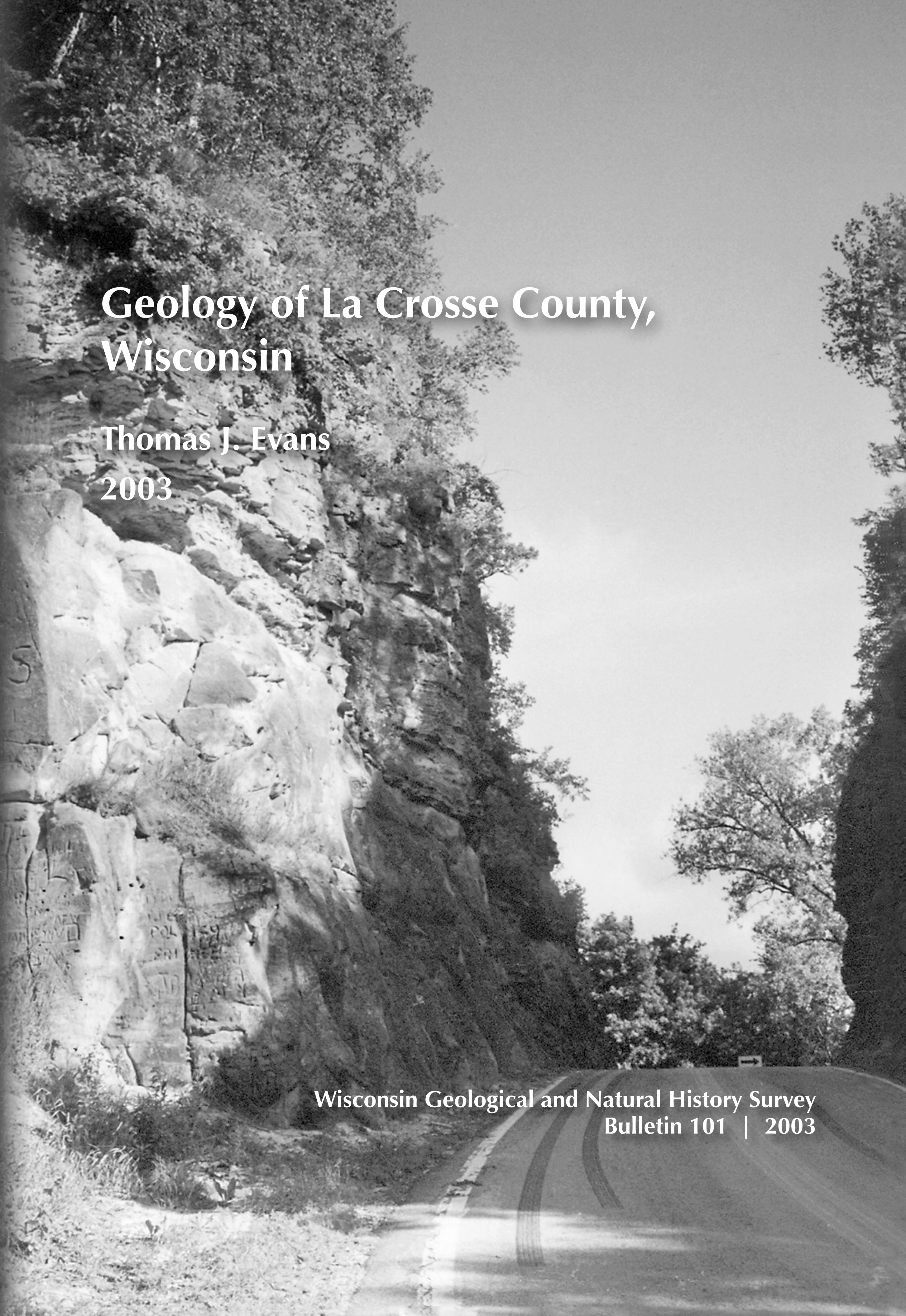
Geology of La Crosse County, Wisconsin

Thomas J. Evans

2003



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Bulletin 101 | 2003

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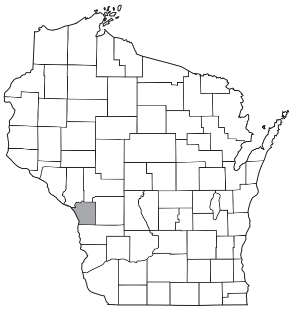

Geology of La Crosse County, Wisconsin

Thomas J. Evans

2003

A description of the Paleozoic and Quaternary materials and the geologic history of La Crosse County, which includes the northwestern part of the Driftless Area adjacent to the valley of the upper Mississippi River

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ABSTRACT

La Crosse County is characterized by contrasts in topography, geology, and land use. Broad, flat river terraces along the western margin of the county are strikingly different from the steep, hilly landscape of the coulee country to the east. Areas underlain by unconsolidated sediment deposited within the past 25,000 years, during and after the most recent glacial period, are alongside near-vertical bluffs of sandstone and dolomite rock that is hundreds of million years old. Contrasts are also evident between the county's rapidly urbanizing corridor along the Mississippi River and the sparsely populated agricultural uplands that are characterized by farms and small communities. Paleozoic bedrock is the result of nearshore marine deposition of sand and silt and the offshore deposition of calcareous sediment from about 325 to 500 million years ago. More recently, within about the past 25,000 years, this landscape was modified by Late Pleistocene glacial meltwater streams, Late Pleistocene and Holocene nonglacial streams, and wind and slope-erosion processes.

INTRODUCTION

La Crosse County is in west-central Wisconsin (fig. 1) within the Western Upland geographic province described by Martin (1965) and in the northwestern part of the Driftless Area—the region in southwest Wisconsin and adjacent parts of Minnesota, Iowa, and Illinois not covered by continental glaciers during the Ice Age.

Three major rivers are present: the Mississippi River along the western border of the county, the Black River along the northwestern part of the county's northern boundary, and the west-flowing La Crosse River, which divides the county into northern and southern halves. The Mississippi and Black Rivers were glacial meltwater streams when the Late Pleistocene continental glaciers covered much of the upper Midwest. Sediment samples collected from the Black River stream terraces include mainly quartz and small amounts of dolomite from nearby Paleozoic rock units as well as igneous and metamorphic rock fragments that are characteristic of meltwater-stream sediment related to the glacial ice that was once present to the west, north, and east. The La Crosse River was a nonglacial stream; its headwaters were west of the westernmost extent of the Wisconsin Glaciation (Clayton and others, 1992). The material in the terraces along the La Crosse River is exclusively of local origin and consists of dominantly sandstone and small amounts of dolomite.

The geologic units at the land surface and the landscape of La Crosse County vary from south to north as well as from west to east (plate 1; fig. 1). To the south are broad, flat uplands developed on erosion-resistant Ordovician dolomite of the Prairie du Chien Group. These uplands contrast with narrow ridges in the north, which are capped by erosional remnants of the Prairie du Chien Group dolomite and interspersed with rolling lowlands and occasional bluffs formed by sandstone of the Elk Mound, Tunnel City, and Trempealeau Groups. The Mississippi River forms the west boundary of La Crosse County; this area is characterized by extensive marsh lowlands within controlled-level water bodies, such as Lake Onalaska. Marshes of Holocene age lie next to broad, flat Late Pleistocene terraces along the eastern edge of the Mississippi River valley. The low-relief terraces contrast, in turn, with the Paleozoic bedrock bluffs along the edge of the uplands immediately to the east. These uplands display dendritic erosional topography developed on

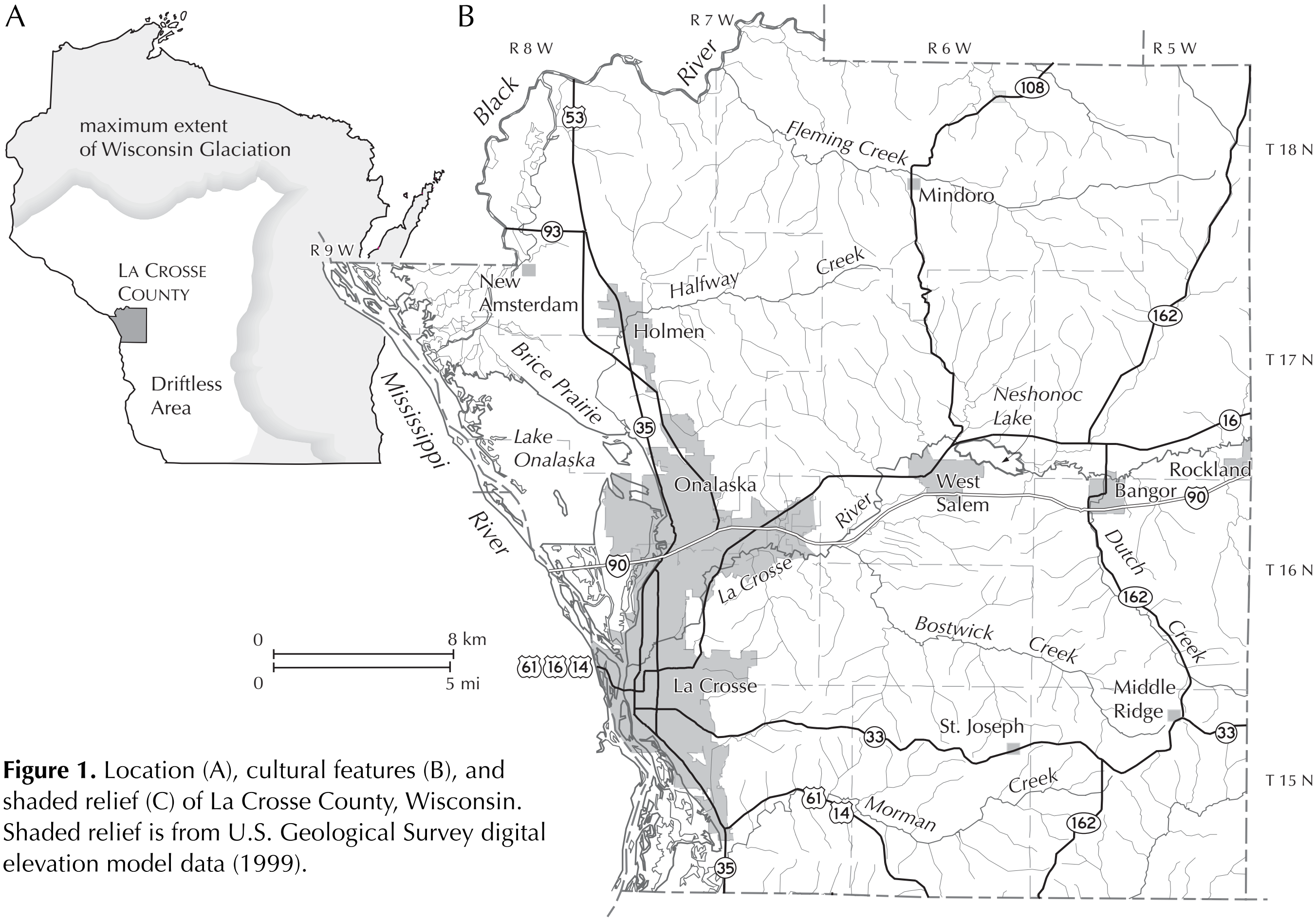


Figure 1. Location (A), cultural features (B), and shaded relief (C) of La Crosse County, Wisconsin. Shaded relief is from U.S. Geological Survey digital elevation model data (1999).

the unglaciated, mature landscape that characterizes the Driftless Area. Thin, discontinuous, windblown silt or loess covers the uplands.

Purpose and scope

This report and accompanying map have been designed to provide readers with an understanding of the general geologic framework of La Crosse County. The results of this study can also be a beginning point for more detailed investigations, whether they are focused on the geologic characteristics of specific sites or in county or regional studies, such as the hydrogeology of the La Crosse area, or investigations of stratigraphic relationships among or within the various rock units in the county.

The report and map were based on field investigations mainly completed in 1988 and 1989, and supplementary fieldwork up to 1995. Field observations were noted on standard 1:24,000-scale topographic quadrangle maps as well as in field notebooks. Standard techniques were used for the field work, including sampling of the subsurface materials in the Quaternary sediment using a truck-mounted drill rig. I incorporated information from well construction reports, engineering boring logs, and road materials survey notes, available from the files of the Wisconsin Geological and Natural History Survey, as well as the results of study of thin sections of selected rock samples in map construction and interpretation. Laboratory data supplement the field observations and include the determination of physical properties of sediment samples at the Quaternary Laboratory of the Department of Geology and Geophysics, University of Wisconsin–Madison. The results of laboratory investigations are available from the Quaternary Laboratory. Soils information (Beatty, 1960) was used to delineate peat and muck

C

deposits in the county as well as to identify the location of ponded (quiet water) sediment. I initially mapped geologic units on U.S. Geological Survey quadrangle maps (7.5-minute series, topographic); I then compiled the map units at a scale of 1:50,000 for publication at a scale of 1:100,000 (plate 1).

Acknowledgments

I acknowledge the helpful comments and suggestions of Anthony C. Runkel (Minnesota Geological Survey), James C. Knox (Department of Geography, University of Wisconsin–Madison), and Lee Clayton, James M. Robertson, Bruce A. Brown, and Stephen J. Gaffield (Wisconsin Geological and Natural History Survey), who reviewed the manuscript, map, and cross sections. Their thorough reviews, comments, and suggestions have added materially to the information presented; however, any errors of fact remaining in the text and the interpretations of the geology of La Crosse County are my responsibility. I thank John W. Attig for his insight into the Quaternary geologic units and his review of an earlier version of the manuscript. Deborah L. Patterson prepared the map and cross sections and Susan L. Hunt completed the illustrations and layout of the report; I gratefully acknowledge their assistance and expertise.

PRECAMBRIAN ROCK

Precambrian rock (greater than 570 million years old) is present beneath younger Paleozoic rock and Quaternary sediment throughout La Crosse County. The thickness of rock and sediment overlying the Precambrian substrate ranges from just less than 400 ft to more than 1,300 ft. In the northeastern corner of the county, Precambrian rock is at an elevation of approximately 500 ft (datum is mean sea level) and is buried beneath a cover of 400 ft of Paleozoic sedimentary rock. The buried Precambrian surface slopes generally southwest at about 13 ft per mile. At the southwest corner of the county, the top of the Precambrian is present at an elevation of about 80 ft. At this point, the Precambrian rock units are covered by almost 200 ft of the Quaternary sediment that fills the Mississippi River valley (Thwaites, 1931, 1957) and by about 400 ft of Cambrian sandstone.

The lithology of Precambrian rock in the county is not well known. In 1980, a U.S. Geological Survey test drilled near Stoddard, Wisconsin, 4.7 miles south of the Vernon–La Crosse county line, penetrated 8 ft into the Precambrian bedrock (well VE-117; well construction report on file at the Wisconsin Geological and Natural History Survey). Samples of the Precambrian rock taken from this test were identified as medium-crystalline, yellow-red granite containing 50 percent quartz, 40 percent orthoclase feldspar, 5 percent biotite, and 5 percent plagioclase. The Precambrian was encountered at an approximate depth of 638 ft (an elevation of about 22 ft) in this test hole. Well records in Minnesota immediately west of the La Crosse County area also show granite (well 221178 near Brownsville, Minnesota; well 219278 near La Crescent, Minnesota; and well 219184 near Winona, Minnesota).

Primarily on the basis of geophysical information, Reed (1993) inferred that La Crosse County straddles two regional-scale terranes of Precambrian (which comprises the Archean and Proterozoic) rock. Most of the county to the north and west overlies Archean (greater than 2,500 million years ago [Ma]) gneiss; the remainder of the county overlies Early Proterozoic rhyolite and granite dated at 1,760 Ma (Sims and Van Schmus, 1993). Reed (1993) also inferred the presence of a small area of Middle Proterozoic granite (1,450–1,500 Ma) at depth in the southwestern part of the county, but granite recovered from the test hole at Stoddard, Wisconsin, which is located in this area, did not yield enough radiometric-datable mineral to confirm the Middle Proterozoic age (W.R. Van Schmus, University of Kansas, Department of Geology, written communication, 2000).

PALEOZOIC ROCK

Paleozoic rock is found throughout La Crosse County, either at the land surface, where it may be covered by a thin layer of loess, or beneath streams, where it is buried by tens to hundreds of feet of unconsolidated Quaternary sediment. Paleozoic rock ranges in age from Late Cambrian to Middle Ordovician. It was deposited along the northeastern edge of the Hollandale Embayment, a slowly subsiding region between the Transcontinental Arch, the Wisconsin Dome, and the Wisconsin Arch (Sloss, 1988). Older Paleozoic bedrock units are not exposed in the county, but are known from well construction reports on file at the Wisconsin Geological and Natural History Survey.

The principal Paleozoic bedrock units recognized at the land surface in La Crosse County are distinguished on the basis of their general physical characteristics, including lithology (color, mineralogy, and texture), nature of bedding and sedimentary structures, and the nature of contacts with geologic units above and below (fig. 2). The ability to show geologic units recognized in the field on a geologic map of the county was based on these factors as well as the map scale (1:100,000; plate 1) selected for publication. Rock types observed in La Crosse County include sandstone, siltstone, shale, silty and sandy dolomite, and dolomite with and without significant amounts of chert. I did not engage in detailed investigation of each lithostratigraphic unit recognized in the county, except that required to identify map units and to portray accurately their position and extent in the La Crosse County landscape at the published map scale of 1:100,000. Although several geologic units contain fossils, which can provide useful biostratigraphic and paleoenvironmental information, I did not analyze fossil content in detail because it was not necessary for preparing the geologic map. I constructed two cross sections (plate 1) from field observations and information from well construction reports.

Regional dip of the Paleozoic rock units generally parallels the Precambrian surface to the southwest, but at a rate of about 10 ft per mile. Runkel (1996), who investigated the bedrock geology of Houston County, Minnesota, immediately west of La Crosse, observed several near-vertical normal faults, including a northeast-trending "structural zone," with offsets due to faulting of several tens of feet to 100 ft. In La Crosse County, however, I observed no similar fault evidence, nor did I observe interruptions in the general dip of Paleozoic rock to the southwest. The structural zone noted by Runkel (1996) in Houston County appears to extend to the northwest part of La Crosse County, but it is in alignment with the mouth of the Black River and related alluvial sediment and is not seen in nearby outcrops of Paleozoic rock. This zone was not identified farther northeast in Trempealeau County (Brown, 1988; B.A. Brown, WGNHS, verbal communication, 2002).

The relationship of Paleozoic rock to the groundwater resources of the La Crosse County has been examined little beyond the U.S. Geological Survey's regional study (Young and Borman, 1973). Runkel (1996), however, noted five "hydrostratigraphic components" in the Paleozoic of Houston County, which he used to identify two "hydrogeologic units": aquifer and confining unit.

Elk Mound Group

The Elk Mound Group was defined by Ostrom (1966, 1967) to include the quartzose sandstone, shaly sandstone, and shale that lie stratigraphically above Precambrian rock and stratigraphically below the fine-grained feldspathic sandstone of the Tunnel City Group, formerly known as Franconia Sandstone. The Elk Mound Group includes, from lowermost (oldest) to uppermost (youngest), the Mount Simon Formation, the Eau Claire Formation, and the Wonewoc Formation. Although the Elk Mound Group is primarily Late Cambrian (Dresbachian), the Wonewoc Formation is Dresbachian in its lower strata and Late Cambrian (Franconian) in its upper strata.

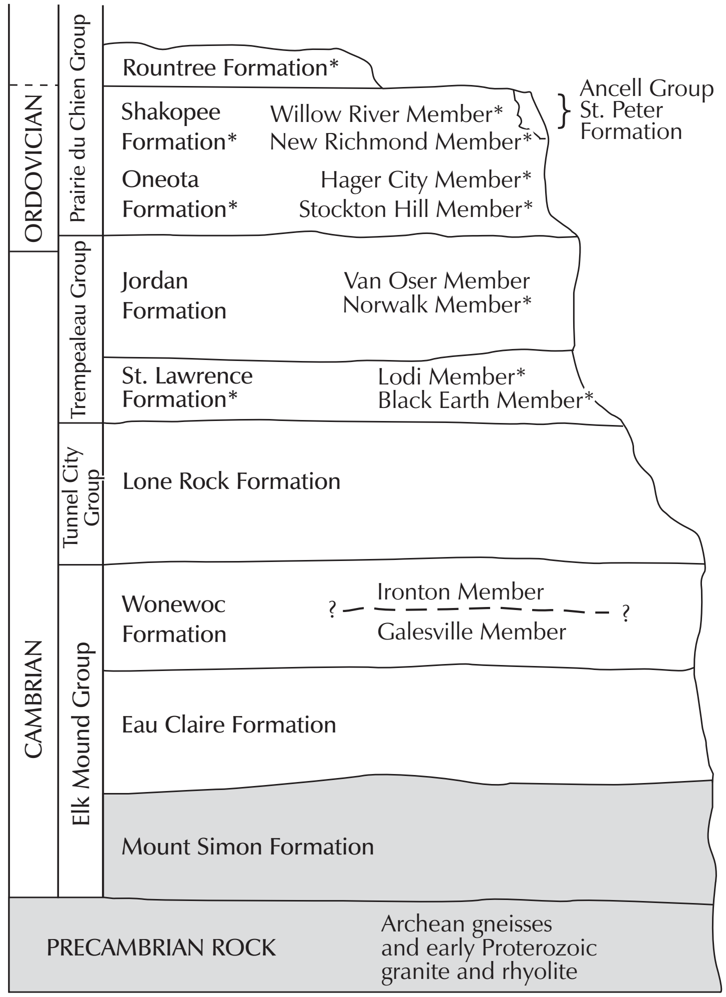


Figure 2. Lithostratigraphic units in La Crosse County. Asterisks indicate units recognized in the county, but not shown separately on plate 1; shading indicates units discussed in text, but not exposed at land surface.

Mount Simon Formation

The Mount Simon Formation is the oldest Paleozoic rock unit present in La Crosse County. It is not exposed at the land surface and is known only from well construction reports for deep wells; therefore, it does not appear on plate 1. The Mount Simon is the oldest Upper Cambrian stratum in the western Wisconsin region and is the basal lithostratigraphic unit of the Sauk II

A

B

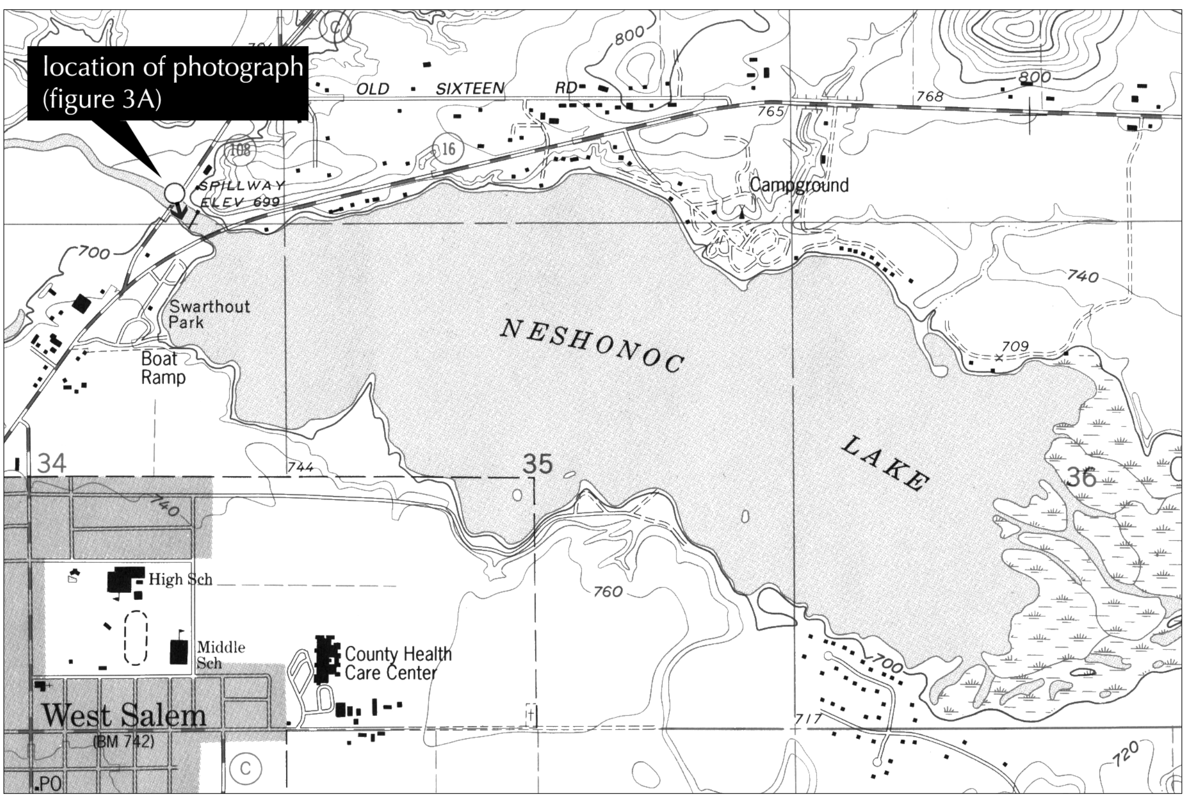


Figure 3. A. Exposure of Eau Claire Formation at Neshonoc Lake outlet near West Salem, taken from County Highway C looking southeast. B. Topographic map showing Neshonoc Lake and surrounding features. Area shown is 3 miles wide; contour interval is 20 ft. (U.S. Geological Survey, West Salem, Wisconsin, quadrangle; 7.5-minute series, topographic, 1993; contour interval is 20 ft).

sequence (Sloss, 1988). The type section of the Mount Simon is in Eau Claire County in exposures along the Chippewa River (SW¼SW¼ sec. 8, T27N, R9W), about 70 miles north–northwest of La Crosse County (Ostrom, 1966).

According to well construction reports, the maximum thickness of the Mount Simon in the county is 295 ft (well LC-131 [Heileman Brewing Co. Well 5]; SW¼NE¼SE¼ sec. 6, T15N, R7W). Descriptions of samples from this well and other wells penetrating the Mount Simon show a range in texture from fine to very coarse; the unit overall is described as typically medium- and coarse-grained sandstone containing abundant well rounded grains of quartz, traces of pyrite, minor to locally abundant feldspar, and mica. The sandstone of the Mount Simon Formation contains minor amounts of dolomitic cement, occasional silica cement, and minor to locally significant amounts of silt and shale matrix.

The Mount Simon Formation was interpreted by Ostrom (1970b) to be marine sandstone formed in shallow water along a shoreline (littoral zone), resulting from the coalescing of beach sands, offshore bars, and sand spits developed in a high-energy, nearshore environment. The Mount Simon sandstone is evidence of the transgression of the Late Cambrian sea across the weathered Precambrian rock of the Midcontinent region of the North American craton.

In La Crosse County the Mount Simon Formation is a water-bearing unit that supplies several high-capacity municipal water wells with good-quality water. It is part of the so-called "sandstone aquifer" (Young and Borman, 1973) and is identified as the Mt. Simon aquifer by Runkel (1996).

Eau Claire Formation

The Eau Claire Formation crops out in a few scattered places in La Crosse County. The Eau Claire Formation is part of the Sauk II sequence of Sloss (1988). The type section of the Eau Claire Formation is described in Ostrom (1966) from exposures in abandoned quarries at Mt. Washington in Eau Claire County (SE¼NE¼NW¼ sec. 25, T27N, R10W).

Schiesser (1948) measured 16.5 ft of the Eau Claire at exposures along a ditch near the intersection of U.S. Highway 14 and State Highway 35 (NW¼NE¼ sec. 27, T15N, R7W). He described the Eau Claire at this location as fine-grained, thin-bedded, fossiliferous sandstone. Although not explicitly noted by Schiesser and based only on his description of the location, the elevation of these exposures of sandstone must have been approximately 680 to 690 ft. At the time of this study, I could not locate these outcrops of fine-grained, fossiliferous sandstone. These exposures were probably covered as a result of reconstruction of the highway intersection, which has an elevation of approximately 685 ft.

However, the Eau Claire Formation can be seen in two other localities in the county, both in the vicinity of the outlet of Neshonoc Lake. One outcrop is located immediately downstream (west) of the lake outlet (fig. 3) and a second exposure is located 1 mile farther west along the La Crosse River. About 20 ft of sandstone is present at these two outcrops, which lie stratigraphically below the sandstone of the Wonewoc Formation and, therefore, occupy the position of the Eau Claire Formation. These exposures are predominantly very fine- to fine-grained quartz sandstone that is in places characterized by trough cross-stratification in small to medium beds. The sandstone is fine grained to medium grained, and no fossils are present. At the Neshonoc Lake outlet, silty, greenish-gray shale lies at the base of the outcrop, but the limited exposure at the water level in the La Crosse River did not provide an opportunity for further observations. The elevation of the outcrops ranges from 675 to 695 ft. Only these individual outcrops of the Eau Claire Formation are noted on plate 1.

More typical very fine- to fine-grained, horizontally thin-bedded, fossiliferous sandstone of the Eau Claire Formation crops out along the cutbanks of the Black River in Jackson County, just north of the La Crosse County line, 11 miles north of Neshonoc Lake (NE¼NW¼ sec. 32, T19N, R6W).

Contacts of the Eau Claire Formation with the underlying Mount Simon Formation and the overlying Wonewoc Formation are not exposed in La Crosse County. On the basis of exposures elsewhere in Wisconsin and in neighboring states, Havholm (1998) and Runkel and others (1998) described the contact with the overlying Wonewoc Formation as gradational and becoming younger to the west. The change in age of this contact is the result of nearshore marine Wonewoc depositional environments prograding to the west across Eau Claire basin sediment.

The Eau Claire Formation is recognized throughout La Crosse County in samples collected from water well cuttings**.** The Eau Claire has a maximum thickness of about 175 ft in well LC-38 (Wedgewood Valley Waterworks Co-op Well, NW¼SW¼NE¼ sec. 10, T15N, R7W). The Eau Claire in this well is predominantly very fine to fine-grained sandstone, sandy siltstone, and silty shale.

In their regional investigation of the Upper Cambrian sandstone in the upper Midwest, Runkel and others (1998) identified nine lithofacies in five lithofacies associations. These associations, arranged from deeper water to shallower water environments of deposition, are 1) offshore siliciclastic, 2) offshore carbonate and shale, 3) shallow carbonate, 4) shoreface, and 5) fluvial and eolian. In La Crosse County, the Eau Claire Formation outcrops would appear to be the offshore siliciclastic lithofacies association of Runkel and others (1988). Havholm (1998) described the Eau Claire Formation as containing two major lithofacies of paleoenvironmental significance. The first lithofacies includes 3- to 9-ft thick intervals of thin-bedded, horizontally bedded, fine- to very fine-grained sandstone and beds of shale; the second lithofacies is characterized by 1- to 8-ft thick intervals of thick-bedded, fine-grained sandstone with cross-stratification and related sedimentary structures suggestive of a high-energy environment of deposition. On a regional scale, these lithofacies indicate a general coarsening-upward trend in texture within the Eau Claire, suggestive of increasing shallow-water deposition and a regression of the Late Cambrian shoreline to the west (Havholm, 1998).

The Eau Claire Formation is part of the sandstone aquifer of Young and Borman (1973), although its generally fine-grained texture indicates that it may retard groundwater flow on a regional scale. Runkel (1996) considered the Eau Claire to be mostly a confining unit because it is dominated to the west in Minnesota by heterolithic, very fine-grained sandstone, siltstone, and shale. The significance of the role of the Eau Claire Formation in regional groundwater flow in La Crosse County requires more investigation.

Wonewoc Formation

The Wonewoc Formation, map unit **Ꞓw** on plate 1, is exposed extensively throughout La Crosse County. It forms the base of bluffs along the Mississippi River and the base of the numerous ridges and upland plateaus that characterize the topography of the county farther to the east (fig. 4). Runkel and others (1998) suggested that the Sauk II–Sauk III subsequence boundary of Sloss (1988) is within the sandstone beds of the Wonewoc at the base of a coarse-grained sandstone unit.

The Wonewoc Formation has its greatest exposed thickness of about 280 ft in La Crosse County in the vicinity of West Salem, where the underlying Eau Claire Formation is present at the Neshonoc Lake outlet and the overlying Tunnel City Group strata are present in the bluffs and ridges to the north and south.

Ostrom (1966, 1967) divided the Wonewoc into two members: from oldest to youngest, the Galesville and Ironton Members.

The Galesville Member of the Wonewoc Formation in La Crosse County is an easily recognized, cliff-forming sandstone. It is composed of buff to white, fine- to medium-grained, moderately to well sorted sandstone that is dominantly (more than 98 percent) composed of quartz. The Galesville is characterized by medium to thick beds of sandstone that display large sets of cross-stratification. I did not observe the basal contact of the Galesville with the underlying Eau Claire Formation in La Crosse County. Where exposed elsewhere in western Wisconsin, the lower contact of the Galesville is generally conformable with the Eau Claire (Ostrom, 1966), although the contact is also known to be at least unconformable due to erosion of the Eau Claire Formation in some places. For example, in Trempealeau County at the type section of the Galesville Member of the Wonewoc Formation (NE¼NW¼ sec. 33, T19N, R8W), evidence of erosion is present (Ostrom, 1966).

The nature of the stratification within the Wonewoc Formation changes from large sets of trough-shaped cross-stratification (lower beds) to smaller sets of cross-stratification bounded by horizontal bedding surfaces (upper beds). The stratigraphically higher sandstone is found in 2- to 5-ft thick beds of low-angle cross-stratified sandstone alternating with 1- to 2-ft thick beds of massive-appearing (burrowed?) sandstone. This change in stratification, along with lithologic changes and changes in fossil content not observed in La Crosse County, but reported elsewhere (Ostrom, 1966), led to the recognition by Ostrom of the Ironton Member of the Wonewoc Formation. The type section of the Ironton Member of the Wonewoc Formation is in Sauk County (NW¼SE¼NE¼ sec. 4, T12N, R3E; Ostrom, 1966).

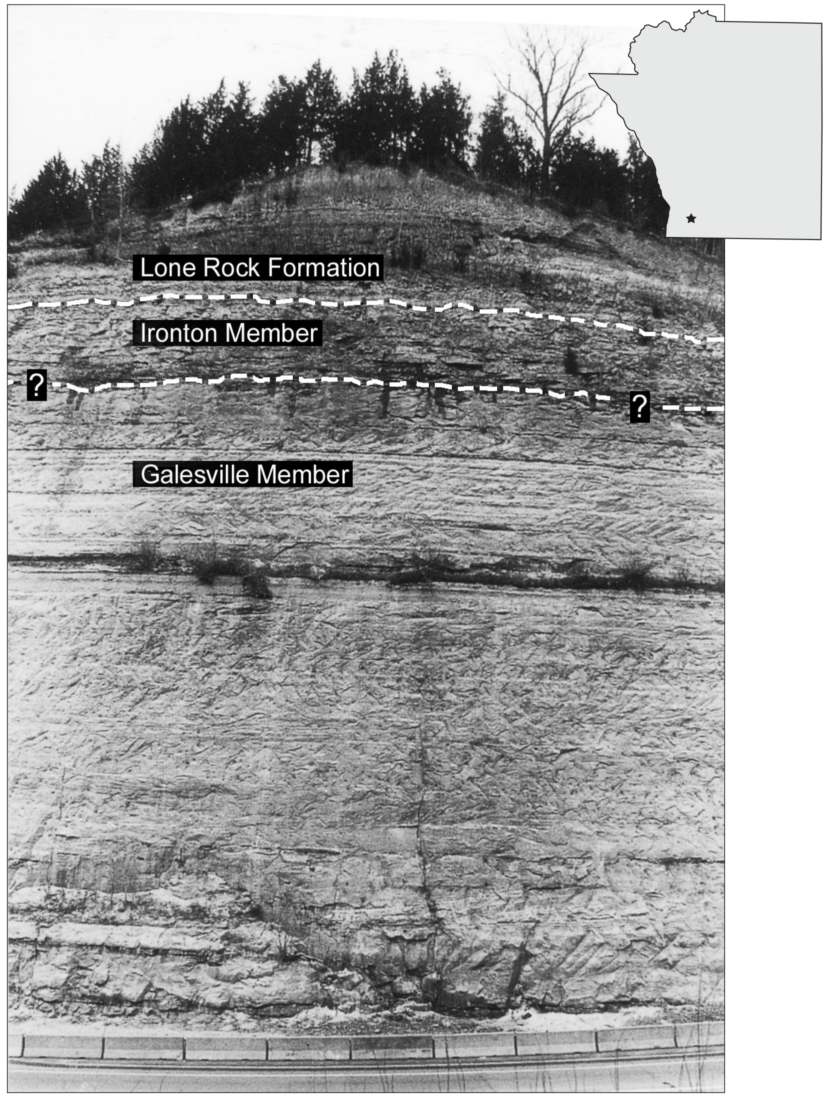


Figure 4. Exposure of Galesville and Ironton Members of the Wonewoc Formation (Elk Mound Group) and the Lone Rock Formation (Tunnel City Group) at intersection of U.S. Highways 14 and 35 (SW¼NW¼NE¼ sec. 27, T15N, R7W). Location of contact of the Galesville with the overlying Ironton Members is uncertain; contact of the Wonewoc Formation with the overlying Lone Rock Formation is gradational.

Lithologically, the Ironton is characterized by poorly sorted, fine- to medium-grained sandstone that contains common coarse-grained quartz. Very fine to fine-grained glauconite is also common in the stratigraphically higher sandstone units. Typically, the finer quartz grains are subangular to subrounded; the medium to coarse quartz grains are subrounded to rounded. Although typically well cemented, the nature of the cementation in the upper sandstone beds varies. Differential cementation results in the presence of ledge-forming and slope-forming units.

I did not map the two members separately on plate 1 for the following reasons: The contact between the Galesville and Ironton sandstone intervals in La Crosse County is not distinct and, if recognized at all, appears gradational; the occasionally prominent topographic expression of the contact due to the change in degree of cementation is not consistently evident in the county; and the Ironton Member, where present, appears to be only 20- to 40-ft thick and is, therefore, not readily shown at the intended publication scale of 1:100,000. Havholm (1998) noted, on the basis of regional study of the Cambrian units in western Wisconsin, that the two members could not be consistently recognized. Runkel and others (1998) noted that the contact between the Galesville and Ironton intervals has been suggested as the Sauk II–Sauk III subsequence boundary; however, they further observed that this contact has not been clearly defined.

Throughout the county the Wonewoc Formation dips gently to the southwest along with the other Paleozoic rock units. However, I observed a dip of 15 degrees (to the south) about 1.5 miles south of Bangor, on State Highway 162 (NW¼NW¼ sec. 17, T16N, R5W). Detailed field investigations failed to indicate any disruption of regional dip in rock units at higher elevations (stratigraphically younger) near this Wonewoc Formation exposure. The observed displacement of the strata at this location appears to be a result of local slumping.

In La Crosse County, the shoreface lithofacies association defined by Runkel and others (1998) characterizes the Wonewoc Formation: The lowermost lithofacies includes shoreface or inner-shelf storm deposits, which is overlain by the generally more coarse-grained sandstone deposited by tide- and wave-generated currents on the upper shoreface. The two lithofacies appear to be roughly equivalent to the Galesville and Ironton Members of Ostrom (1966, 1970) and show a general pattern of coarsening upward from the Eau Claire Formation below, to a 2- to 6-ft thick coarse-grained to locally pebbly sandstone unit (Sauk II–Sauk III subsequence boundary?) within the Wonewoc (Runkel and others, 1998), and then to a fining-upward interval from the coarse sandstone toward the contact with fine-grained, glauconitic sandstone of the Tunnel City Formation. I did not observe this medial, coarse-grained sandstone in La Crosse County, although this unit is reported to be present in outcrops in other west-central Wisconsin counties (Anthony Runkel, Minnesota Geological Survey, verbal communication, 2000).

The Wonewoc Formation is part of the "sandstone aquifer" of Young and Borman (1973) and is a minor source of water for private wells in the upland areas east of the city of La Crosse. The Wonewoc plays a limited role as a water source for area residences and farms because shallower bedrock units are more commonly used. Runkel (1996) identified the Wonewoc as an aquifer throughout most of its vertical and lateral extent.

Tunnel City Group

Ostrom (1967) defined the Tunnel City Group as the strata above the Elk Mound Group and below the St. Lawrence Formation or, where the St. Lawrence is absent, the Jordan Formation, of the Trempealeau Group. Tunnel City Group strata consist of a glauconite-rich fine-grained sandstone, nonglauconitic fine-grained sandstone, and shaly sandstone. Ostrom (1966, 1967) assigned the glauconite-rich sandstone to the Lone Rock Formation and nonglauconitic sandstone to the Mazomanie Formation. In La Crosse County, only the Lone Rock Formation is exposed, although the Mazomanie Formation has been shown to interfinger with the Lone Rock farther east (Ostrom, 1967; Thwaites and others, 1922). Ostrom (1966) suggested that the westernmost limit of Mazomanie sandstone extends into eastern La Crosse County, but I could find no outcrops to support this.

Lone Rock Formation

Sandstone of the Lone Rock Formation of the Tunnel City Group (Ostrom, 1967) is present at the land surface throughout La Crosse County, forming gentle, well vegetated slopes. The type section of the Lone Rock Formation was identified by Ostrom (1966) as a series of exposures and quarries along State Highway 21, northwest of the village of Lone Rock in Monroe County (SW¼SW¼NW¼ sec. 25, T18N, R2W). The Lone Rock Formation is a part of the Sauk III subsequence (Sloss, 1988) and is identified on plate 1 by the map unit **€l**.

The Lone Rock Formation in La Crosse County varies in thickness irregularly from 80 to 120 ft thick throughout much of the county, but reaches a thickness of nearly 200 ft in the Onalaska area. The Lone Rock is a series of sandstone beds that are buff to brown and greenish brown; the green is due to the presence of the green-black mineral, glauconite, in amounts varying from a few percent to as much as 20 to 30 percent. The other minerals present are mostly quartz and feldspar. The Lone Rock includes thin- to medium-bedded, cross-stratified, and horizontally bedded intervals of very fine to fine-grained sandstone overlying the white to buff-colored Wonewoc Formation (fig. 4). In places, minor beds of intraformational conglomerate are present as well as occasional brown nonglauconitic sandstone intervals up to 1-ft thick.

Ostrom (1966, 1967) further subdivided the Lone Rock Formation into three members: from oldest to youngest, Birkmose, Tomah, and Reno. However, I did not differentiate the members of the Lone Rock Formation on plate 1.

Ostrom (1970b) referred to the Lone Rock Formation as an "argillaceous lithotope" and, therefore, analogous to the Eau Claire Formation. The Lone Rock was interpreted by Ostrom (1970b) as resulting from sediment deposited in a low-energy marine shelf environment. This is consistent with the more recent work of Runkel and others (1998), who documented that the Lone Rock Formation in La Crosse County is the result of sediment deposition below the storm and fair-weather wave base on the offshore marine shelf: Deeper water environments shifted landward toward the east across the county because of a relative rise in sea level during the Franconian.

The Lone Rock Formation was quarried for road-shoulder surface aggregate because the fine-grained sand, silt, and shale material produced an aggregate with good binding characteristics when packed down. This unit is also a part of the "sandstone aquifer" of Young and Borman (1973), although its hydrogeologic characteristics are likely less favorable to groundwater flow due to its fine-grained nature. Runkel (1996) mapped the Franconia Formation (stratigraphically equivalent to the Lone Rock Formation) in Houston County, Minnesota, as a confining unit. He noted that it was dominated by heterolithic, fine-grained sandstone, siltstone, and shale.

Trempealeau Group

The Trempealeau Group refers to the interval of rocks between the fine-grained sandstone of the Tunnel City Group and the sandy dolomite of the lower Prairie du Chien Group. The Trempealeau Group includes the St. Lawrence and Jordan Formations and is Late Cambrian (Trempealeauan) in age. Ostrom (1966, 1967), among others, adapted a time-stratigraphic term (Trempealeauan) by using it in a lithostratigraphic sense and attaching the word "Group" to refer to the interval that includes the St. Lawrence and Jordan rock units. Trempealeau rocks are part of the Sauk III subsequence of Sloss (1988). The "type section" of the Trempealeau Group was defined by Twenhofel and others (1935) and Ostrom (1966) from a series of outcrops in Trempealeau County (SE¼SW¼NW¼ sec. 20, T18N, R5W).

Figure 5. Exposure of sandy and silty dolomite beds of St. Lawrence Formation (Trempealeau Group) in small quarry south of Bangor, Wisconsin (SE¼SE¼NW¼ sec. 16, T15N, R5W).

St. Lawrence Formation

Thin-bedded sandy dolomite, dolomitic sandstone, and dolomitic siltstone of the St. Lawrence Formation (*see,* for example, Ostrom 1966 and 1967) overlie glauconitic sandstone of the Tunnel City Group in La Crosse County. The St. Lawrence Formation was named by Nelson (1956) for exposures near St. Lawrence, Minnesota.

The St. Lawrence Formation is present throughout La Crosse County, but is poorly exposed. The limited exposures and an apparent maximum thickness of 30 to 40 ft on steep slopes did not permit showing the distribution of the St. Lawrence on plate 1.

The St. Lawrence Formation crops out (fig. 5) along a quarry-access road south of Bangor (N½NW¼ sec. 16, T16N, R5W). The St. Lawrence at this location includes 25 ft of silty to sandy dolomite and 10 to 15 ft of dolomitic siltstone. The dolomite is finely crystalline and forms 1- to 6-in.-thick beds that have even, thin laminations; the siltstone to very fine-grained sandstone is typically thin-bedded with wavy laminations. The siltstone appears to interfinger with the sandy dolomite.

The St. Lawrence crops out at two other locations: 1) Thin-bedded dolomitic siltstone is seen in a small, ground-level exposure along State Highway 108 just south of Mindoro Cut, and 2) several feet of very dolomitic siltstone with silty shale partings are exposed along County Highway M about 2 mi north of a junction with County Highway W (SW¼NE¼SW¼ sec. 31, T8N, R6W).

Nelson (1956) recognized two members of the St. Lawrence Formation: a stratigraphically higher, fine-grained silty and dolomitic unit named the Lodi Shale or Lodi Member, and a lower sandy dolomite interval named the Black Earth Dolomite or Black Earth Member. Ostrom (1970b), using this two-member lithostratigraphy, considered the St. Lawrence to be the result of the development of a biogenic carbonate shelf environment near low-energy shelf depositional zones characterized by very fine-grained sediment. The alternation of these closely associated shelf environments resulted in the variations observed in this interval. Hughes and Hesselbo (1997) studied the St. Lawrence Formation in western Wisconsin and did not consider the members noted above particularly useful, but instead recognized three lithofacies: a highly variable fine-grained dolomite, siltstone, and sandstone unit; a flat-pebble conglomerate and laminated sandstone; and stromatolitic dolomite. They considered this assemblage of lithofacies, when viewed in a regional context, to be the result of the transgression of a Late Cambrian sea to the north followed by shoreline retreat toward the west and south as the level of the ocean fell and sediment was deposited along a prograding shore.

Dolomite of the St. Lawrence Formation has been quarried in places as a crushed stone resource of minor importance. The role of the St. Lawrence Formation has not been evaluated within the "sandstone aquifer," although its fine-grained texture suggests that it would tend to restrict groundwater movement. Runkel (1996), working immediately to the west in Houston County, Minnesota, considered the St. Lawrence to be variably a confining unit and an aquifer. This is the result of the variable hydrostratigraphic components: the heterolithic, very fine-grained sandstone, siltstone, and shale (in the confining unit) and the carbonate rock (in the aquifer).

Jordan Formation

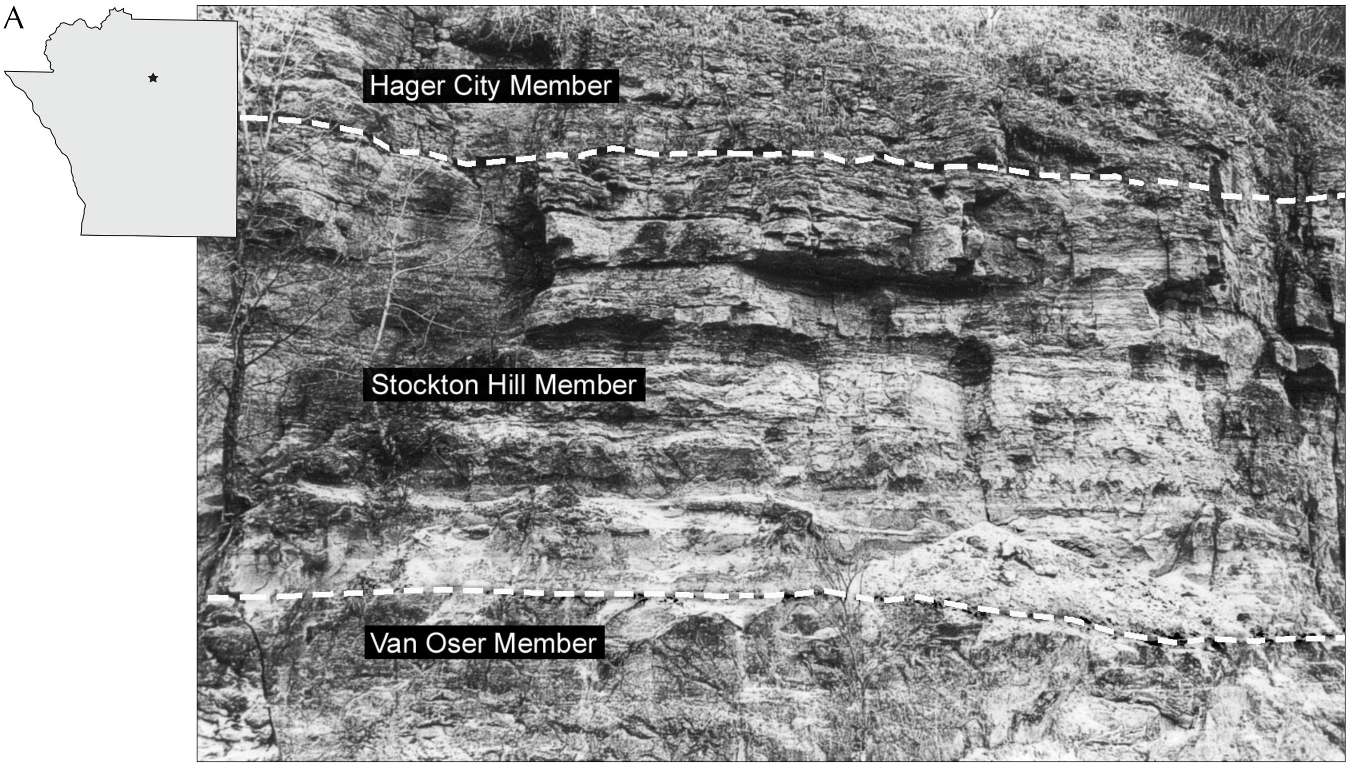
The Jordan Formation is part of the Sauk III subsequence (Sloss, 1988). The Jordan, map unit **€**j on plate 1, forms the middle part of the numerous bluffs and ridges throughout the county and ranges in thickness from about 100 to 150 ft. The Jordan exposures in La Crosse County that are most prominent are the near-vertical outcrops of quartz-rich sandstone in medium- to large-scale sets of cross-stratification (fig. 6). Other lithologic intervals are present and are included in the Jordan interval shown on plate 1. To replace the original type section, which is no longer well exposed, Runkel (1994) established a new reference section for the Jordan Formation: NE¼NW¼NE¼ sec. 9, T106N, R6W, on Winona County Road 15, 2 mi south of Homer, Minnesota.

The lithologic (and related biostratigraphic) characteristics of the Jordan Formation are problematic. Runkel (1994) recognized two lithofacies: a feldspathic interval and a quartzose interval. Byers and Dott (1995) distinguished two lithofacies within the predominantly quartzose sandstone interval of Runkel (1994) and, therefore, recognized three lithologically distinct intervals: 1) a light brown, horizontally bedded to hummocky cross-stratified, fine-grained, moderately sorted, feldspathic sandstone (30 or 40 percent feldspar; the remainder is quartz); 2) a buff to white, fine- to medium-grained, moderately to well sorted, small- to medium-bedded, trough cross-stratified quartzose sandstone (about 98 percent quartz); and 3) a white or very pale gray, fine- to coarse-grained, moderately to well sorted quartzose sandstone in large-scale wedge-shaped sets of cross-bedding.

In La Crosse County, I recognized the three lithofacies of Byers and Dott (1995), but both quartzose lithofacies are within the near-vertical outcrops of cross-bedded sandstone, which is the most distinctive and easily mapped expression of the Jordan in the county. This interval of quartz sandstone is typically referred to as the Van Oser Member of the Jordan Formation and lies stratigraphically above feldspathic sandstone of the Norwalk Member of the Jordan Formation. Occurrences of the feldspathic sandstone interval within the Van Oser interval have been observed and have led some workers to identify them as members within the Jordan Formation (for example, Odom and Ostrom, 1978). However, in La Crosse County, I did not observe the feldspathic sandstone except in its most typical and widespread occurrence—stratigraphically below the cross-bedded quartzose sandstone in the position of the Norwalk Member.

The lower contact of the Jordan Formation with the underlying St. Lawrence Formation is

A



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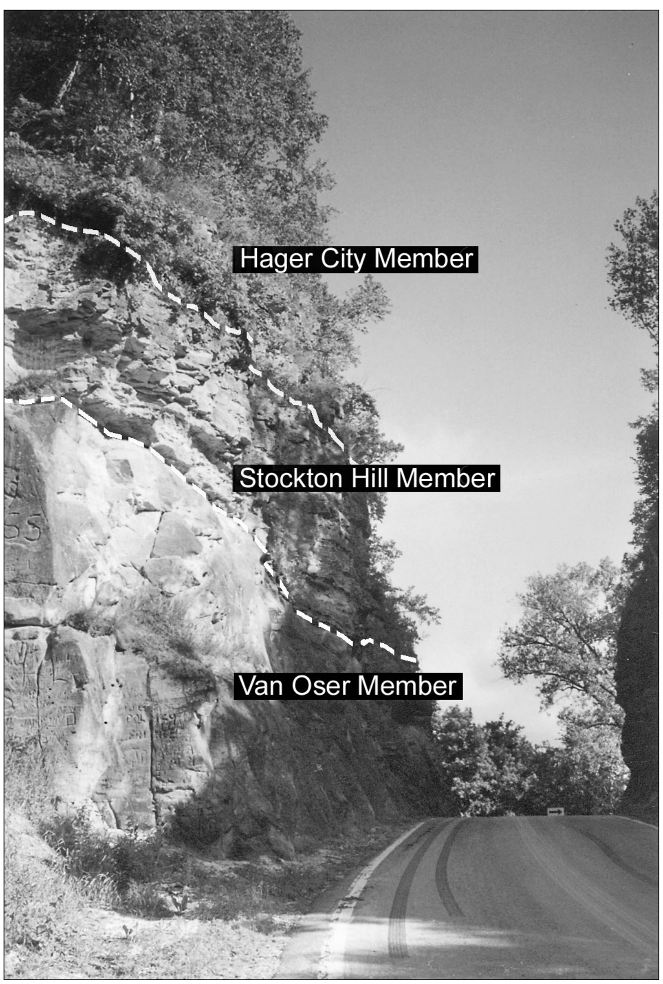


Figure 6. Two views (A, B) of exposure of the Van Oser Member of the Jordan Formation (Trempealeau Group) and the Hager City and Stockton Hill Members of the Oneota Formation (Prairie du Chien Group) at Mindoro Cut along U.S. Highway 108 (NW¼SE¼SE¼ sec. 4, T17N, R6W). The basal contact of the Stockton Hill Member is defined as the contact between horizontally bedded, dolomitic sandstone with the large, cross-stratified quartz-rich sandstone of the Van Oser Member.

poorly exposed, but is recognized at the first appearance of fine-grained, feldspathic sandstone, stratigraphically above the St. Lawrence dolomite. This interval is referred to as the Norwalk Member and is a 20- to 30-ft thick sandstone that is poorly cemented and easily weathered and is extensively covered by vegetation and sandy slopewash from the overlying Van Oser sandstone. Because of its limited thickness and few outcrops, the Norwalk Member is mapped with the Van Oser Member (plate 1).

Locating the upper contact of the Jordan Formation (top of the Van Oser Member) is problematic. The interval above the Van Oser Member of the Jordan Formation is characterized by mixed lithologies of sandstone, dolomitic sandstone, silty and sandy dolomite, and dolomite. This interval forms slopes that are typically covered with vegetation in La Crosse County, which makes identification of the top and bottom contacts difficult. This interval of varying lithologies was informally termed the Coon Valley Member of the Jordan Formation (Odom and Ostrom, 1978), but other workers (Davis, 1970, for example) place this variable interval wholly within the Prairie du Chien Group. For purposes of preparing the geologic map of La Crosse County (plate 1), I mapped the top of the Jordan Formation as the top of the sandstone of the Van Oser Member and included the transitional interval as the lowermost strata of the Oneota Formation (Stockton Hill Member) (fig. 6). This usage is consistent with the more recent field investigations of the Jordan and Oneota intervals in western Wisconsin (Smith, 1991; Runkel, 1994; Byers and Dott, 1995).

Many geologists have traditionally accepted the Jordan and Oneota contact as the boundary between the Cambrian and Ordovician Systems. This systemic boundary was considered coincident with the lithologic change from sandstone (below) to dolomite (above). However, detailed examination of the Jordan interval (dominantly sandstone) has shown that the contact with the Oneota interval (predominantly dolomite) is time-transgressive (Runkel, 1994). Parsons and Clark (1999) used conodont biostratigraphy to refine the traditional (but less definitive) trilobite biostratigraphy for identifying the Cambrian–Ordovician boundary. They demonstrated that this major systemic boundary is within the Jordan (Van Oser) sandstone.

The Jordan Formation in La Crosse County includes at least two marine environmental settings. Byers and Dott (1995) interpreted the fine-grained feldspathic sandstone intervals of the Norwalk and stratigraphically higher intervals to be the result of deposition in areas where fine-grained sands were deposited below the fair-weather wave base or about 20 to 50 m water depths on the continental shelf of the Cambrian sea. The sandstone of the Norwalk Member is an example of this depositional environment in La Crosse County. The cross-bedded quartzose sandstone of the Van Oser member is the result of deposition of medium-grained sand in shallower marine waters subject to strong nearshore currents. The cross-stratification indicates deposition mainly in the form of subaqueous dunes; the variation from trough cross-stratification to large-scale tabular and wedge sets of cross-bedding is the result of variation in the strength and persistence of submarine currents.

The Jordan Formation is part of the sandstone aquifer of Young and Borman (1973), although it is not a significant source of groundwater in La Crosse County. The Jordan interval is considered by Runkel (1996) to be primarily an aquifer, due to the dominance of quartzose sandstone. In Pierce and Jackson Counties, the Van Oser sandstone has been mined for a specialty or industrial sand used for hydrofrac sand in the petroleum industry.

Prairie du Chien Group

The Lower Ordovician Prairie du Chien Group, map unit **Op** on plate 1, is a sequence of predominantly thin- to thick-bedded dolomite, sandy dolomite, and dolomitic sandstone (fig. 7). It is the uppermost rock unit of the Mississippi River bluffs. The Prairie du Chien forms broad uplands in the southern part of La Crosse County and is at its maximum observed thickness of about 200 ft along North Ridge in the southwestern part of the county near the Vernon County line. It caps narrow ridgetops north of the La Crosse River, where as much as 100 ft or more is present in locations such as the unnamed ridge along County Highway S northwest of Onalaska. The Prairie du Chien interval is the upper part of the Sauk III subsequence in western Wisconsin (Sloss, 1988).

The Prairie du Chien Group includes medium crystalline dolomite, cherty dolomite, and fine, sandy dolomite that has occasional silty and clayey layers. It is not fossiliferous, most

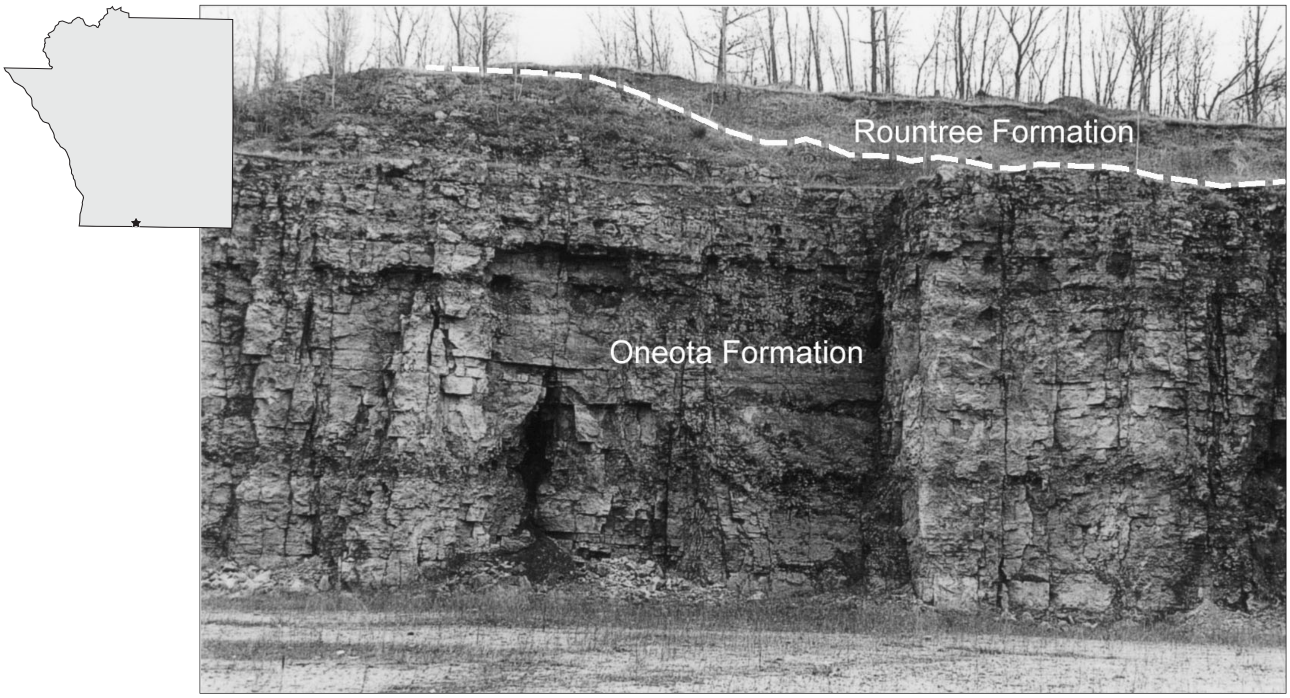


Figure 7. Exposure of Oneota Formation (Prairie du Chien Group) and Rountree Formation in a small quarry along Brinkman Ridge (NE¼NW¼SE¼ sec. 32, T15N, R6W).

likely due to the effects of extensive dolomitization, although stromatolitic layering is evident in certain bedding units within the Hager City Member of the Oneota Formation and the Willow River Member of the Shakopee Formation. Except where wavy and irregular stromatolitic layering is present, it has predominantly massive, horizontal beds that are typically 1 to 3 ft thick.

Davis (1970) identified two formations within the Prairie du Chien Group, from oldest to youngest: the Oneota and Shakopee Formations. Each of the two formations was further subdivided into two members each: Stockton Hill and Hager City Members of the Oneota Formation and the New Richmond and Willow River Members of the Shakopee Formation. I have chosen not to subdivide the Prairie du Chien Group on plate 1 primarily because outcrops of the unit are near vertical and the Oneota–Shakopee contact is exposed in only a few locations.

I followed the terminology of Davis (1970) and included the interval of silty and sandy dolomite and dolomitic sandstone at the base of the Prairie du Chien as the Stockton Hill Member of the Oneota Formation (fig. 6). The Stockton Hill is overlain by the Hager City Member, which is characterized by thin to medium beds of laminated and stromatolitic dolomite with little to no silt or sand. Within the Shakopee Formation, underlying the stromatolitic and wavy laminated sandy dolomite of the Willow River Member, is the New Richmond Member, which is characterized by fine-grained, feldspathic, quartz sandstone. The base of the New Richmond is unconformable to the top of the Hager City interval of the Oneota Formation.

Smith and others (1996) provided a basis for understanding the Prairie du Chien units deposited on the northwestern edge of the Hollandale Embayment, west of the Wisconsin Arch. Prairie du Chien strata represent four intervals of regional significance, which coincide with the four members recognized above. According to Smith and others (1996), the Stockton Hill interval is the result of the transgression of a shallow Ordovician sea from west to east followed by a minor regression of the sea in this area. The Hager City Member includes the highstand of the next transgressive interval and the development of the thickest interval of carbonate sediment on the marine shelf in this area. Following this highstand, the sea retreated, resulting in exposure and erosion of this part of the craton. As the Ordovician sea later re-flooded the craton, sand-dominated shallow marine environments and, farther to the east toward the Wisconsin Arch, eolian environments developed, as seen in the New Richmond Member. After another minor regression of the Ordovician sea, renewed transgression re-established carbonate-dominated depositional environments on the shallow marine shelf resulting in the formation of the Willow River interval.

The Prairie du Chien Group dolomite is considered part of the sandstone aquifer of Young and Borman (1973), but is not a significant source of groundwater in La Crosse County. The dominantly carbonate rock of this interval led Runkel (1996) to identify the Prairie du Chien as an aquifer, with the exception of the lower heterolithic, mixed carbonate and clastic interval that is equivalent to the "Coon Valley" or Stockton Hill interval. Numerous quarries have been developed in the Hager City Member of the Oneota Formation and, to a lesser extent, in the Willow River Member of the Shakopee Formation. Dolomite quarries provide an important source of crushed stone in the county.

Clay-rich sediment is found on top of the Prairie du Chien Group in parts of the county. A 9- to 10-ft exposure of this material, sampled along Brinkman ridge (NE¼NW¼SE¼ sec. 32, T15N, R6W), yielded a gravelly, sandy, silty red clay; the gravel part was dominantly chert (fig. 7). A similar thickness of red-brown silty clay was found in drill samples taken for this study on Bina Road on Cattail Ridge (SW¼NE¼SW¼ sec. 8, T15N, R5W). Subsurface records from three water wells located on the uplands of southern La Crosse County showed 1) 48 ft of brown clay, very calcareous, including dolomite pebbles (LC-11, Villa St. Joseph Convent Well; SE¼ sec. 12, T15N, R6W); 2) 10 ft of orange-brown gravel, granular to small pebble in size, with much clay and silt and little sand (LC-107, Arbor Hills Addition Well; NE¼NE¼ sec. 3, T15N, R7W), and 3) 30 ft of brown-yellow and red clay, siliceous, trace of sand and gravel and, rarely, pebbles of oolitic chert; SW¼SE¼ sec. 12, T15N, R6W].

This predominantly clay interval appears to be equivalent to the Rountree Formation (fig. 7), as defined by Knox and others (1990). Although the Rountree is not part of the Prairie du Chien Group, I included the Rountree with the Prairie du Chien on plate 1. The Rountree Formation in La Crosse County is most likely a regolith developed on cherty dolomite of the Prairie du Chien Group in southern La Crosse County. The age of the Rountree is uncertain, but according to Knox and others (1990), it is unlikely to be as old as Paleozoic, may be as old as the Windrow Formation (Cretaceous), and is definitely older than the oldest loess units in southwest Wisconsin.

Ancell Group

The interval of rocks above the Prairie du Chien Group dolomite (Early Ordovician) and below the dolomite of the Sinnipee Group (Middle Ordovician) is referred to as the Ancell Group (Middle Ordovician) and in Wisconsin includes the St. Peter Formation (lowermost) and the Glenwood Formation (uppermost). In La Crosse County, however, only isolated occurrences of St. Peter sandstone are known—this is the northernmost edge of the depositional basin for these Middle Ordovician clastics. Stratigraphically equivalent rocks are found extensively throughout the Midwest and east regions of the United States, where they are present at the surface and in the subsurface.

St. Peter Formation

Quartz-rich sandstone of the St. Peter Formation is present in one heavily vegetated outcrop in La Crosse County (NW¼SE¼SE¼ sec. 2, T15N, R5W), just west of the intersection of State Highways 33 and 162 near the small settlement known as Middle Ridge in the town of Washington. At locations where this contact is better exposed, the major regional unconformity at the base of the St. Peter is recognized as the base of the Tippecanoe Sequence of Sloss (1988).

The St. Peter at this single location is fine- to medium-grained sandstone that appears to occupy a low area on an erosional surface developed on the dolomite of the Prairie du Chien Group. C.A. Lueth described a then sparsely vegetated roadcut at this location in 1939 as an "old erosion valley filled with St. Peter sandstone" (Wisconsin Geological and Natural History Survey, Road Materials Survey Files, La Crosse County Report No. 1176). Lueth described the sandstone as massive, firmly cemented, coarse grained, poorly sorted, and light buff to brown. I collected a sample of fine-grained sandstone composed of well sorted, subangular to subrounded grains at this location. Quartz was the predominant mineral, with minor iron-oxide staining and clay particles along grain boundaries. The bedding of the sandstone unit was not exposed. Due to extensive vegetative cover, the true thickness of the St. Peter Formation at this location could not be determined. Irregular blocks (erosional remnants?) of St. Peter Formation sandstone were also reported in WGNHS Road Material Survey Note 1776 for La Crosse County near the Vernon County line in sec. 31, T15N, R5W. In these notes, the sandstone blocks were reported to be at an elevation of about 1,220 ft. I was unable to locate the blocks at the time of this study.

Mai and Dott (1985) did not show the St. Peter in La Crosse County; they terminated the northern erosional edge of this unit in southwestern Wisconsin at exposures to the south in Vernon County. With the exception of isolated outcrops farther north in Pierce and St. Croix Counties, the La Crosse County locality extends the outcrop belt of St. Peter slightly north of its previously recognized position. Regional investigation of the St. Peter suggests that this extensive sandstone package developed on a highly eroded Ordovician carbonate surface as a result of the influence of stream erosion and karst development (Mai and Dott, 1985).

QUATERNARY SEDIMENT

A variety of unconsolidated sediment deposited during approximately the past 25,000 years, the latter part of the Pleistocene Epoch, is found in La Crosse County. Sediment ranging from clay-sized material to coarse pebbly gravel lies along the streams in La Crosse County. These deposits are stream sediment from glacial meltwater that flowed away from ice margins that were present to the west, north, and east during the later stages of the Wisconsin Glaciation during the Late Pleistocene Epoch. In addition, other sediment was deposited by streams that have their drainage basins located wholly within nonglaciated drainage basins. Scattered areas of silt and clay are present within the La Crosse River valley and Mormon Creek Coulee. These deposits of ponded (quiet water) sediment were formed in short-lived bodies of water within these river valleys during periods of rapid aggradation by the ancestral Mississippi River and temporary blockage of the tributary streams.

Extensive deposits of silt, sand, and, in places, fragments of sandstone and dolomite are found along the base of the prominent ridges of Paleozoic sandstone and dolomite. These hillslope materials form a rolling topography between the distinct ridges of consolidated bedrock and the flat-lying terraces and stream sediment in the valleys. Predominantly silt-sized material ranging in thickness from a few inches to more than 30 ft covers much of the land surface of La Crosse County (Hole, 1968; Beatty, 1960). Although the thicker deposits of silt most likely include material eroded from nearby hillslopes, most of the silt on the landscape was originally transported to upland sites by wind. Extensive marshy areas containing organic sediment, peat, and muck are present throughout the modern Mississippi River valley and along small streams and creeks in La Crosse County.

Stream sediment

Pleistocene glacial meltwater stream sediment

Braided rivers carrying meltwater from the Laurentide Ice Sheet flowed down the Mississippi and Black River valleys during the Pleistocene Epoch and deposited sediment as prominent outwash terraces in the La Crosse County area. The terraces are composed dominantly of quartz sand with abundant feldspar grains and dark-colored igneous and metamorphic rock fragments. The outwash ranges from sandy gravel and gravelly sand to coarse- to fine-grained sand, depending on where the sediment was deposited on the valley bottom. Fine-grained sand was deposited in low energy backwater environments. Glacial meltwater sediment ranges from dark grayish brown and dark yellowish brown to light brown and yellow.

The presence of prominent outwash terraces in the La Crosse area indicates that at times glacial sediment nearly filled the Mississippi River valley. Episodic filling and cutting of river valleys by meltwater streams typically left older, higher terraces within the valleys. Younger terraces, formed later by sediment-rich, aggrading streams that were, in turn, incised by sediment-poor floodwaters, are lower terrace surfaces.

Terrace surfaces in the La Crosse County area are customarily referred to as prairies, reflecting their distinctive topography and grassy vegetation. These terrace surfaces have been extensively modified by wind, which has created distinct dunes. Where dunes are evident, they are shown as unit **ws** on plate 1. Where urban development has occurred, however, sand dunes have been destroyed. Dune forms are now most evident in undeveloped areas or in areas of low-intensity development, such as in cemeteries and other open areas. Dune crests are a few feet to as much as 40 ft above the surrounding terrace surface.

High terrace. The elevation of the highest Mississippi River terrace in La Crosse County ranges from 700 to 705 ft near Onalaska to 720 to 725 ft approximately 12 miles to the north—a south to north slope of less than 2 ft per mile. The highest part of this terrace surface is in the northwest part of the county along the floodplain of the Black River. At this northern point, the terrace is more than 60 to 65 ft above the river level and 55 to 60 ft above the modern floodplain of the Black River. This high terrace, mapped as **sh** on plate 1, is characterized by slightly gravelly to gravelly sand that contains common to abundant igneous and metamorphic rock fragments within the dominantly quartz-rich sediment. Low-angle trough cross-stratification, typical of braided streams, characterizes these deposits (fig. 8). Gravel content ranges from 10 to 15 percent; the sand-sized material is dominantly medium- to coarse-grained sand with significant quantities of very coarse-grained sand in places.

Sand and gravel deposits are excavated in places along the margins of the high terrace for various construction applications. Intervals of tens to hundreds of feet of Pleistocene sand and gravel in the Mississippi River valley are the primary source of high-quality groundwater in La Crosse County (Young and Borman, 1973).

Intermediate terrace. The city of La Crosse is built on a terrace surface that is mapped as unit **si** on plate 1. The elevation of the terrace ranges from 675 ft at La Crosse to about 645 ft near Maple Grove, a distance of about 6 miles to the south. The slope of this surface is steeper (about 5 ft per mile) as compared to the high terrace to the north (<2 ft per mile) and the slope of the Mississippi River itself (about 0.5 ft per mile). The steep slope of this terrace and its distinctly lower elevation suggest that the terrace surface at La Crosse is not a continuation of the high terrace in the Onalaska area, but is a younger terrace (Lee Clayton, Wisconsin Geological and Natural History Survey, verbal communication, 2000).

Similarities between the high terrace and this intermediate terrace are their positions

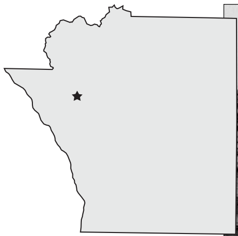


Figure 8. Exposure of Late Pleistocene high terrace near Midway in sand and gravel pit located on County Highway XX (NE¼SE¼SE¼ sec. 13, T17N, R6W).

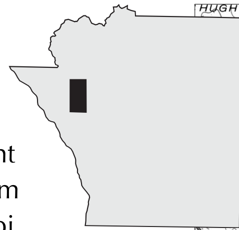
along the east bank of the Mississippi River valley, the composition and grain size of the sand and gravel found in the terraces, and the distinctive modification of the surfaces by wind.

Sand and gravel deposits are excavated in places along the margins of the intermediate terrace for various construction applications.

Low terrace. A lower terrace surface or set of surfaces along the Mississippi River valley, shown as map unit **sl** on plate 1, extends from Brice Prairie (elevation approximately 680 ft) south to French Island (elevation approximately 650 ft) and farther south to Goose Island (elevation approximately 635 ft). This surface slopes southward at about 2 ft per mile. Sediment in this terrace is similar in composition to the sediment of the high and intermediate terraces: It consists predominantly of quartz and abundant dark-colored igneous and metamorphic rock fragments. However, the sediment on the lower terrace surface appears to be finer-sized material (indicating lower energy environments of deposition) of predominantly medium-grained sand with minor amounts of coarse-grained sand and gravel (0–9%). Eolian processes have modified the lower terrace surface in places, but the extent of this activity is small compared to that of the intermediate and high terraces.

Halfway Creek fan. Poorly to moderately sorted, medium-grained sand composed almost entirely of quartz forms a slightly conical land surface in the Holmen area. This alluvial fan was deposited by Halfway Creek where it flows from east to west across the high terrace (map unit **sh**, plate 1) and cuts into the terrace edge before depositing its sediment load in the lowland just east of Brice Prairie, the low terrace in this area (map unit **sl**, plate 1). This feature is the Halfway Creek fan (map unit **sf,** plate 1). The Halfway Creek fan fills the lowland between the two terrace surfaces (fig. 9) and extends farther south toward Redbud Island in Lake Onalaska. The position of the fan demonstrates that the fan is younger than both the high and low terraces in this area.

Age of terraces. The high terrace in the area of La Crosse County may be correlative with a set of terraces farther to the south, defined by Flock (1983) as the Savanna Terrace, which has a similar relative position within the Mississippi



River valley. The stream sediment forming this surface resulted from the rapid filling of the Mississippi River over the period of 25,000 to 14,000 years BP (Knox, 1996), when the river was largely a braided stream complex. From about 14,000 to 9,000 BP, the Mississippi River valley was subjected to various episodes of flooding resulting from the release of sediment-poor floodwaters down the Mississippi River valley; a complex of lower, younger terraces known as the Bagley Terrace was formed (Knox, 1999). The lower terrace in La Crosse County may be equivalent to the Bagley Terrace. At Brice Prairie (fig. 10) and immediately south of New Amsterdam, the lower terrace surface shows evidence of significant fluvial scour probably related to large flooding events; such flooding would be consistent with the large-magnitude floods that Knox (1999) postulated are responsible for forming the Bagley Terrace.

Halfway Creek has been incised into the high terrace. A carbon-14 test on wood buried near the base of a relict channel cut into this terrace yielded a date of 13,545 ±85 years BP (Knox, 1999). This date indicates the minimum age of the high terrace at this location. The distribution of sediment in the fan is affected by the low terrace (Brice Prairie) to the west, indicating that fan sediment was deposited after the formation of the low terrace in this area; that is, the low terrace at Brice Prairie is also older than 13,545 BP. The Halfway Creek fan began filling the channel between the two terraces near Holmen during the Late Pleistocene and has probably been active continuously throughout the Holocene.

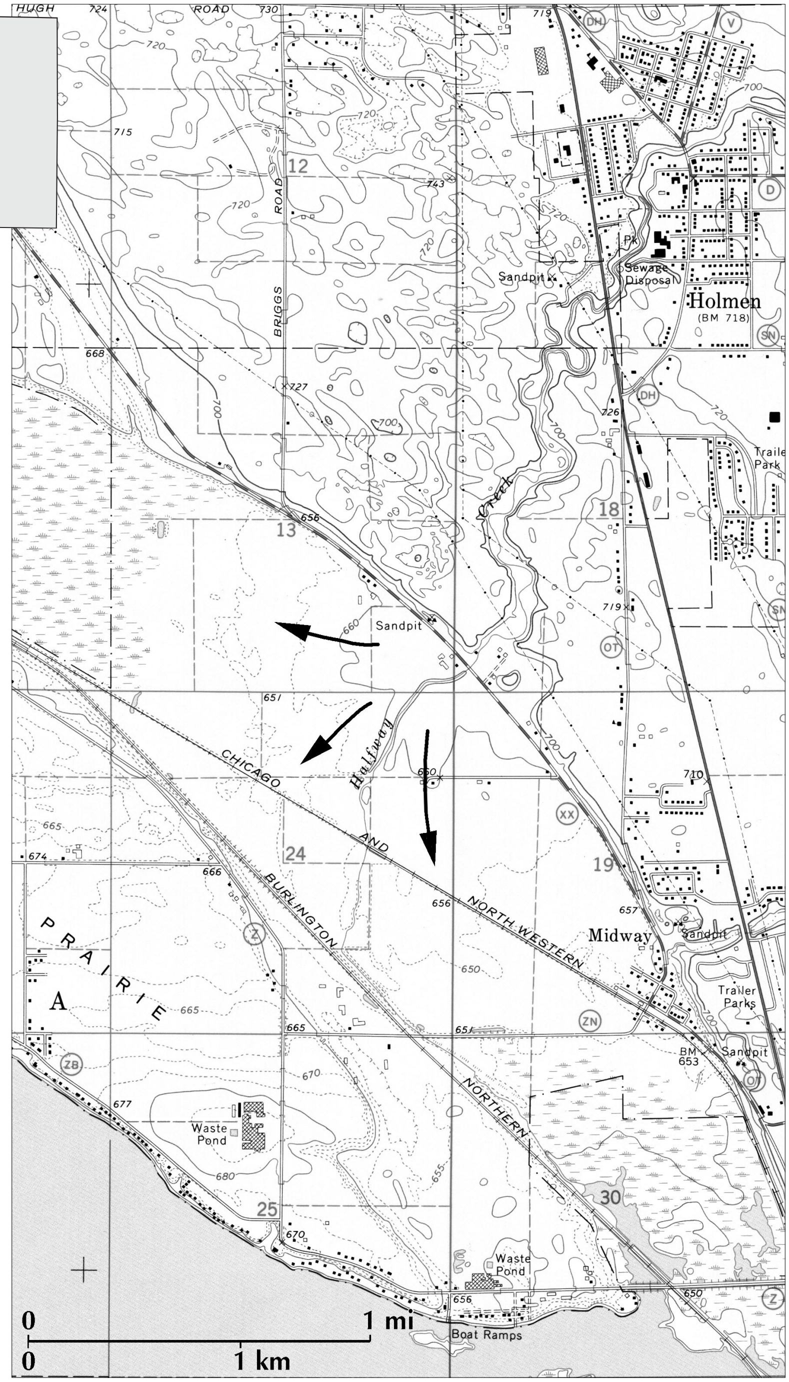


Figure 9. Alluvial fan formed by Halfway Creek where it cut across the Late Pleistocene high terrace. Fan deposits are younger than the Late Pleistocene low terrace (Brice Prairie). Long arrows indicate inferred directions of sediment dispersal. Area shown is about 10 square miles (U.S. Geological Survey, Holmen, Wisconsin, quadrangle, 7.5-minute series, topographic, 1973; contour interval is 20 ft).

Pleistocene and Holocene nonglacial stream sediment

The La Crosse River, Halfway Creek, and Mormon Creek drainage basins lie wholly

Figure 10. Late Pleistocene low terrace (Brice Prairie) near Midway (NE¼NW¼NE¼ sec. 25, T17N, R6W).

within the unglaciated area of southwestern Wisconsin. Smaller nonglacial streams in the county include Fleming, Fish, Dutch, and Bostwick Creeks and Sand Lake Coulee. Sediment carried by these river systems today is typically very fine- to fine-grained quartz-rich sand containing only minor amounts of dark-colored igneous and metamorphic minerals. The fine-grained sandy sediment is moderately sorted and composed of subrounded to rounded grains. The sediment is typically yellow to yellowish brown. I mapped this unit as Holocene stream sediment (map unit **sm,** plate 1); it is found in the central parts of these stream valleys.

Glacial activity did have an impact on the sediment deposition of the nonglacial streams in areas where these streams enter into the Mississippi River system. Gray and reddish-brown clay, silt, and very fine sand were deposited within ephemeral lakes or areas of ponded water formed from the blockage of the nonglacial streams due to the rapid aggradation of the Mississippi River. In addition, older colluvial sediment related to periods of active mass wasting of nearby Paleozoic sandstone and dolomite hillslopes grades into stream sediment of these nonglacial streams (Mason and Knox, 1997).

A system of terraces is present along these nonglacial stream valleys and is composed of sandy sediment similar to that present elsewhere along the stream course. Two levels of nonglacial stream terraces are shown on plate 1. The higher terrace, shown as map unit **sa** on plate 1, is a flat to gently sloping region between the rounded topography of undifferentiated hillslope sediment (map unit **hu**, plate 1) at the base of bluffs and hills and the flat topography characteristic of central areas of stream valleys where modern stream sediment (map unit **sm**, plate 1) is present. The edge of the terrace is typically a noticeable slope break and is a recognizable cutbank in places. Cutbanks have a scalloped or concave shape in plan view, indicating a former position of the stream. The higher nonglacial stream terrace lies at an elevation of approximately 740 ft in the Halfway Creek and La Crosse River valleys and at an elevation of approximately 730 ft in Mormon Creek Coulee. A lower terrace surface or set of surfaces, shown as map unit **sb** on plate 1, is in the La Crosse River valley at an elevation of about 720 ft, primarily east of Neshonoc Lake, and at an elevation of approximately 720 ft in Mormon Creek Coulee at Mormon Coulee Park.

Terrace surfaces in the valleys of nonglacial streams in the La Crosse County area formed in response to changes in the base level of these streams related to rapid filling and downcutting of the glacial meltwater streams into which the nonglacial streams flowed. The raising of the base level of the Mississippi and Black Rivers raised the base level of the nonglacial streams as well, resulting in aggradation or filling of these stream valleys. Later downcutting of the Mississippi and Black Rivers caused a lowering of the base level of the nonglacial tributaries; downcutting in these stream valleys typically left terraces behind.

Holocene stream sediment

Sediment deposited by rivers and streams active during the Holocene (past 10,000 years) is found along the major and minor stream courses that occupy the lower parts of the La Crosse County landscape (map unit **sm,** plate 1). This sediment ranges from fine sand to slightly gravelly sand and is characterized by quartz grains with igneous and metamorphic rock fragments common along the Black and Mississippi River valleys. Color ranges from dark brown to brown. In stream courses originating in and draining the Paleozoic bedrock areas of the county, quartz grains are predominant and lack igneous or metamorphic minerals.

Also included in map unit **sm** (plate 1) are extensive areas of peat and muck within the Mississippi River Valley where modern stream sediment is at or close to the controlled level of the river (639-ft elevation north of Lock and Dam No. 7 at the south end of Lake Onalaska and 631-ft elevation south of Lock and Dam No. 7). In Lake Onalaska, this sediment is related to the large sediment fan developed at the mouth of the Black River at its confluence with the Mississippi River. South of Lock and Dam No. 7, numerous areas of modern stream sediment are present at Taylor Island, Barron Island, and numerous unnamed islands throughout this part of the Upper Mississippi River Fish and Wild Life Refuge.

Ponded sediment

Within the La Crosse River, Halfway Creek, and Mormon Creek Coulee stream valleys, isolated deposits of clay and silt material are present (map unit **l**, plate 1). About 9 ft of clayey silt was identified in material sampled for this investigation along McKinney Coulee Road just north of Interstate 90 (NW¼NW¼SE¼ sec. 11, T16N, R7W). Color of the sediment was light olive brown. The elevation of the top of the drillhole was approximately 710 ft. Under the 9 ft of clayey silt in the drillhole (elevation approximately 701 ft), unconsolidated fine sand was encountered. Along the south side of the La Crosse River valley, an area of reddish-brown silty clay was also sampled for this investigation along the edge of the Gate of Heaven Catholic Cemetery (SW¼NE¼SW¼ sec. 14, T16N, R7W). Silty clay at this site was about 6 ft thick (elevation about 700 ft). The drillhole was started at an elevation of about 705 to 710 ft and unconsolidated, well sorted, fine sand was encountered underneath the 6 ft of silty clay. I mapped these deposits of ponded sediment on the basis of the drilling results and by the presence of the very fine-grained Zwingle and Medary silt loam soils formed on the generally flat-lying surfaces of the higher terraces within the westernmost 4 to 5 mi of the La Crosse River valley.

In Mormon Creek Coulee, reddish-brown fine sandy and clayey silt is present along a southeast-trending terrace extending across the mouth of the coulee. Soils mapped in this area include Medary silt loam (Beatty, 1960). The clayey silt noted at this location is the same material that was used by the Meier Brick Company, which is no longer in operation. About 5 ft of this material is present at the top of the terrace (elevation 695–700 ft); the rest of the terrace material is gravelly sand and sand.

I interpret the deposits of clayey silt and silty clay to be the result of temporary ponding of streams in these valleys due to blockage of the tributary streams by sand, gravelly sand, and gravel deposited by the rapidly aggrading Mississippi River, perhaps most recently at about 14,000 years BP. The elevation of the Mississippi

River terrace (equivalent to the Savanna Terrace) in the vicinity of the mouth of the La Crosse River (approximately 700–710 ft) suggests that the temporarily blocked La Crosse River may have produced a shallow lake. Alternatively, Flock (1983) noted the presence of similar deposits associated with the Savanna Terrace along the Mississippi River from Illinois into Wisconsin as far north as the Chippewa River. J.C. Knox (University of Wisconsin Department of Geography, written communication, 2000) suggested that the relatively thin deposits of fine-grained sediment deposited under lower energy conditions within the tributary channels are the facies-equivalent (at one time laterally continuous) to the sand and gravel underlying the Savanna Terrace. More detailed field investigation is needed to work out the relationships of the fine-grained sediment within tributary valleys such as those of La Crosse River, Halfway Creek, and Mormon Creek Coulee to the sandy and gravelly sediment underlying the main Mississippi River terraces.

Hillslope sediment

A prominent feature in the La Crosse County landscape is the extensive area of rolling topography along the lower slopes of the Paleozoic bedrock ridges. This is the result of the downslope movement of the primarily sandstone and dolomite bedrock due to mass-wasting processes such as solifluction, soil creep, and slope failure (fig. 11) and the accumulation of mass-wasted sediment along the toe slopes of the steep ridges. Loess is also present in this colluviated material because it has been eroded from the surrounding uplands and moved downslope along with the underlying bedrock. On the basis of carbon-14 dating and associated stratigraphic relationships observed in correlative deposits along the Root River in Minnesota, immediately west of La Crosse County, Mason and Knox (1997) suggested that these deposits formed during the Late Wisconsin. These deposits appear to grade into sediment beneath the high terrace surface along the Mississippi River (Savanna Terrace), which was in turn cut by later stream erosion, suggesting that deposition of the hillslope sediment or colluvium was synchronous with the formation of the high terrace. On the basis of these stratigraphic relationships and the carbon-14 dates, Mason and Knox (1997) suggested that the sediment accumulated beginning about 20,000 BP (before 18,700 years BP), continuing at least until some time after 13,400 years BP; the major period of accumulation was likely between approximately 13,000 and 11,000 years BP.

Up until about 12,500 BP, permanently frozen ground (permafrost) was present in this part of Wisconsin, so infiltration of precipitation into the land surface was not common, thus promoting slopewash erosion. In periods of thaw during summer seasons, slopewash erosion and mass-wasting processes were probably active. More recently, however, slopewash processes have probably modified the land surface to only a minor degree because the sandy nature of the bedrock and surficial soils promote infiltration of precipitation and minimizes erosion.

Where exposed in La Crosse County, hillslope sediment is composed of silt, sand, sandstone, and some dolomite rock fragments, and is very poorly sorted. An exposure dominantly of loess was yellow, slightly clayey silt with noticeably contorted layering; a sandier exposure of this unit was slightly gravelly, reddish-yellow, and yellow fine sand. Large fragments or blocks of bedrock can be observed within or on the surface of this material in places. I mapped the hillslope sediment in areas where I inferred deposits of hillslope material were at least 5 to 6 ft thick (map unit **hu,** plate 1).

Windblown sediment

Sand

Sand dunes are well developed on the Amsterdam Prairie and north of Onalaska, where individual longitudinal dune forms may be as high as 40 ft (fig. 12; map unit **ws**). Dunes are

A

B

Figure 11. Two views (A, B) of exposure of hillslope sediment near Barre Mills in a small quarry on County Highway M, 0.5 miles north of the village of St. Joseph (SW¼SW¼NE¼ sec. 12, T15N, R6W).

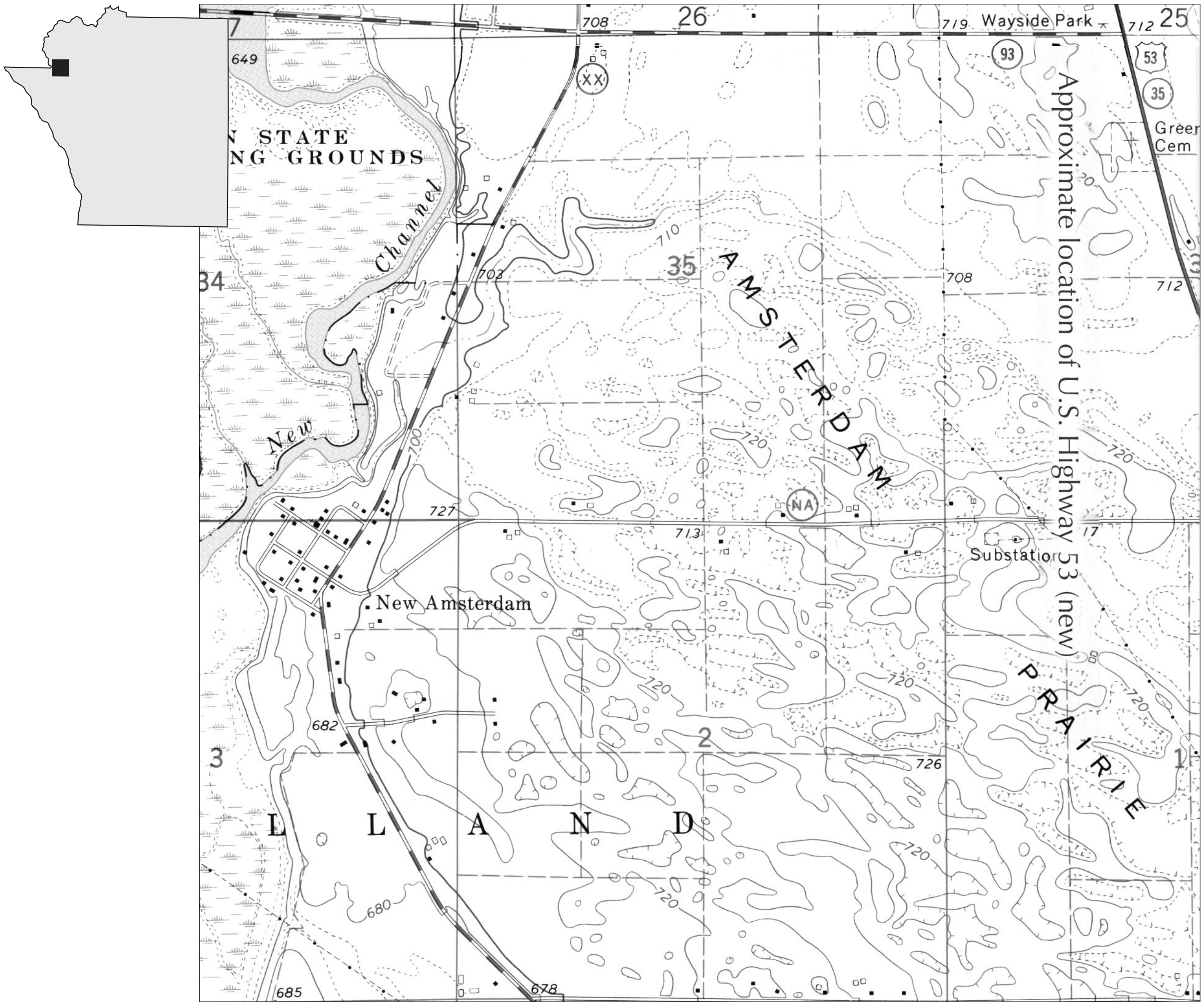


Figure 12. Sand dune development on the high terrace near New Amsterdam. Area shown is 2 miles wide (U.S. Geological Survey, Holmen, Wisconsin, quadrangle, 7.5-minute series, topographic, 1973; contour interval is 20 ft with supplementary 5-ft contours, shown as dotted line).

present, but are less noticeable, in the Onalaska area where urban development has destroyed or modified dune morphology. Similarly, in the city of La Crosse, sand dunes are particularly noticeable only where urbanization has been less intense (for example, in cemeteries). Dune morphology on the lower terraces is less well developed; however, dunes more than 10 ft high are present on Brice Prairie, French Island, and Isle La Plume.

Sediment in dune fields on the river terraces is moderately to well sorted, very fine- to fine-grained sand, and is nearly pure quartz. Colors range from olive yellow to dark yellowish brown and brown.

Silt

Windblown sediment of predominantly coarse-silt-sized material has been deposited throughout the county by prevailing westerly winds; these winds carried the silt from the broad terraces formed in the Mississippi River valley onto the uplands to the east and up into the nearby river valleys, such as the La Crosse River. The thickness of the loess exceeds 30 ft in the valleys and ranges from 8 to 16 ft along the westernmost uplands to as little as 2 ft farther east (Hole, 1968). Loess deposits are thinner to the east because of the greater distance from the source of the silt; they are also thinner on the steeper slopes where erosion has moved loess down into the valleys. The windblown silt in La Crosse County is dominantly Late Wisconsin Peoria loess (Beatty, 1960), although other workers have also identified the Middle Wisconsin Roxana loess in the county (Leigh, 1991). Most of the silt present today on the uplands in La Crosse County was deposited between about 25,000 and 14,000 BP during the last glacial advance in the Upper Mississippi River valley (Leigh and Knox, 1994).

Thick loess deposits, shown as unit **wz** on plate 1, lie along County Highways B and M south of West Salem (secs. 4, 8, 9, 16, 20, 21, and 28, T17N, R6W). The area is characterized by a distinctive surface topography of alternating parallel ridges and valleys trending east–west (fig. 13). The generally straight ridges and valleys vary from 200 ft from interfluve to interfluve to just more than 1,000 feet between interfluves. The height of the ridges relative to surrounding valleys is about 10 to 15 ft. Length of ridges ranges from several hundred feet to about 5,000 ft. A sandpit located on the northern end of this deposit (center SE¼ sec. 4, T17N, R6W) exposes more than 15 ft of the loess. The color of the silt ranges from yellowish red to brownish yellow. The loess deposits appear to overlie the high terrace of the nonglacial La Crosse River and abut the western face of the Paleozoic rock upland.

The topographic expression of the loess in this area is most similar to the paha topography described in Illinois by Flemal and others (1972): Longitudinal loessal dunes are believed to have formed directly from the deposition of coarse loess carried by the strong winds. In La Crosse County, I postulate that loess originated from deflation of the exposed Mississippi River braided-stream channels and point-bar complexes by strong winds blowing toward the east into the La Crosse River valley. Here, the river valley provided a topographic opening through the Mississippi River bluffs, essentially funneling the strong winds that were moving west to east across the sandy flats of the braided-stream and point-bar complexes. Thick deposits of loess were formed at the base of the bedrock highlands directly east of the valley mouth. The location of individual ridges perhaps indicates a localized influence that caused initial deposition of loess. Additional investigation is needed to determine the origin of this distinctive landscape.

Organic material

Areas of muck and peat, deposited during the Holocene (map unit **p,** on plate 1), are found in places along several stream valleys in the county. These areas are the result of the accumulation of organic material under saturated conditions, although now some locations are not saturated because of tiling for agricultural purposes. I derived the extent and distribution of muck and peat on plate 1 solely from soil mapping by Beatty (1960) because the formation of these sediments left no distinct expression on the landscape.

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B

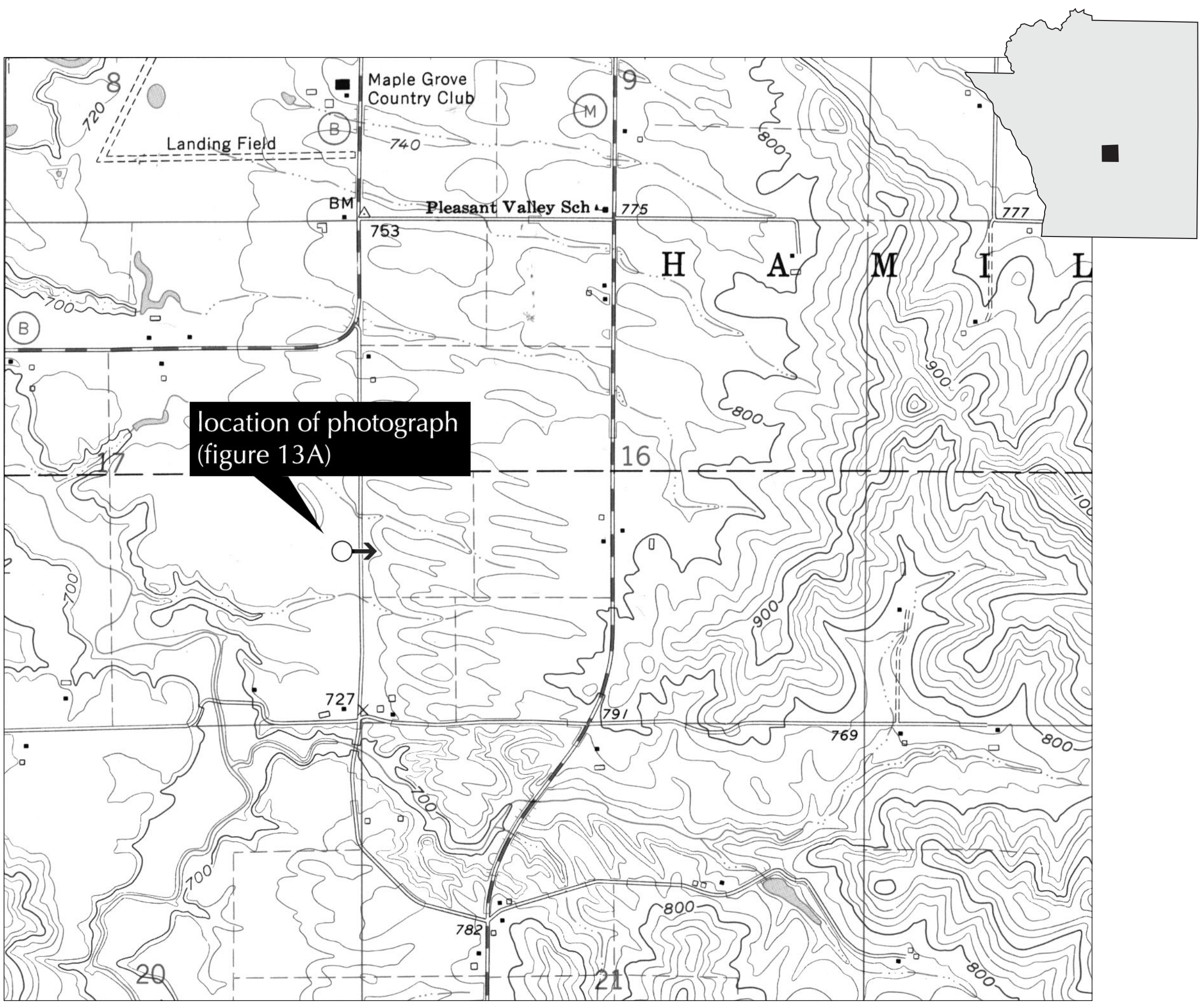

Figure 13. Panoramic view (A) and topographic expression (B) of paha landscape near West Salem east of County Highway B (SW¼NW¼SW¼ sec. 16, T16N, R6W) and is about 2 miles wide (U.S. Geological Survey, West Salem and St. Joseph, Wisconsin, quadrangles, 7.5-minute series, topographic, 1993 and 1974; contour interval is 20 ft).

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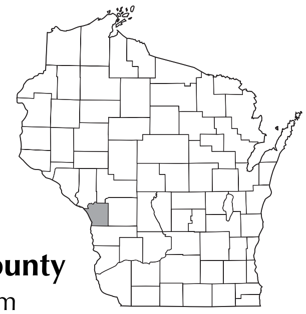
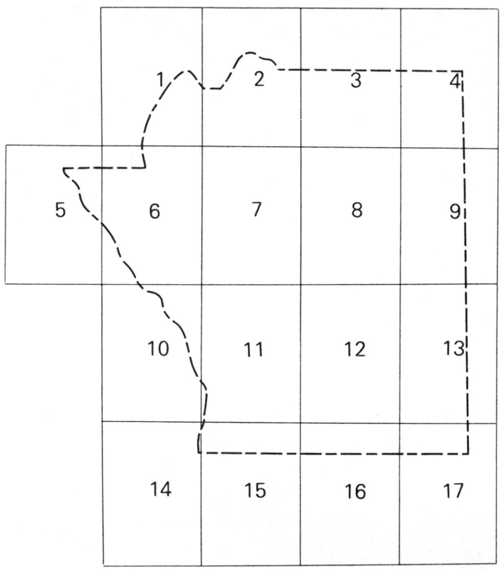


La Crosse County
location diagram

Index to U.S. Geological Survey topographic quadrangles

(scale 1:24,000)



1 Galesville–1973
2 Stevenstown–1969 (PR 74)
3 North Bend–1969
4 Four Corners–1983
5 Pickwick–1973
6 Holmen–1973
7 Onalaska–1993
8 West Salem–1993
9 Bangor–1983
10 La Crescent–1991
11 La Crosse–1998
12 St Joseph–1963 (PR 74)
13 Middle Ridge–1983
14 Brownsville–1980
15 Stoddard–1983
16 Coon Valley–1983
17 Esofea–1983 (PR 85)

PR = Photorevised

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Cover: Mindoro Cut, an exposure of the Trempealeau and Prairie du Chien Group contact along U.S. Highway 108. The cut was constructed by hand in 1907–08 to facilitate travel between the villages of Mindoro and West Salem.