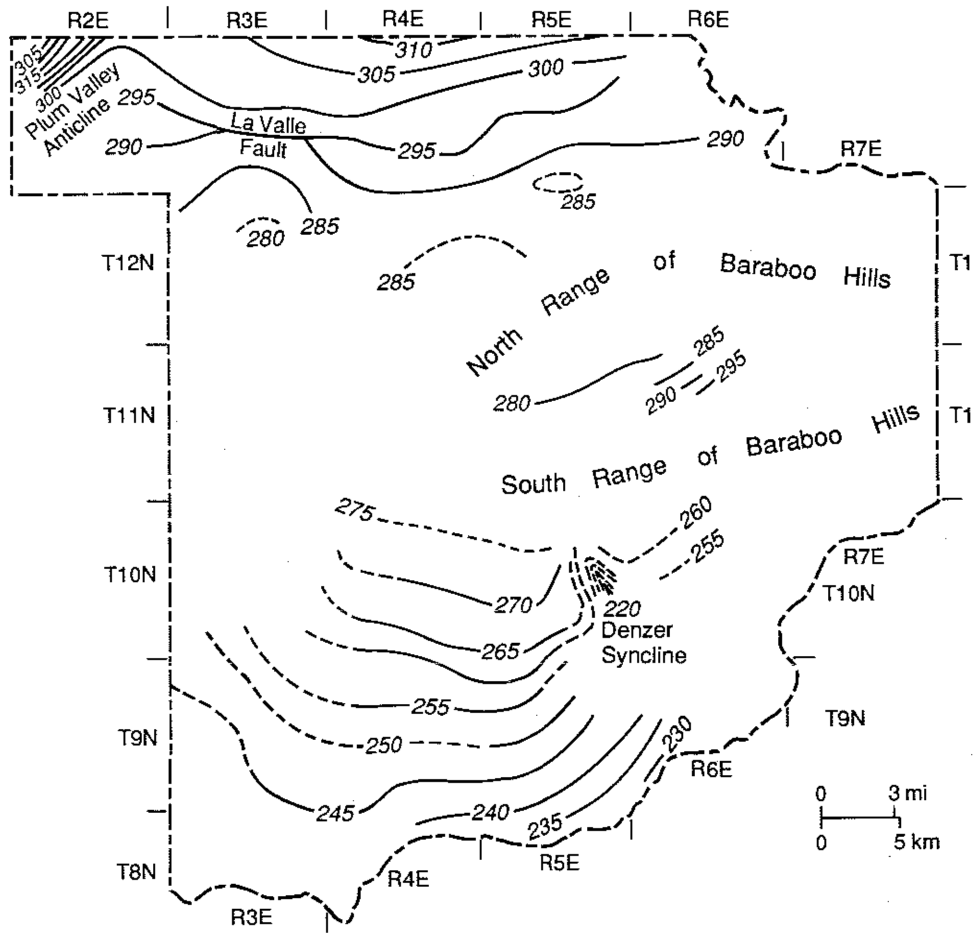


Figure 13. *Contour map showing elevation (in metres) of the base of the Tunnel City Formation, derived largely from the surface distribution of the contact (plate 1). Contour interval 5 m; contour line dashed where uncertain.*

perhaps several metres higher on the crest of the North Range. South of the North Range, the base is at about 320 m (1,050 feet). This structure was considered by these geologists to represent initial depositional dip. However, this dip could be partly tectonic, and at least some of the dip is due to differential compaction over a steeply dipping Precambrian-Cambrian unconformity. Wilson and Sibley (1974) have suggested that the sandstone of the Baraboo area has been compacted as much as 25 percent.

ORDOVICIAN TO PLIOCENE HISTORY

No Paleozoic rock younger than the St. Peter sandstone (Middle Ordovician) has been recognized in Sauk County. However, west Blue Mound, which is 40 km south of the Baraboo Hills, is capped with Silurian rock that is 70 m higher than the top of the Baraboo Hills, indicating that Sauk County was buried under Silurian rock. Similarly, because Devonian, Mississippian, and Pennsylvanian rock is present in the Michigan and Illinois Basins, it is likely that rock of these ages was also present in Sauk County. Much of the Silurian to Pennsylvanian rock was probably eroded during Mesozoic time, but no evidence is known for any post-Ordovician event in Sauk County until the deposition of gravel of the Windrow Formation.

Windrow Formation

The Windrow Formation was named after Windrow Bluff, which is west of Tomah in Monroe County, west-central Wisconsin, 45 km northwest of Sauk County (Thwaites and Twenhofel, 1921).

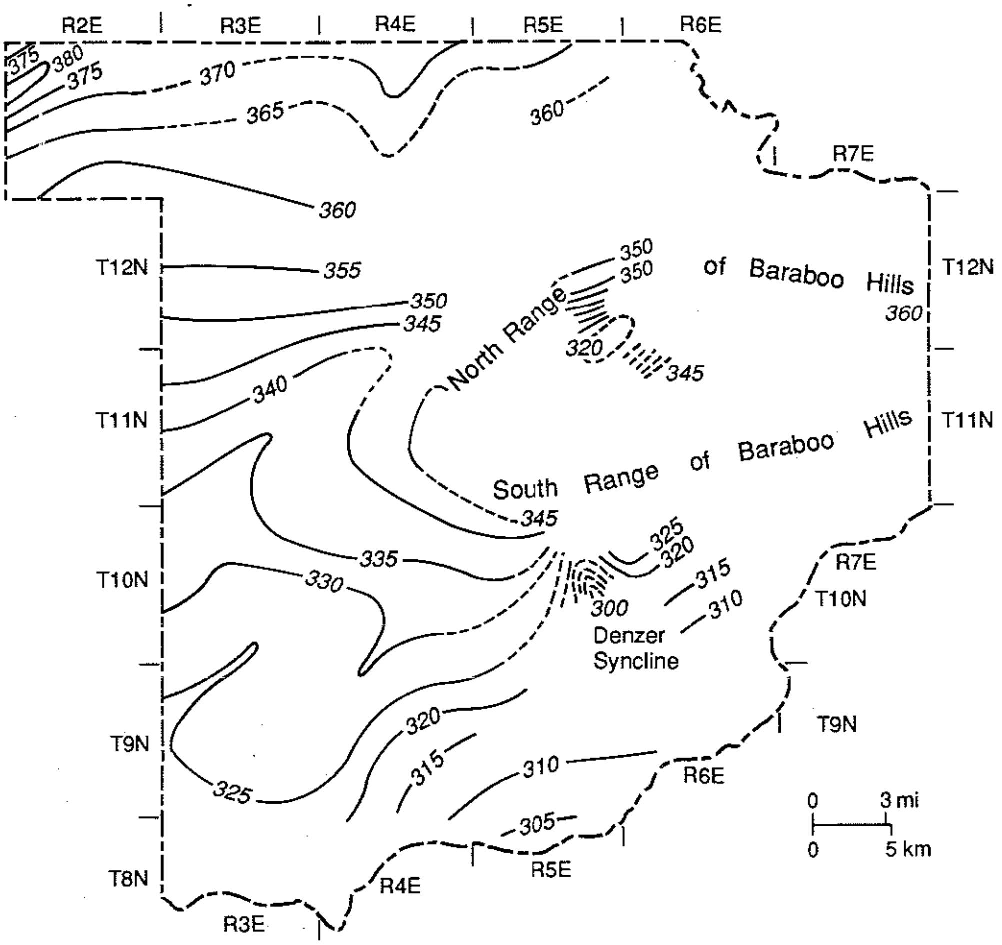


Figure 14. *Contour map showing elevation (in metres) of the base of the Oneota Formation, derived largely from the surface distribution of the contact (plate 1). Contour interval 5 m; contour line dashed where uncertain.*

It occurs as small, isolated bodies of stream gravel on uplands in western and southwestern Wisconsin and in adjacent areas.

The only reported occurrence of supposed Windrow Formation in Sauk County is on East Bluff, on the east side of Devils Lake gorge, near UTM coordinates 279,900mE, 4,810,200mN (Thwaites and Twenhofel, 1921, p. 296). Pebble gravel has been found in potholes scoured into the surface of the quartzite at the top of the bluff (15 to 75 m west of the point where the Potholes Trail crosses the brink of the bluff) and in the side of the gorge as much as 20 m down the Potholes Trail from the brink. However, we have not seen it in place, nor have most geologists who have reported it here. The "Windrow gravel" commonly observed on East Bluff consists of scattered loose pebbles on the surface of the quartzite or lag pebbles in Pleistocene slope deposits. Thwaites and Twenhofel (1921), for example, do not actually state that they saw any in place. Salisbury (1895, p. 657) found "a pint or so" in one pothole, and K.I. Lange (Wisconsin Department of Natural Resources, verbal communication, 1986) collected a pail of gravel from a pothole below the brink. Black (1964) described and mapped "more than a dozen well developed potholes" that are less than 1 m in diameter and depth. If all the observed in-place Windrow Formation occurred in the potholes mapped by Black, its total known volume may have been less than 1 m^3, little of which remains because it has been dug out by the early observers. According to Alden (1918, p. 99), the surface lag here is primarily coarse pebbles or smaller grains of polished chert, many of which

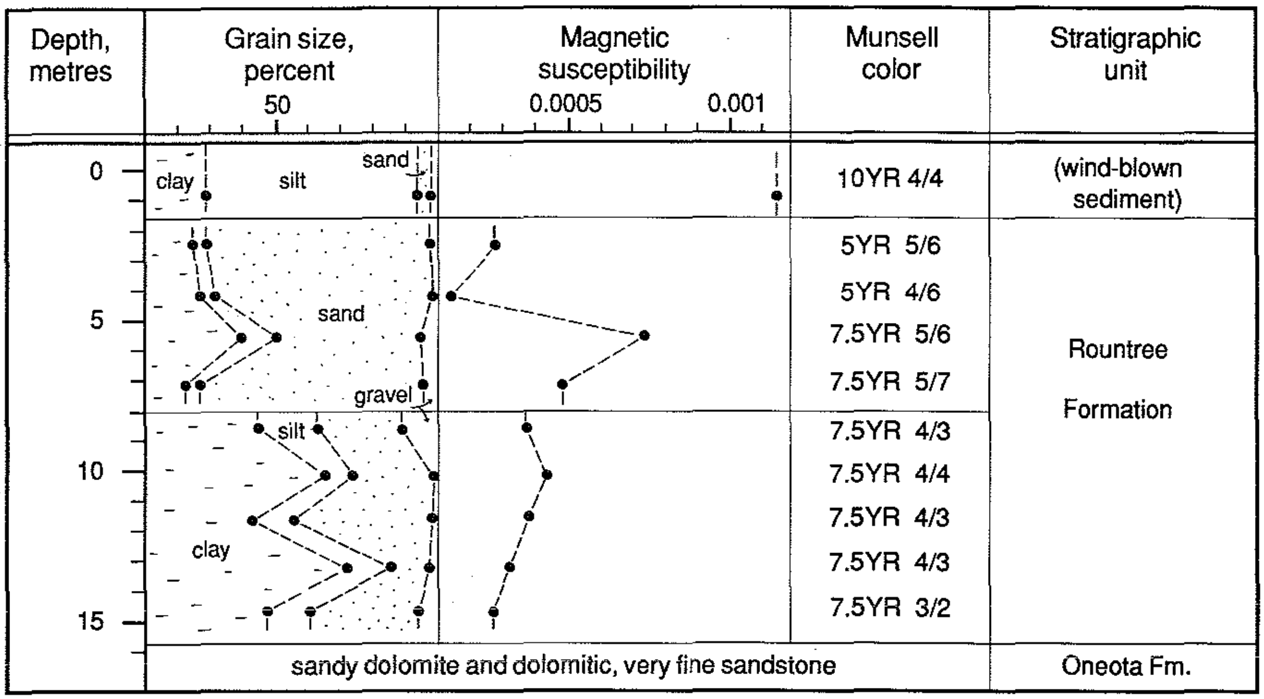


Figure 15. *Reference section of the Rountree Formation (WGNHS Geologic Log SK-286-F); northwest corner of SW1/4 sec. 30, T12N, R4E, 8 km east of the village of Lime Ridge (UTM coordinates 736,690mE, 4,819,100mN).*

are rounded and some of which contain Silurian fossils.

The age of the Windrow Formation reported on East Bluff or elsewhere is unknown. The gravel in the potholes is probably the same age as the potholes; it was deposited by a river that flowed at the level of the bluff top, at an elevation of about 445 m (1,460 ft), and cut down below the bluff top to about 423 m (1,390 ft). This probably occurred when the Baraboo Hills were beginning to be exhumed in Mesozoic or Cenozoic time, and it certainly occurred after the chert was originally deposited in Silurian time.

Thwaites and Twenhofel (1921, p. 307-310) correlated the Windrow Formation with Cretaceous material in Iowa and Minnesota. Others have suggested that the Windrow is Pliocene (discussed by Thwaites and Twenhofel, 1921, p. 308). Andrews (1958) defined a lower "Iron Hill member" of the Windrow Formation, consisting of iron oxide and named for a site in northeastern Iowa, and an upper "East Bluff member" of the Windrow Formation, consisting of sand and gravel and named for the East Bluff of Devils Lake gorge. He correlated his East Bluff member with the Ostrander Member of the Dakota Formation (Early Cretaceous) of southeastern Minnesota. We know of no direct evidence for any of these correlations. Many episodes of river-gravel deposition probably occurred during the Mesozoic and Cenozoic Eras. The Windrow Formation, where identified in the Driftless Area, may be a valid lithostratigraphic unit, but it probably includes material of various ages, and it is unlikely that the material at East Bluff is the same age as the Ostrander Member. Andrews (1958, p. 599, 601) designated no type section for his East Bluff member. It is unlikely that the Windrow Formation was exposed on East Bluff when Andrews was there -- he probably observed Pleistocene sediment containing pebbles eroded from the Windrow. For these reasons, we consider the East Bluff member to be an invalid stratigraphic name.

Black (1964) considered the Windrow gravel on East Bluff to be a glacial-meltwater sediment, deposited during the Late Pleistocene Age. However, this is unlikely because there are no glacial erratics in the gravel and because there is no evidence that the bluff here was ever glaciated or that glacial meltwater flowed across the bluff.

The age of the Windrow gravel reported on East Bluff must be greater than the amount of time required for rivers to remove 250 m of material from Devils Lake gorge and from areas to the north, east, and south of the Baraboo Hills; 250 m is the difference in elevation between the potholes on East Bluff and the base of the Pleistocene fill in the gorge. Anderson (1988, p. 255, fig. 5a) argued that the general surface of the Baraboo region has been lowered that amount since the Pliocene Epoch. However, the general surface of the uplands of western Wisconsin has been lowered little since the deposition of the Hersey till, which, according to Baker (1986), may have occurred as early as the Late Pliocene Age.

Rountree Formation (new)

The Rountree Formation was named after Rountree Branch in Grant County, southwestern Wisconsin, 50 km southwest of Sauk County. (The formal definition of this unit is in the appendix at the end of this report.) The Rountree Formation occurs as a nearly continuous sheet a few metres thick over the Oneota uplands in the western part of the county (map unit **Oo**, plate 1), and it generally occurs on the Prairie du Chien and Sinnipee uplands elsewhere in the Driftless Area.

The Rountree Formation is generally described as clay. According to Gundlach (1980), the Reedsburg, Valton, and Wildale soil series, which occur on the Rountree Formation in Sauk County, at a depth of 1.5 m have B2t horizons consisting of clay with 15 to 35 percent gravel. Where exposed in quarries and roadcuts, it commonly appears to be clay with pebbles, cobbles, and boulders. WGNHS Geologic Log SK-286-F shows 6 m of clayey sand with only a small amount of silt and a trace of gravel overlying 7.5 m of sandy clay with a small amount of silt and gravel (fig. 15). Geologic Log SK-287-F shows 3 m of clayey sand.

All of the gravel and much of the sand consists of angular chert. The chert described in Geologic Log SK-286-F consists of weathered white chert, commonly oolitic, and unweathered dark gray chert. Much of the material described in Geologic Logs SK-286-F and 287-F consists of well rounded, medium sand composed of clear quartz. Fragments of yellowish-red pure waxy clay occur near the base of the sandy clay described in Geologic Log SK-286-F. Generally, bedding can be seen in good exposures in dolomite quarries. Except for the base of the unit where it overlies dolomite, the unit is noncalcareous and nondolomitic.

The Rountree Formation commonly appears to be yellowish red in roadcuts. Geologic Logs SK-286 and 287-F show the upper clayey sand as yellowish red and the lower sandy clay as dark brown.

According to Black (1970b, p. I-4 and I-5), the material here considered to belong to the Rountree Formation averages only a few centimetres thick on the dolomite in the Driftless Area. However, county soil surveys commonly describe more than 1 m of this material on dolomite. In Sauk County it is generally thicker than the depth of roadcuts; in most places Oneota dolomite is not exposed except in quarries and in roadcuts at the edges of uplands. Wisconsin Department of Natural Resources Well Constructor's Reports show 2 to 20 m of red clay on Oneota uplands in Sauk County (with a median value of about 6 m); the average thickness on the uplands is probably greater than the median at these sites, however, because they tend to be near the edges of the uplands, where it is thinnest. At two WGNHS auger sites on the Oneota upland (Geologic Logs SK-286-F and 287-F), it is 3 m and 13.5 m thick. In summary, the Rountree Formation probably averages nearly 10 m thick in the middle of Oneota uplands in Sauk County.

The origin of the material in the Rountree Formation is uncertain. The Rountree Formation overlies Oneota dolomite in most places in Sauk County, and it was not seen below the edge of the Oneota upland. The correspondence between the clay and the dolomite might be considered evidence that the clay was derived from the dolomite; the clay is referred to in county soil-survey reports as "residuum." Some of the clay and much of the chert probably did originally result from the solution of the dolomite; solution left behind the insoluble residue in the dolomite and also the cherty clay that had filled the caves in the dolomite. However, where observed in outcrop, the clay generally shows evidence of down-slope movement, indicating that at least the near-surface part of the unit is not residuum, although it may have been originally derived from residuum. From a study of its clay mineralogy, Frolking (1978) concluded that the clay cannot be unaltered residuum because the mineralogy of the clay and the insoluble residue in the underlying dolomite are significantly different. In Sauk County the Rountree Formation seems far too thick to have been derived solely from the insoluble residue of the Oneota dolomite. Frolking (1978) concluded that much of the clay in the unit in southwestern Wisconsin is of pedogenic rather than residual origin, and that some may have been illuviated from overlying loess. The scarcity of silt in the Sauk County material indicates that little loess was intermixed with clay by slope processes. The source of the well rounded quartz sand, as shown in Geologic Logs SK-286-F and 287-F, is unclear, but the sand was probably transported by slope processes from a nearby sandstone source, most likely from St. Peter sandstone.

Little evidence is available about the age of the Rountree Formation. The relationship between the Rountree and Windrow Formations is unclear; parts of the Rountree Formation could be younger than, the same age as, or older than parts of the Windrow. The base of the Rountree Formation is probably still accumulating today as the underlying dolomite is dissolved. The contact with the overlying loess is sharp, indicating that little hillslope movement has occurred since the last glaciation. The upper part of the unit was probably deposited by soil flowage during the last glaciation and earlier glaciations, but the scarcity of silt in most of the unit (fig. 15), indicates that little loess has been intermixed, suggesting a pre-Pleistocene age for much of it. Geologic Logs SK-286-F and 297-F are from auger holes on or near local drainage divides; the clayey sand at these sites is a hillslope deposit, but there are now no higher hillslopes it could have been derived from, indicating that it formed before the topography there assumed its present shape.

In summary, the top and bottom of the Rountree Formation probably accumulated during the last part of the Cenozoic, but the bulk of the unit (middle part) is more likely to have accumulated earlier, perhaps during the middle part of the Cenozoic or even the early part of the Cenozoic.

The Rountree Formation is unlikely to be confused with any unit other than the Readstown Member of the St. Peter Formation and the "Iron Hill member" of the Windrow Formation. The Readstown Member is similar but much older. By definition, the material above the Tonti Member of the St. Peter Formation is the Rountree Formation; the material below, the Readstown Member. In Sauk County, the two units are easily confused with each other where the Tonti Member is missing. Although chert fragments are considered by others to be characteristic of the Readstown Member, where we saw it below the Tonti Member in Sauk County, chert is scarce or absent. Sandstone breccia, ironstone, and slickensided surfaces with shiny iron-oxide coatings were seen in the Readstown Member but not in the Rountree Formation in Sauk County. The "Iron Hill member" of the Windrow Formation, like the Rountree Formation, is fine grained and is commonly red; however, it is largely iron oxide, not clay minerals (Andrews, 1958, p. 605).

LATE CENOZOIC HISTORY

The last ice age probably began in the midcontinent region during the Late Pliocene Age (Richmond and Fullerton, 1986), but little is known of events in Sauk County until the Late Pleistocene. In this section we discuss the geologic events and the resulting landforms and deposits in Sauk County, emphasizing the events of the past 20,000 years, during the last part of the Wisconsin Glaciation (fig. 16). In the following discussion, spans of time are given in radiocarbon years before A.D. 1950 (using the standard half life of 5,570 years) rather than in calendar years. The vegetational and climatic history of Sauk County during postglacial time, which is not discussed here, has been evaluated by Maher (1982) and Winkler (1988).

Stratigraphy

The late Cenozoic sediment in Sauk County is included in the Big Flats and Horicon Formations and in the top and bottom of the Rountree Formation. However, the bulk of the Rountree Formation, which was discussed in the previous section, probably accumulated before the last part of the Cenozoic. The Big Flats Formation (Attig, Clayton, and Mickelson, 1988, p. 19-24) is characterized by rounded quartz sand and other material that was derived from hillslopes underlain by Paleozoic sandstone and was transported and deposited by nonglacial water. In Sauk County the Big Flats typically occurs in lake basins west of the Johnstown outwash plain. It is a few tens of

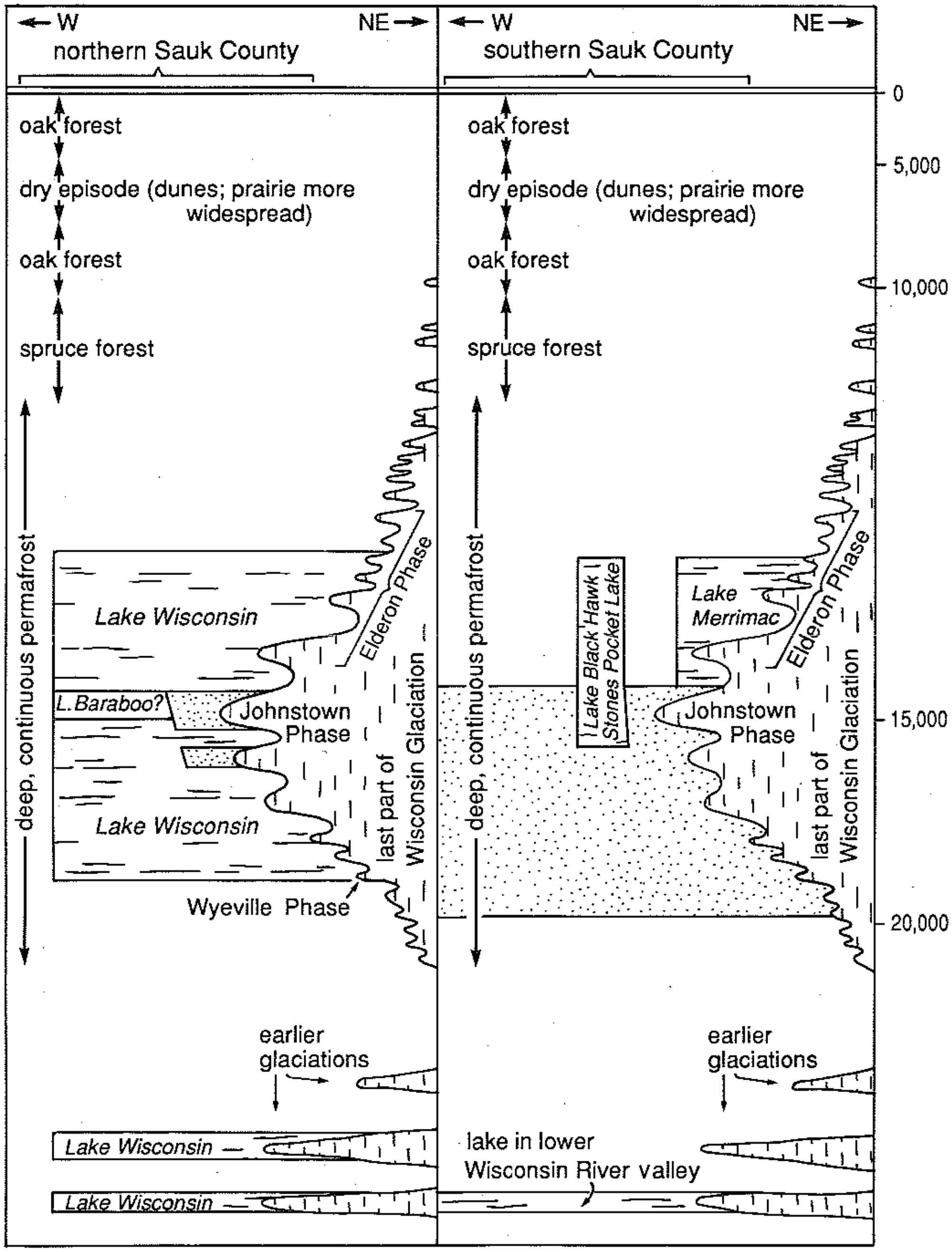


Figure 16. *Schematic representation of Late Pleistocene events in northern Sauk County (left) and southern Sauk County (right). The vertical axis shows time (radiocarbon years before present), and the horizontal axes show distance parallel to a glacial flow line from near the west edge of Sauk County northeast to Lake Superior (distance northeast of the county is greatly condensed). Vertical dashes indicate the presence of a glacier; horizontal dashes indicate the presence of a lake; dots indicate the presence of meltwater streams from the Green Bay Lobe.*

metres thick in some places. The Horicon Formation (Mickelson, Clayton, Baker, Mode, and Schneider, 1984, p. A9-1) is characterized by more angular, mostly nonquartz sand; much of it was derived from Paleozoic dolomite or Precambrian igneous and metamorphic rock of eastern and northern Wisconsin, northern Michigan, and Ontario and was transported and deposited by glaciers and glacial meltwater. In Sauk County, the Horicon occurs from the Johnstown outwash plain eastward and is several tens of metres thick in many places. In addition, some smaller deposits of late Cenozoic sediment in Sauk County have yet to be formally included in any stratigraphic unit.

Glacial geology

About 20,000 years ago, the Green Bay Lobe of the Laurentide Ice Sheet moved down the Green Bay lowland. The west side of the lobe moved directly westward to the approximate present locations of the Wisconsin Dells, West Baraboo, Devils Lake, and Prairie du Sac (plate 1) about 15,000 or 16,000 years ago, during the Johnstown Phase of the Wisconsin Glaciation. The glacier wasted eastward from the county, perhaps around 14,000 years ago, and it wasted from the state about 9,500 years ago. Most of the glacial sediment and glacial-meltwater sediment in the area is part of the Horicon Formation.

Glacial sediment

The near-surface glacial sediment (till) in eastern Sauk County has been described by Socha (1984) and Lundqvist and others (in press). It is typically yellowish brown and consists of about 5 to 10 percent clay, 15 to 30 percent silt, 60 to 75 percent sand, and roughly 10 percent gravel. The coarse-silt fraction is roughly one-third dolomite, and the pebble fraction is commonly more than half dolomite. Surface boulders are generally not abundant in lowland areas, but on the Baraboo Hills boulders of Baraboo quartzite are. All of the known till in Sauk County was deposited during the last part of the Wisconsin Glaciation.

Johnstown (Almond?) Phase

Evidence from outside Sauk County (Mickelson, Clayton, Fullerton, and Borns, 1983) indicates that the Green Bay Lobe was advancing between about 20,000 and 15,000 years ago (fig. 16), but little direct evidence for this is available in Sauk County. The first well known glacial event in the county occurred when the Green Bay Lobe reached its maximum extent, roughly 15,000 years ago (Attig, Clayton, and Mickelson, 1985). The moraine that formed then has been traced southeastward, with some gaps, to the moraine at the communities of Johnstown and Johnstown Center in southeastern Wisconsin (Alden, 1918, p. 209-222; Mickelson, 1983). The Johnstown Phase of the Wisconsin Glaciation is defined as the geologic event responsible for that moraine (fig. 16).

The moraine formed during the Johnstown Phase can be traced northward from Sauk County to the village of Coloma in central Wisconsin (Clayton, 1987). There, it apparently corresponds to the moraine formed during the Almond Phase rather than with that formed during the Hancock Phase, which occurs west of the Almond moraine from Coloma northward to near Antigo (Clayton, 1986; Attig, 1989; Mickelson, 1986).

In the lowland part of eastern Sauk County, the Johnstown moraine is commonly 100 m to 1 km wide and 5 to 20 m high on the west side of the ridge and 5 to 50 m high on the east side (map unit gj, plate 1). Smaller ridges are commonly superimposed on this larger ridge. In most places the moraine is bordered on the west by an outwash plain and on the east by thinner till or by collapsed supraglacial stream or lake sediment.

Several Johnstown moraines occur on the South Range of the Baraboo Hills. The westernmost one is typically several metres high and a few tens of metres wide. The others are smaller and generally occur no more than 0.5 km to the east of the main ridge. An outwash plain is present at only a few places west of the moraine on the South Range, and it is bordered on the east by thin till.

The Johnstown moraine is most conspicuous in Devils Lake gorge. North of the lake the moraine is about 0.3 km wide and 20 m high, and southeast of the lake it is about 1 km wide and 20 m high, as viewed from the west and 50 m high as viewed from the east.

Lundqvist and others (in press) have described the internal structure of the main western ridge of the Johnstown moraine in four gravel pits: at the north side of the city of Baraboo, near a radio tower at the crest of the South Range, at the south edge of the Badger Army Ammunition Plant south of the South Range, and on the east side of the Wisconsin River east of Sauk City. The internal structure of the moraine is strikingly similar at all four pits and therefore is probably representative of the moraine throughout the county (fig. 17).

At two of the pits, the glacier advanced across an outwash plain, and the moraine is on outwash gravel (fig. 17a), but at the other two pits the base of the moraine was not exposed. Much of the mass of the moraine consists of esker-like bodies of boulder gravel perpendicular to the moraine (fig. 17b); they grade westward into the apexes of outwash fans (fig. 17c). Draped over these gravel bodies is a layer of stratified subglacial till consisting of alternating layers of slightly different composition. This is overlain by or interbedded with uniform till (fig. 17d). The moraine is capped by a thin layer of washed supraglacial or postglacial debris (fig. 17e).

Elderon (Milton?) Phase

In central Wisconsin, the next glacial event after the Johnstown (Almond?) Phase of the Wisconsin Glaciation was the Elderon Phase (fig. 16), about 13,500 years ago (Clayton, 1986; Attig, 1989; Attig, Clayton, and Mickelson, 1985). During the Elderon Phase, the glacier formed at least six separate small moraines east of the Almond moraine. These Elderon moraines, as a group, can be traced southward from Marathon County to northeastern Sauk County. The moraine north of the Baraboo Hills in sec. 35, T13N, R7E, and in sec. 3, 11, and 14, T12N, R7E (plate 1), probably correlates with an Elderon moraine to the north near Lewiston, Briggsville, and Oxford.

South of the Baraboo Hills, a moraine that probably formed during the Elderon Phase occurs in sec. 34, 35, and 26. It may be equivalent to the moraine to the southeast of Sauk County that Mickelson (1983) has correlated with the one formed during the Milton Phase in southeastern Wisconsin (Alden, 1918, p. 259-263).

Was the Driftless Area glaciated?

The term drift has been used a variety of ways, but in the Midwest it has commonly meant the debris deposited by glaciers, by glacial-meltwater rivers, and in glacial lakes; silt blown off meltwater floodplains has also sometimes been included (for example, Hobbs and Goebel, 1982). The term Driftless Area is applied to a geographic region in southwestern Wisconsin that is characterized by rugged, nonglacial topography with flat uplands between deeply incised valleys (Martin, 1916, p. 73-92). Drift in the form of meltwater-stream sediment occurs in abundance along the major rivers in the Driftless Area, offshore sediment occurs in glacial lake basins along its margins, and wind-blown silt is present across the whole area; as a result, geologists have generally thought of the area as being unglaciated rather than driftless, despite its name. However, from time to time, arguments have been put forward that the area not only has drift but was in fact glaciated.

In a series of papers, Squire (1897, 1898, 1899, 1905a, 1905b, 1909, 1916) reported his findings about various parts of the Driftless Area. He concluded that small valley glaciers and ice caps existed in the Driftless Area, but none of the evidence seems convincing and none of the evidence was from Sauk County. Sardeson (1897) identified glacial deposits near Dodgeville in southwestern Wisconsin, but Smith (1949) reinterpreted them as hillslope deposits.

Weidman (1904, p. 18, 99-102), who grew up on the west end of the North Range (Cole, 1918, p. 1043-1044), thought that at least central Sauk County had been glaciated. Weidman (1904) considered boulders west of the village of North Freedom to be possible evidence of glaciation; he somewhat skeptically mentioned the alternate interpretation (favored by most geologists) that

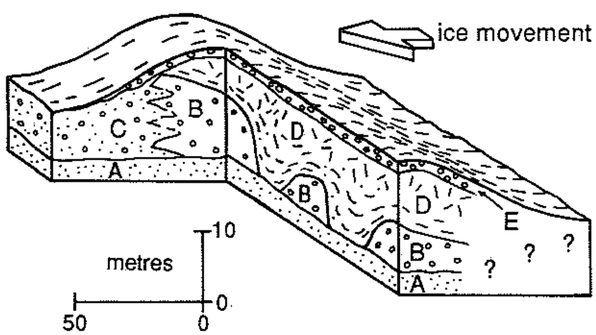


Figure 17. *Block diagram showing the internal structure of the outer ridge of the Johnstown moraine, based on observations by Lundqvist, Clayton, and Mickelson (in press). A: meltwater-stream sand and gravel deposited before the moraine was formed. B: poorly sorted sand and gravel, probably deposited in esker tunnels. C: sand and gravel deposited by meltwater streams while the moraine was forming. D: interbedded layered and uniform till. E: poorly sorted gravelly sediment, probably supraglacial debris and postglacial solifluction debris.*

they had been rafted there on icebergs in glacial Lake Wisconsin. Weidman though that the "Denzer drift," 11 km west of the Johnstown moraine, was convincing evidence of glaciation. This material, which we interpret to be nonglacial stream sediment, consists of a thin blanket of gravel composed of quartzite, chert, and sandstone overlying a pediment surface on Wonewoc sandstone, 25 m above present drainage (shown covered by windblown silt on plate 1). It is exposed where the road cuts through the south edge of the pediment surface at UTM coordinates 266,070mE, 4,804,000mN, 1 km north of the community of Denzer. Alden (1918, p. 170) and Thwaites (1920 field notes in WGNHS files; 1928, p. 623), who apparently looked at better exposures than now exist, also saw no evidence that this is glacial sediment.

Weidman (1904, p. 102) considered Devils Washbowl, 1 km southwest of the village of New Freedom and 10 km west of the Johnstown moraine, at UTM coordinates 267,000mE, 4,815,000N, to be a glacial ice-block depression. However, as pointed out by Alden (1918, p. 170) and Thwaites (1958, p. 155), the depression is walled by sandstone (Tunnel City Formation). They suggested a more likely explanation: it is a sinkhole, resulting from the collapse of a cavern formed by solution of dolomite in the Freedom Formation, which here is at a depth of 140 m (Schmidt, 1951).

Black, in a series of papers and abstracts (1964, 1968, 1970a, 1974), also argued that the Driftless Area was glaciated. His evidence from outside Sauk County has been evaluated by Mickelson, Knox, and Clayton (1982), but much of his evidence was from Sauk County, and it will be discussed here.

Black (1970a, p. 71-72) identified three glacial ice-block depressions west of the Johnstown moraine. One, west of the center of sec. 16, T12N, R6E, 2 km west of the Johnstown moraine, is shown as a closed depression on the U.S. Geological Survey Wisconsin Dells, Wisconsin, quadrangle (15-minute series, topographic, 1957). However, on a more recent map (U.S. Geological Survey Wisconsin Dells South, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975), it appears to be a small valley eroded by subaerial processes, not a closed depression.

Two other depressions, in the NW1/4 sec. 18, T12N, R6E (UTM coordinates 271,200mE, 4,822,500mN) and the NE1/4 sec. 15, T10N, R6E (UTM coordinates 275,700mE, 4,802,700mN), are several tens of metres in diameter and several metres deep. They resemble Devils Washbowl, but lack exposures of sandstone in their sides. Both depressions occur behind the foreset face of an outwash delta, 6 and 2 km west of the Johnstown moraine, respectively. Thwaites (1958, p. 157-158) suggested the second of these formed where an iceberg was buried, and that explanation is reasonable for the first as well.

Black (1970a, p. 71) identified an esker 5 km west of the Johnstown moraine in the NE1/4 sec. 18, T12N, R6E (UTM coordinates 271,700mE, 4,822,400mN). However, the ridge is merely one of hundreds of small interfluves on the eroded western side of the Johnstown outwash delta. The material in the ridge is well exposed in a borrow pit; it is eolian, fluvial, and offshore sand that is much finer grained than most eskers.

Black (1970a, p. 72) identified a kame 6 km west of the Johnstown moraine in the SE1/4 sec. 25, T12N, R5E, but he gave no convincing evidence for the interpretation. The material, which is no longer exposed, has generally been interpreted to be shore sediment of Lake Baraboo or Lake Wisconsin (references listed by Black). On the basis of a photograph of the gravel in WGNHS files (photograph 2584), the shore-sediment interpretation seems most likely.

Black (1970a, p. 72) identified glacial erratics 0.5 km from the Johnstown moraine, northwest of Devils Lake. They were identified in a temporary exposure, and the site is too imprecisely identified to relocate. As a result, we have not been able to evaluate this interpretation.

Black (1964, p. 169-171, figs. 1, 2, 6; 1968, p. 143, fig. 11; 1970a, p. 72-73; 1974, p. 106, figs. 65 and 81) argued that glacial erratics are present east of East Bluff of Devils Lake gorge, 2 km west of the Johnstown moraine. His erratics consist of boulders of Baraboo quartzite, some a few metres across, lying on in-place Baraboo quartzite of the South Range. He stated that "no higher quartzite surface is nearby" (1970a, p. 73) and that one large boulder "rises conspicuously above the general level of the rounded summit of the upland" (1964, p. 169), "on the highest part of

South Bluff" (1974, p. 127). For that reason, he argued that they must have been moved uphill to their location by a glacier. However, all the large boulders we have seen are downhill from probable source outcrops. The large boulder illustrated by Black (1964, figs. 1 and 6; 1968, fig. 11; 1974, figs. 65 and 81) is not on "the highest part of South Bluff" but is on a hillslope, well below nearby summits underlain by quartzite. It seems most likely to us that Black's large "erratics" have been moved by hillslope processes, probably during times when permafrost was present, and it seems likely that quartzite blocks on hill crests are the result of frost heave from the underlying quartzite. Boulders of igneous rock are present on the summit, but they are at the edge of service roads, where they were removed from the fill used to construct the roads. We have seen no evidence for glaciation above East Bluff.

Black (1964) suggested that the potholes at the top of East Bluff (discussed in this report in the section on the Windrow Formation) were cut by glacial meltwater, but he gave no evidence. Because Windrow gravel has apparently been found in the potholes, it is likely they were cut by the same river that deposited the Windrow gravel. Black (1964, p. 168-169, 171-172) also suggested that a cascade down East Bluff was fed by glacial meltwater; he interpreted the potholes here to be plunge pools of the cascade, but we interpret them as potholes of a river flowing below the crest of the bluff, not plunge pools. Gravel like that of the Windrow Formation has been collected from one of the "cascade" potholes by K.I. Lange (Wisconsin Department of Natural Resources, verbal communication); the potholes below the crest of the bluff were therefore cut by the Windrow river sometime after it had eroded down below the level of the upland.

Black (1968, p. 145-146) reported glacial meltwater channels on the upland surface south of South Bluff, and he showed a photograph of "part of a channel" (one bank, presumably) that "crosses through the crest of the range" south of Devils Lake. We have walked the crest of the range here and saw no channels, nor are any shown on the U.S. Geological Survey Baraboo, Wisconsin, quadrangle, (7.5-series, topographic, 1975) (20-foot contour interval). The photographed "channel" bank is probably a scarp formed by hillslope processes when permafrost was present (discussed later in this report in the section about evidence for permafrost).

In summary, we know of no convincing evidence that the area west of the Johnstown moraine in Sauk County was ever glaciated.

Lake geology

Glacial Lake Wisconsin

The name Lake Wisconsin is applied to two different lakes. The name is used for the reservoir that has existed since 1914 upstream from the dam on the Wisconsin River at Prairie du Sac, in southeastern Sauk County. This reservoir will not be discussed further here. The name has also been applied as early as 1900 to the glacier-dammed lake that existed in south-central Wisconsin during the Wisconsin Glaciation. This Lake Wisconsin has been described in detail by Clayton and Attig (1989); only a brief outline will be given here, with emphasis on Sauk County.

Lake Wisconsin formed whenever the Green Bay Lobe of the Laurentide Ice Sheet moved westward onto the east end of the Baraboo Hills south of the city of Portage (fig. 18). The lake then rose until it spilled across the lowest point of the drainage divide to the southwest or northwest of the ice dam, either through the Devils Lake gorge to the lower reach of the Wisconsin River, in eastern Sauk County, or down the East Fork Black River, in Wood County in west-central Wisconsin. Lake Wisconsin occupied a number of separate basins, which are shown in figure 18.

The Lewiston basin was occupied by an arm of Lake Wisconsin sometime after the Johnstown moraine formed and until the last part of the Elderon Phase of the Wisconsin Glaciation, roughly from 15,000 until 14,000 or 13,000 years ago. In Sauk County, the basin is generally underlain by 30 to 100 m of the Horicon Formation, which overlies the Mount Simon Formation. Much of the Horicon Formation is sand, but considerable silt and clay are indicated in some well logs, and much of this is offshore sediment that was deposited in Lake Wisconsin during the last part of the Wisconsin Glaciation and probably also during earlier glaciations. Considerable till and meltwater-stream sediment is also present. The Lewiston basin received water from the Reedsburg, Loganville, and Baraboo basins by way of the Lower Narrows channel through the

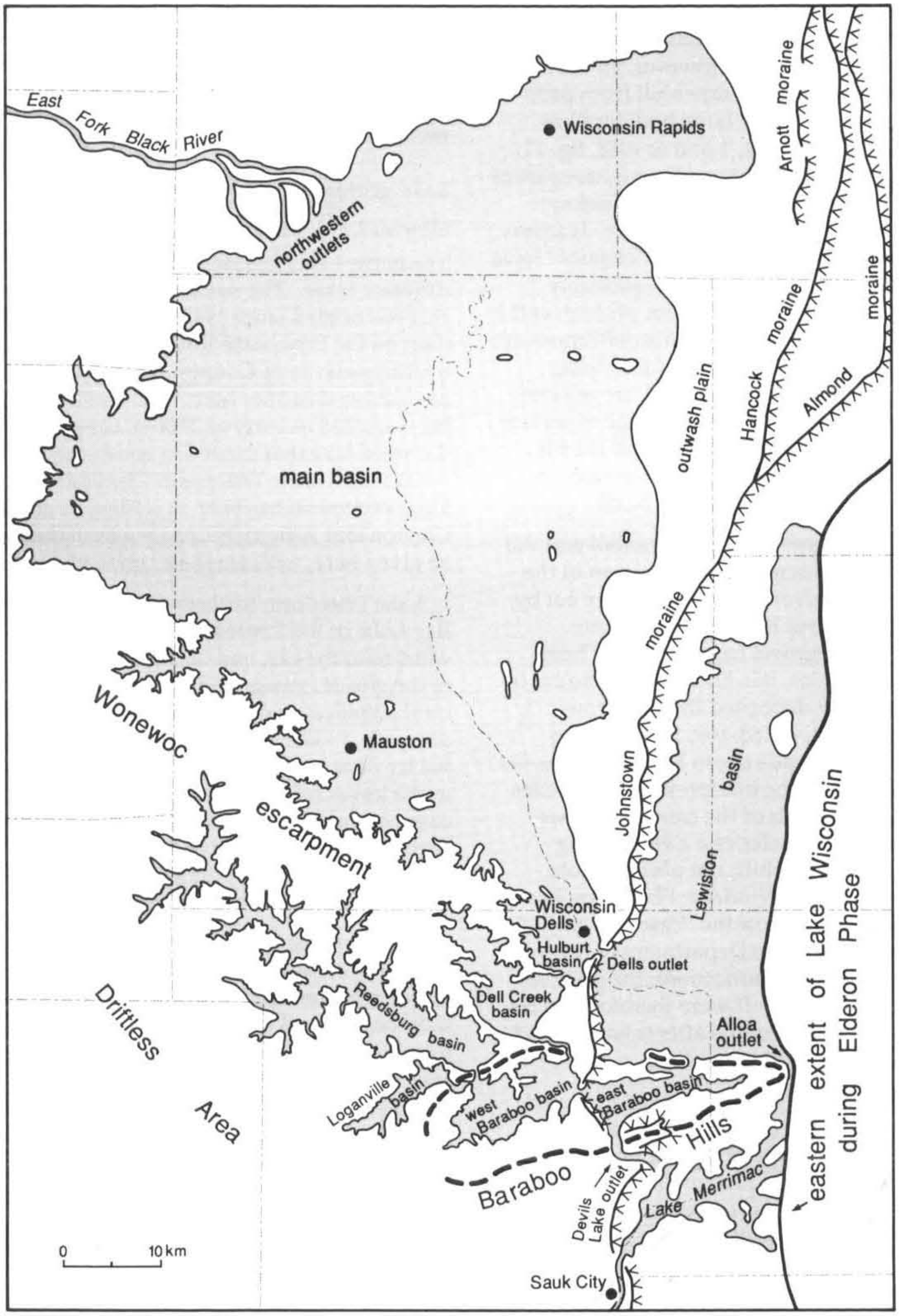


Figure 18. *Map of central Wisconsin showing the main features of glacial Lake Wisconsin. The map shows the maximum extent of the lake during the last part of the Wisconsin Glaciation, but it never occupied this entire area at one time. The heavy dashed line is the crest of the Baraboo Hills.*

North Range, and it received water from the Dell Creek, Hulburt, and main basins of Lake Wisconsin by way of the channel cut through the Johnstown moraine at the southeast end of the Wisconsin Dells. Lake Wisconsin finally drained when the glacier melted back off the east end of the Baraboo Hills, and water catastrophically drained into glacial Lake Merrimac through the Alloa outlet at the southeast corner of the Lewiston basin (fig. 18).

The Hulburt basin came into existence as a separate basin of Lake Wisconsin when a moraine and outwash plain were formed between this basin and the Lewiston basin during the Johnstown Phase of the Wisconsin Glaciation or earlier. The Hulburt basin was connected to the main basin by a broad strait (fig. 18). In contrast to the other lake basins, it was swept free of most Pleistocene sediment when the lake drained. Cambrian sand and sandstone occur at the surface in most places except for narrow valley bottoms and an area at the village of Lake Delton (map unit **oe**, plate 1), where a few tens of metres of Horicon offshore sand occur.

The Dell Creek basin, like the Hulburt basin, is separated from the Lewiston basin by the Johnstown moraine and outwash plain. Since at least the Johnstown Phase, water flowed from the Dell Creek basin to the Hulburt basin by way of a narrow sandstone gorge now occupied by Mirror Lake, at the overpass of Interstate 90/94. A few tens of metres of offshore sand, silt, and clay (Big Flats Formation) occur in the deepest middle part of the Dell Creek basin (map unit **ob**, plate 1).

The Reedsburg basin is in the Baraboo River valley upstream from the North Range of the Baraboo Hills. Water flowed from the Reedsburg basin through the Upper Narrows (at the north edge of the village of Rock Springs) to the west Baraboo basin. During its highest stages, the arm of Lake Wisconsin in the Reedsburg basin was generally as wide as 1 to 3 km, but it was 0.2 km wide where the valley narrows 2 km northwest of the village of La Valle. The bottom of the basin generally contains a few tens of metres of offshore sand, silt, and clay of the Big Flats Formation (map unit **ob**, plate 1).

The Loganville basin is in the Narrows Creek valley upstream from the North Range of the Baraboo Hills. The bottom of the basin contains several metres to a few tens of metres of offshore sand, silt, and clay of the Big Flats Formation (map unit **ob**, plate 1).

The Baraboo basin occurs in the part of the Baraboo River valley between the North and South Ranges of the Baraboo Hills. The east and west Baraboo basins are separated from each other by the Johnstown moraine and outwash plain.

The west Baraboo basin received water from the Loganville and Reedsburg basins. For a short time, during the Johnstown Phase of glaciation, it received water from the Devils Lake basin. During the Johnstown Phase and for some time after, it spilled northward into the Dell Creek basin. The west basin received water from the east basin during the last part of the Johnstown Phase and the earliest part of the Elderon Phase, but the direction of flow reversed later in the Elderon Phase when water flowed from the west to the east basin. The west Baraboo basin is underlain by several tens of metres of offshore clay, silt, and sand of the Big Flats Formation. The east Baraboo basin is underlain in most places by 30 to 60 m of Pleistocene sand, silt, clay, and gravel of the Horicon Formation, consisting of glacial, offshore, and meltwater-stream sediment. The Horicon Formation and Big Flats Formation in the east and west basins overlie a variety of units, including the Baraboo, Seeley, Freedom, and Mount Simon Formations.

Most of the beaches of Lake Wisconsin have been destroyed, probably by erosion immediately after the lake drained while permafrost was still present in the area. Nevertheless, the highest shoreline positions have been reconstructed using a variety of evidence, including scattered beach deposits and terraces, lake outlets, ice-rafted erratics, offshore deposits, and shore-ice collapse trenches (Clayton and Attig, 1989). These shorelines are now tilted to the southwest as a result of rebound of the earth's crust when the weight of the glacier was removed (plate 2). In the following paragraph, shoreline elevations are given in reference to present-day sea level.

When Lake Wisconsin first came into existence as the glacier advanced onto the east end of the Baraboo Hills during the Wyeville Phase of the Wisconsin Glaciation, it stood at a shoreline that is now at an elevation of about 294 m (965 ft) near

Wisconsin Dells (40 m above the reservoir behind the dam at the Dells) and at about 292 m (958 ft) in the southwestern part of the Loganville and Reedsburg basins (plate 2); it has been tilted S 45° W at 0.1 m/km. During the Johnstown Phase, the lake stood at a shoreline now at 290 m (951 ft) near the Dells and 280 m (919 ft) in the southwestern part of the Dell Creek basin. If the part of the lake in the Baraboo River valley was at the same level as the rest of Lake Wisconsin during the Johnstown Phase, the Johnstown shoreline is at about 272 m (892 ft) in the southwestern part of the Reedsburg and Loganville basins; it has been tilted S 60° W at 0.6 m/km. However, there is some evidence that a separate lake -- Lake Baraboo -- then existed in the Baraboo valley, perhaps standing as much as 10 m higher than Lake Wisconsin (fig. 18). When Lake Wisconsin finally drained during the last part of the Elderon Phase of glaciation, it stood at a shoreline that is now at an elevation of 292 m (958 ft) near the Dells and 284 m (932 ft) in the southwestern part of the Reedsburg and Loganville basin (plate 2); it has been tilted S 55° W at 0.3 m/km.

Devils Lake State Park

Devils Lake is the focus of Devils Lake State Park, in eastern Sauk County. Devils Lake is in the middle of Devils Lake gorge, which today is 1 km wide, 5 km long, and 140 m deep (fig. 19). The sides of the gorge consist of Baraboo quartzite, mantled in many places by talus (discussed in a later section). At least 115 m of Pleistocene fill occurs in the bottom of the gorge.

The gorge has had a complex history, and little is known about the earliest stages (Attig, Clayton, Lange, and Maher, 1990; Clayton and Attig, 1989). The gorge was originally cut into the Baraboo quartzite no later than the Late Cambrian. Evidence for this is an occurrence of sandstone of the Parfreys Glen Formation near the southwest shore of the lake (plate 1), indicating that the gorge was cut at least that deep before the sandstone was deposited during the Cambrian. The gorge started to be exhumed in the last part of the Paleozoic or the Mesozoic or Cenozoic, when a river was flowing at the level of the summit plateau above East Bluff and cut the potholes and deposited the Windrow gravel mentioned earlier.

The final stage in the flushing of the sandstone from the gorge probably occurred during the Pleistocene, when an early version of Lake Wisconsin spilled out through the gorge, probably sometime before the Wisconsin Glaciation. We know of no positive evidence for this, but water from the lake had flowed south through the gorge whenever the bottom of the gorge was near or below the present level of Devils Lake, until sandstone had been removed to at least 115 m below the present gorge bottom. Lake Wisconsin may also have spilled through the gorge during subsequent glaciations, keeping it flushed clean of sediment. Finally, perhaps during the glaciation preceding the last one, the glacier advanced far enough to clog part of the gorge with glacial material above the level of the present Devils Lake -- that is, high enough so that Lake Wisconsin was forced to discharge through its northwest outlet rather than through the Devils Lake gorge.

During the Johnstown Phase of the Wisconsin Glaciation, large moraines were formed in the gorge north and southeast of modern Devils Lake (plate 1). At that time a proglacial version of Devils Lake, about 30 m above the present lake, drained to the northwest to Lake Wisconsin (or Lake Baraboo). After the glacier retreated from the Johnstown moraine, the water of Devils Lake broke through the moraine at the north end of the lake (through a channel now occupied by the railroad), and the lake level dropped to near the level of Lake Wisconsin, which was near the level of modern Devils Lake.

Several small glacier-margin lakes occurred in the eastern part of Devils Lake State Park (Attig, Clayton, Lange, and Maher, 1990). Their position in shown on plate 1 by map unit **oh**.

Lake Merrimac

Lake Merrimac was a proglacial lake in the Wisconsin River valley east of the village of Prairie du Sac in southeastern Sauk County (fig. 18). It was dammed by the Johnstown moraine, and it came into existence after the glacier wasted back from the moraine during the last part of the Johnstown Phase (fig. 16). At first its outlet was 5 km north of Prairie du Sac, at the south edge of the Badger Army Ammunition Plant (plate 1; sec. 23 and 24, T10N, R6E). The water level here varied from about 253 m (830 ft) to 248 m (815 ft), measured from present-day sea level. The shorelines of the lake rise to the northeast, as a result of crustal rebound when the weight of the glacier was re-

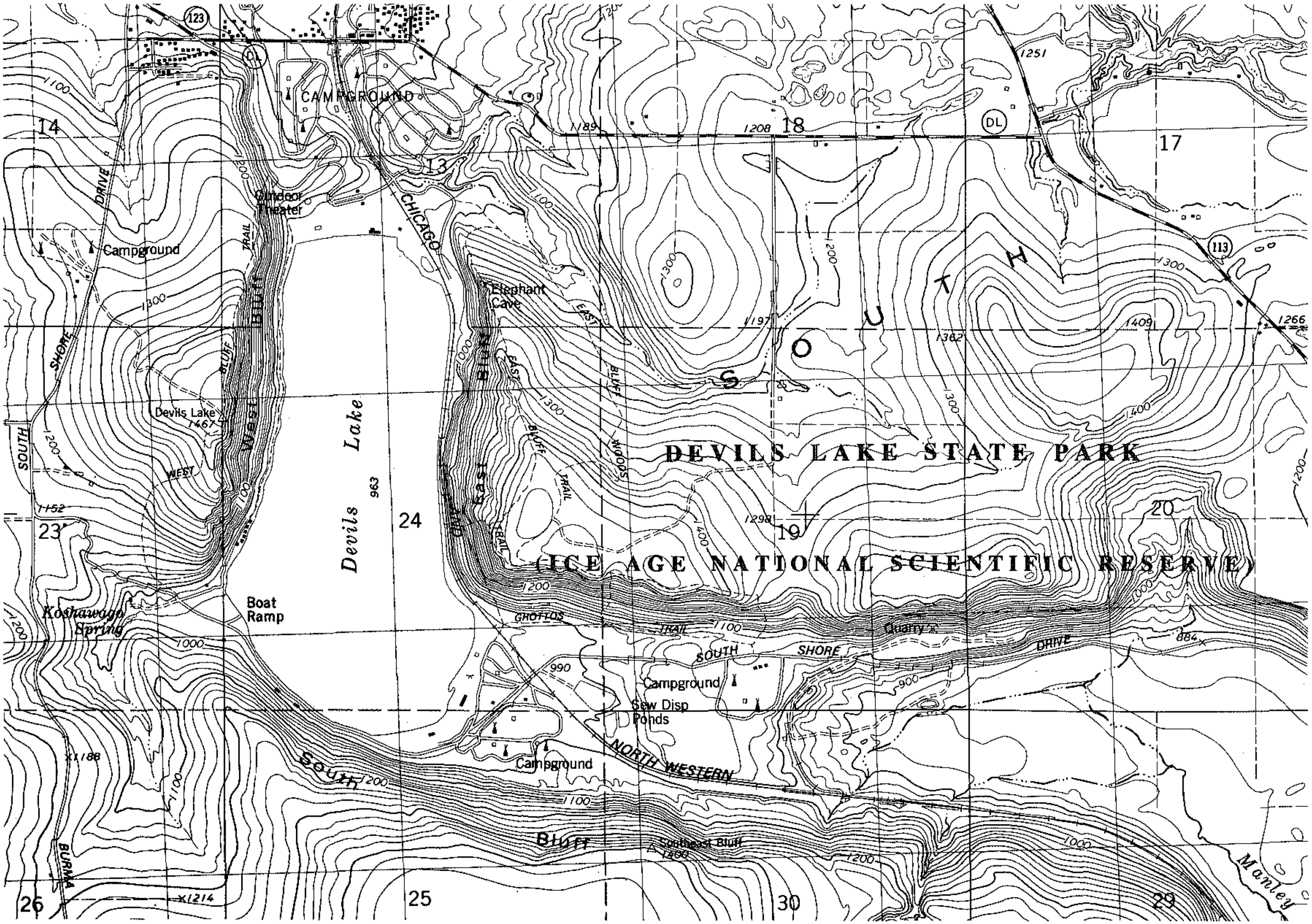


Figure 19. *Topographic map of the Devils Lake gorge. Area shown is 5.5 km wide. Contour interval 20 feet. (U.S. Geological Survey, Baraboo, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975.)*

moved from the earth's crust. When Lake Wisconsin drained, the outlet of Lake Merrimac shifted to the Sauk City area, and Lake Merrimac drained. Offshore sediment deposited in Lake Merrimac is indicated on plate 1 by map unit **oh**, 3 km northwest of the village of Merrimac.

Lake Black Hawk

We here give the name Lake Black Hawk to a former lake in Honey Creek valley that has previously been described by Alden (1918, p. 193-194). This lake (fig. 20) formed when the aggrading outwash plain west of Sauk City blocked Honey Creek at Loddes Mill (called Lodi Mill on some maps), probably during the early part of the Johnstown Phase of glaciation (fig. 16). The plain of Lake Black Hawk is underlain by as much as 60 m of Pleistocene sand, silt, and clay of the Big Flats Formation, much of which is offshore sediment (map unit **ob**, plate 1).

The east side of the lake is marked by a delta foreset face that has been nearly obliterated by gullying since the lake drained. The outlet of the lake was at Loddes Mill, where the top of the foreset face -- the presumed lake level -- is today at an elevation of about 245 m (805 ft). Lake Black Hawk probably drained when Lake Wisconsin and Lake Merrimac drained, causing the Wisconsin River to rapidly downcut, during the last part of the Elderon Phase of glaciation. After that time, the earth's crust in this area tilted about 0.2 m/km, S 50° to 55° W (Clayton and Attig, 1989). That is, the western shore of the lake should have been at an elevation of about 242 m (795 ft), measured above present sea level, and the lake should have extended up the Honey Creek valley nearly to the village of Plain.

Stones Pocket Lake

Another smaller lake, which we here call Stones Pocket Lake, was dammed in front of the outwash plain a few kilometres north of Lake Black Hawk, on the south side of the Baraboo Hills (fig. 16). It existed in the part of Otter Creek valley around Stones Pocket Road and the former Stones Pocket School (the present community hall) at an elevation of roughly 260 m (855 ft), measured above modern sea level, at about the same time as Lake Black Hawk. The lake plain is underlain by a few metres to a few tens of metres of offshore sand, silt, and clay (map unit **ob**, plate 1). The present-day Otter Creek flows in the outlet channel, near St. Ida Convent (sec. 15, T10N, R6E).

Shore-ice collapse trenches?

About five obscure trenches occur on the bottom of the spillway from glacial Lake Merrimac and on the nearby Johnstown outwash plain between the deltas on the east sides of Lake Black Hawk and Stones Pocket Lake (plate 1). They can be traced intermittently in a north-south direction for about 4 km. They are several metres wide, no more than 1 m deep, and several tens of metres apart. They are not obvious in the field, but are easily noticeable on aerial photographs.

Similar features in southern Adams County have been interpreted to be lake-ice collapse trenches (Clayton and Attig, 1987b). There, lake ice was apparently buried beneath Johnstown outwash along the east shore of glacial Lake Wisconsin; trenches formed when the buried ice later melted, causing the overlying outwash to collapse. Such an explanation is also possible for the Sauk County trenches, but we have no other evidence that a lake shore ever existed in this position. The trenches might instead be collapse trenches formed where outwash buried a series of small ice-cored moraines, or possibly they are animal trails.

Lake in the lower Wisconsin River valley

Other lakes, similar to Lake Black Hawk and Stones Pocket Lake, were undoubtedly dammed in other tributaries in Sauk County by the rising level of the outwash along the Wisconsin River during the Wisconsin Glaciation, but we have little evidence for them. However, there is evidence for a higher-level lake occupying the lower Wisconsin River valley.

Offshore sediment consisting of 2 m of horizontally laminated silt and clay was observed in a roadcut in Big Hollow, 6 km northwest of the village of Spring Green (UTM coordinates 734,450mE, 4,789,330mN), at an elevation of about 232 m (760 ft; fig. 21). An auger hole in Big Hollow (WGNHS Geologic Log SK-294-F) exposed 25 m of offshore silt, clay, and sand; the ground surface here is also at an elevation of about 232 m. Offshore sediment is mapped (map unit **ob**, plate 1) in Big Hollow up to an elevation of 238 m (780 ft; fig. 21). The Johnstown outwash in the adjacent Wisconsin valley bottom has been

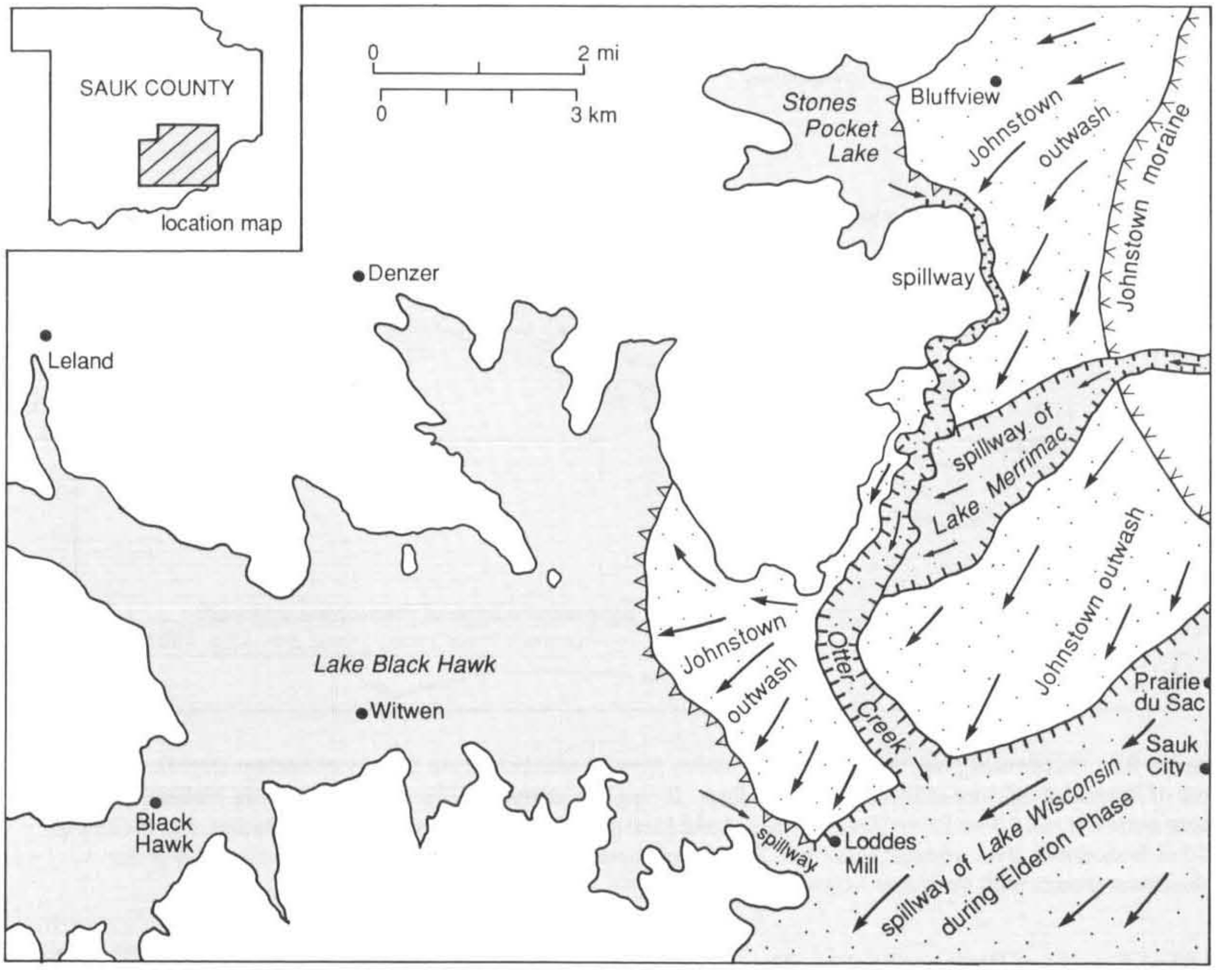


Figure 20. *Map showing location of Lake Black Hawk, Stones Pocket Lake, and meltwater-stream surfaces (dotted areas). Lines with hatch marks are river cut banks, and the lines with triangles are delta foreset faces.*

removed by erosion, but it probably was never high enough to dam a lake above this level in Big Hollow (line of question marks in fig. 21).

Offshore sediment has also been found 40 km to the west in Richland County, north of the village of Blue River (Leigh, 1988, p. 56). This material occurs up to an elevation of 230 m (755 ft; fig. 21), several metres above the highest outwash deposited along the adjacent Wisconsin River during the Wisconsin Glaciation.

Much of the material in Big Hollow is fine-grained offshore sediment, deposited in at least a few metres of water, indicating that a lake existed in the lower Wisconsin valley at a level of at least 240 m (790 ft; fig. 21). One dam for this lake had to be located to the west farther down the Wisconsin River or on the Mississippi River south from the mouth of the Wisconsin. Leigh (1988, p. 56-57) suggested that the mineralogy of the lake sediment near Blue River indicates that the lake was formed by a glacier that moved eastward out of Iowa to dam the Mississippi River or the Wisconsin River near its mouth. He argued that this occurred sometime before the Illinois Glaciation but after the Bridgeport Phase of glaciation because the remanent magnetism of the Bridgeport sediment has reversed polarity.

In addition, another glacial dam may have existed to the east. At the present time, nothing to the east is high enough to contain a lake in the lower Wisconsin valley: the present divide between the Wisconsin River and the Fox River (which drains to Lake Michigan) is at about 239 m

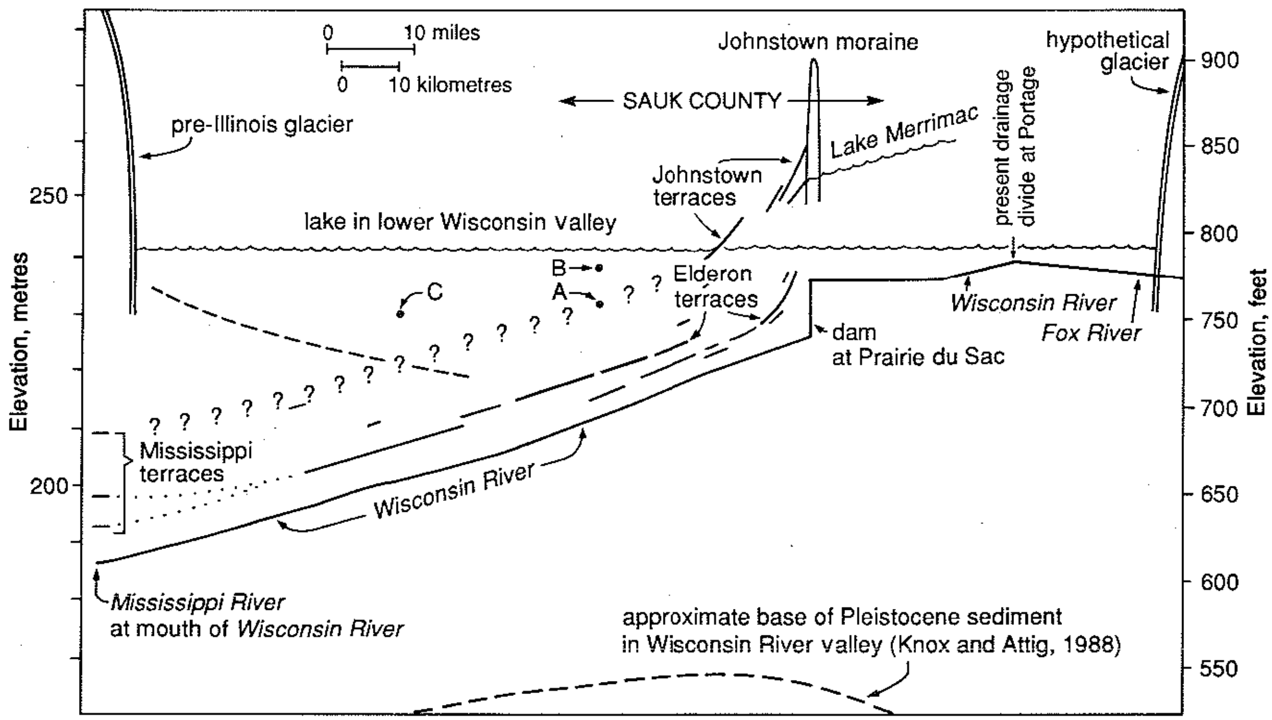


Figure 21. *Profile along the Wisconsin River valley from its mouth (left) to the city of Portage (right). A: outcrop of laminated offshore sediment in Big Hollow. B: highest mapped offshore sediment in Big Hollow. C: offshore sediment near Blue River (Leigh, 1988). Lake Merrimac is tilted because of crustal rebound, but the lake at 240 m is shown as if no rebound occurred. The line of question marks indicates a possible correlation of the Johnstown terrace with the upper Mississippi terrace.*

(783 ft) at the city of Portage (fig. 21). The lower Wisconsin River probably flowed eastward across the divide at Portage in Bridgeport time (Knox and Attig, 1988, fig. 1); projecting the Bridgeport outwash surface eastward (Knox and Attig, 1988, fig. 3) shows that the divide was considerably lower in Bridgeport time than it is today. The lake in the lower Wisconsin valley therefore probably was dammed to the east by a glacial lobe in the Lake Michigan and Green Bay lowlands ("hypothetical glacier" in fig. 21). The outlet of the lake may have been to the southeast through Dane County to the Rock and Illinois Rivers (Knox and Attig, 1988, fig. 1).

Stream geology

Meltwater streams

The earliest known meltwater streams in Sauk County deposited sand west of the Green Bay Lobe during the Johnstown Phase of the Wisconsin Glaciation (fig. 16; map unit sj, plate 1).

North of the South Range of the Baraboo Hills, Johnstown stream sediment was deposited on the outwash plain between the Johnstown moraine on the east and Lake Wisconsin or Lake Baraboo on the west. The plain is now no more than a few kilometres wide in most places, but it was wider during the Johnstown Phase. As the level of Lake Wisconsin rose during the Elderon Phase, waves washed away the easily eroded sand of the delta face; when the lake drained during the last part of the Elderon Phase, groundwater suddenly released from the outwash sapped gullies deep into the western edge of the outwash plain (map unit **oe**, plate 1). Much of the plain slopes westward at about 3 m/km, but it is steeper near the moraine. Braided channel scars can be seen on aerial photographs of the plain in a few places. The outwash plain is underlain by tens of metres of Pleistocene sediment, including offshore sediment below the level of Lakes Wisconsin and Baraboo. Before the west side of the outwash plain was eroded, meltwater-stream sediment thickened eastward from near zero at the shoreline to about 20 m at the edge of the moraine. The remaining outwash consists largely of sand, but it coarsens eastward to the edge of the moraine, where gravel is abundant. Most gravel pits in Sauk County occur at the east edge of the outwash plain.

South of the Baraboo Hills and west of the Johnstown moraine, the Johnstown outwash plain slopes southwestward at about 2 m/km toward Stones Pocket Lake, Lake Black Hawk, and the Wisconsin River valley (figs. 20 and 21; map unit **sj**, plate 1). The plain is cut into three separate surfaces by the spillways from Stones Pocket Lake and Lake Merrimac. The surface between Lake Black Hawk and the spillway of Stones Pocket Lake (Otter Creek) and the surface north of the Merrimac spillway appear to be slightly higher than the surface south of the Merrimac spillway. The outwash plain is underlain by tens of metres of Pleistocene sediment, largely sand. Much of it is Johnstown meltwater-stream sediment, but the most deeply buried could have been deposited before the Wisconsin Glaciation. The meltwater-stream sediment at the land surface is coarsest at the edge of the moraine, where it consists of gravel.

South of the Baraboo Hills and east of the Johnstown moraine, the meltwater-stream sediment has hummocky topography (map unit **sc**, plate 1), not flat topography as on the outwash plain west of the moraine. During the last part of the Johnstown Phase or the first part of the Elderon Phase, when the active-ice margin had retreated eastward from the Johnstown moraine, but before glacial Lake Merrimac came into existence, meltwater-stream sand was deposited on inactive glacial ice. This buried ice later melted, perhaps around 13,000 years ago when the permafrost in the region melted, causing the overlying sand to collapse and produce the hummocky topography.

In the area of Loddes Mill and the villages of Sauk City and Prairie du Sac are a series of terraces that are vertically separated from each other by no more than a few metres but are at least 15 m lower in elevation than the Johnstown outwash plain. Like the Johnstown outwash plain, these surfaces (fig. 20; map unit **ss**, plate 1) are probably also underlain by thick Johnstown meltwater-stream sand. However, the surfaces were cut well after the Johnstown Phase -- probably during the last part of the Elderon Phase when Lakes Merrimac and Wisconsin drained (Clayton and Attig, 1989). In the Sauk City area these surfaces are blanketed by Elderon meltwater-stream sand, which contains ice-rafted boulders in some places, but it is probably only a thin veneer on the underlying Johnstown sand.

Downstream from Loddes Mill, a series of terraces occurs on either side of the Wisconsin River, generally 3 to 9 m above present day river level (fig. 21). Most of these terraces appear to have formed at the same time as the Sauk City terrace, when Lakes Merrimac and Wisconsin drained during the last part of the Elderon Phase of glaciation, perhaps about 14,000 years ago. The resulting flood apparently washed away most of the Johnstown meltwater-stream sand that had been deposited in this part of the Wisconsin valley (fig. 21). In many places in Sauk County the terraces are underlain by 50 to 60 m or more of Pleistocene sand, most of which is probably meltwater-stream sediment; a paleosol is mentioned in several WGNHS geologic logs between the villages of Spring Green and Mazomanie, indicating that about the upper third of this sand may have been deposited during the Wisconsin Glaciation.

During much of the Wisconsin Glaciation, the upper Mississippi River was aggrading as the result of the outwash it was receiving from Minnesota, Iowa, and Wisconsin, reaching the level of the highest Mississippi terrace shown on the left part of figure 21. If the time of maximum aggradation along the Mississippi occurred at the same time as the maximum advance of the Green Bay Lobe, during the Johnstown Phase, outwash must have existed in the Wisconsin valley up to the level of the line of question marks shown in figure 21, but there are too few terrace remnants downstream from Sauk County to confirm this correlation.

The Mississippi River then entrenched its valley bottom to well below its present level because of the large volume of clean water that it received from glacial Lakes Agassiz and Superior, 13,000 years ago or earlier, but more certainly between about 12,000 and 11,000 years ago and again between about 9,900 and 9,500 years ago (Clayton, 1982). As a result, the Wisconsin River near its mouth also continued to aggrade until 13,000 or 12,000 years ago, when it too entrenched its valley bottom, probably below its present level. The terraces downstream from Sauk County have not been mapped, and correlation with Mississippi terraces is uncertain, but the Elderon terraces seem to correlate with the lower terraces along the Mississippi River, as indicated by the dotted lines in figure 21. If this is true, the Elderon Phase occurred after the Mississippi had begun to entrench -- after glacial Lakes Agassiz and Superior came into existence. On the other hand, correlations of glacial margins led Attig, Clayton, and Mickelson (1985, figs. 4 and 6) to conclude that the Elderon Phase ended while the Superior basin was still covered with ice. The Wisconsin River continued to receive, at least intermittently, glacial meltwater from northern Wisconsin until after the Winegar Phase, about 12,000 years ago, but none was available to the river after that time (Attig, Clayton, and Mickelson, 1985).

The Wisconsin valley bottom is bordered by a nearly continuous series of bluffs and cliffs that are 50 to 100 m high. Conspicuous examples are at Cassell Prairie, across the Wisconsin River from Arena. They were probably cut by glacial meltwater streams, and the steepest bluffs were probably cut during the Wisconsin Glaciation. During glaciation, braided streams swept across the width of the valley bottoms, undercutting and trimming back intertributary ridges that had projected farther into the center of the valley.

Nonmeltwater streams

Most stream sediment deposited in Sauk County was deposited by glacial-meltwater streams. However, some was deposited by streams that received no glacial meltwater before, during, or after the last glaciation.

Map unit **sg** on plate 1 indicates the distribution of stream and gravel on terraces several metres above the modern floodplains. The sand is largely quartz derived from Cambrian formations; the gravel, largely chert nodules derived from the Oneota Formation. Similar material in Juneau County (Clayton, in press) and elsewhere in the Driftless Area (Thwaites, 1928; Knox, 1982, p. 43-50) probably was deposited before the Wisconsin Glaciation.

Map unit **sp** on plate 1 indicates the distribution of stream sand on terraces that are generally no more than a few metres above the modern floodplains. It probably includes stream sediment deposited during postglacial time and may also include material deposited by nonglacial streams during the Wisconsin Glaciation. The map unit also includes bodies of slopewash sediment and mass-movement deposits that are too small to map separately.

During the past 9,500 years the upper Mississippi River has aggraded its bed at least 20 m at the mouth of the St. Croix River, where Lake St. Croix -- the yet unfilled part of the St. Croix River channel -- is still that deep. The Mississippi at the mouth of the Wisconsin River and the lower Wisconsin itself probably also has aggraded during that time, but the amount of aggradation in Sauk County is unknown. The material deposited by the modern Wisconsin River and its tributaries is indicated by map unit **sm** on plate 1.

The Wisconsin Dells

The Wisconsin Dells consist of a series of sandstone gorges around the city of Wisconsin Dells (formerly Kilbourn) in northeastern Sauk County and adjacent Columbia, Juneau, and Adams Counties. The name Wisconsin Dells has been primarily applied to the gorge of the Wisconsin River, which is about 10 km long, typically about 0.2 km wide (but only 15 m wide at The Narrows), and about 40 m deep in many places.

The name Wisconsin Dells can also be applied in a broader sense to include the series of sandstone gorges on either side of the main gorge (fig. 22). Tributary gorges such as Witches Gulch and Coldwater Canyon (in Adams County) are tens of metres deep but narrow to 1 m in places. Some gorges are much larger than the streams that flow through them (for example, the gorge in Rocky Arbor State Park, discussed below). The gorges tend to form a complex network, and several gorges contain no stream at all where they cross local drainage divides (fig. 22).

The origin of the Wisconsin Dells is uncertain. Martin (1916, p. 329) suggested that the gorges on the east side of the Wisconsin River were cut by meltwater rivers flowing from the glacier to the east. However, no rivers could have existed here at that time, because Lake Wisconsin then covered the area. Martin (p. 330-331) thought that other gorges were cut by rivers flowing in them today. Some, such as the Wisconsin River gorge, have

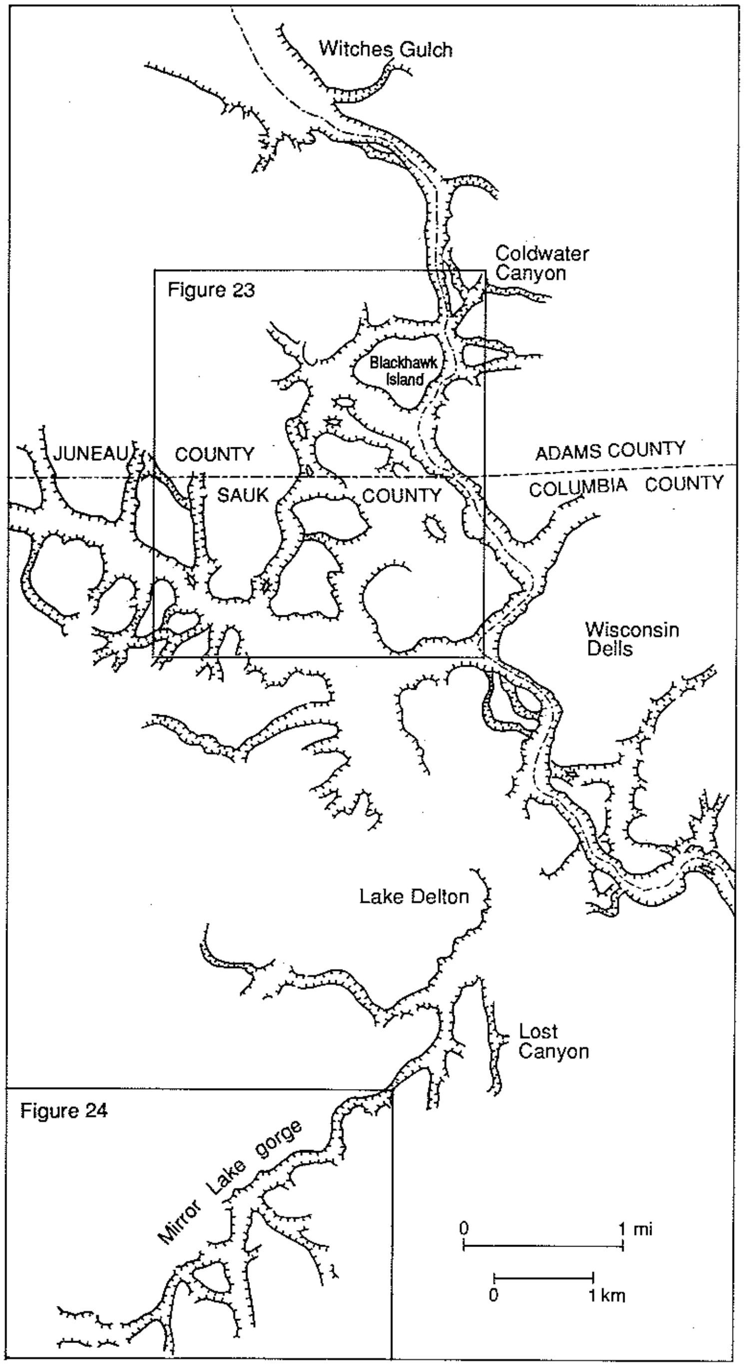


Figure 22. *Gorges around the city of Wisconsin Dells. The border between Sauk and Columbia Counties and between Juneau and Adams Counties marks the Wisconsin River.*

undoubtedly been at least altered by the rivers now flowing in them. However, those gorges that are much larger than their present-day streams and those with no stream at all must have been cut by rivers that no longer exist.

Clayton and Attig (1987a, 1989) suggested that the Wisconsin Dells were cut by a flood (or floods) from glacial Lake Wisconsin when it drained. They suggested that water was suddenly released from the Lewiston basin of Lake

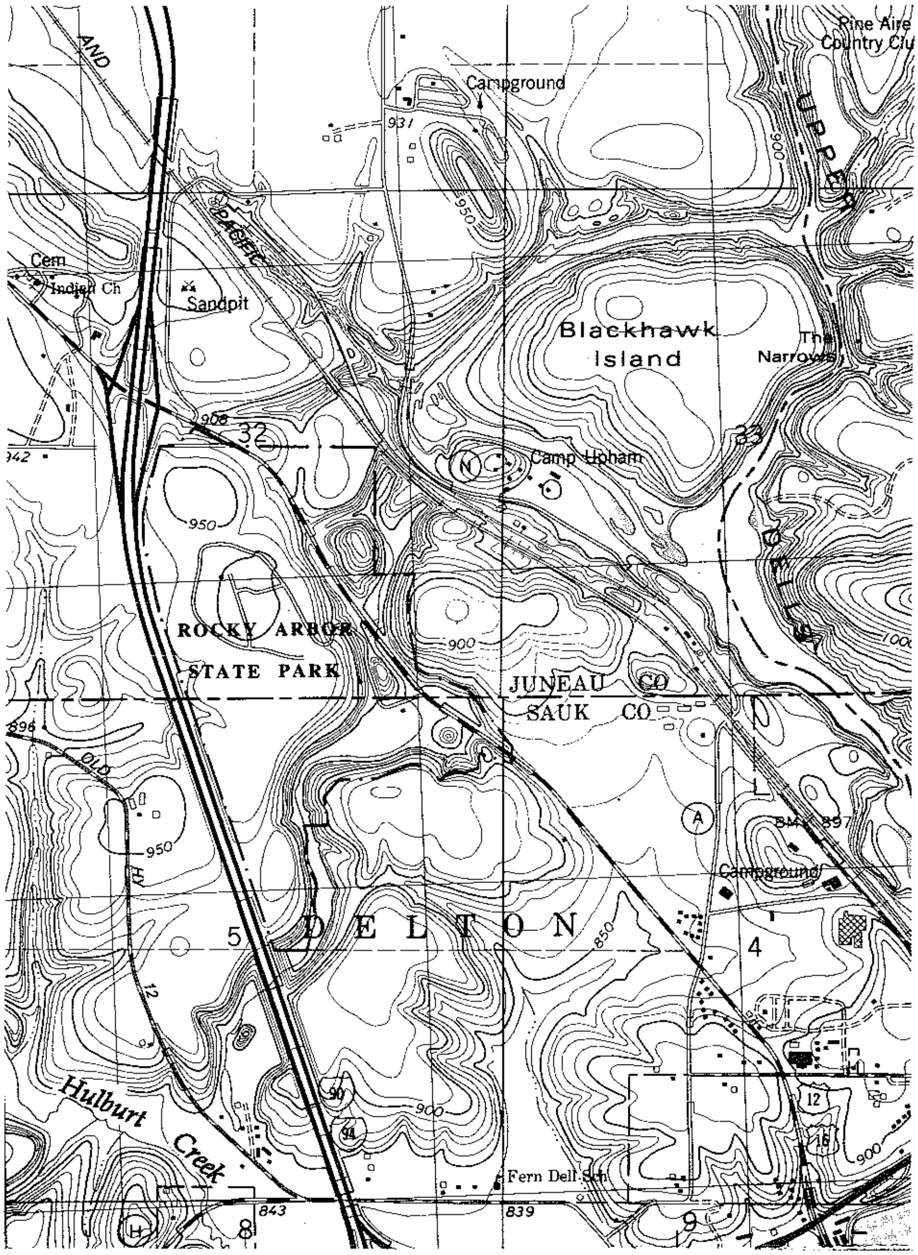


Figure 23. *Topographic map showing sandstone gorges in and around Rocky Arbor State Park. Area shown is 3 km wide; contour interval 10 feet. (U.S. Geological Survey Wisconsin Dells North, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975.)*

Wisconsin (fig. 18) when the glacial dam at the east end of the Baraboo Hills broke during the last part of the Elderon Phase of glaciation. This caused the water level in the Lewiston basin to suddenly drop, perhaps 30 m in a few days, which in turn caused the water in the Hulburt basin of Lake Wisconsin to suddenly sweep through a breach in the Johnstown moraine, which separated it from the Lewiston basin. Most of the Pleistocene sediment in the Dells area was quickly washed away, exposing the soft Cambrian sandstone, which was entrenched as water continued to pour out of the Dell Creek, Hulburt, and main basins of Lake Wisconsin.

Gorge in Rocky Arbor State Park

Rocky Arbor State Park spans the border between Sauk and Juneau Counties, northwest of the city of Wisconsin Dells (fig. 23). A good example of the sandstone gorges (dells) that were probably cut when glacial Lake Wisconsin drained occurs along the east edge of the park.

This gorge is about 0.2 km wide, 20 to 30 m deep, and 2 km long, and it contains a creek that is generally no more than 1 m wide. The northeast end of the Rocky Arbor gorge joins a loop of the Wisconsin River gorge around Blackhawk Island, and its southwest end joins the Hulburt Creek gorge (figs. 22 and 23). Sandstone in the upper part of the Mount Simon Formation is exposed in the walls of the gorge. The north wall of the gorge can be viewed from a foot path that is west of the parking area near the entrance of the park.

Gorge in Mirror Lake State Park

Mirror Lake State Park is just southwest of the village of Lake Delton. It contains a good example of the sandstone gorges that are present throughout the Wisconsin Dells area (fig. 24).

The gorge is about 0.1 km wide, 20 to 35 m deep, and 3 km long, and it extends from the southwest part of the park northeastward into the village of Lake Delton. The gorge contains Dell Creek, which has been dammed northeast of the park to create Mirror Lake.

The lower part of the canyon walls, up to about 10 m above lake level, consists of sandstone in the upper part of the Mount Simon Formation. Above that may be the thin Eau Claire Formation (poorly exposed), and where the canyon is deepest the upper part consists of the Galesville Member of the Wonewoc Formation. The Ironton Member is at the top of the canyon walls at the overpass of Interstate 90/94, northeast of the park.

The gorge was cut by water flowing from the Dell Creek basin of glacial Lake Wisconsin, southwest of the interstate overpass, to the Hulburt basin of Lake Wisconsin, northeast of the overpass (figs. 18 and 24). Although water flowed this way during most of the time Lake Wisconsin was in existence, the gorge probably attained its present depth when the lake suddenly drained near the end of the Elderon Phase of the Wisconsin Glaciation.

Skillet Falls area

The reach of Skillet Creek from Skillet Falls to Pewits Nest (northwest of Devils Lake) has attracted the attention of geologists for the past century. Several of the geologic features of the area are shown in figure 25 (see also plate 1).

Skillet Falls descends about 5 m over a series of sandstone benches 0.5 km west of Highway 12. The upper part of the Wonewoc Formation is exposed in the falls, and Tunnel City sandstone crops out in the valley wall just south of the falls. The falls are shown 0.5 km too far upstream on U.S. Geological Survey topographic maps, but are shown in the correct place in figure 25. Photographs of the falls, which are on private land, are shown by Salisbury and Atwood (1900, plate 16) and Trowbridge (1935, fig. 124).

Pewits Nest (fig. 25) is the name applied to an "extremely-picturesque" sandstone gorge 1 km downstream from Skillet Falls (Martin, 1916, p. 113-114). Its name derives from a nineteenth-century handyman's workshop, which was carved out of the sandstone in an overhanging part of a wall of the gorge; according to Cole (1918, p. 8-9), the shop was thought to resemble the nest of a phoebe (pewit). The gorge is about 3 to 20 m wide, 20 m deep, and 0.3 km long and is in the Wonewoc Formation. It deepens westward and contains a series of falls and pools. It is in a Department of Natural Resources Natural Area.

Between Pewits Nest and Skillet Falls, on the upland south of the Skillet Creek, are segments of the channel of a river that was tens of metres wide (the present creek is only a few metres wide). Like the present creek, but unlike the braided meltwater stream on the adjacent outwash plain, it was a meandering river. It apparently carried water from Devils Lake when the glacier stood far enough east of the Johnstown moraine for the outwash plain to be inactive but before the glacier had wasted far enough from the moraine at the north end of Devils Lake to allow Devils Lake to drain northward to the east Baraboo basin (plate 1).

The valley of Skillet Creek between Pewits Nest and Skillet Falls is a basin that is about 0.2 km

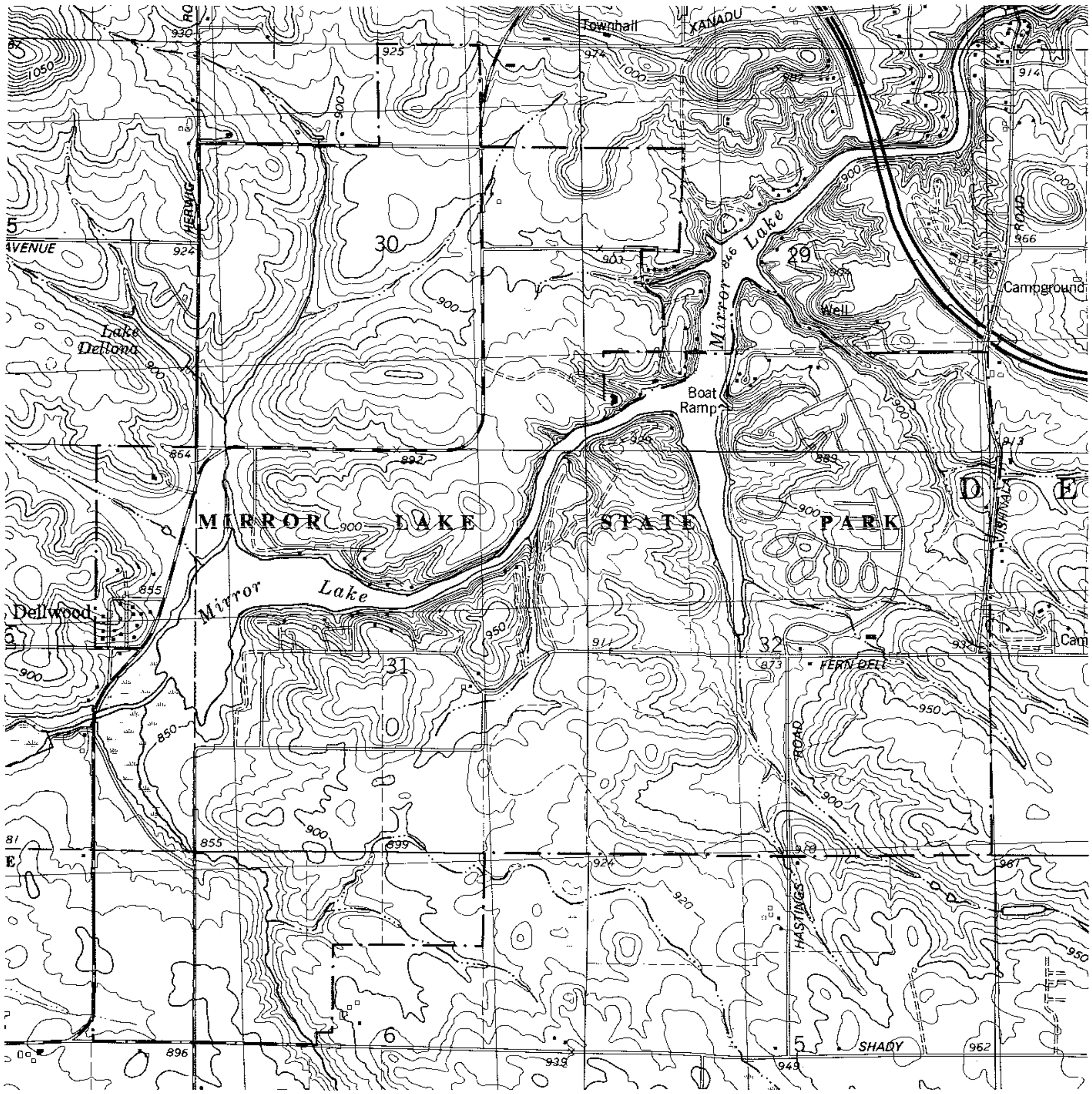


Figure 24. *Topographic map showing sandstone gorges in and around Mirror Lake State Park. Area shown is 4.5 km wide; contour interval 10 feet. (U.S. Geological Survey Wisconsin Dells South, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975.)*

wide. A saddle on the northwest side of this basin is several metres lower than the top of Pewits Nest gorge (fig. 25). This saddle seems a more likely route for the creek than through the gorge, but the saddle is younger than the gorge. The present path of the creek through the gorge was established while Lake Baraboo or Lake Wisconsin existed a short distance to the north-

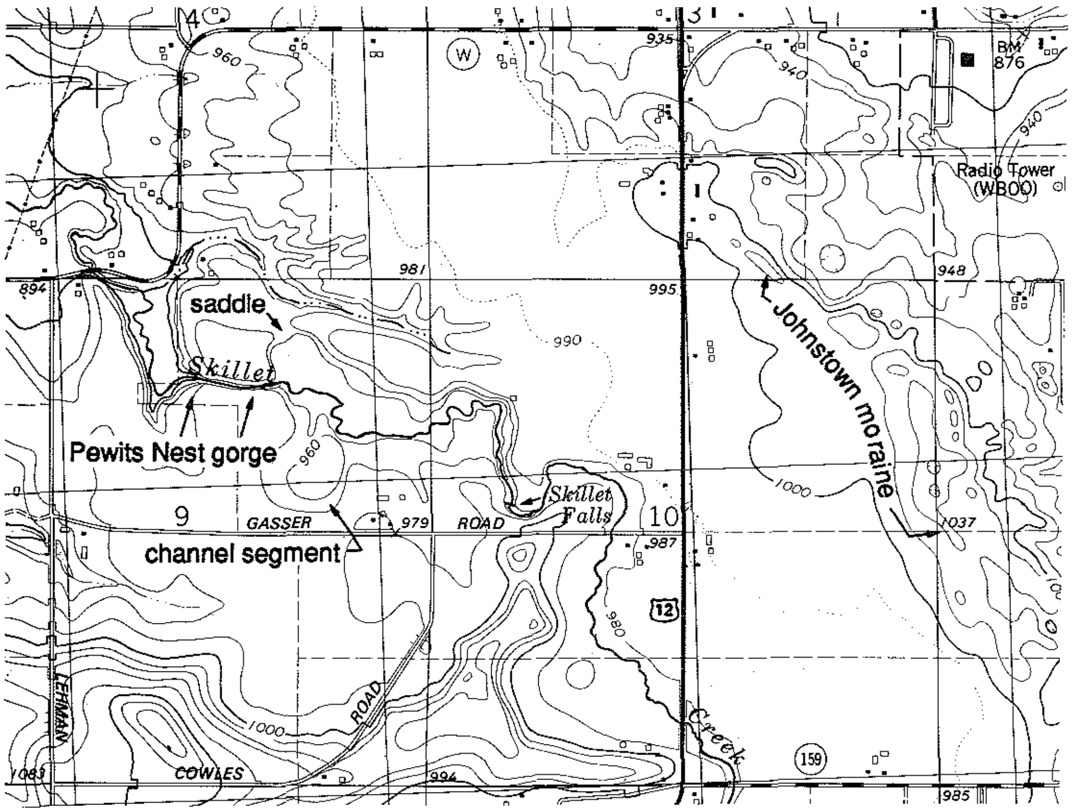


Figure 25. *Topographic map of the Skillet Falls area. Area shown is 3.5 km wide; contour interval 20 feet. (U.S. Geological Survey North Freedom, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975.)*

west, but the saddle was cut after the lake drained, when gullies were being eroded eastward into the face of the outwash delta.

Hillslope geology

Hillslope processes have been active in Sauk County during the Pleistocene and Holocene, and they have left behind a variety of evidence, but much of the hillslope material in the county was deposited when permafrost was present during glaciations (Attig and Clayton, 1986; Smith, 1949). More than 100 samples of trees buried in Pleistocene deposits in Wisconsin have been radiocarbon dated, but dates are lacking for the period from 13,000 to 25,000 radiocarbon years ago, probably because tundra vegetation -- and therefore permafrost -- existed during that time.

Talus

The most conspicuous hillslope deposits in the county are the talus cones along steep bluffs of Baraboo quartzite, especially in Devils Lake gorge. There, the talus cones are up to 100 m high and are composed of angular boulders of quartzite, some more than 3 m across (map unit t, plate 1; Attig, Clayton, Lange, and Maher, 1990).

We know of no evidence that this talus is still accumulating. The abrupt termination of the talus southeast of Devils Lake at the edge of the Johnstown moraine at the east ends of East Bluff and South Bluff indicates that talus formation occurred primarily during or before the Johnstown Phase of the Wisconsin Glaciation. This suggests that the talus formed when permafrost was present and frost action was most active in the quartzite cliffs above the talus (Smith, 1949, p. 199-203).

Block streams

Block streams on the South Range (plate 1) have been described by Smith (1949, p. 203-207), and the locations of several block streams in Devils Lake State Park are shown on the map by Attig, Clayton, Lange, and Maher (1990). These block streams consist of masses of quartzite boulders, commonly with little material in the pore space between the boulders. In places, the boulders are as large as a few metres across. The block streams are commonly a few hundred metres long and a few tens of metres wide, and they are probably generally no more than several metres thick. The down-hill ends of the block streams are lobate and are bordered by low ridges of boulders. Smith argued that these block streams formed in the presence of permafrost because they resemble block streams found in present-day permafrost areas.

Many of these block streams are conspicuous features because they are free of vegetation due to a lack of fine debris in the pore space. Elsewhere in the Baraboo Hills, scattered exposures indicate that most of the lower hillslopes are covered with a blanket of bouldery rubble with fine material filling the pore space between the boulders; this hillslope sediment is generally covered with trees. This material was probably also deposited when permafrost was present in the region.

Cliffs above block streams

Block streams occur in the bottoms of steep, shallow valleys, some distance below the summit plateaus on the South Range. Uphill, the block streams become less distinct, but scattered blocks generally can be traced to low cliffs, many of which are shown on the map in Attig, Clayton, Lange, and Maher (1990). These cliffs are commonly near the edge of the summit plateaus and have been eroded into the scarp formed during the Paleozoic (discussed in an earlier section), but some occur farther down the slope.

The scattered blocks on the hillside and in the block streams were derived from these cliffs, probably by frost fracturing during times of permafrost. Blocks a few metres away from the cliff commonly are the same size and shape as the adjacent opening in the cliff face, like pieces from a huge jigsaw puzzle. Farther down the hillslope, the blocks have been further fractured and are smaller than those at the cliff face. We know of no reason to think that these blocks have moved since permafrost melted.

Ice-wedge polygons

Other evidence of permafrost in the county includes ice-wedge polygons. Only those seen on aerial photographs (scale 1:20,000) taken in 1968 are shown on plate 1 by a star symbol.

Like those seen elsewhere in Wisconsin, the polygons generally have no topographic expression, but show up as a difference in the color of soil or vegetation resulting from the greater amount of moisture in the ice-wedge cast than in the surrounding material. During the drought in the summer of 1988, many ice-wedge polygons could be seen from the ground.

The polygons shown on the east side of St. Aloysius Cemetery southwest of Sauk City (plate 1) are up to 100 m across, and the ice-wedge casts are no more than a few metres across. The ice-wedge casts here have been detected using ground-penetrating radar (Attig, Clayton, Bradbury, and Blanchard, 1987).

Other hillslope deposits

The most noticeable hillslope deposits, associated with the Rountree Formation, talus cones, and block streams, have been discussed in earlier sections. Much of the rest of Sauk County is blanketed with 1 m or more of hillslope material that is seldom seen because it commonly occurs near the base of hillslopes where natural and artificial exposures are rare. Most of it was deposited during the Late Pleistocene and Holocene.

The hillslope deposits on Cambrian sandstone are composed primarily of sand, but blocks of sandstone are present below steep cliffs. Hillslope deposits are thicker in southern than in northern Sauk County, and they contain more silt, probably because of the presence of windblown silt washed down from higher slopes.

Natural Bridge State Park

Natural Bridge State Park is just northeast of the community of Leland (sec. 17 and 18, T10N, R5E). It includes one of the largest natural bridges in the Driftless Area (fig. 26).

The topography of the park is largely the result of hillslope processes such as slopewash and soil creep, which are active today, and soil flowage, which was active when permafrost was present at the time glaciers existed in the eastern part of the county. These processes caused soil to move downhill to the creek next to Highway C, which washed it southwest into the valley of North Branch Honey Creek.

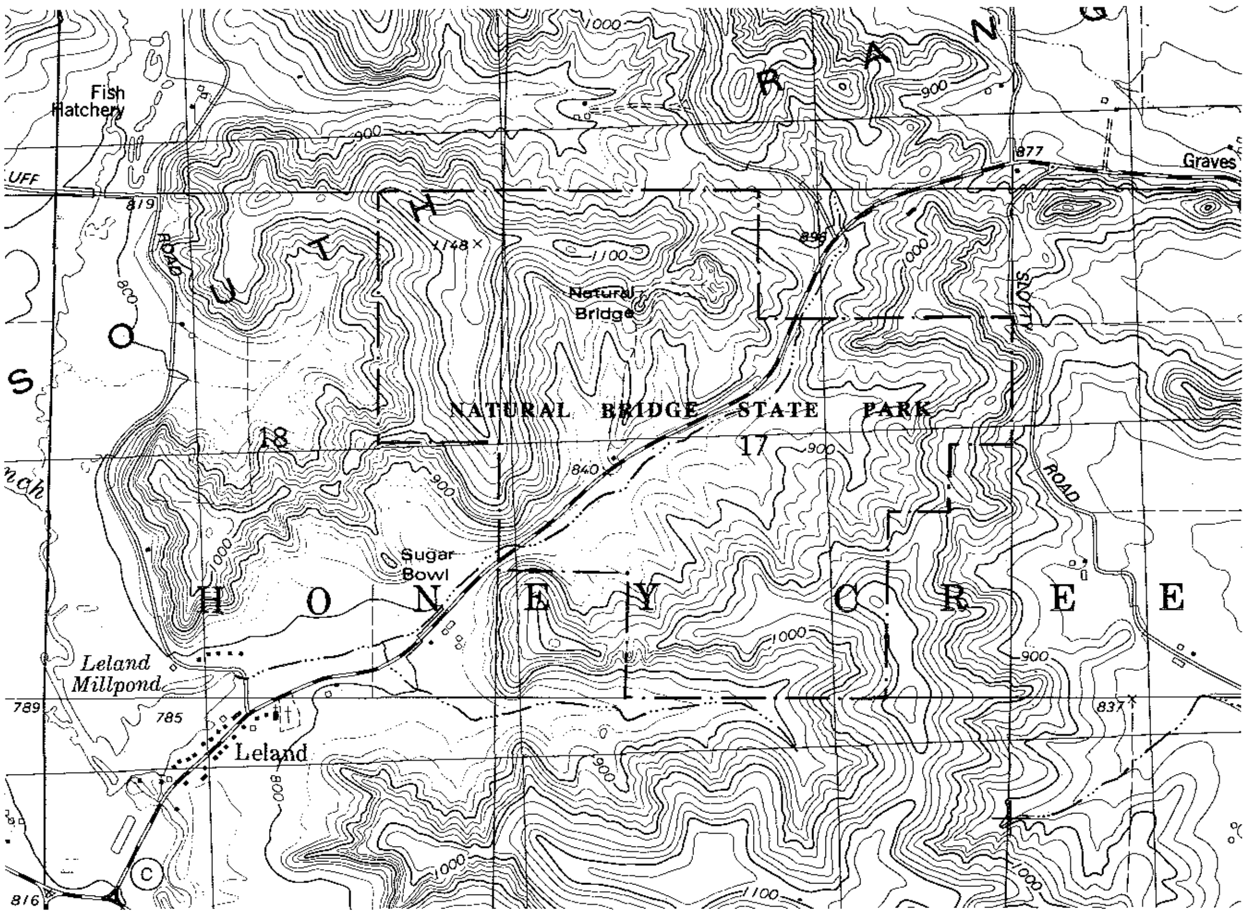


Figure 26. *Topographic map of Natural Bridge State Park and adjacent areas. Area shown is 4 km wide; contour interval 20 feet. (U.S. Geological Survey Black Hawk, Wisconsin, quadrangle, 7.5-minute series, topographic, 1975.)*

Overhanging cliffs occur throughout this region where softer sandstone has been eroded from under harder sandstone. The natural bridge in the northern part of the park probably formed where an overhanging cliff on one side of a narrow ridge was eroded back far enough to pierce the steep hillslope on the other side of the ridge.

The natural bridge, which is about 10 m high, is formed in sandstone of the Mazomanie Member of the Tunnel City Formation. The sandstone is cross-bedded and contains pebbles of Baraboo quartzite. The typical hummocky topography of the Mazomanie Member can be seen along the footpath just south of the bridge. The Wonewoc Formation occurs near the bottom of the valley; the St. Lawrence Formation is above the level of the natural bridge. The Jordan Formation is on steep slopes at the edge of uplands in the northwestern part of the park and in the southeast corner of the park, and the Oneota Formation underlies the uplands.

Eolian geology

A thin layer of windblown silt occurs on the more gently sloping surfaces throughout the county. In a few places it is more than 1.5 m thick (map units **wt** and **wc**, plate 1). Most was deposited during the last part of the Wisconsin Glaciation.

Windblown sand (map unit **ws**, plate 1) occurs on the sand plains along the Wisconsin River in southern Sauk County. It occurs in the form of longitudinal dunes that are elongated east-west, parallel to the valley, and generally no more than a few metres high. Most of the sand was probably deposited during the drier middle part of the Holocene.

REFERENCES

Adams, R.L., 1978, Stratigraphy and petrology of the lower Oneota Dolomite (Ordovician)--south-central Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 3, p. 82-90.

Alden, W.C., 1918, The Quaternary geology of southeastern Wisconsin: U.S. Geological Survey Professional Paper 106, 356 p.

Anderson, R.C., 1988, Reconstruction of preglacial drainage and its diversion by earliest glacial forebulge in the upper Mississippi Valley region: Geology, vol. 16, p. 254-257.

Anderson, R.C., and Ludvigson, G.A., 1986, Baraboo interval quartzite in Washington County, Iowa: Geoscience Wisconsin, vol. 10, p. 15-27.

Andrews, G.W., 1958, Windrow formation of upper Mississippi Valley region, a sedimentary and stratigraphic study: Journal of Geology, vol. 66, p. 597-624.

Anstett, T.F., 1977, Distribution of burrows in upper Cambrian sandstones, Baraboo area, Wisconsin: University of Wisconsin, Madison, Master's thesis, 83 p.

Asthana, V., 1969, The Mount Simon Formation (Dresbachian Stage) of Wisconsin: University of Wisconsin, Madison, Ph.D. dissertation, 159 p.

Attig, J.W., 1989, Pleistocene geology of Marathon County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 65, 27 p.

Attig, J.W., and Clayton, Lee, 1988, Late Wisconsin permafrost history and tunnel channel formation in Wisconsin: American Quaternary Association Program and Abstracts, p. 104.

Attig, J.W., Clayton, Lee, Bradbury, K.R., and Blanchard, M.C., 1987, Confirmation of tundra polygons and shore-ice collapse trenches in central Wisconsin and other applications of ground-penetrating radar: Geological Society of America Abstracts with Programs, vol. 19, p. 187.

Attig, J.W., Clayton, Lee, Lange, K.I., and Maher, L.J., 1990, The Ice-Age geology of Devils Lake State Park: Wisconsin Geological and Natural History Survey.

Attig, J.W., Clayton, Lee, and Mickelson, D.M., 1985, Correlation of late Wisconsin glacial phases in the western Great Lakes area: Geological Society of America Bulletin, vol. 96, p. 1585-1593.

Attig, J.W., Clayton, Lee, and Mickelson, D.M., 1986, Pleistocene stratigraphic units of Wisconsin, 1984-87: Wisconsin Geological and Natural History Survey Information Circular 62, 61 p.

Baker, R.W., 1986, Evidence for an early Pleistocene minimum age for the upper Mississippi Valley: Geological Society of America Abstracts with Programs, vol. 18, p. 532.

Berg, R.R., 1954, Franconia formation of Minnesota and Wisconsin: Geological Society of America Bulletin, vol. 65, p. 857-882.

Berg, R.R., Nelson, C.A., and Bell, W.C., 1956, Upper Cambrian rocks in southeast Minnesota: Geological Society of America Guidebook for Field Trip 2, Minneapolis meeting, p. 1-23.

Black, R.F., 1964, Potholes and associated gravel of Devils Lake State Park: Wisconsin Academy of Sciences, Arts and Letters, vol. 53, p. 165-175.

Black, R.F., 1968, Geomorphology of Devils Lake area, Wisconsin: Wisconsin Academy of Sciences, Arts and Letters, vol. 56, p.117-148.

Black, R.F., 1970a, Glacial geology [of the Baraboo district]: Wisconsin Geological and Natural History Survey Information Circular 14, p. 65-77.

Black, R.F., 1970b, Blue Mounds and the erosional history of southwestern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 15, p. H1-H11.

Black, R.F., 1974, Geology of Ice Age National Scientific Reserve of Wisconsin: U.S. National Park Service Scientific Monograph Series 2, 234 p.

Boebel, R.W., 1950, Sedimentology of the St. Lawrence dolomite and relationship to Wisconsin Arch: University of Wisconsin, Madison, Master's thesis, 108 p.

Clayton, Lee, 1982, Influence of Agassiz and Superior drainage on the Mississippi River: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 83-87.

Clayton, Lee, 1986, Pleistocene geology of Portage County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 56, 19 p.

Clayton, Lee, 1987, Pleistocene geology of Adams County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 59, 14 p.

Clayton, Lee, in press, Geology of Juneau County: Wisconsin Geological and Natural History Survey Information Circular 66.

Clayton, Lee, and Attig, J.W., 1987a, Drainage of Lake Wisconsin near the end of the Wisconsin Glaciation, *in* Mayer, L., and Nash, D., Catastrophic Flooding: Boston, Allen & Unwin, p. 139-153.

Clayton, Lee, and Attig, J.W., 1987b, Lake-ice collapse trenches in Wisconsin, U.S.A.: Earth Surface Processes and Landforms, vol. 12, p. 167-172.

Clayton, Lee, and Attig, J.W., 1989, Glacial Lake Wisconsin: Geological Society of America Memoir 173, 88 p.

Cole, H.E., 1918, A standard history of Sauk County, Wisconsin: Chicago, Lewis Publishing Company, 1128 p.

Dalziel, I.W.D., and Dott, R.H., Jr., 1970, Geology of the Baraboo district, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 14, 164 p.

Dalziel, I.W.D., and Stierwalt, G.L., 1975, Stress history of folding and cleavage development, Baraboo Syncline, Wisconsin: Geological Society of America Bulletin, vol. 86, p. 1671-1690.

Davis, R.A., Jr., 1970, Prairie du Chien Group in the Upper Mississippi Valley: Wisconsin Geological and Natural History Survey Information Circular 11, p. 35-44.

Dott, R.H., Jr., 1974, Cambrian tropical storm waves in Wisconsin: Geology, vol. 2, p. 243-246.

Dott, R.H., Jr., 1983, The Proterozoic red quartzite enigma in the north central United States: resolved by plate collision?: Geological Society of America Memoir 160, p. 129-141.

Dott, R.H., Jr., and Byers, C.W., 1980, SEPM research conference on modern shelf and ancient cratonic sedimentation–the orthoquartzite-carbonate suite revisited: University of Wisconsin, Madison, Department of Geology and Geophysics, 62 p.

Dott, R.H., Jr., Byers, C.W., Fielder, G.W., Stenzel, S.R., and Winfree, K.E., 1986, Aeolian to marine transition in Cambro-Ordovician cratonic sheet sandstones of the northern Mississippi valley, U.S.A.: Sedimentology, vol. 33, p. 345-367.

Dott, R.H., Jr., and Dalziel, I.W.D., 1972, Age and correlation of the Precambrian Baraboo Quartzite of Wisconsin: Journal of Geology, vol. 80, p. 552-568.

Dury, G.H., and Knox, J.C., 1971, Duricrusts and deep-weathering profiles in southwestern Wisconsin: Science, vol. 174, p. 291-292.

Emrich, G.H., 1966, Ironton and Galesville (Cambrian) sandstones in Illinois and adjacent areas: Illinois State Geological Survey Circular 403, 55 p.

Fielder, G.W., III, 1985, Lateral and vertical variation of depositional facies in the Cambrian Galesville sandstone, Wisconsin Dells: University of Wisconsin, Madison, Master's thesis, 194 p.

Flint, A.E., 1956, Stratigraphic relations of the Shakopee dolomite and the St. Peter sandstone in southwestern Wisconsin: Journal of Geology, vol. 64, p. 396-421.

Frolking, T.A., 1978, The upland red clays of the Driftless Area of southwestern Wisconsin: their genesis, distribution, and geomorphic significance: University of Wisconsin, Madison, Master's thesis, 175 p.

Gates, R.M., 1942, Baxter Hollow granite cupola: American Mineralogist, vol. 27, p. 699-711.

Geiger, C.A., 1986, Mineralogy and sedimentology of rock overlying the Baraboo Quartzite: Geoscience Wisconsin, vol. 10, p. 28-36.

Greenberg, J.K., 1986, Magnetism and the Baraboo interval: breccia, metasomatism, and intrusion: Geoscience Wisconsin, vol. 10, p. 96-112.

Greenberg, J.K., and Brown, B.A., 1984, Cratonic sedimentation during the proterozoic: an anorogenic connection in Wisconsin and the Upper Midwest: Journal of Geology, vol. 92, p. 159-171.

Grether, W.J., 1977, Conodonts and stratigraphy of the Readstown Member of the St. Peter Sandstone in Wisconsin: University of Wisconsin, Madison, Master's thesis, 133 p.

Gundlach, H.F., 1980, Soil survey of Sauk County, Wisconsin: U.S. Department of Agriculture Soil Conservation Service, 248 p.

Habermann, G.M., 1978, Mineralogic and textural variations of the duricrust in southwestern Wisconsin: University of Wisconsin, Madison, Ph.D. dissertation, 153 p.

Hart, R.R., 1963, Biostratigraphic relations of the basal St. Peter sandstone in northeast Iowa and southwest Wisconsin: State University of Iowa, Ph.D. dissertation, 220 p.

Hempton, M., Gordon, M., Kirschner, D., 1986, Analysis of structures within phyllitic layers of the Baraboo Syncline, Wisconsin: a new interpretation of deformation history: Geoscience Wisconsin, vol. 10, p. 66-77.

Henry, D.M., 1975, Sedimentology and stratigraphy of the Baraboo Quartzite of south-central Wisconsin: University of Wisconsin, Madison, Master's thesis, 90 p.

Heyl, A.V., Agnew, A.F., Lyons, E.J., and Behre, C.H., Jr., 1959, The geology of the upper Mississippi Valley zinc-lead district: U.S. Geological Survey Professional Paper 309, 310 p.

Hinze, W.V., 1957, A gravity investigation of the Baraboo Syncline region: University of Wisconsin, Madison, Ph.D. dissertation, 136 p.

Hobbs, H.C., and Goebel, J.E., 1982, Geologic map of Minnesota, Quaternary geology: Minnesota Geological Survey State Map Series S-1, scale 1:500,000.

Hotchkiss, W.O., and Thwaites, F.T., 1911, Map of Wisconsin showing geology and roads: Wisconsin Geological and Natural History Survey, scale 1:380,000.

Irving, R. D., 1877, Geology of central Wisconsin, *in* Geology of Wisconsin, vol. 2: Madison, Commissioners of Public Printing, p. 408-636.

Jank, M. E., and Cambray, F. W., 1986, Pressure solution and cleavage development in the Baraboo Quartzite: Geoscience Wisconsin, vol. 10, p. 54-65.

Johnson, D. P., 1947, The areal geology and stratigraphy of the Hillsboro quadrangle, Wisconsin: Madison, University of Wisconsin, Master's thesis, 60 p.

Johnson, S. E., 1936, The topography and geology of the Ableman Gorge: Madison, University of Wisconsin, Bachelor's thesis, 9 p.

Junemann, P.M., 1951, Some sedimentary studies of the Lodi shale in western Wisconsin: University of Wisconsin, Madison, Masters's thesis, 29 p.

Knox, J.C., 1982, Quaternary history of the Kickapoo and lower Wisconsin River valleys, Wisconsin, *in* Knox, J.C., Clayton, Lee, and Mickelson, D.M., eds., Quaternary history of the Driftless Area: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 1-65.

Knox, J.C., 1989, Long- and short-term episodic storage and removal of sediment in watersheds of southwestern Wisconsin and northwestern Illinois: International Association of Scientific Hydrology Publication 184, p. 157-164.

Knox, J.C., and Attig, J.W., 1988, Geology of the pre-Illinoian sediment in the Bridgeport terrace, lower Wisconsin River valley, Wisconsin: Journal of Geology, vol. 96, p. 505-513.

Knox, J.C., and Maher, L.M., 1974, Late Quaternary environments of the Driftless Area, southwestern Wisconsin, *in* Knox, J.C., and Mickelson, D.M., eds., Late Quaternary environments of Wisconsin, American Quaternary Association Field Trip Guidebook, 1974 Biennial Meeting: Madison, p. 24-43.

Leigh, D.S., 1988, Pleistocene stratigraphy and geomorphology of the Bridgeport terrace of the lower Wisconsin River valley near Muscoda and Blue River, Wisconsin: University of Wisconsin, Madison, Masters' thesis, 167 p.

Leith, Andrew, 1935, The pre-Cambrian of the Lake Superior region, the Baraboo district, and other isolated areas in the upper Mississippi valley, *in* Trowbridge, A.C., ed., Guide Book: Kansas Geological Society Ninth Annual Field Conference, p. 320-332.

Lorenzen, R.M., 1952, The areal geology and stratigraphy of the southeastern quarter of the Richland Center quadrangle, Wisconsin: University of Wisconsin, Madison, Master's thesis, 58 p.

Lundqvist, Jan, Clayton, Lee, and Mickelson, D.M., in press, Deposition of the late Wisconsin Johnson moraine, south-central Wisconsin, *in* Fenton, M.M., and Clayton, Lee, eds., Glacial terrain and glacial sediment facies: Rotterdam, A.A. Balkema.

Maher, L.J., Jr., 1982, The palynology of Devils Lake, Sauk County, Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 119-135.

Mai, Huazhao, and Dott, R.H., Jr., 1985, A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 47, 26 p.

Martin, Lawrence, 1916, The physical geography of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 36, 549 p.

McGee, W.J., 1891, Pleistocene history of northeastern Iowa: U.S. Geological Survey Annual Report 11, p. 189-577.

Mickelson, D.M., 1983, A guide to the glacial landforms of Dane County, Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 6, 53 p.

Mickelson, D.M., 1986, Glacial and related deposits of Langlade County, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 52, 30 p.

Mickelson, D.M., Clayton, Lee, Baker, R.W., Mode, W.N., and Schneider, A.F., 1984, Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Miscellaneous Paper 84-1, 15 p.

Mickelson, D.M., Clayton, Lee, Fullerton, D.S., and Borns, H.W., Jr., 1983, The late Wisconsin glacial record of the Laurentide ice sheet in the United States, *in* Porter, S.C., ed., Late-Quaternary environments of the United States, vol. 1, The Late Pleistocene: Minneapolis, University of Minnesota Press, p. 3-37.

Mickelson, D.M., Knox, J.C., and Clayton, Lee, 1982, Glaciation of the Driftless Area: an evaluation of the evidence: Wisconsin Geological and Natural History Survey Field Trip Guide Book 5, p. 155-169.

Myers, M.D., 1981, The stratigraphy and sedimentology of the upper Wonewoc Formation -- a critique of the Ironton Member: University of Wisconsin, Madison, Master's thesis, 130 p.

Nelson, C.A., 1956, Upper Croixan stratigraphy, Upper Mississippi Valley: Geological Society of America Bulletin, vol. 67, p. 165-184.

Nienow, J.A., McKay, C.P., and Friedmann, E.I., 1988, The cryptoendolithic microbial environment in the Ross Desert of Antarctica: Light in the photosynthetically active region: Microbial Ecology, vol. 16, p. 271-289.

Odom, I.E., 1975, Feldspar-grain size relations in Cambrian arenites, upper Mississippi Valley: Journal of Sedimentary Petrology, vol. 45, p. 636-650.

Odom, I.E., 1978a, Lithostratigraphy and sedimentology of the Lone Rock and Mazomanie Formations, Upper Mississippi valley: Wisconsin Geological and Natural History Survey Field Trip Guide Book 3, p. 91-96.

Odom, I.E., 1978b, Mazomanie (School) Bluff: Wisconsin Geological and Natural History Survey Field Trip Guide Book 3, p. 121-124.

Odom, I.E., and Ostrom, M.E., 1978, Lithostratigraphy, petrology, sedimentology, and depositional environments of the Jordan Formation near Madison, Wisconsin: Wisconsin Geological and Natural History Survey Field Trip Guide Book 3, p. 23-45.

Ostrom, M.E., 1962, Subsurface lithologic cross sections: Wisconsin Geological and Natural History Survey Open-File Reports 62-1--62-8, scale 1:500,000.

Ostrom, M.E., 1966, Cambrian stratigraphy in western Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 7, 79 p.

Ostrom, M.E., 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 8, 1 sheet.

Ostrom, M.E., 1971, Preliminary report on results of physical and chemical tests of Wisconsin silica sandstones: Wisconsin Geological and Natural History Survey Information Circular 18, 61 p.

Ostrom, M.E., 1978a, Mazomanie Bluff: Wisconsin Geological and Natural History Survey, Geology of Wisconsin, Outcrop Description DN8/6E/16A, 5 p.

Ostrom, M.E., 1978b, La Rue Quarry: Wisconsin Geological and Natural History Survey, Geology of Wisconsin, Outcrop Description SK11/5E/22, 3 p.

Ostrom, M.E., 1987, Cambrian stratigraphy at Whitehall, Wisconsin: Geological Society of America Centennial Field Guide, vol. 3, p. 185-188.

Ostrom, M.E., and Davis, R.A., Jr., 1970, Stratigraphy and sedimentation of Cambrian and Ordovician rocks in western Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 11, p. 45-106.

Owen, D.D., 1847, Preliminary report of the geological survey of Wisconsin and Iowa: U.S. General Land Office Report, p. 160-173.

Petro, W.L., 1983, Igneous rocks of the Baraboo district, Wisconsin (abstract): Institute on Lake Superior Geology Proceedings, vol. 29, p. 33.

Raasch, G.O., 1935, Paleozoic strata of the Baraboo area, *in* Trowbridge, A.C. ed., Guide Book: Kansas Geological Society Ninth Annual Field Conference, p. 405-414.

Raasch, G.O., 1952, Oneota Formation, Stoddard quadrangle: Illinois Academy of Science Transactions, vol. 45, p. 85-95.

Raasch, G.O., 1958, The Baraboo (Wis.) monadnock and paleo-wind direction: Journal of Alberta Society of Petroleum Geologists, vol. 6, p. 183-187.

Richmond, G.M., and Fullerton, D.S., 1986, Summation of Quaternary glaciations in the United States of America: Quaternary Science Reviews, vol. 5, p. 183-196.

Salisbury, R.D., 1895, Preglacial gravels on the quartzite range near Baraboo, Wis.: Journal of Geology, vol. 3, p. 655-667.

Salisbury, R.D., and Atwood, W.W., 1900, The geography of the region about Devil's Lake and the Dalles of the Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 5, 151 p.

Salstrom, P.L., 1962, The areal geology and stratigraphy of the Reedsburg quadrangle, Wisconsin: University of Wisconsin, Madison, Masters's thesis, 52 p.

Sardeson, F.W., 1897, On glacial deposits in the driftless area: American Geologist, vol. 20, p. 392-403.

Schmidt, R.G., 1951, The subsurface geology of Freedom township in the Baraboo iron-bearing district of Wisconsin: University of Wisconsin, Madison, Master's thesis, 40 p.

Sims, P.K., and Peterman, Z.E., 1980, Geology and Rb-Sr age of lower Proterozoic granitic rocks, northern Wisconsin: Geological Society of America Special Paper 182, p. 139-146.

Sloss, L.L., Krumbein, W.C., and Dapples, E.C., 1949, Integrated facies analysis: Geological Society of America Memoir 39, p. 91-123.

Smith, E.I., 1978, Introduction to Precambrian rocks of south central Wisconsin: Geoscience Wisconsin, vol. 2, p. 1-17.

Smith, E.I., 1983, Geochemistry and evolution of the early Proterozoic, post-Penokean rhyolites, granites, and related rocks of south-central Wisconsin, USA: Geological Society of America Memoir 160, p. 113-128.

Smith, H.T.U., 1949, Periglacial features in the Driftless Area of southern Wisconsin: Journal of Geology, vol. 57, p. 196-215.

Socha, B.J, 1984, The glacial geology of the Baraboo area, Wisconsin, and application of remote sensing to mapping surficial geology: University of Wisconsin, Madison, Master's thesis, 154 p.

Squire, G.H., 1897, Studies in the driftless region of Wisconsin: Journal of Geology, vol. 5, p. 825-836.

Squire, G.H., 1898, Studies in the driftless region of Wisconsin II: Journal of Geology, vol. 6, p. 182-192.

Squire, G.H., 1899, Studies in the driftless region of Wisconsin: Journal of Geology, vol. 7, p. 79-82.

Squire, G.H., 1905a, Notes on the gravels of Monroe County, Wisconsin: Wisconsin Geological and Natural History Survey Open File Report 05-2, 26 p.

Squire, G.H., 1905b, Studies in the driftless region of Wisconsin: Wisconsin Geological and Natural History Survey Open File Report 05-1, 16 p.

Squire, G.H., 1909, Peculiar local deposits on bluffs adjacent to the Mississippi: Wisconsin Academy of Sciences, Arts and Letters, vol. 16, pt. 1, p. 258-274.

Squire, G.H., 1916, Discussion of the phenomena of local glaciation region: Wisconsin Geological and Natural History Survey Open File Report 16-2, 15 p.

Stark, J.T., 1930, Pre-Cambrian water-laid tuff in the Baraboo, Wisconsin, district: Journal of Geology, vol. 38, p. 466-471.

Stark, J.T., 1932, Igneous rocks in the Baraboo district, Wisconsin: Journal of Geology, vol. 40, p. 119-139.

Stenzel, S.R., 1983, Stratigraphy and sedimentology of the Upper Cambrian Wonewoc Formation in the Baraboo and Kickapoo River valleys, Wisconsin: University of Wisconsin, Madison, Master's thesis, 235 p.

Strong, Moses, 1882, Geology of the Mississippi Region north of the Wisconsin River, *in* Geology of Wisconsin, vol. 4: Madison, Commissioners of Public Printing, p. 1-98.

Templeton, J.S., and Willman, H.B., 1963, Champlainian Series (Middle Ordovician) in Illinois: Illinois State Geological Survey Bulletin 89, 260 p.

Thwaites, F.T., 1923, The Paleozoic rocks found in deep wells in Wisconsin and northern Illinois: Journal of Geology, vol. 31, p. 529-555.

Thwaites, F.T., 1928, Pre-Wisconsin terraces of the Driftless Area of Wisconsin: Geological Society of America Bulletin, vol. 39, p. 621-641.

Thwaites, F.T., 1931, Buried pre-Cambrian of Wisconsin: Geological Society of America Bulletin, vol. 42, p. 719-750.

Thwaites, F.T., 1935, Physiography of the Baraboo district, Wisconsin, *in* Trowbridge, A.C. ed., Guide Book: Kansas Geological Society Ninth Annual Field Conference, p. 395-404.

Thwaites, F.T., 1958, Land forms of the Baraboo district, Wisconsin: Wisconsin Academy of Sciences, Arts and Letters, vol. 47, p. 137-159.

Thwaites, F.T., 1960, Evidences of dissected erosion surfaces in the Driftless Area: Wisconsin Academy of Sciences, Arts and Letters, vol. 49, p. 17-49.

Thwaites, F.T., 1961, The base of the St. Peter sandstone in southwestern Wisconsin: Wisconsin Academy of Sciences, Arts and Letters, vol. 50, p. 203-219.

Thwaites, F.T., and Twenhofel, W.H., 1921, Windrow formation; an upland gravel formation of the Driftless and adjacent areas of the upper Mississippi valley: Geological Society of America Bulletin, vol. 32, p. 293-314.

Thwaites, F.T., Twenhofel, W.H., and Martin, Lawrence, 1922, Sparta-Tomah folio: Wisconsin Geological and Natural History Survey Open-File Report 22-3, 162 p.

Trowbridge, A.C., ed., 1935, Guide Book: Kansas Geological Society Ninth Annual Field Conference, 471 p.

Trowbridge, A.C., and Atwater, G.I., 1934, Stratigraphic problems in the upper Mississippi valley: Geological Society of America Bulletin, vol. 45, p. 21-80.

Twenhofel, W.H., and Thwaites, F.T., 1919, The Paleozoic section of the Tomah and Sparta quadrangles, Wisconsin: Journal of Geology, vol. 27, p. 614-633.

Twenhofel, W.H., Raasch, G.O., and Thwaites, F.T., 1935, Cambrian strata of Wisconsin: Geological Society of America Bulletin, vol. 46, p. 1687-1744.

Ulrich, E.O., 1916, Correlation by displacements of the strand-line and the function and proper use of fossils in correlation: Geological Society of America Bulletin, vol. 27, p. 451-490.

Ulrich, E.O., 1920, Major causes of land and sea oscillations: Washington Academy of Sciences Journal, vol. 10, p. 57-78.

Ulrich, E.O., 1924, Notes on new names in table of formations and on physical evidence of breaks between Paleozoic systems in Wisconsin: Wisconsin Academy of Sciences, Arts and Letters, vol. 21, p. 71-107.

Usbug, Enis, 1968, The geology of the western end of the Baraboo syncline: University of Wisconsin, Madison, Master's thesis, 50 p.

Van Hise, C.R., 1893, Some dynamic phenomena shown by the Baraboo quartzite ranges of central Wisconsin: Journal of Geology, vol. 1, p. 347-353.

Van Hise, C.R., and Leith, C.K., 1911, The geology of the Lake Superior region: U.S. Geological Survey Monograph 52, 641 p.

Van Schmus, W.R., 1978, Geochronology of the southern Wisconsin rhyolites and granites: Geoscience Wisconsin, vol. 2, p. 19-24.

Walcott, C.D., 1914, Cambrian geology and paleontology: Smithsonian Miscellaneous Collections, vol. 57, p. 345-412.

Wanenmacher, J.M., 1932, Paleozoic strata of the Baraboo region, Wisconsin: University of Wisconsin, Madison, Ph.D. dissertation, 105 p.

Wanenmacher, J.M., Twenhofel, W.H., and Raasch, G.O., 1934, The Paleozoic strata of the Baraboo area, Wisconsin: American Journal of Science, vol. 28, p. 1-30.

Weidman, Samuel, 1904, The Baraboo iron-bearing district of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 13, 190 p.

Wilson, T.V., and Sibley, D.F., 1974, Pressure solution and porosity reduction in a shallow buried quartz arenite: Geological Society of America Abstracts with Programs, vol. 7, p. 1230.

Winchell, Alexander, 1872, Report of a geological survey of the vicinity of Belleplaine, Scott County, Minnesota: Saint Paul, Minnesota, 16 p.

Winchell, N.H., 1874, The geology of the Minnesota Valley: Minnesota Geological and Natural History Survey Second Annual Report, p. 127-212.

Winkler, M.G., 1988, Effects of climate on development of two *Sphagnum* bogs in south-central Wisconsin: Ecology, vol. 69, p. 1032-1043.

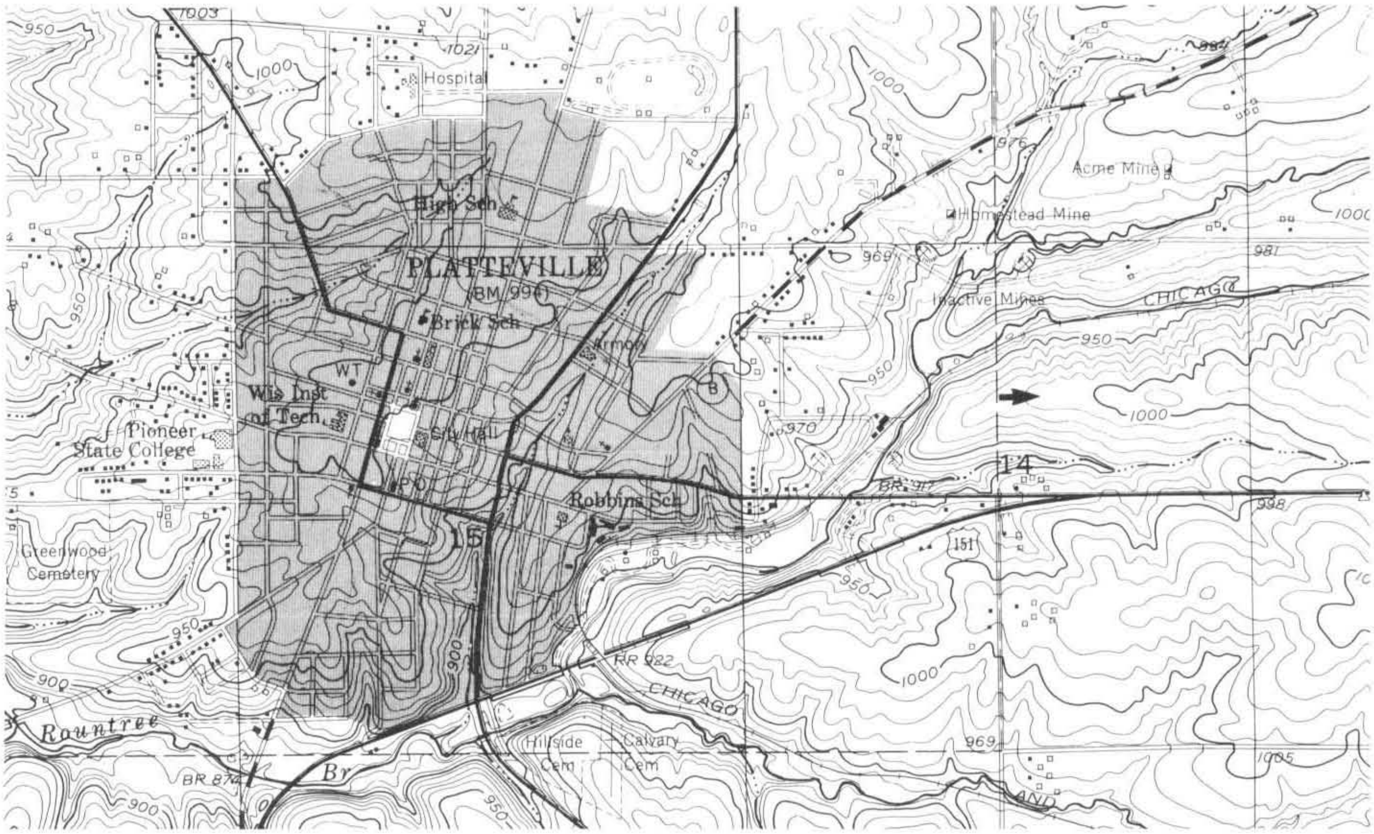


Figure A1. *Location of the type section of the Rountree Formation (arrow) in Grant County, southwestern Wisconsin. Area shown is 4.5 km wide; contour interval 10 feet. (U.S. Geological Survey, Platteville, Wisconsin, quadrangle, 7.5-minute series, topographic, 1952.)*

APPENDIX:

ROUNTREE FORMATION (NEW)

James C. Knox, David S. Leigh, and Tod A. Frolking

Source of name

The Rountree Formation is named after Rountree Branch, a tributary of the Little Platte River. Rountree Branch flows adjacent to the upland dolomite quarry containing the type section of the Rountree Formation. Rountree Branch was named for John H. Rountree, pioneer lead miner and co-founder of the city of Platteville in 1827.

Location and description of type section

The type section is in a dolomite quarry on a narrow interfluve in the SE1/4 NW1/4 SW1/4 NE1/4 sec. 14, T3N, R1W (fig. A1). The type section is a west-facing exposure at the east edge of the quarry and located at the crest of the interfluve. This site has been previously identified as the Rosemeyer Farm Quarry (Knox and Maher, 1974). At this site, loess of the Peoria and Roxana Formations overlies the red clay of the Rountree Formation, which in turn overlies cherty dolomite of the lower member of the Galena Formation (Middle Ordovician) at an elevation of about 295 m (970 ft) (fig. A2).

The overlying Peoria Formation consists of about 2.2 m of dark yellowish-brown (10YR 4/4 to 10YR 5/4) to yellowish-brown (10YR 5/5) loess that averages about 76 percent silt, 23 percent clay, and less than 1 percent sand below the depth of leaching (fig. A2). The Peoria was deposited during the last part of the Wisconsin Glaciation. A dark brown silt (10YR 4/3), at 2.23 to 2.35 m depth, underlies the Peoria Formation; it is correlated with the Roxana Formation in north-

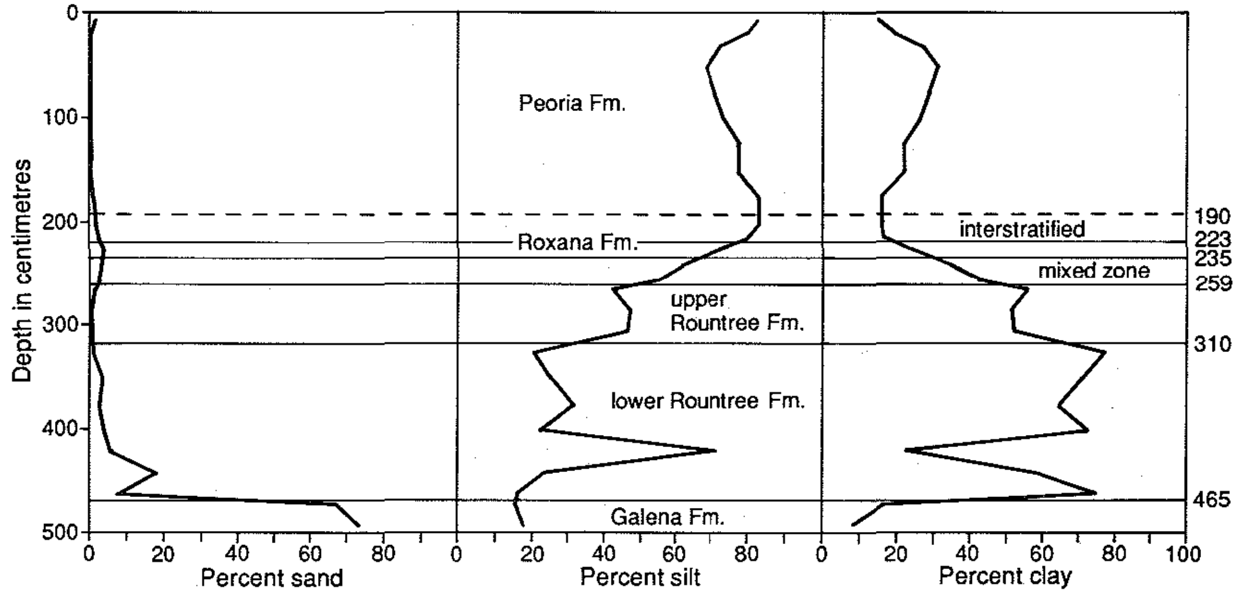


Figure A2. *Grain-size analysis of the type section of the Rountree Formation, SE1/4 NW1/4 SW1/4 NE1/4 sec. 14, T3N, R1W.*

western Illinois. The Roxana Formation here tends to be slightly less silty and more clayey than the overlying unleached lower Peoria Formation (fig. A2). The Roxana is characterized by a moderately coarse, platey structure and it is leached. Small charcoal bits are common. The basal yellowish-brown silt of the Peoria Formation between depths of about 1.90 and 2.23 m is interstratified with dark brown silt eroded from the Roxana Formation. In turn, the main unit of the Roxana Formation is separated from the Rountree Formation by a leached, dark brown (7.5YR 4/4) mixed zone occurring between depths of 2.35 and 2.59 m (fig. A2). Unlike the basal Peoria, where thin bedding identifies the interstratification within the Roxana, no bedding is apparent in the mixed zone representing the interface between the Roxana and Rountree Formations. The mixed zone is distinguished from the Roxana by its redder hue and the inclusion of occasional chert fragments.

The dark brown (7.5YR 4/3) to reddish-brown (5YR 4/3) Rountree Formation directly underlies the mixed zone at a depth of 2.59 m on the crest of the divide at the type section (fig. A2). The Rountree Formation consists of two prominent subdivisions: an upper reddish-brown (5YR 4/3) clay unit and a lower dark brown to strong brown (7.5YR 4/4 to 4/6) clay unit. The clay content in the less-than-2-mm fraction ranges from 50 to 60 percent in the upper unit; in the lower unit, from 60 to 80 percent. A lens of yellow (2.5Y 8/8) carbonate-leached silt occurs within the lower Rountree Formation between 4.16 and 4.27 m and contains chert fragments; it is unclear whether this silt is residuum or material illuviated from above. Although angular chert fragments are common in both units, the quantity of chert is considerably greater in the lower than in the upper unit. The redder hues of the Rountree Formation in comparison to the overlying loess deposits are due to more abundant extractable iron, which commonly ranges from 3 to 6 percent (citrate-bicarbonate-dithionite extraction). The reddish-brown to strong brown cherty clay of the Rountree Formation abuts brownish-yellow (10YR 6/6) dolomitic sand on the weathered surface of the lower Galena Formation at a depth of 4.65 m.

Reference section

The section east of Lime Ridge (fig. 15) is designated a reference section of the Rountree Formation.

Description of unit

At the type section on the crest of the divide, the Rountree Formation is 2.06 m thick. The upper reddish-brown clay has a strong, fine, angular, blocky structure and is 0.51 m thick. The lower, 1.55-m thick, dark brown to strong brown clay contains many metallic black manganese coatings on ped faces; its strong, coarse, platey structure increases with depth (fig. A2). Both units are leached of carbonates throughout. The less abundant clay in the upper Rountree Formation is mainly associated with more abundant silt. Grain-size differences between the two units reflect an influx of silt from overlying loess units as well as the downward illuviation of clay within the Rountree Formation. The clay mineralogy and a modest increase of organic carbon in relation to depth support the notion that illuviation is an active process.

At the type section, Frolking (1978) found that montmorillonite and mixed-layer intergrades dominate the clay fractions, kaolinite and quartz tend to occur in moderate amounts, and mica and vermiculite are present in small amounts. Except for greater amounts of vermiculite in the overlying loess, its clay mineralogy is similar to that of the Rountree Formation, but the underlying dolomite insoluble residue is dominantly mica and quartz. Nevertheless, the mineralogy of the clay within dolomitic sand weathered from the Galena dolomite is similar to that of the overlying Rountree clay, indicating that a slow alteration of mica to montmorillonite and kaolinite is occurring. Vertically undisturbed chert beds can be traced laterally from unweathered dolomite into the lower, more clayey unit of the Rountree Formation. This indicates that the red clay is moving downward and replacing the dolomite on a volume-per-volume basis: the amount of clay that would be produced by the volume of weathered dolomite is incapable of providing the quantity of clay underlying these chert beds.

Regional extent and thickness

The thickness and distribution of the Rountree Formation varies with the type of underlying bedrock, slope steepness, and interfluve width. Rountree Formation at the Rosemeyer Quarry can be absent or greater than 2 m across the interfluve. Some of the variation in thickness at the Rosemeyer Quarry is due to the highly irregular surface of the weathering front on the Galena dolomite, but much is due to slope steepness. Mass wasting and fluvial erosion on side slopes at the Rosemeyer Quarry, much having occurred prior to deposition of the loess of the Peoria Formation, progressively eroded the thickness of the Rountree clay toward the valley sides, resulting in concentrated chert lag deposits (up to 50 cm thick) and stone lines and little to no remaining red clays (Knox and Maher, 1974). The Rountree Formation is mainly concentrated in areas underlain by carbonate formations for which the greatest thicknesses are associated with those Paleozoic units that are rich in chert, such as the lower parts of the Prairie du Chien and Galena Formations. The chert lag deposits have provided a protective armor that has reduced the erosional susceptibility of the red clay of the Rountree Formation. The red clay usually is absent or in thin horizons on slopes steeper than 3 to 5 percent.

Thicknesses of the Rountree tends to be greater on wide flat upland interfluves than on narrow interfluves, but the relationship is not strong due to the previously mentioned factors. Because of the wide range of thicknesses of the Rountree Formation, it is meaningless to assign an average thickness for the entire region. The greatest thicknesses occur north of the lower Wisconsin River; they appear to be related to karst depressions on upland interfluves underlain by the chert-rich Prairie du Chien Formation where depths exceeding 15 m are not uncommon.

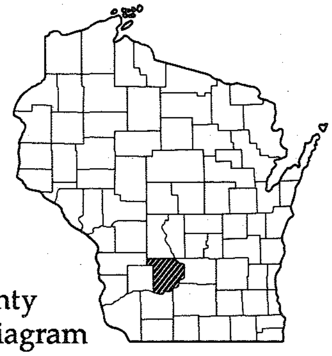
South of the Wisconsin River the Galena dolomite is the main source of chert on uplands, but chert is considerably less abundant than in the lower part of the Prairie du Chien Formation. Consequently, south of the Wisconsin River, maximum thicknesses of the Rountree Formation generally do not exceed 3 m on uplands underlain by the Galena dolomite and average thicknesses may be closer to 1.5 m. Thicknesses commonly range from zero to a few centimetres on other upland landscapes not underlain by cherty dolomite bedrock south of the Wisconsin River.

Origin

The Rountree Formation had a complex origin that involved illuviation from overlying loess deposits and slow accretion of residual sediment from underlying dolomite. Frolking (1978) concluded that the large amount of fine and medium clay, the textural and mineralogical homogeneity throughout the profile, the concentrations of organic matter and amorphous iron, and oriented clays at the base of the Rountree Formation are strong evidence for clay illuviation. Frolking also suggested that the montmorillonite dominance of the fine and medium red clay is similar to that of the overlying loess and distinctly different from the dominance of the dolomite insoluble residues by mica and quartz. Frolking (1978) used neutron activation analysis on the 0.001-to-0.01-mm clay fraction and found that an undisturbed red clay sample directly overlying dolomite was similar to that of the underlying dolomite but that a red clay sample higher in the profile had trace-element concentrations intermediate between those of the dolomite and loess, suggesting mixing. In contrast to the clay fraction, the mineralogy of the silt and sand fractions within the Rountree are generally quite similar to the dolomite insoluble residues, indicating that most of this sediment is residual (Frolking, 1978).

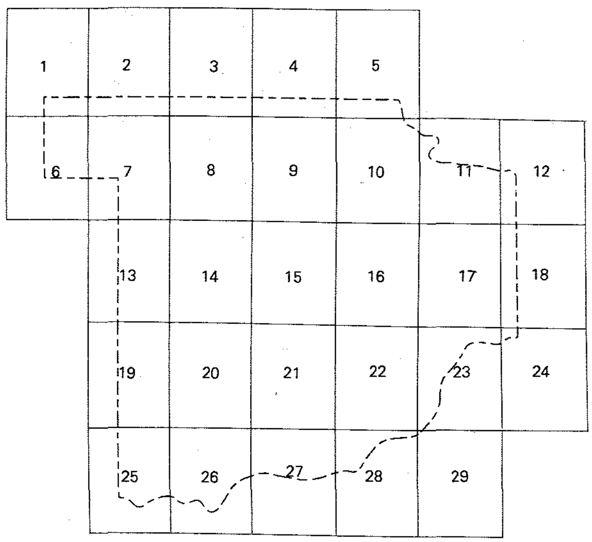
Age and correlation

The Rountree Formation is older than the Peoria and Roxana Formations that bury it on upland sites, but its complex evolutionary origin makes it impossible to assign a specific age. On some upland sites in western Wisconsin it is found in association with the Windrow Formation, which might indicate that it has been forming since the Cretaceous (Andrews, 1958). It is unlikely to be of great antiquity at most places in the Driftless Area because severe mass wasting during Pleistocene periglacial climates in the region have resulted in severe erosional stripping of the upland landscapes (Knox, 1982). For example, a study of a small southwestern Wisconsin watershed showed that the loss of sediment from upland hillslopes between 20,000 and 12,000 B.P. was about 200 Mg $km^{-2}yr^{-1}$ (Knox, 1989). This rate is approximately double the modern agriculturally accelerated rate of 112 Mg $km^{-2}yr^{-1}$. The number of such erosional episodes during the Pleistocene is unknown, but such events probably have occurred several times and they explain why the Rountree Formation is either relatively thin or absent at many locations throughout the southwestern Wisconsin region.



Sauk County
location diagram

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



1 Hillsboro–1983
2 Wonewoc–1975
3 Potato Hill–1975
4 Lyndon Station–1975
5 Wisconsin Dells North–1975
6 Valton–1983
7 La Valle–1975
8 Reedsburg West–1975
9 Reedsburg East–1975
10 Wisconsin Dells South–1975
11 Lewiston–1975
12 Pine Island–1975
13 Lime Ridge–1983
14 Loganville–1983
15 Rock Springs–1975
16 North Freedom–1975
17 Baraboo–1975
18 Durwards Glen–1975
19 Bear Valley–1983
20 Plain–1983
21 Black Hawk–1975
22 Sauk Prairie–1975
23 Sauk City–1975
24 Lodi–1975
25 Lone Rock–1983
26 Spring Green–1983
27 Arena–1962
28 Mazomanie–1962
29 Black Earth–1962 (82 PR)

PR Photorevised