65th Annual Tri-State Geological Field Conference

2-3 October 2004

Weis Earth Science Museum
Menasha, Wisconsin

The Lake & The Ledge

Geological Links between the Niagara Escarpment and Lake Winnebago

Joanne Kluessendorf & Donald G. Mikulic
Organizers

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by

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With contributions by
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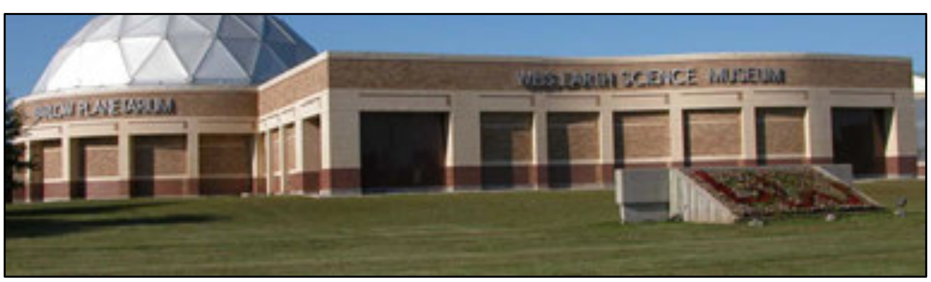
Weis Earth Science Museum
University of Wisconsin-Fox Valley

Menasha, Wisconsin

WELCOME TO THE 65TH ANNUAL TRI-STATE GEOLOGICAL FIELD CONFERENCE.

The Tri-State Geological Field Conference was founded in 1933 as an informal geological field trip for professionals and students in Iowa, Illinois and Wisconsin. The first Tri-State examined the LaSalle Anticline in Illinois. Fifty-two geologists from the University of Chicago, University of Iowa, University of Illinois, Northwestern University, University of Wisconsin, Northern Illinois State Teachers College, Western Illinois Teachers College, and the Illinois State Geological Survey attended that trip (Anderson, 1980). The 1934 field conference was hosted by the University of Wisconsin and the 1935 by the University of Iowa, establishing the rotation between the three states. The 1947 Tri-State visited quarries at Hamilton Mound and High Cliff, two of the stops on this year's field trip. Through the years, attendance at the Tri-State continued to grow, and, by the 1960s, buses replaced the earlier car caravans. Led by Leonard Weis (now Associate Professor Emeritus at UW-Fox Valley and founding donor of the Weis Earth Science Museum which is hosting this Tri-State), Gene LaBerge (now Professor Emeritus at UW-Oshkosh) and C.E. Dutton, the 1968 Tri-State to the Precambrian greenstone belt of northern Wisconsin drew over 450 attendees. Since then, annual Tri-State attendance has declined to approximately 50 to 100 participants, probably reflecting the de-emphasis of field geology in university education. The informality of the Tri-State has provided an excellent opportunity for students and professional geologists to see regional geology firsthand and to discuss geological ideas. In this collegial atmosphere, the National Association of Geology Teachers was established at the Schoonmaker Reef (Fuller Quarry) in Wauwatosa, Wisconsin, on the 1938 Tri-State.

Only in its second year of operation, it is an honor for the Weis Earth Science Museum to be hosting the 65th Annual Tri-State Geological Field Conference. From meteorites to mammoths, from volcanoes to glaciers, the Weis Earth Science Museum tells the fascinating story of Wisconsin's ancient past. We also depict the State's rich mining heritage—a proud legacy that extends back to the last Ice Age when Native Americans first mined stone for tools in this area. Because of our unique focus, in 2001, then-Governor Tommy Thompson designated the Weis Earth Science Museum as the Official Mineralogical Museum of Wisconsin.



Weis Earth Science Museum
University of Wisconsin-Fox Valley, Menasha, Wisconsin

The idea of an earth science museum on the University of Wisconsin-Fox Valley campus originally was conceived in 1999 by Campus Dean/CEO Jim Perry and several members of the Fox Valley community. Over the next year or so, museum development plans were helped along by geologists Gene and Sally LaBerge. UWFox Associate Professor Emeritus Len Weis and his wife Donna provided financial support for the museum and endowed the museum directorship. The entire museum was funded through private philanthropy and grants (including an IMLS grant received through the efforts of U.S. Senator Herb Kohl); the museum receives no financial support from the university, or from county, state, or federal tax dollars. In January, 2001, the founding director, Joanne Kluessendorf, was hired to design and operate the museum. Ground was broken for the museum on March 27, 2001, and by the end of that year, the building was completed. The museum dedication on May 6, 2002, was highlighted with a presentation by Apollo astronaut Harrison Schmitt, the only geologist ever to walk on the moon. On November 16, 2002, the museum opened to the public.

The mission of the Weis Earth Science Museum is to preserve and promote the geology of Wisconsin and to underscore the importance of the earth sciences to society. It fulfills this purpose through education, research, and through the collection, conservation, and display of minerals, rocks, fossils, and historical objects depicting the physical and historical geology of Wisconsin and its mining heritage.

We hope that you enjoy your visit to Wisconsin, the University of Wisconsin-Fox Valley, and the Weis Earth Science Museum, and that you gain an appreciation for the unique and scenic geology of the Fox Valley/Lake Winnebago region.

ACKNOWLEDGEMENTS

We would like to thank Craig Kisser of Fond du Lac Stone, Inc., Bob Bingen of Michels Materials Corp., Fred Nast and Mindy Manegold of Western Lime Corp., Mark and Michelle Schultz of the Glacial Ridge Bison Farm, Joe Hennlich, Cindy Mueller, and the staff at High Cliff State Park, Ron Zahringer and the staff at Ledge View Nature Center, Jamie Robertson and Mindy James of the Wisconsin Geological and Natural History Survey, Mae Ibe and Chris Church of the Fox Cities Convention and Visitors Bureau, Bruce Danz, Eric Fowle of the East-Central Wisconsin Regional Planning Commission, and the staff at University of Wisconsin-Fox Valley and the Weis Earth Science Museum.

Several of the field trip stops are on private property and permission of the property owners must be secured before entering. No specimen collecting or hammering on outcrops is allowed at High Cliff State Park or Ledge View Nature Center.

INTRODUCTION

The Lake Winnebago/Fox River Valley region has played a key role in Wisconsin history. Early settlers came to this area for the water transportation link between the Great Lakes and the Mississippi River and for the industrial potential that its waterpower promised. Before long, the region became one of Wisconsin's major population and industrial centers. These important water resources, which are the result of geologic forces, serve as excellent examples of how geology influences the location, development, and character of many communities, even those without gold mines or oil fields. As communities continue to grow and technologies change through time, the importance of specific resources may vary; however, geology continues to have an important impact on the landscape.

On this field trip we will highlight various aspects of geology in the Lake Winnebago region, while focusing on a particularly important and prominent feature—the Niagara Escarpment. As one of the most prominent geomorphologic features in the state, the Escarpment has played a significant role in the region, influencing the regional physiography, geology and geography, and serving as an important source of natural resources for society. Because of its scenic beauty, the Escarpment has also attracted tourists to the region for more than a century. As you discover the complex connections between the geologic properties and processes that shaped the landscape of northeastern Wisconsin, we hope that you gain an enhanced appreciation for the lake and the Ledge.

LAKE WINNEBAGO AND THE FOX RIVER VALLEY

The fundamental geomorphology and geology of the Lake Winnebago/Fox River Valley region is the result of a complex history related to Paleozoic marine strata with specific depositional and diagenetic characteristics, which have been modified by post-Paleozoic tectonism and erosion, including, most recently, Quaternary glaciation.

The Fox River Valley and Lake Winnebago lie in the Eastern Ridges and Lowlands Physiographic Province of Wisconsin, which trends nearly north-south from the border with Michigan to that of Illinois. This province varies from 50 to 100 miles in width, with its eastern border at the Lake Michigan shoreline. Basic topography in this province is characterized by cuestas, which are long, low, erosion-resistant rock ridges marked by a steep-faced escarpment on the west side and a long, gentle backslope dipping east toward the Michigan Basin (Paull and Paull, 1977). There are two main cuestas in the province: the low and narrow western cuesta comprising the Ordovician Prairie du Chien Group and the higher and broader eastern cuesta, known as the Niagara Escarpment, composed of Silurian dolomite and Ordovician Maquoketa Shale. Between them is the Green Bay-Lake Winnebago-Rock River lowland, which lies on Ordovician Sinnipee Group (Galena-Platteville) (Martin, 1916). Quaternary glaciation removed most of the Ordovician Maquoketa Shale from this lowland, and it occurs chiefly at the base of the Niagara Escarpment. The Prairie du Chien cuesta lies east of a lowland composed of Cambrian sandstones, whereas the lowland east of the Niagara Escarpment lies on Devonian shales (Martin, 1916), which are mostly submerged beneath Lake Michigan.

The Lower Fox River is part of northeast Wisconsin's Fox-Wolf River system (Fig. 1). The Fox is the largest tributary to Lake Michigan in Wisconsin, draining approximately 6,330 square miles. It flows approximately 39 miles northeast from Lake Winnebago to its mouth, which discharges into lower Green Bay.

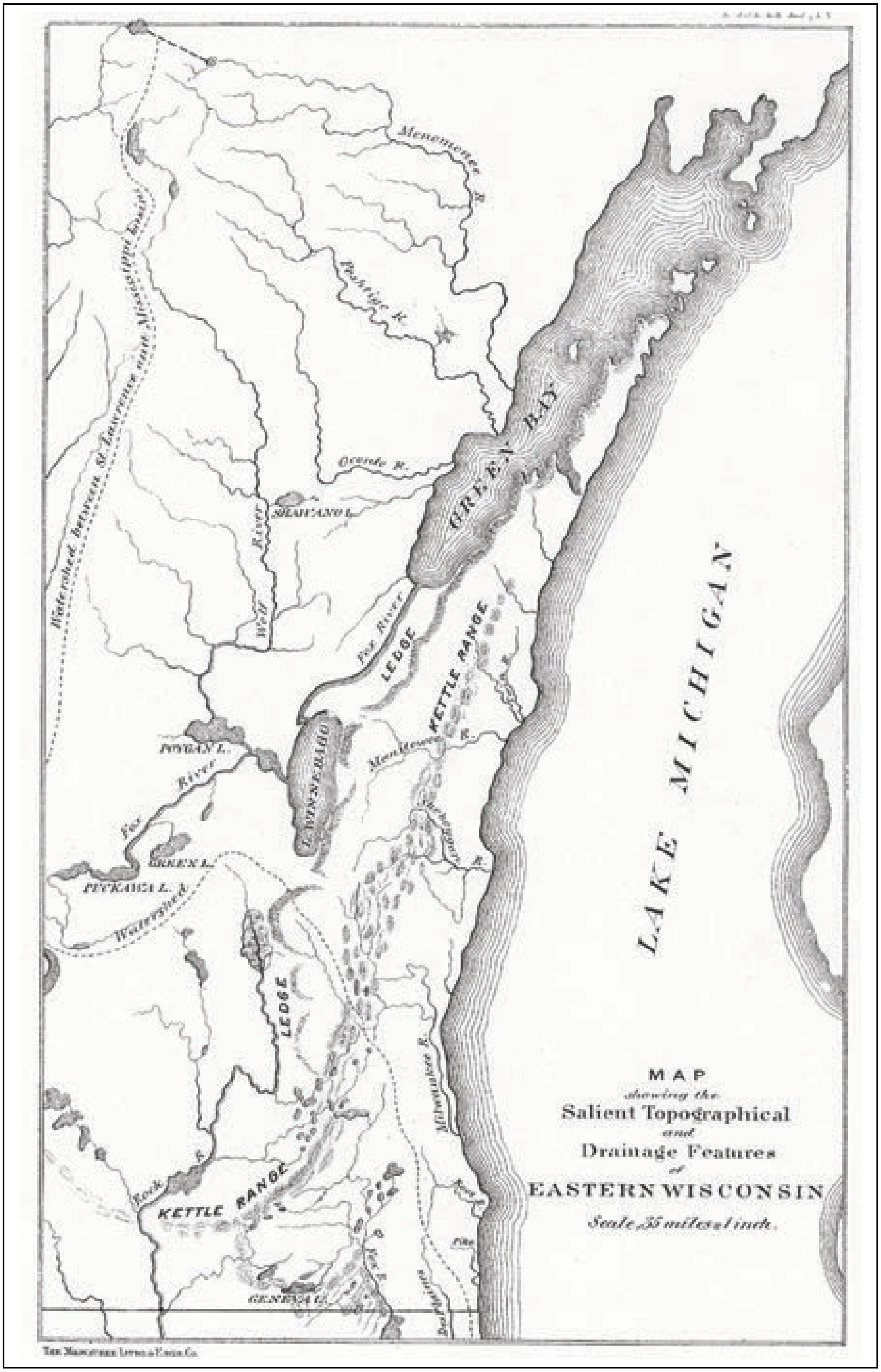


Figure 1. Plate from Chamberlin (1877) showing the "Ledge" (Niagara Escarpment), Lake Winnebago, the Fox River Valley, and other topographical and drainage features in eastern Wisconsin.

The Fox River is a post-glacial stream cutting mainly through glacial sediments and Ordovician shales. It flows chiefly from south to north because the erosion-resistant Niagara Escarpment keeps it from flowing east, directly into Lake Michigan (Whitbeck, 1915). The average grade of the Fox River is five feet per mile, but it is steeper near Lake Winnebago. Between the rapids at Appleton and Kaukauna, the river descends 134 feet in nine miles and has cut through as much as 60 feet of glacial red till (Martin, 1916). Eighty percent of the fall of the lower Fox River valley is concentrated in this nine-mile distance (Whitbeck, 1915). This dramatic descent occurs because the river here flows eastward, cutting through the till and running on the underlying bedrock (Whitbeck, 1915). This bedrock (Ordovician Galena-Platteville) is part of a pre-glacial river valley that slopes rapidly and unevenly towards the east, and the present Fox River descends the steep valley wall, creating several rapids in the process (Martin, 1916).

The eight rapids along the Fox furnished the best waterpower in Wisconsin, and these geologically controlled features spurred development of the most important industrial district in the state during the nineteenth and early twentieth centuries. Eighteen locks and 35 miles of canals were built between Lake Winnebago and Green Bay. The locks were closed to navigation in 1982, but in September, 2004, plans to reopen most of them were announced. The rapids at Appleton, Kaukauna, Neenah, Menasha, and DePere became the sites of major manufacturing cities, with additional development at Kimberly, Little Chute, Combined Locks, and Little Rapids. Nowhere else in Wisconsin has a chain of cities developed in such close succession as along the Fox (Whitbeck, 1915), and the lower Fox River once boasted the greatest concentration of paper mills in the world (Martin, 1916). In 1882, Henry J. Rogers built the first residence in the world lighted by a central hydroelectric station, using the Edison light system, in Appleton; the home now is an historic site known as Hearthstone.

Well before this industrial development, the Fox River served as an important transportation route for Native Americans and early explorers and fur traders. With only a short (1.25 mile) portage required (Whitbeck, 1915) to reach the Wisconsin River at the present site of the city of Portage, the Fox linked the Great Lakes to the Mississippi River in a time when water routes afforded the only reliable means of travel. In 1673, Marquette and Jolliet traveled the entire length of the Fox before using this portage to the Mississippi (Paull and Paull, 1977). In 1809, John Jacob Astor used this route to reach the Pacific Ocean (Whitbeck, 1915). It was also the regular route of French fur traders from the seventeenth century onward, for not only was there a short portage to the Mississippi and, subsequently, to the Gulf of Mexico, the Fox was also the main outlet of the rich fur-yielding region of northern Wisconsin (Whitbeck, 1915). In 1856, a canal connecting the Fox and Wisconsin rivers was completed, which opened this major route to navigation (Martin, 1916). The importance of this canal was short-lived, however, because railroads were being built throughout the Midwest at the same time, diminishing the significance of water transportation.

Lake Winnebago is part of the Fox River system (Fig. 1). The river enters the lake near the center of the western shore at Oshkosh and exits its northwest corner at Neenah-Menasha. This is the largest inland lake in Wisconsin. At 28 miles long and 10.5 miles wide, the lake covers 215 square miles; however, it is only 21 feet deep at its maximum (Martin, 1916).

The existing lake is a remnant of the much larger Glacial Lake Oshkosh, which formed in front of the ice margin during retreat of the Green Bay Lobe (see Stops 2 and 5). That lake extended from the present shore of Green Bay south to Lake Winnebago and stood 65 feet above the present-day lake (Paull and Paull, 1977). The lake basin was excavated from the readily eroded Ordovician Maquoketa Shale. Initially, Lake Oshkosh drained southeastward to ancestral Lake Michigan, but as Green Bay became ice-free, it drained northward via the Fox River. The Manitowoc River, which is the only stream to cut through the Niagara Escarpment, may have been the outlet of an earlier stage of Lake Oshkosh (Paull and Paull, 1977). Although most of Lake Oshkosh eventually was drained, several bodies of water, including Lake Winnebago, remained in irregularities on the former lake floor (Paull and Paull, 1977).

THE NIAGARA ESCARPMENT

In its entirety, the Niagara Escarpment is one of the longest geomorphologic features in North America. This prominent bedrock-controlled ridge follows a path along parts of Lake Michigan, Lake Huron, and Lake Ontario, extending from central New York through southern Ontario, Canada, west into the Upper Peninsula of Michigan, then south through Door County and along the east side of Lake Winnebago, ending in Waukesha County in southeastern Wisconsin. As a prominent, erosion-resistant rock ridge ringing much of the Michigan Basin, the Escarpment and cuesta help to impart the configuration of the northern border of the Great Lakes by defining the Bruce Peninsula and Manitoulin Islands of Lake Huron, the southern boundary of Lake Ontario, and the northern and western boundaries of Lake Michigan. Throughout its extent, the Niagara Escarpment has been important to the development of the regions through which it runs, providing resources for waterpower, the stone industry and tourism.

The profile of the Escarpment has had a considerable impact on settlement and commerce of the Great Lakes region. Originally, the Escarpment formed a barrier between Lake Ontario and the rest of the Great Lakes, which was traversed naturally only by the Niagara River at Niagara Falls. The opening, in 1825, of the Erie Canal, which climbs the Escarpment through a series of locks at Lockport, New York, furnished the first navigation route between the Atlantic Ocean through Lake Ontario to rest of the Great Lakes, promoting immigration and trade in the west. Later, construction of the Welland Canal across the Escarpment expanded this transportation system. Completion of the Erie Canal was followed by attempts in the western Great Lakes area to extend this water transportation system to the Mississippi River, ultimately reaching New Orleans and the Gulf of Mexico. The most successful attempts were the Illinois & Michigan Canal and the Sanitary & Ship Canal at Chicago, but the canal at Portage, Wisconsin, connecting the Fox and Wisconsin rivers marked another effort to make this connection.

In the western Great Lakes, very few rivers or significant streams cross the Escarpment, yielding little waterpower. In contrast, the Escarpment is a significant source of waterpower in New York and eastern Ontario, specifically at Niagara Falls where large amounts of energy are generated for the U.S. and Canada, and at other rivers crossing the Escarpment such as the Genesee River at Rochester, New York.

The Escarpment has long been utilized as a source of building material throughout its extent. Beginning with pioneer settlement, lime and stone for building was quarried at numerous places, and its extraction has been the prime industry of the Escarpment. In Wisconsin, some brick and iron ore have also been produced at select locations along the Escarpment.

Tourists have been attracted to the Niagara Escarpment for its scenic beauty along its entire length. Although Niagara Falls is arguably the most famous site and has the longest history of tourism, the Escarpment in Wisconsin has been popular with tourists for over a century. Known for its scenic cliffs and a magnificent view of Green Bay from the top of the 150-foot-high Escarpment, Peninsula State Park in Door County was one of the first state parks designated in Wisconsin, in 1909**.** Peninsula continues to be the most popular camping location in the state park system. On Lake Winnebago, High Cliff has long served as a recreation destination because of its scenic rock outcrops and the panoramic view of the lake afforded by the Escarpment. In the late 1880s a tavern, dance hall and amusement park, dubbed High Cliff Park, were built at the top of the Escarpment. Excursion boats would steam across the lake every Sunday, bringing families from Oshkosh, Appleton and other communities to enjoy a day at the park (Funk, 1997). Beginning in the 1920s, park owners made an unusual use of the Escarpment here by driving cars over the cliff—even rigging some to ensure a fiery crash. The amusement park eventually closed, but, in 1957, High Cliff State Park was opened to the public, providing more natural and reflective ways to enjoy the Escarpment.

Efforts to preserve the scenic beauty and biotic uniqueness of the Niagara Escarpment have been undertaken throughout the Great Lakes region. Perhaps none are as comprehensive and successful as those of the Niagara Escarpment Commission in Ontario, which was established in 1973 (www.escarpment.org). Although the Escarpment is just as unique and important in Wisconsin and Michigan, efforts to preserve and promote it in the states have lagged far behind Ontario. Canada's oldest and longest footpath, at 800 km, the Bruce Trail in Ontario provides public access to the Niagara Escarpment, promoting protection of the Escarpment and appreciation of its natural beauty (www.brucetrail.org). In 1990, this part of the Escarpment was named a UNESCO World Biosphere Reserve, an important internationally recognized ecosystem. More recently, efforts in Wisconsin to draw attention to the Escarpment have been undertaken by the Niagara Escarpment Resource Network (NERN). Founded in 1998, the Network promotes balanced land-use decisions and an appreciation of the Escarpment by providing education and scientific information and promoting sound planning and management concepts that conserve the integrity of the Escarpment (NERN brochure, 2004). In 2002, the Wisconsin Department of Natural Resources inventoried the natural resources of much of the Escarpment in Wisconsin (Anderson, et al., 2002). Although Ontario's Niagara Escarpment Commission initially formed to address concerns about the impact of the stone industry on the Escarpment in some of the more urban areas, the stone industry has not been the primary impact on the Escarpment in Wisconsin in recent decades. Instead, residential development has altered the Escarpment most significantly, converting much of the rural and natural viewscapes to suburban sprawl and removing potential public access to this feature.

In Wisconsin, the Niagara Escarpment, known locally as "the Ledge," is a discontinuous bedrock-controlled, geomorphologic feature composed of outcrops that form a rock ridge or series of ridges at the bedrock surface along the western edge of the Silurian outcrop belt (Fig. 1). In eastern Wisconsin, all Paleozoic strata dip a few degrees east toward the Michigan Basin, situated in Michigan's lower peninsula (Fig. 2). Along the Escarpment in northeast Wisconsin, resistant Silurian dolomite was undercut by the more rapid erosion of underlying soft Ordovician shale, which superimposed a steeper west-facing cliff on these dipping rocks. The Niagara Escarpment in Wisconsin differs in many important aspects from one end to the other. For example, the middle portion is more than 300 feet higher than the northern and southern ends (Martin, 1916). In general, most of the Escarpment in Wisconsin is composed of Ordovician rocks overlain by Silurian rocks. These Silurian rocks commonly belong to the "Mayville Dolomite." However, younger Silurian strata belonging to the Burnt Bluff Group and Manistique Formation compose the steep bluffs of the Escarpment in northern Door County, where "Mayville" and Ordovician strata plunge below the level of Green Bay following the eastward dip of Paleozoic rocks.

The Niagara Escarpment and cuesta exercised significant control on movement of Quaternary ice. Forming a resistant ridge between two easily eroded lowlands (Ordovician shales to the west and Devonian shales to the east), the resistant Silurian escarpment and cuesta forced the southward-flowing ice to diverge into the distinct Green Bay and Lake Michigan lobes. The Lake Michigan Lobe moved southward east of the Niagara Escarpment and cuesta, scouring out the Lake

Michigan basin. The Green Bay Lobe moved down the Green Bay-Lake Winnebago-Rock River lowland, removing strata down to the Galena-Platteville and creating basins for Lake Winnebago and Horicon Marsh (Paull and Paull, 1977). Although the Green Bay lobe was predominantly a southward-flowing ice sheet, eventually, it had subsidiary flow to the east over the Escarpment.

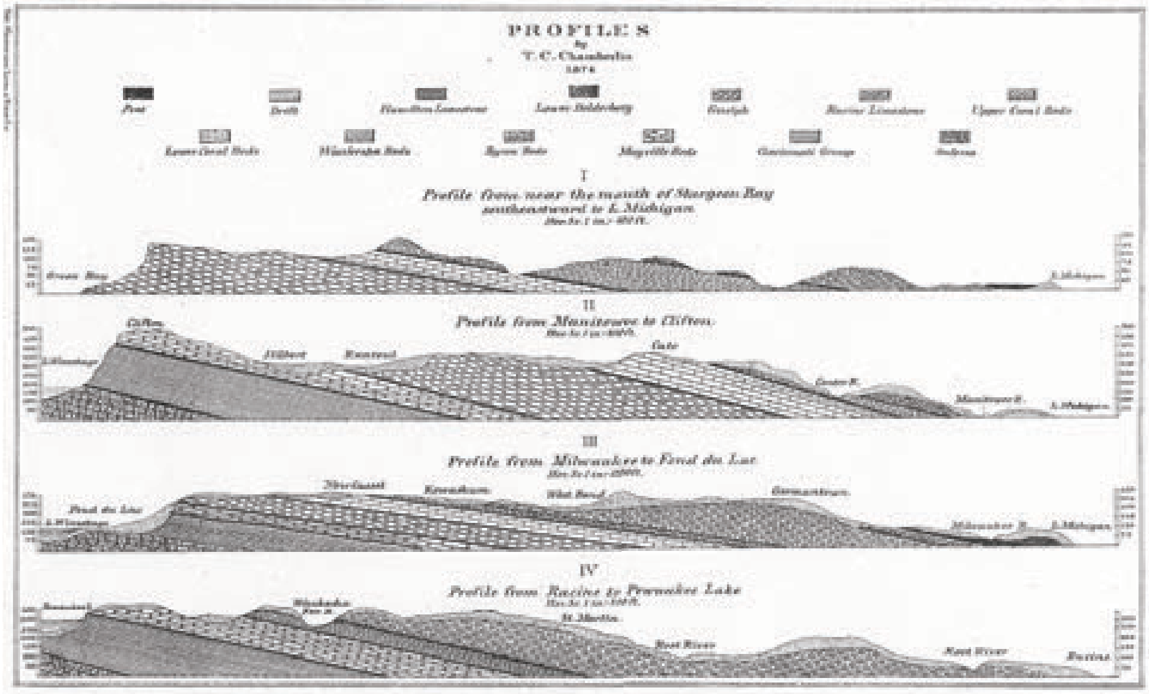


Figure 2. Plate from Chamberlin (1877) showing the eastward dip of Paleozoic rocks in eastern Wisconsin. II shows the profile from Manitowoc to Clifton (now High Cliff, Stop 6) and III from Fond du Lac (near Stop 3) to Milwaukee. Peat, Drift = Quaternary deposits; Hamilton Limestone and Lower Helderberg = Devonian units; Cincinnati Group and Galena = Ordovician units; the rest are Silurian units.

Formation of the escarpments and cuestas in the Eastern Ridges and Lowlands Province was due mainly to pre-glacial weathering and erosion (Martin, 1916). Quaternary glaciation, however, controlled the expression of the Niagara Escarpment in a variety of ways related to ice movement, including eliminating irregularities along its front, planing off bedrock highs and filling bedrock lows, and plastering it with drift (Paull and Paull, 1977). Ice movement was roughly parallel to the Niagara Escarpment from north of Green Bay south to about Fond du Lac, so its face is simple and without outliers (Martin, 1916). Martin postulated that the Escarpment was simplest east of Lake Winnebago because here 1) the ice moved parallel to it, 2) the glaciers were thick and powerful, 3) erosion occurred over several glacial episodes, 4) there were no streams to dissect the ledge subsequently, and 5) there has not been enough time for appreciable modification since the ice retreated. A similar situation may have existed along the Escarpment at Oakfield in Fond du Lac County. Just south of Fond du Lac, in the Hamilton area, ice movement was perpendicular to the Escarpment. As the glacier rode over the Escarpment here, it plucked Silurian strata from specific levels, perhaps related to differences in rock type, creating several “steps” along its front. Farther south, where the ice moved obliquely, the outline of the

Escarpment is more irregular. The southern portion of the Escarpment is partly buried by glacial deposits.

In some areas, the different composition of rocks making up the Escarpment adds to the complexity of the cliff face. Where easily-eroded Ordovician shale makes up a significant part of the Escarpment, the overlying fractured Silurian dolomite strata have been undermined and huge blocks have split off and slid downslope. This can be observed readily at Oakfield (Paull, 1992) and High Cliff. These blocks are not prominent along the Escarpment in Door County where Silurian strata compose the entire cliff face or the Ordovician strata are composed of less shaley, more indurated rock.

THE NIAGARA ESCARPMENT AND THE STONE INDUSTRY IN WISCONSIN

The Silurian dolomites of the Niagara Escarpment have been an important source of stone construction materials since the early 1800s when pioneer settlement of eastern Wisconsin began. In a region with otherwise-limited natural rock exposures, the extensive outcrops of the Escarpment have served as a convenient source of high quality building stone, lime, and crushed stone. Since initial settlement, the markets, products, and technologies of the stone industry have changed significantly, but extraction of stone from the Escarpment and cuesta has remained one of the most successful commercial operations in the region. This success derives from a mixture of geological, societal and technological factors, which together have ensured both continuous supply and demand for this material.

The Lake Winnebago region, comprising parts of Calumet, Outagamie, Winnebago, and Fond du Lac counties, exhibits fairly simple bedrock geology, with Silurian dolomite underlying the region east and south of the lake and Ordovician rocks underlying the areas to the west and north. The Niagara Escarpment parallels the east side of the lake, marking the boundary between these two areas. With the exception of the Escarpment, natural rock exposures are not common or extensive in this area. The value of the Escarpment as a source of construction materials is due to a combination of geologic features, such as rock composition, exposure, and accessibility, which is rarely found elsewhere in the region.

The rocks of the Escarpment exhibit a wide range of characteristics that impacted their use as construction materials. Ordovician shales and dolomites, which constitute the lower and generally buried portions of the Escarpment, seldom have been utilized for construction materials because their characteristics make them unsuitable. Notable exceptions are the Maquoketa Shale that was excavated from the lower portions of the Escarpment to make bricks near Stockbridge in the mid-nineteenth and early twentieth centuries and at Oakfield in the early to mid-twentieth century. In contrast, the overlying Silurian dolomite strata have been used extensively in construction materials. These rocks are all relatively pure carbonates, a characteristic that forms the basis of their value to the stone industry. Their bedding characteristics, which are related to depositional and diagenetic processes, ranging from massive to exceptionally well-bedded, figure into the types of stone products produced. For example, well-bedded strata generally make the best building stone. All of the purest dolomites have been used to produce lime, regardless of their bedding styles.

Only limited urban development has taken place near the Escarpment. Even today, most of the Escarpment remains quite rural, although it is becoming increasingly covered with residential development. It is still more expensive to haul rock from the Escarpment to some communities in the region than it is to use local stone (see Stop 1). During the early 1800s, settlers usually had to rely on local sources of construction materials because of the cost and difficulty of transporting them any significant distance. While wood and, to a lesser extent, bricks were commonly available in most communities, stone products were, for geologic reasons, more sporadic in their distribution and more expensive to obtain. Initially, this was not a significant problem as homes, farms, and other small buildings were usually built using only wood or brick. As communities grew and larger structures needed to be built, however, more durable and stronger materials such as dimension stone and lime were required. For example, the load bearing walls of most large structures had to be constructed on foundations of large stone blocks, and lime was needed for the mortar in brick and stone work.

Because the distribution of stone materials was more limited compared to wood and they were more expensive to extract and transport, a balance had to be struck between stone quality and transportation costs. This can be seen in the use of stone materials used in the Lake Winnebago region. Most of the urban centers in this area are located along the Fox River where it intersects the west side of the lake. Here, Ordovician dolomites of the Galena and Platteville commonly occur near the ground surface, although exposures are limited. These rocks were quarried to supply building stone during much of the nineteenth century, and many prominent structures built from these rocks can still be seen in these cities. However, the quality of this rock as building stone was marginal and, according to Daniels (1861), was "only fit for rough work." He further commented, "It will not dress well or polish, and its irregular texture and density renders it necessary to take great care in selection where it is to be exposed to the weather." Despite these negative characteristics, this rock was used extensively during the mid- to late 1800s as indicated by Buckley 's (1898) description of the numerous quarries in the area producing this material. He did not think that the stone was much better than described by Daniels, but attributed its extensive use to the close proximity of the quarries to the market of growing communities. His work indicates that, while these rocks were well-bedded and hard, they were too rough-textured and variable when compared with other building stones in the state. These rocks also did not make the best quality lime, and were little used for that purpose.

Other stone sources, especially for lime, were required to meet the needs of these communities. The Niagara Escarpment was discovered to be an excellent source of rock for making this product, even though the nearest exposures were on the opposite side of the lake from the growing communities. The Escarpment runs north-south along the east side of Lake Winnebago, but reaches the lakeshore for only a few miles at High Cliff. The quality of these Silurian rocks was determined to be so good for lime and the local Ordovician rocks so poor that it was economical, lacking rail transportation and good system of roads, to haul both lime and unprocessed rock across Lake Winnebago by boat during the summer and by sled on its frozen surface during the winter. By the mid 1800s, a major lime industry utilizing the Silurian rocks at High Cliff was in operation to supply the communities across the lake. Some building stone was also quarried here for markets along the Fox River.

On the south end of the lake, the city of Fond du Lac had similar needs and geological conditions. Although underlain by Ordovician rocks also, they were not as well exposed as in the communities to the north, so, they were seldom used to make building stone or lime. The Niagara Escarpment lies to the east of Fond du Lac for some distance south of the lake, but then makes a turn to the west and is situated only a few miles south of the city, at the area now called Hamilton. Lime was made at this site for use in Fond du Lac, but, more importantly, the Byron Dolomite, which yielded some of the best building stone in the state, was at the top of the Escarpment here. The Byron is an excellent building stone because it is very well bedded, occurring in layers from a few inches to over a foot in thickness, and it is very dense, even-textured, hard, and uniformly colored. With only a short overland trip to reach Fond du Lac, the Byron rock was employed extensively in construction there. Daniels (1861) reported that by 1860 over 60,000 square feet of stone had already been quarried at that locality. Throughout the late 1800s and early 1900s the nature of the stone industry changed as the numbers of quarries increased along with the amount of building stone and lime produced. Although overgrown by suburban sprawl in recent years, the Escarpment has never had a large local market for its lime and stone. The Fox River communities and Fond du Lac still use these products, but most of the lime and stone produced in the area is now shipped by rail or truck to more distant markets throughout the Midwest.

BEDROCK GEOLOGY

Ordovician

The Ordovician rocks are poorly exposed in this region, with the exception of quarries such as the Ben-Carrie Quarry in Neenah (Stop 1). In recent years, the sequence stratigraphy of some of these rocks has received considerable study (e.g., Simo, et al., 1997).

In brief, the geologic history of the Ordovician (488-444 mya) in this area is as follows (see Johnson and Simo, 2002). Early Ordovician shallow water carbonate and clastic sediments of the Prairie du Chien Group buried the underlying Cambrian surface. Subsequently, these strata became emergent and were intensively eroded and karstified. The North American craton then underwent extensive marine flooding during the Middle and Late Ordovician. During this time period, this part of North America was situated about 10° south of the equator in an arid, tropical setting. The St. Peter Sandstone, which is now an important aquifer in Wisconsin, was the first sediment deposited across this erosion surface, but a shift to carbonate sedimentation followed with deposition of the Sinnipee Group (Platteville and Galena formations). The Maquoketa Shale, which marked a return to clastic sedimentation, was deposited during the Late Ordovician. In this area, the Maquoketa occurs locally, mainly at the base of the Niagara Escarpment. The youngest Ordovician strata in the state belong to the Neda Iron Ore, which is a ferruginous oolite that may be related to soil formation; it is found north and south of the Lake Winnebago area.

A profound mass extinction event, second only to the end-Permian extinction in its impact, occurred at the close of the Ordovician, when approximately 60 percent of all life on Earth became extinct. It has been postulated that this event was caused by glaciation in the southern hemisphere, which initiated global climate cooling, a lowering of worldwide sea level and a reduction in ecospace on the continental shelves, establishing the scenario for mass extinction (Brenchley, 1990). In 2004, astronomers from the University of Kansas and NASA theorized that a nearby supernova may have led to this extinction event by first destroying the ozone layer with a gamma-ray burst, which then allowed strong ultraviolet radiation to attack life on Earth's surface. The chemicals produced by the gamma-rays may have formed a smog that triggered glaciation.

Silurian

The Silurian rocks are the most prominent bedrock exposed in the area and have the most control on the configuration of the Escarpment. These rocks were all deposited in the early part of Silurian (Llandovery, 444-428 mya). In older literature, these strata are referred to as Alexandrian or Niagaran, North American terms that are no longer used. During the Silurian this part of North America lay approximately 20° south of the equator in a tropical climate.

Glaciation that had begun in the Late Ordovician continued at the South Pole into the Early Silurian. All of the Silurian rocks in the Lake Winnebago area are carbonates that were deposited in marine environments in shallow epeiric seas and later dolomitized. Some of the Silurian depositional environments were restricted, even hypersaline, at times. In contrast to much of the Ordovician, these rocks are poorly fossiliferous, probably because of the restricted depositional conditions.

Although the Silurian is well exposed in the Niagara Escarpment, a complete section of the lower Silurian rocks is seldom exposed in any one location. As these rocks vary considerably in lithology and generally lack biostratigraphically-useful fossils, these sections are difficult to correlate. Usually, any well-bedded lithology has been referred to as "Byron" and everything else below that as "Mayville." Superficially, the Silurian rocks of the Lake Winnebago area were thought to be rather featureless from a stratigraphic standpoint, and early geologists compared them with rocks described in New York, such as the Clinton and Niagara limestones. (Daniels, 1861; Hall, 1862). The first attempt to make a detailed subdivision of these rocks was made by Chamberlin (1877).

Chamberlin (1877) named the basal Silurian rocks in Wisconsin the Mayville Beds of the Niagara Group. He included the Neda Iron Ore as the base of the Silurian because of its similarity to the Silurian Clinton Iron Ore of New York; the Neda is now known to be latest Ordovician. He described the Mayville as rough, coarse, thick-bedded, gray magnesian limestone, containing chert locally, and topped by thick beds characterized by abundant brachiopod molds (*Virgiana*). His type section was located in the Niagara Escarpment near Neda, south of Mayville in Dodge County. However, the lower part of the Silurian section is not exposed at that locality.

Chamberlin (1877) also proposed the name Byron Beds for strata overlying the Mayville. He didn't designate a specific type section for the Byron; however, the name is obviously derived from the Town of Byron in Fond du Lac County, where these strata were being quarried extensively for building stone at the time. Chamberlin did not mention any location in that township where he could see the contact between the Byron and the Mayville, although he described this contact at other localities, such as the Mayville type section. He described the Byron Beds as well-bedded, white to light gray magnesian limestone, with a compact texture and conchoidal fracture, and he also observed laminae, mudcracks and ripple marks in this unit.

Above the Byron, Chamberlin (1877) designated the Lower Coral Beds. He described this unit as being gray, coarse, crystalline, granular, rather soft, pure dolomite in massive beds containing many cavities and occasional layers of chert or silicified fossils, predominantly the coral *Favosites* and the brachiopod *Pentamerus.* He considered the contact between the Byron and the Lower Coral Beds to be transitional. Chamberlin also described younger Silurian units that will not be seen on this field trip and are not discussed here.

Shrock (1939) modified Chamberlin's (1877) Silurian stratigraphy by introducing terminology from the Upper Peninsula of Michigan. Shrock retained Mayville as the Mayville Dolomite and the Byron Dolomite as part of the Burnt Bluff Formation. Chamberlin's Transition Beds between the Byron and Lower Coral Beds were labeled as the Hendricks Dolomite of the Burnt Bluff Formation and the Lower Coral Beds were correlated with the Schoolcraft Dolomite of the Manistique Formation. Shrock's terminology was used until quite recently; however, expanded quarrying and new subsurface cores indicate that the relationships between these units are more complex than previously thought and that some of these units have been miscorrelated and misdated (Mikulic and Kluessendorf, 1998).

The Silurian-Ordovician boundary is a major sequence boundary in the Paleozoic rocks of the Midwest. At the end of the Ordovician, the seas withdrew from this area because of a global lowering of sea level related to glaciation, and Ordovician sediments were subjected to a long period of erosion. In some places, such as the Chicago area and northeastern Iowa, a considerable topography of broad hills and valleys developed on this surface, creating relief of as much as 100 feet (Mikulic and Kluessendorf, 1998). In the Lake Winnebago area, there is no good evidence for a similar erosional topography on top of the Ordovician, but exposures and subsurface information may be too limited to determine this conclusively. North and south of the Lake Winnebago area, the Neda Iron Ore composes the uppermost Ordovician where it is believed that the Maquoketa is thickest (Mikulic and Kluessendorf, 1983). The Neda has not been observed in the Lake Winnebago area. As glaciation waned and ice sheets began to melt at the beginning of the Silurian, seas slowly flooded the region, eroding and redepositing Maquoketa clastic sediments. As a result, the basal Silurian is usually composed of highly argillaceous sediments, which fill in irregularities on the Ordovician surface. Depending on the amount of erosional topography on top of the Maquoketa, these basal Silurian sediments can range considerably in thickness, from as little as a few inches where the Maquoketa is very thick to almost 100 feet where it is very thin. The argillaceous basal Silurian unit in Iowa and northwestern Illinois is known as the Mosalem Formation and in northeastern Illinois as the Wilhelmi Formation. In the Lake Winnebago region, these sediments can be seen at the base of the Silurian around High Cliff, where they are exposed in the J&E Construction Quarry in Sherwood and at High Cliff State Park (Stop 6); both locations lack any evidence of Neda Iron Ore. In contrast, a relatively clean basal Silurian sits on top of the Neda at Katell Falls in Brown County and at Iron Ridge in Dodge County (Mikulic and Kluessendorf, 1983).

In the Lake Winnebago area, the basal Silurian rocks that overlie either the Ordovician or the Mosalem/Wilhelmi have been referred to historically as the Mayville Dolomite. At the type locality of the Mayville, the lower part of the Silurian section is not exposed. In recent years, it has become apparent that precise correlation of the Mayville here with the lower Silurian beds that have been called "Mayville" to the north and south in Wisconsin is difficult (Mikulic and Kluessendorf, 1998). Most people have assigned any *Virgiana*–rich rocks to the top of the Mayville; however, it is now clear that *Virgiana* occurs in at least two separate zones. Interestingly, Savage (1916) identified two different subspecies of *Virgiana* (*V. barrandei* var. *mayvillensis* and *V. barrandei* var. *major*) as occurring in the *Virgiana* beds at Mayville and Marblehead, respectively. This suggests that the two *Virgiana* zones may differ in age. For this field trip, we are defining the "Mayville" as all the rocks between the Mosalem/Wilhelmi equivalent and the Byron. Preliminary studies indicate that the "Mayville" displays some significant differences between the Lake Winnebago region and the type section, but a lack of information makes it difficult to correlate these two areas. The "Mayville" in this area is typically thick-bedded to massive, light brown to reddish brown, granular, vuggy dolomite with scattered chert.

In Byron Township in Fond du Lac County, the Byron Dolomite is well exposed and is characterized by laminites, although there are common cycles of laminated to burrowed zones. The Byron overlies the "Mayville," which is marked by a weak zone of *Virgiana* brachiopods at its top. In turn, the Byron is overlain by a more pronounced *Virgiana* zone. This upper *Virgiana* zone is probably equivalent to the Lime Island Dolomite of Michigan, as described by Ehlers and Kesling (1957). This zone can be recognized readily in the same stratigraphic position from Fond du Lac County north into the Upper Peninsula of Michigan. The Lime Island is succeeded by a laminite-dominated unit that is part of the Burnt Bluff Group. This laminite unit has been commonly misidentified as the lithologically-similar, but older, Byron Dolomite in northeastern Wisconsin and Michigan (e.g., Harris and Waldhuetter, 1996; Ehlers and Kesling, 1957). This laminite unit is overlain by the Hendricks Dolomite of the Burnt Bluff Group, which is characterized by interbedded laminites, burrowed layers and beds containing corals, especially *Favosites.* The Hendricks is succeeded by another brachiopod zone. This one contains *Pentamerus* and belongs to the Schoolcraft Member of the Manistique Formation. These post-Lime Island units are not exposed along the Niagara Escarpment in the Lake Winnebago area, but are present in various nearby bedrock hills to the east, such as at Ledge View Nature Center near Chilton (Stop 7).

The depositional pattern represented by these pentamerid brachiopod to laminite cycles represents a shallowing-upward succession from subtidal to intertidal/supratidal conditions typical of a highstand system tract, in which prograding tidal flats cap the sequence. It may represent an early highstand transgressive period in which sedimentation is in a catch-up mode and vertical accretion is dominant (Jones and Desrochers, 1992). These cycles typify the lower Silurian from Fond du Lac County north into the Upper Peninsula of Michigan, but a significantly different depositional setting prevailed to the south (see Mikulic and Kluessendorf, 1998).

FIELD TRIP STOPS

STOP 1. BEN-CARRIE QUARRY, NEENAH

Location: Michels Materials Corporation quarry located on the west side of Tullar Rd., just north of the intersection with Co. Hwy JJ, Neenah, Winnebago County, Wisconsin

Stop Leaders: Bruce A. Brown and Maureen Muldoon

The Ben-Carrie Quarry is a large crushed stone operation owned by Michels Materials Corporation. located on the western edge of Neenah. The quarry has operated for many years, and was named for the original owners, Ben and Carrie Schultz, who once farmed here before urban growth surrounded the site.

General Geology of Winnebago County

The bedrock of Winnebago County consists of a series of siliciclastic sediments and carbonates dipping gently to the east off of the Wisconsin arch toward the Michigan Basin at a rate of several feet per mile. The Precambrian basement is not exposed in Winnebago county, but meta-rhyolite and related granite of the 1760 m.a. granite-rhyolite terrane of the Fox River valley are exposed just west of the Green Lake County line at Berlin. The crystalline basement is overlain by sandstones and minor shale of Cambrian age, which are, in turn, overlain by the carbonates and siliciclastic rocks of the Ordovician Prairie du Chien Group, the St. Peter Sandstone of the Ancell Group, and the carbonates of the Sinnipee Group (Platteville and Galena Formations) (Fig. 1-1). The St. Peter Sandstone is more restricted in aerial extent than previously believed. It is not a uniform blanket of sandstone as depicted on earlier geologic maps, but appears to be restricted to channels up to 200 feet deep incised into the underlying Prairie du Chien, and may, in some cases, cut this unit out entirely and rest on Cambrian sandstone.

Geology of Ben-Carrie Quarry

Ben-Carrie Quarry is particularly interesting in that it is in an area where little or no St. Peter is present between the mixed siliclastic and carbonate beds of the Shakopee Formation of the Prairie du Chien and the overlying Platteville carbonates. Johnson and Simo (2002) studied the Shakopee Formation in eastern Wisconsin, and concluded that it consisted of two distinct sequences separated by an unconformity of regional extent (Fig. 1-2). The lower sequence consists of shallowing upward cycles and peritidal dolostones, representing highstand deposits. The unconformity separating the two sequences within the Shakopee represents significant exposure and erosion, which produced incised valleys now filled by the lower beds of the upper sequence. The deposits immediately above the unconformity surface can appear quite complex, consisting of interbedded sands and shales including blocks of reworked carbonate and large blocks and masses of underlying carbonate that probably resulted from collapse of karst developed in the underlying rocks during the period of exposure and erosion. The sequence stratigraphic interpretation for the Prairie du Chien of eastern Wisconsin proposed by Johnson and Simo is reproduced in the following figure, along with their interpretation for the Ben-Carrie Quarry based on faces exposed at the time. Because this is an active quarry, much of what Johnson and Simo observed has been removed, but we can see the same relationships in other areas of this large site.

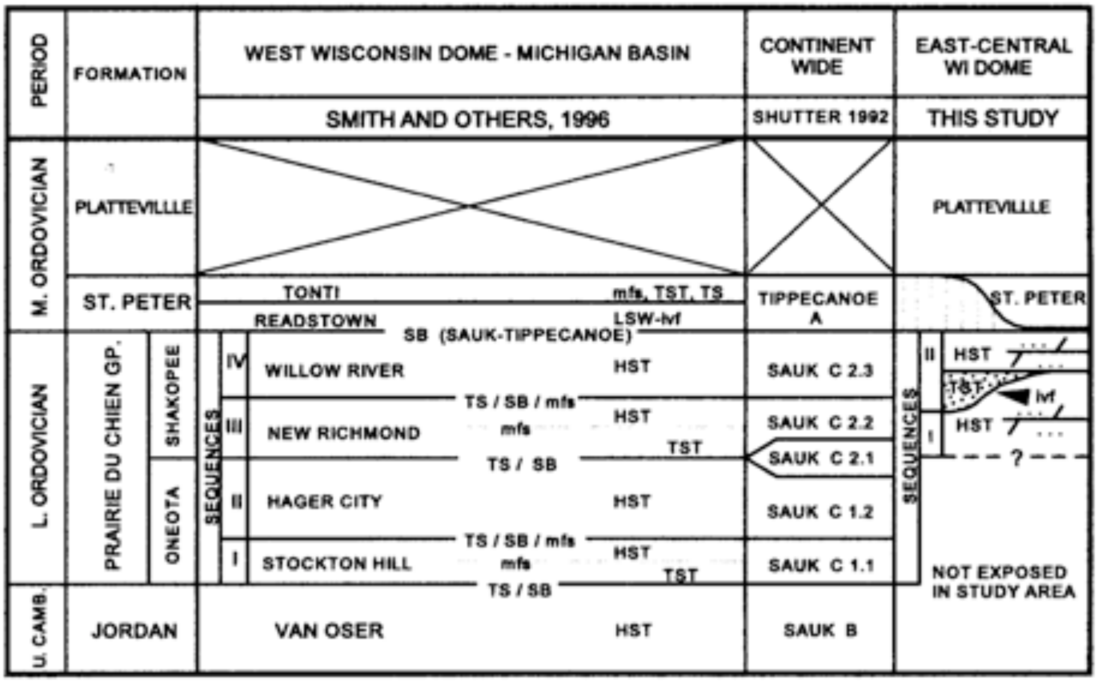


Figure 1-1. Formations and sequence stratigraphic interpretations of the Lower Ordovician in Wisconsin. HST: highstand system track, TST: transgressive system track; LSW-ivf: incised valley fill of lowstand system wedge; mfs: maximum flooding surface; TS: transgressive surface; SB: sequence boundary; ivf: incised valley fill (from Johnson and Simo, 2002).

Economic Geology of Ben-Carrie Quarry

The Ben-Carrie Quarry is one of many aggregate quarries developed in the Sinnipee and Prairie du Chien carbonate rocks in the Fox Valley region. Rapid growth in this area has led to increased demand for construction aggregate along the U.S. Hwy. 41 corridor for both concrete and asphalt pavement and a variety of construction uses. Because this area was covered by lake deposits in the Quaternary, it has relatively meager sand and gravel deposits. The Silurian carbonate rocks of the Niagara Escarpment are too distant from the western side of Lake Winnebago to be economically transported to most of the Fox Cities-Oshkosh metropolitan area, and the Sinnipee and Prairie du Chien rocks are the only source of material.

The Platteville Formation generally produces quality aggregate that meets most state specifications for asphalt and concrete. The Prairie du Chien carbonates are also an excellent source of aggregate, with the exception of the sandy and shaly facies of the Shakopee, which have little use except as fill material if not highly mineralized.

The St. Peter Sandstone, when present in sufficient thickness, has been mined for foundry sand in southwestern Winnebago County and in adjacent Green Lake County. The Cambrian Jordan Sandstone is known only in the subsurface of Winnebago County, but it has also been mined for industrial sand in Green Lake County.

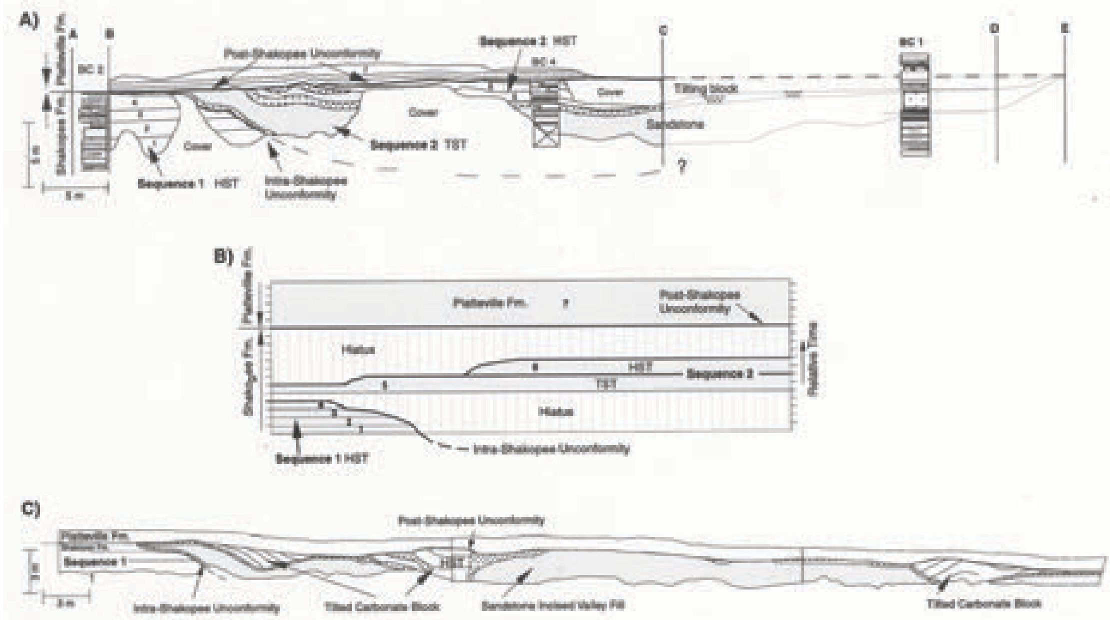


Figure 1-2. Cross-sections and Wheeler diagram from Ben-Carrie Quarry. A) Cross-section with stratigraphic sections illustrating the west axis of the incised valley system. B) Wheeler diagram illustrating depositional sequences 1 and 2, hiatus periods of no deposition, and the two unconformities. C) Cross-section illustrating east axis of the incised valley, tilted carbonate blocks, and convoluted shale beds (from Johnson and Simo, 2002).

Hydrologic Setting of the Fox Valley

The Ben-Carrie Quarry lies within the Fox-Wolf River surface water basin. The Fox River and its principal tributary, the Wolf River, drain an area of approximately 6,500 square miles in east-central and northeastern Wisconsin (see Fig. 1-3). The basin receives approximately 28 to 30 inches of rainfall annually of which approximately 18 to 20 inches are lost to evaporation, leaving approximately 8 to 12 inches for groundwater infiltration and surface runoff. The potentiometric surface generally slopes to the east-southeast, and Lake Winnebago and the Fox River function as discharge areas for the regional flow system (Olcott, 1968).

This region of the state was one of the earliest to be settled by Europeans as these waterways provided early explorers access to the interior of the state and were subsequently used as a means of transporting lumber from northern Wisconsin to the mill towns in the Fox Valley.

Water Supplies

Both groundwater and surface water resources have been used as water sources for industry and drinking water. Several communities utilize Lake Winnebago for public water supplies (i.e., Appleton, Neenah, Menasha, and Oshkosh), while many others use groundwater resources (i.e, Kimberly, Kaukana, Fond du Lac). Figure 1-4 is a generalized geologic cross section of the Fox River region. A shallow aquifer, consisting of the Pleistocene surficial deposits, the Ordovician Prairie du Chien Dolomite and St. Peter Sandstone, is commonly tapped by shallow domestic wells. The Sinnipee Group is considered a confining unit. The deeper Cambrian sandstone aquifer provides water to larger municipal water supply systems.

Effects of Water Withdrawals

Withdrawal of water from both the shallow and deep aquifers has led to problems in the Fox Valley region. The deep sandstone aquifer has experienced drastic declines in water levels since the initiation of pumping. Originally, the confined sandstone aquifer exhibited artesian conditions and the elevation of the potentiometric surface was above the land surface. By the mid-1950s researchers noted that water levels in the sandstone aquifer were declining drastically (see Fig. 1-5). This observation prompted the city of Green Bay to turn to Lake Michigan as its primary water supply (note the sharp rise in water levels in the late 1950s). Groundwater pumping, however, continued in the surrounding communities and water levels in the sandstone aquifer are continuing to decline at a rate of approximately 3 feet/year. Recently, the communities surrounding Green Bay, have decided to develop their own pipeline to Lake Michigan at an estimated cost of $132 million. The effects of groundwater withdrawals are not limited to the deep sandstone aquifer.

The Arsenic Problem

What is arsenic and why do we have a naturally-occurring arsenic problem in eastern Wisconsin? Arsenic is an element that is often found in trace amounts in sulfide minerals. As this problem drew attention, it was noted that logs of many wells that tested positive for arsenic reported dark-colored sulfide-cemented sandstone at the top of the St. Peter, which was a common aquifer of choice for rural residential wells. For example, while pyrite is typically thought of as iron sulfide (FeS), arsenic can substitute for some of the iron atoms. In the early 1990s, the Wisconsin Department of Natural Resources (DNR) conducted several groundwater sampling programs in order to delineate the extent of the arsenic problem (Fig. 1-6A). These data led DNR personnel to suggest that sulfide mineralization occurring at the contact of the St. Peter and Galena formations was the source of the elevated arsenic levels (Burkel, 1993; Burkel & Stoll, 1995). Work by Simo et al. (1996) helped define a Sulfide Cement Horizon (SCH) that occurs across eastern Wisconsin at the base of the Platteville Formation and contains up to 1.0 weight % of arsenic (Simo, et al., 1996). Figure 1-6B illustrates the stratigraphic location of the SCH within the St. Peter, Sinnipee, and Prairie du Chien Groups.

Why do we care about trace amounts of arsenic? Drinking water with elevated levels of arsenic over long periods of time increases risks of “skin, bladder, lung, liver, colon and kidney cancer. Other health effects may include blood vessel damage, high blood pressure, nerve damage, anemia, stomach upsets, diabetes, and skin changes” (DHFS, 2001).

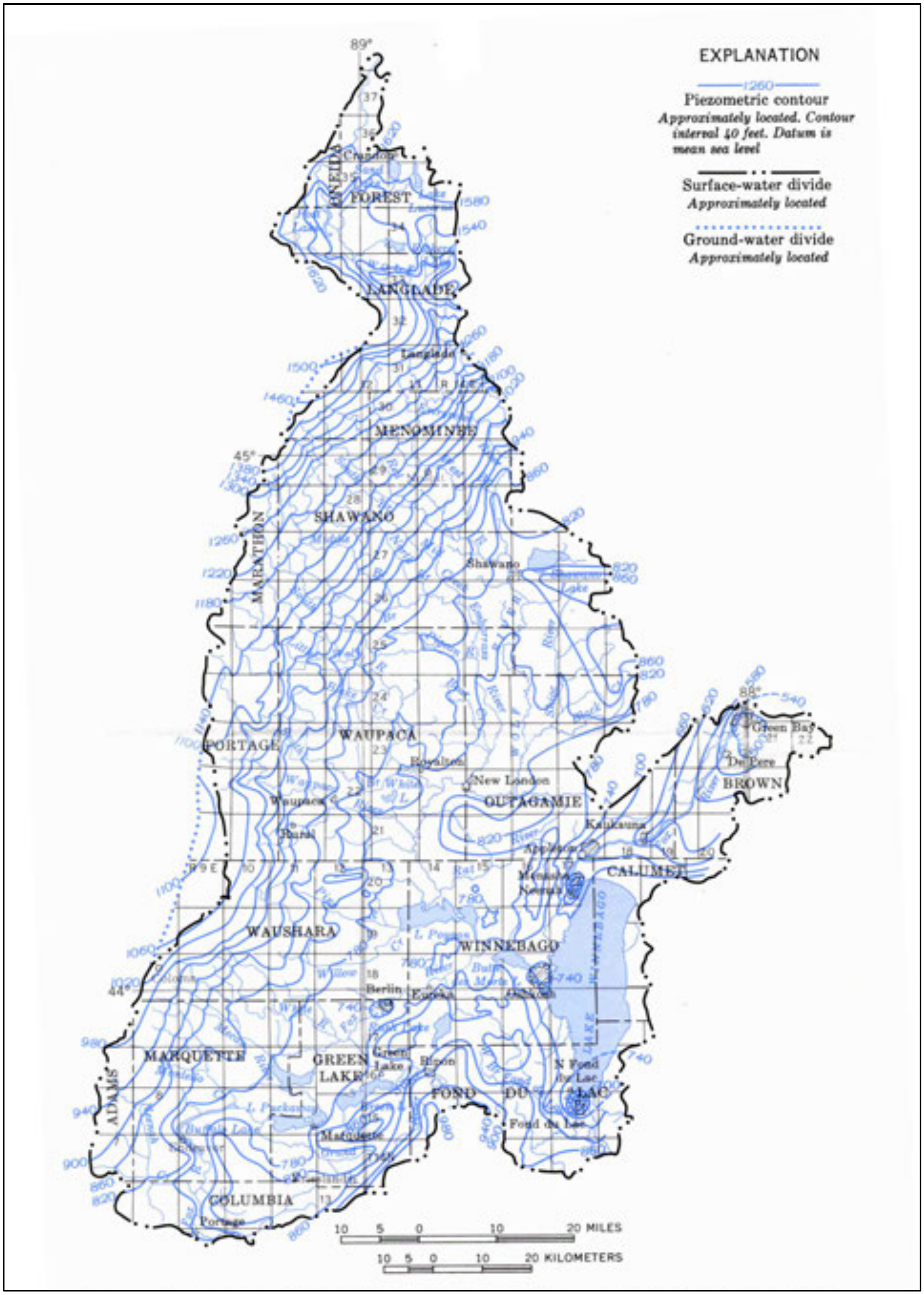


Figure 1-3. Generalized potentiometric surface of the Wolf-Fox watershed (from Olcott, 1968).

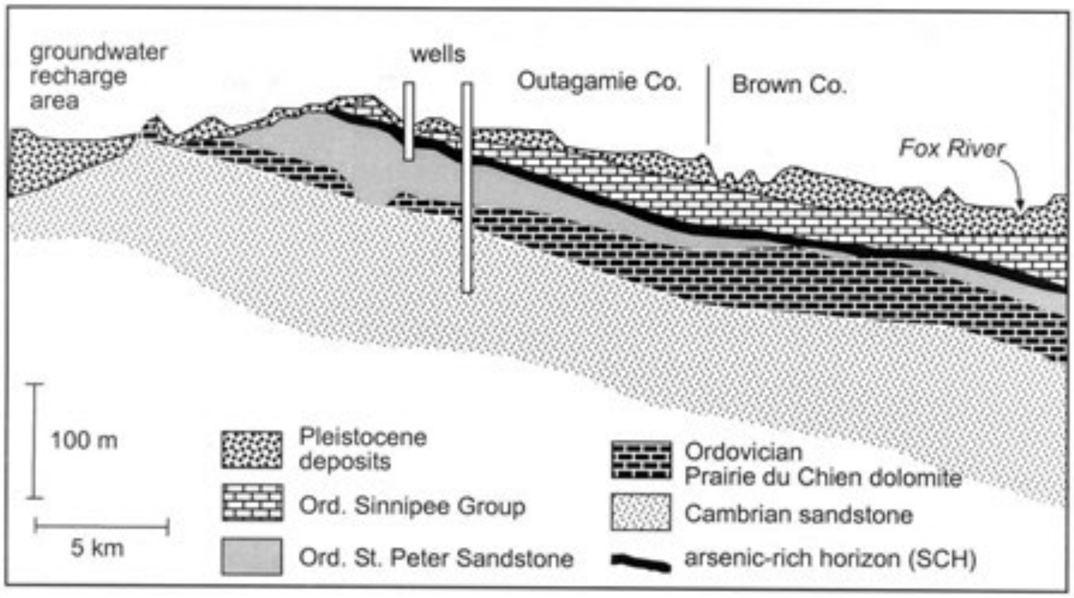


Figure 1-4. Geologic cross-section of the Fox Valley region showing the major stratigraphic units (modified from Batten and Bradbury, 1996).

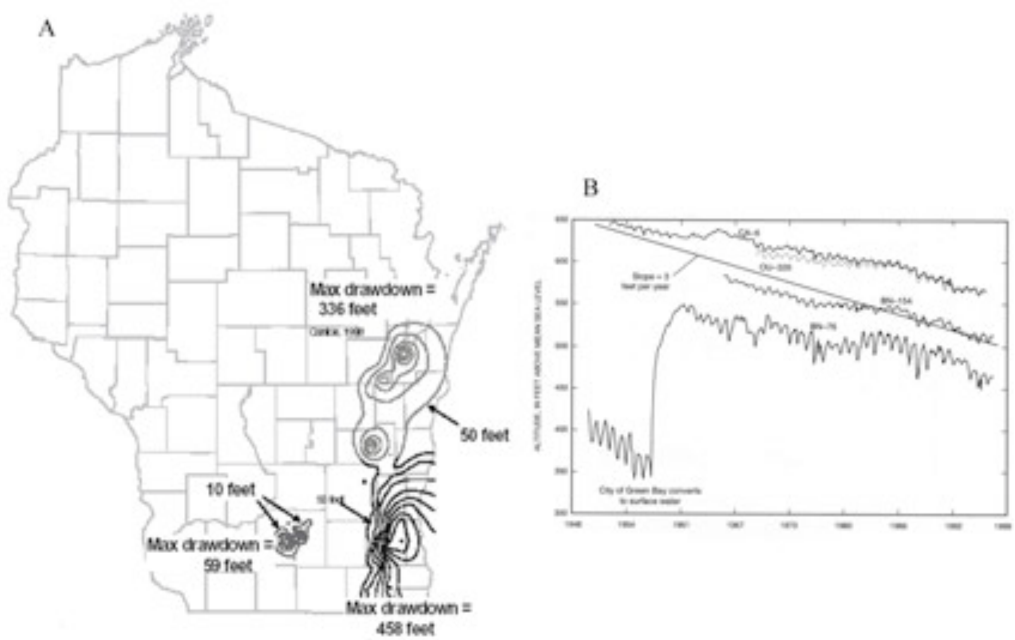


Figure 1-5. A) Drawdown in the Cambrian sandstone aquifer throughout Wisconsin. B) Water levels Fox Valley that are completed in the Cambrian sandstone aquifer (from Walker, et al., 1998).

How does arsenic get into groundwater? First, we must ask, "How did the sulfide minerals get to Wisconsin?" The prevailing theory is that sulfide-rich brines came from the Michigan Basin. As sedimentary layers were being deposited in the Michigan Basin, brines developed in the deep portion of the basin. During Devonian time, Eurasia collided with North America and created a compressional force that was transmitted all the way to the interior of the continent. The force squeezed the brines in an up-dip direction to the west where pyrite, marcasite and galena were precipitated within the rock and along joint surfaces (Girard and Barnes, 1995). The highly permeable St. Peter Sandstone was a preferential pathway for brine transport, and that is why the sulfide cement horizon was deposited here (e.g. Winter, et al., 1995). This mineralization, which also can be present as veins and sulfide coatings on joint and bedding surfaces in the carbonates is similar in form and origin to Mississippi Valley Type (MVT) deposits such as occur in southwest Wisconsin. Although origin and mineralogy may be similar, no deposits of sufficient size to be economic have been found in eastern Wisconsin.

Arsenic gets into our groundwater through oxidation of sulfide-rich minerals (Schreiber, et al., 2000). Sulfide-rich minerals are relatively insoluble in water with low concentrations of dissolved oxygen. In general, groundwater does not contain much dissolved oxygen except at the water table. This is why the position of the water table is so important in determining whether arsenic gets into the groundwater system. When the water table is at or below the sulfide cement horizon oxygen is introduced into the system. When the oxygen is added to sulfide minerals (which generally consists of a metal cation and sulfur as the anion), the oxygen combines with the sulfur to form sulfate (SO_4-) and the metal goes into solution. Sulfate (SO4-) combined with water forms sulfuric acid and the pH of the groundwater drops. Metals are much more mobile under acidic conditions. Work by Schreiber, et al. (2000) suggests that elevated levels of arsenic can be expected: 1) where the SCH intersects the water table and 2) in areas where groundwater withdrawals have lowered the water table. In addition, the water-level fluctuations that occur in a domestic well as the pump cycles on and off appear to introduce enough oxygen to cause elevated arsenic levels. Continued development of subdivisions in the arsenic advisory area will exacerbate the arsenic problem if the subdivisions draw water from the shallow aquifer.

The drinking water standard for arsenic in public water supplies has recently changed from 50 parts per billion (ppb) to 10 ppb. Approximately one third of domestic wells in Outagamie and Winnebago counties have arsenic concentrations >5 ppb, and 3.5 percent of these wells exceed the 50 ppb standard. The new standard will take effect in 2006 for public water supplies. It is predicted that approximately 30,000 domestic wells in northeast Wisconsin exceed the new standard.

At the Ben-Carrie stop, it is obvious that the sandy beds in the upper Shakopee sequence are highly mineralized with sulfide. What we have in this region are two significant unconformities each overlain by porous sands concentrated in a complex of incised channels. The result is an extremely complex plumbing system for distribution and precipitation of MVT mineralization, a situation that makes predicting the distribution of arsenic in individual wells very difficult.

The Wisconsin Geological and Natural History Survey is currently mapping the bedrock geology of Winnebago and Outagamie counties in an attempt to better understand the origin and distribution of arsenic-bearing mineralization, and is working with the Wisconsin Department of Natural Resources to develop new well construction rules to avoid this hazard. Preliminary results suggest that mineralization is sufficiently widespread, and the undesirable metals can be released to groundwater under both oxidizing and reducing conditions. At present, wells are required to be cased into the deep Cambrian sandstone aquifer if a sufficient thickness of Sinnipee carbonate or surficial material is not present to yield an adequate water supply

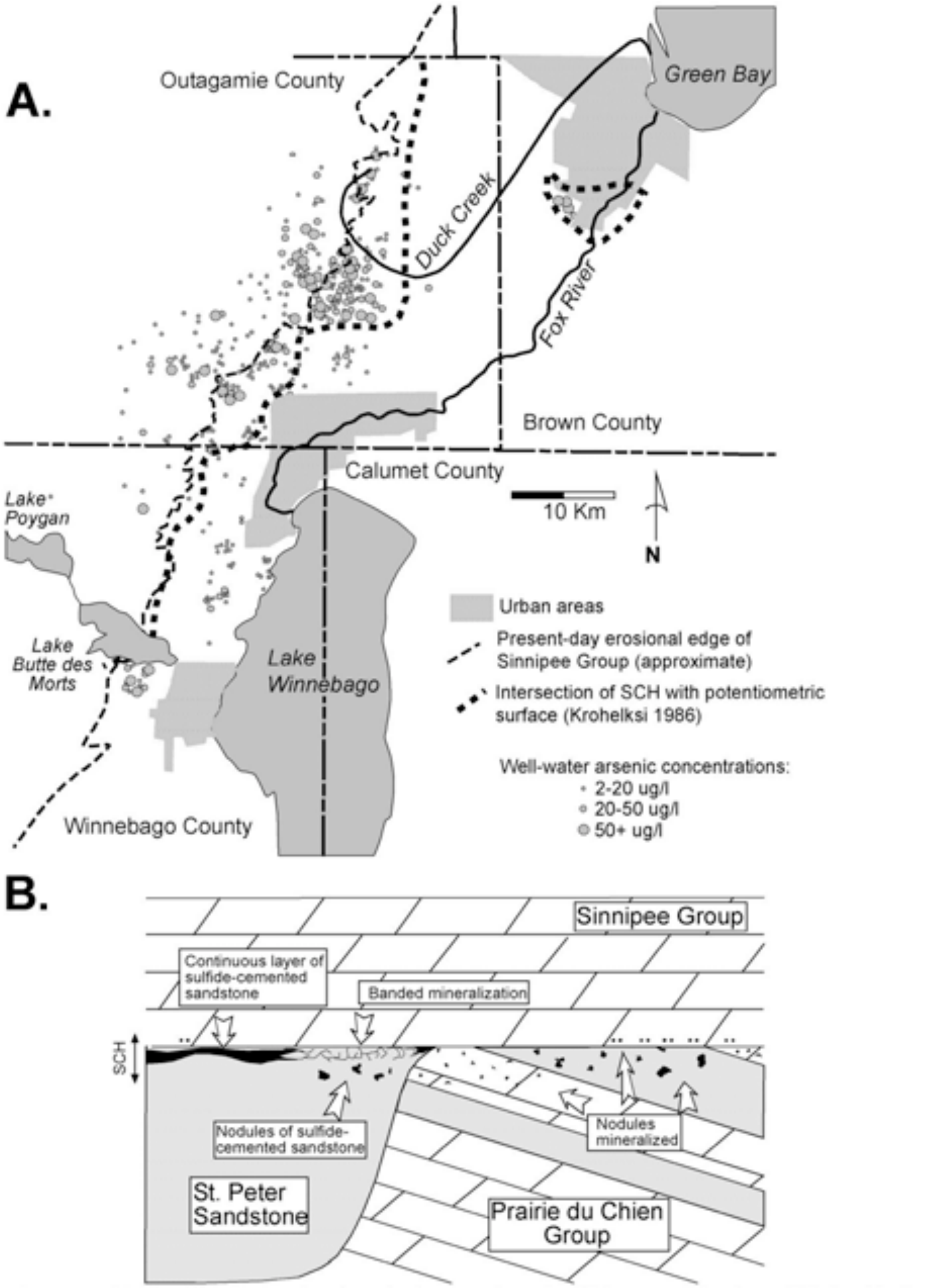


Figure 1-6 A) Simplified map showing the intersection of sulfide cement horizon (SCH) with the potentiometric, the present edge of the Sinnipee Group, and locations of wells with elevated arsenic lconcentrations B) Generalized cross-section through the Prairie du Chien-Sinnipee contact showing the morphology of the SCH (modified from Simo, et al., 1996).

STOP 2. EUREKA MORAINE, GLACIER RIDGE BISON FARM GRAVEL PIT

Location: NW, SW, Section 3, T16N, R16E, Fond du Lac County, Wisconsin

Stop Leaders: Tom Hooyer and Bill Mode

The Laurentide Ice Sheet covered a large area of North America during the Late Wisconsin glacial maximum approximately 21,000 years ago. This ice sheet was centered in northern Canada and extended eastward to the Atlantic Ocean, west to the Rocky Mountains, north to the Arctic Ocean, and southward into the upper Midwest. Six lobes of this ice mass extended into the state of Wisconsin (Fig. 2-1). The Green Bay Lobe (GBL) was the largest of these lobes and covered all of east-central Wisconsin. The lobe terminated in the south near the Wisconsin/Illinois border and to the west by an area commonly referred to as the Central Sand Plain. To the east, the lobe abutted the Silurian Escarpment and the much larger Lake Michigan Lobe that covered the Lake Michigan basin and extended southward into central Illinois.

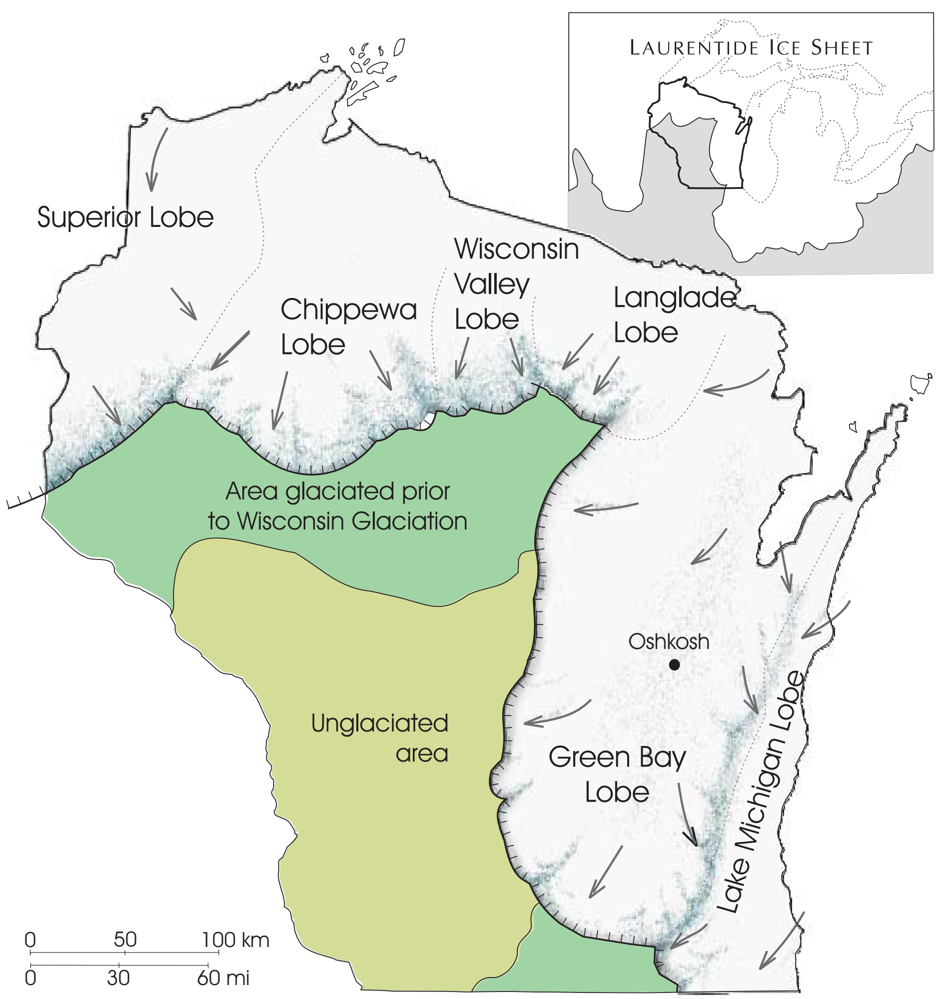


Figure 2.1. Location of the city of Oshkosh (a) in relation to the Laurentide Ice Sheet (b) and its lobes during the last part of the Wisconsin Glaciation.

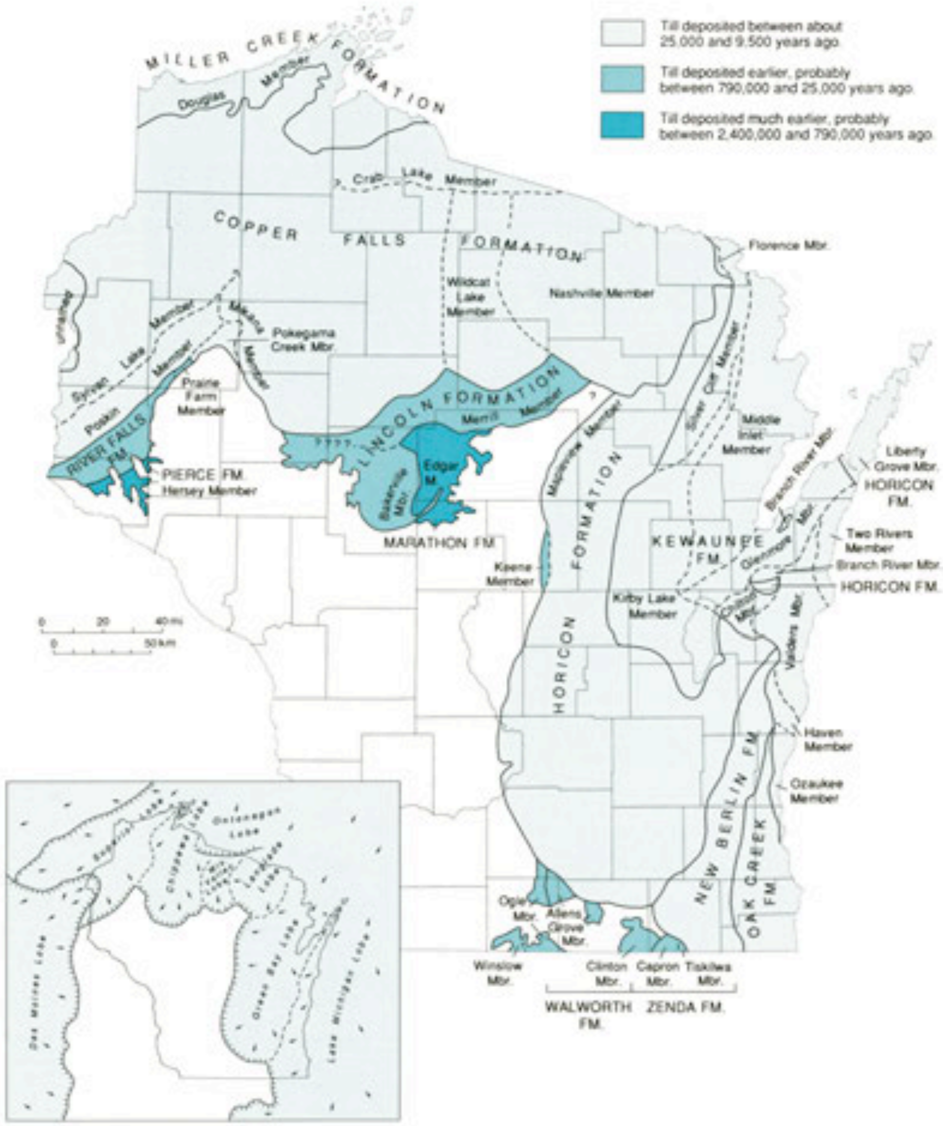


Figure 2-2. Distribution of Pleistocene lithostratigraphic units in Wisconsin. In this figure, formations are separated by solid lines, and members are separated by dashed lines. Only the extent of fairly continuous till in each member is shown here; scattered small patches of till, and meltwater-stream and glacial-lake sediment are not shown. This figure is taken from L. Clayton, J.A. Attig, D.M. Mickelson, and M.D. Johnson, 1992, Glaciation of Wisconsin, Wisconsin Geological and Natural History, Survey Educational Series 36.

In east-central Wisconsin along the Fox River Valley, the GBL, when at its maximum extent, appears to have removed most all unlithified sediment and eroded the bedrock surface. This material was transferred subglacially or in the basal ice to the southern half of the lobe where it was deposited on the bedrock surface and formed the outermost terminal moraines. This material, primarily till, is called the Horicon Formation and is widely distributed in the southern half of the area formerly covered by the GBL (Figure 2-2). The till is usually brown to yellowish brown (7.5YR hues) and consists primarily of silica sand and dolomite gravel and cobbles. The size distribution of grains less than 2 mm shows that the average sand, silt and clay content are 65, 25, and 10 percent, respectively (Figure 2-3). The source of the sand is the Jordan and the St. Peter sandstones of the upper Cambrian and Ordovician, respectively. The source of the dolomite gravel and cobbles is the Ordovician Prairie du Chien and the Sinnipee Groups. All these bedrock units are exposed at the bedrock surface in the area formerly covered by the GBL, thereby explaining the composition of the Horicon till.

During retreat of the GBL to the north, a large lake formed in front of the ice margin and covered a vast area of the Fox River lowland. This lake is called glacial Lake Oshkosh and it covered a large area of east-central Wisconsin (Fig. 2-4). Within this lake, red clay-rich sediment was deposited. Glacial Lake Oshkosh initially drained southward into the lower Wisconsin River via an outlet located near Portage, Wisconsin. With further retreat of the ice lobe, a series of lower outlets opened across the Door Peninsula, eventually lowering glacial Lake Oshkosh to the level of water in the Lake Michigan basin (see Stop 5). Eventually, the GBL readvanced twice into the Fox River lowland around 15,000 and 13,500 years ago. During both readvances and subsequent recessions, glacial Lake Oshkosh was reactivated in front of the ice margin.

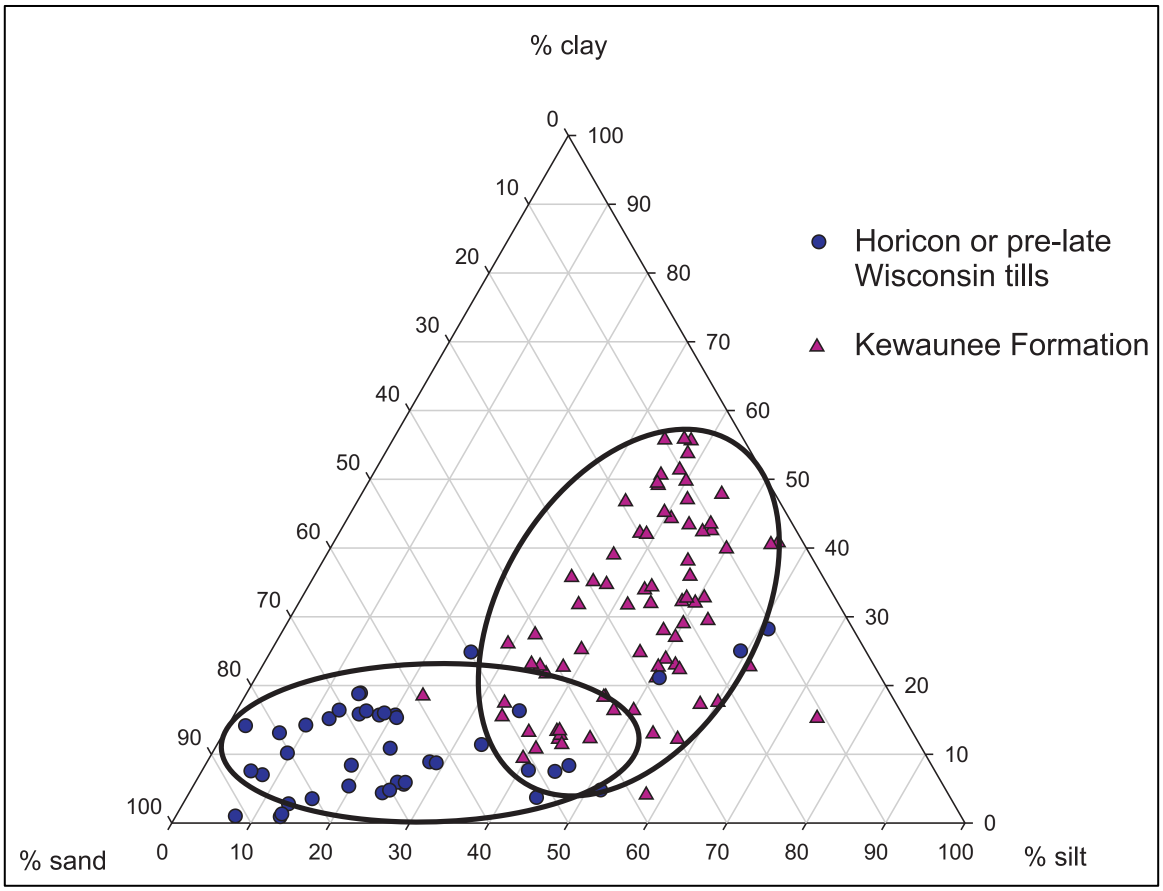


Figure 2.3. Grain-size distribution of tills collected from the Kewaunee and Horicon Formations.

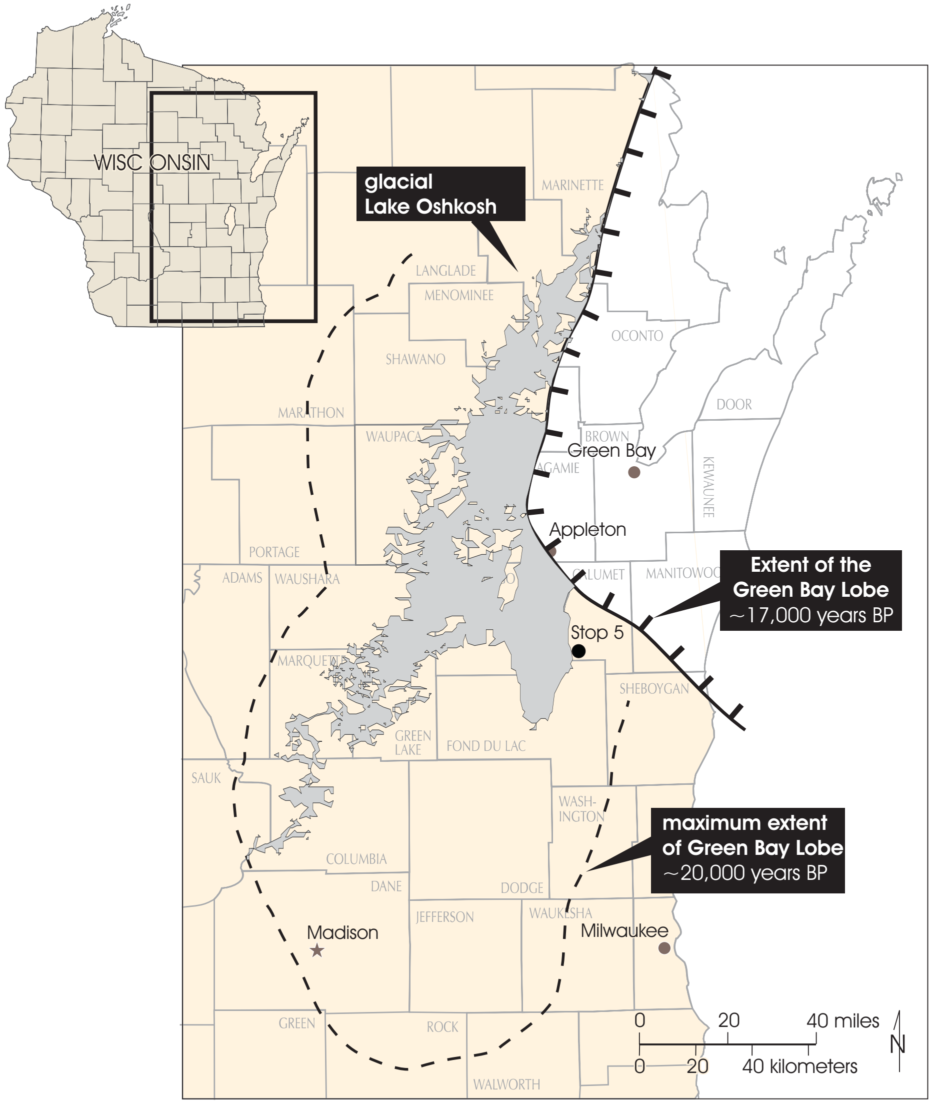


Figure 2-4. Map of eastern Wisconsin showing the location of glacial Lake Oshkosh and the extent of the receding Green Bay Lobe about 17,000 years ago.

In the area surrounding the cities of Oshkosh and Appleton, the lake covered a large part of the landscape, coating it with a layer of fine-grained sediment consisting primarily of clay and silt. With the first readvance of the ice sheet, much of this lake sediment was reworked by the glacier and plastered onto the upland areas. Part of the readvancing lobe terminated where we stand today, forming a prominent ridge called the Eureka moraine. This moraine is composed of till consisting mainly of reworked lake sediment. This red till, called the Kirby Lake Member of the Kewaunee Formation (Fig. 2-2), covers most upland areas that were not covered subsequently by sediment deposited in glacial Lake Oshkosh. In addition, The Kirby Lake and other Kewaunee tills are extremely fine-grained compared to the sand-rich Horicon till that was deposited when the GBL was at its maximum extent. Grain-size analyses on 76 samples of Kewaunee till indicates that sand, silt and clay average 26, 44 and 30 percent, respectively (Fig. 2-3). As a result of this difference in texture, the extent of the clay-rich Kirby Lake till in east-central Wisconsin is a convenient stratigraphic marker for delimiting the extent of the readvancing GBL into Wisconsin.

The Eureka moraine cuts across several counties and represents the maximum extent of the ice margin during the lobe's first readvance into Wisconsin around 15,000 years ago. From the study of modern glaciers, geologists know that many large streams carrying sand and gravel usually emerge from beneath the ice. This sand and gravel is usually deposited directly in front of the ice margin as the stream flows away from the ice lobe (Fig. 2.5). Thick accumulations of sand and gravel can occur where the ice sheet stabilizes and forms a moraine.

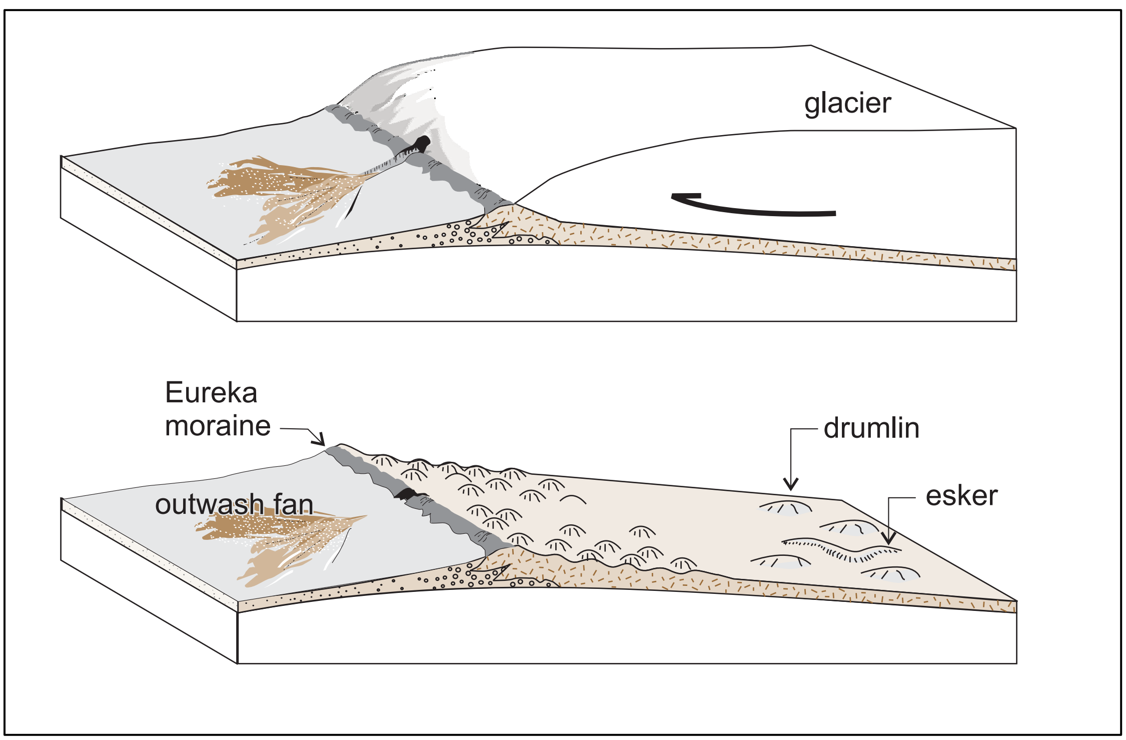


Figure 2-5. Margin of the Green Bay Lobe forming the Eureka moraine and associated proglacial outwash fans (a). Many feature such as drumlins and eskers that formed on the bed of the glacier (b) have been buried beneath lake sediment in the Fox River Valley (Modified from J.A. Attig, D.M. Mickelson, and L. Clayton, 1989, Late Wisconsin landform distribution and glacier-bed conditions in Wisconsin, Sedimentary Geology, 62).

Such is the case here at the Glacier Ridge Bison Farm where sand and gravel is excavated at the crest of the moraine. Please note that in the main part of the pit up to ten feet of red glacial till (reworked lake sediment) overlies nearly 30 feet of sand and gravel. This sand and gravel was most likely deposited in a deep river channel that was emerging from the base of the ice lobe close to its margin. The extent of this old river channel is not obvious, but it appears to extend across the property and has apparently been mined for many decades.

In other parts of this gravel pit, the clay and silt-rich Kewaunee till directly overlies the Horicon till. This indicates that parts of the Eureka moraine may be palimpsest in that the readvancing ice margin stabilized on top of a previously deposited recessional moraine of the GBL.

STOP 3. HAMILTON HILL AREA

Fond du Lac Stone Company building stone quarry on east side of Hwy. 175/Co. Hwy. B, Hamilton area, W1/2, NW, SE, Section 10, T14N, R17E, Town of Byron, Fond du Lac County, Wisconsin.

Stop Leaders: Joanne Kluessendorf and Donald Mikulic

Niagara Escarpment and Highway 41

Along the east shore of Lake Winnebago, the Niagara Escarpment runs parallel to the main direction of Quaternary ice flow, resulting in a relatively continuous, straight, and well exposed cliff face. In contrast, the Escarpment south of Fond du Lac turns to the west, trending perpendicular to the direction of ice flow for several miles. This segment of the Escarpment has a significantly different appearance, being characterized by five discontinuous, broad, northward-facing segments running along a northeast-southwest line from Marblehead to Oakfield. These segments are roughly one mile wide and are separated by lower elevation gaps that cover a similar distance. From north to south, each segment exhibits one or more widely spaced steps that climb the Escarpment.

In this area, the Escarpment formed a barrier to the southward flowing ice, which could not plow directly through the relatively thick section of Silurian rocks. Instead, the ice had to flow up and over some resistant segments of the Escarpment in a step-like manner, creating benches by removing less-resistant units like the well-bedded Byron Dolomite building stone beds. The gaps are areas where the Escarpment is generally missing, however, they seem to be underlain by Silurian rocks that rise toward the south. This suggest that, for unknown reasons, ice flow was able to cut deeper into the Silurian rocks at these locations and flow over the area at a more gentle angle.

The results of this process are well displayed along Hwy. 41, where it crosses several prominent benches as it climbs the Escarpment near Hamilton Hill. The first well-defined bench occurs about a quarter mile south of Lost Arrow Road at an elevation of about 960 feet above sea level (Fig. 3-1). Although no rock can be seen here, as one follows this bench to the west, a prominent segment of the Escarpment begins near Hwy. 175. This bench forms the most extensive part of the Escarpment in this area. It can be traced from Hwy. 175 to the west, tracing an irregular pattern to Oakfield and then south past the Dodge County line. Based on core information, the elevation of this bench, at least near Hamilton Hill, marks the contact between the more massive "Mayville " and the overlying building stone beds of the Byron.

The next highest bench occurs about three-quarters of a mile to the south, where Hamilton Road formerly crossed Hwy. 41. Somewhat obscured by quarrying and road development, this bench has an elevation of about 1010 feet and marks the top of the Byron building stone beds at this site. It has a more limited exposure throughout the area but is very prominent just east of Hwy 41.

A short distance to the southeast, a higher rock-controlled hill (1100 feet) can be seen to the east of the highway at the Rademann Stone & Landscaping quarry. This forms the highest Escarpment exposure of the area. Consisting of Lime Island equivalent strata, this unit forms the top of the Escarpment at Marblehead, although at a lower elevation (1050 feet), reflecting the eastward dip of strata (Fig. 2). The highest bedrock exposure in the area occurs about two miles south at the intersection with Co. Hwy. F, where a roadcut on Hwy 41 exposes a few feet of rock that might be part of the Lime Island. The elevation of this hill (1140 feet) is much higher than other exposures of the Lime Island in the area.

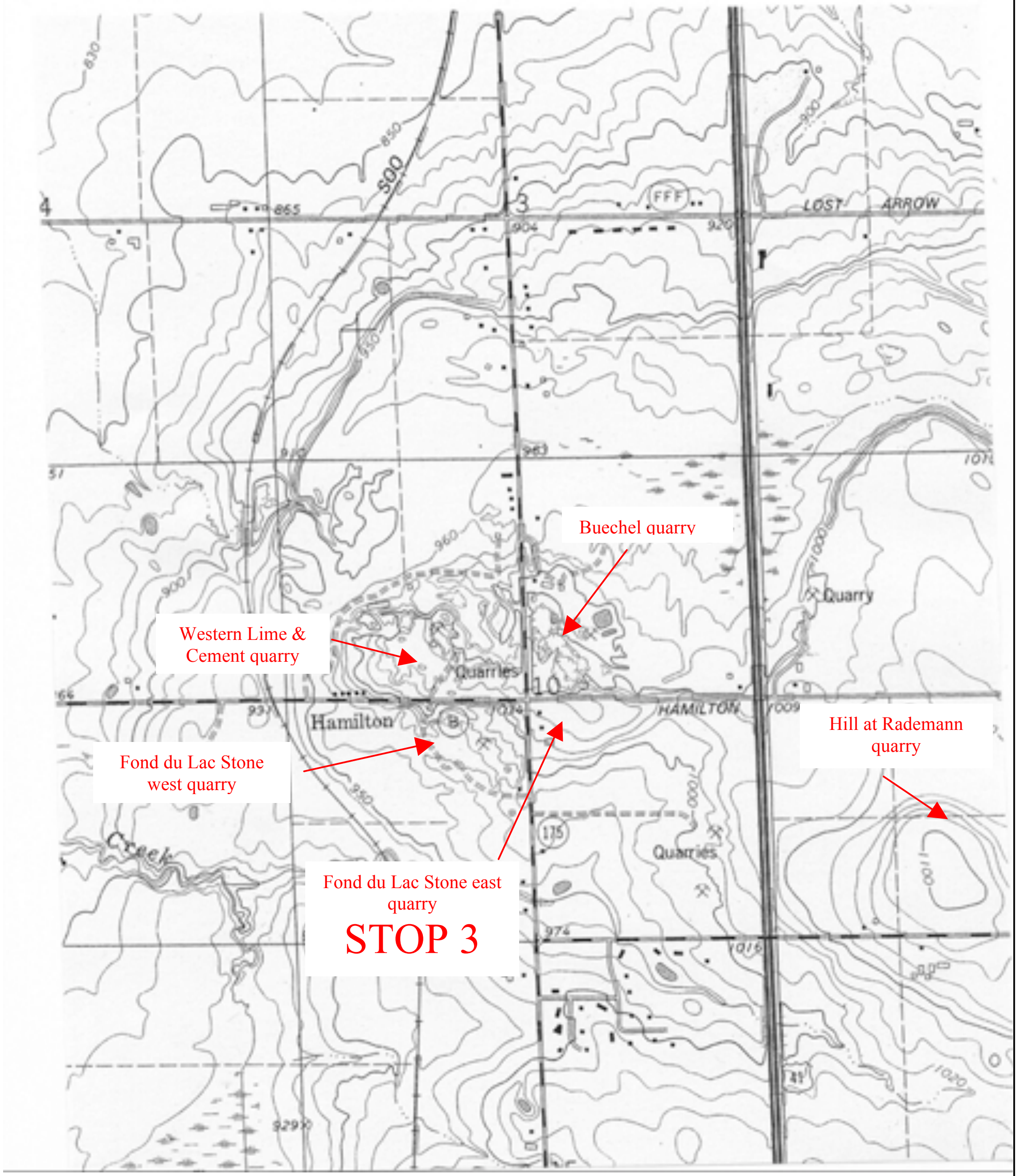


Figure 3-1. Quarries in the Hamilton Hill area

Hills in the Hamilton Area

There are two distinct bedrock hills in the Hamilton area: Hamilton Hill near the intersection of Hwy. 175 and Co. Hwy. B, and the hill to the east across Hwy. 41, north of Co. Hwy B, at the Rademann Stone & Landscaping quarry (SE, SW, Sec. 11, T14N, R17E) (Fig. 3-1). The hill at Rademann's quarry is as much as 1100 feet high, 50 feet higher than the one at Hamilton. Although *Virgiana* brachiopod deposits are present in both hills; the one at the Rademann quarry is stratigraphically higher, belonging to an equivalent of the Lime Island of Michigan, whereas that at Hamilton is older. Both of these hills sit atop the Niagara Escarpment, but their origins are different. Hamilton Hill is controlled by depositional features related to a buried mound in the "Mayville Dolomite." The hill at Rademann's quarry is an erosional feature.

Younger rocks than those in Hamilton Hill are exposed in the hill at Rademann's quarry, and a core drilled at the top of the latter hill yielded the following section:

Silurian section from core at top of hill at
Rademann's Stone & Landscaping Quarry

24 feet	Lime Island equivalent. *Virgiana* deposits with some laminated to burrowed cycles in middle
122 feet	Byron Dolomite. Dominated by laminated to burrowed cycles; middle 30 feet are very even-textured, dense, light olive gray, laminated dolomite. The Rademann quarry exposures and those in the Fond du Lac Stone Co. east quarry overlap in these even-textured beds.
66 feet	"Mayville Dolomite." Dominantly yellowish brown, vuggy, dense, massive dolomite with common chert.
18 feet	Mosalem/Wilhelmi equivalent. Dominantly dark brownish gray, argillaceous dolomite to dolomitic mudstone. This unit is underlain by Ordovician strata.

The quarries in the Hamilton Hill area provide a composite section of some of the "Mayville Dolomite" and the lower Byron Dolomite. In the Fond du Lac Stone Co. west quarry (Fig. 3-1), Elger (1979) reported 28 feet of Mayville Dolomite succeeded by 11.5 feet of Byron Dolomite. He reported that the Mayville exposed here is primarily mud-rich stromatoporoid and/or ostracode wackestone, and he interpreted the numerous ostracode-rich layers as storm-deposited coquinas. According to Elger, the Mayville/Byron contact was sharp, with a rapid change from massive to laminated bedding; a *Virgiana* zone present just below the contact. Elger noted that the *Virgiana* deposit was not well developed at Western Lime & Cement Co. quarry, but where the brachiopods are abundant, they are disarticulated and randomly oriented. Typically, the brachiopods occurred with ostracodes and sparse corals at this site.

At present, the *Virgiana* zone at Fond du Lac Stone is represented by only rare and scattered specimens. In 1904, Warren Du Pres Smith (unpublished notes) observed a layer "thickly strewn" with "*Pentamerus*" occurring about 40 feet above the base of a lime quarry near the railroad tracks on the west side of Hamilton Hill. No present exposure of this bed has been found; however, old lime kilns in this area are partially constructed with *Virgiana*-rich blocks. This indicates a possible local thickening of the *Virgiana* bed, which may be related to microenvironments associated with the main "Mayville" mound.

Elger (1979) believed that the "Mayville" displayed cyclic sedimentation, alternating between normal marine and semi-restricted marine environments and varying salinities, as suggested by a general faunal scarcity, the presence of euryhaline organisms, and probable gypsum crystal molds. He postulated that the "Mayville" represented a shallowing-upward succession from a subtidal to intertidal setting, with numerous small intermediate shallowing cycles. Brooks (1978) believed that the diminutive fauna of ostracodes, crinoids, brachiopods, and gastropods suggested higher-than-normal salinity in the upper part of the "Mayville."

Fond du Lac Stone Company east quarry

Approximately 32 feet of Byron Dolomite are exposed on three main levels in the northern part of the quarry at Fond du Lac Stone Company just east of Hwy. 175 (Fig. 3-1). Laminated lime mudstones dominate the lithologies exposed in this pit, including both planar to undulating laminae and more irregular, crinkly laminae. Most of these laminites are probably related to microbial (cyanobacterial) mats. Some of these laminites display more than two feet of undulatory relief. Laminoid fenestral porosity, which marks gas pockets created by decaying organic matter between microbial mats, is common and conspicuous in the laminated lithologies. Intraclasts reworked from desiccated mats are present locally.

Section at Fond du Lac Stone east quarry
measured along north wall from top down

17.5 feet	<u>Byron Dolomite.</u> Dominantly light gray to light brownish gray, fine to medium crystalline, thin- to medium-bedded, laminated dolomite, commonly displaying laminoid fenestrae. This lithology alternates with pale brown to yellowish gray, fine to medium crystalline, vuggy, massive dolomite, which is mounded locally.
14.4 feet	<u>Byron Dolomite</u>. Dominantly yellowish brown to brownish gray, fine to medium crystalline, thick-bedded to massive dolomite containing zones of common to abundant biomoldic porosity, having a wackestone-packstone texture. Leperditiid ostracodes and/or small brachiopods dominate the biomolds. These strata contain some laminae with laminoid fenestrae locally.

All of the strata in this pit dip gently to the south and southeast off a large buried mound in the underlying "Mayville Dolomite." Elger (1979) discussed this large mound, noting that its center peaked just north of Co. Hwy. B in the old Western Lime & Cement Company quarry northwest of this pit (Fig. 3-1). He found that "Mayville" and Bryon strata overlying this mound dipped as much as 15-20° on the north and 5-10° on the south. Based on these dips, he figured that the mound had original depositional relief of 30 feet. This east quarry was not yet opened when Elger conducted his field studies. This "Mayville" mound has not yet been exposed by quarrying and its composition remains unknown.

One of the most conspicuous features in the east quarry is the presence of several small domes on the quarry floor, currently showing as much as six feet of relief. These domes are elliptical to circular in outline and are draped by laminites that can be traced from dome to dome. Some of these mounds definitely originate in the Byron; however, some may have developed during "Mayville" deposition. Elger (1979) reported common small-scale mounds having three to five feet of relief, within the "Mayville" in the western pit of the Fond du Lac Stone Company. He also observed small-scale ellipsoidal mounds with three to five feet of relief within the Byron in the Western Lime & Cement Company quarry (Fig. 3-1). Shrock (1939) conjectured that the doming originated as draping beds over "concealed mounds." Elger could not recognize any skeletal framework to suggest an organic origin of the small mounds, noting that the cross-sections of many of the mounds showed "algal laminated mudstones." He believed that the mounds formed by "selective binding, trapping and/or precipitation of lime mud by an organic (blue-green algae) mat."

The Byron and "Mayville" strata of east-central and northeastern Wisconsin have long been known for the conspicuous large- and small-scale doming, as is seen at Hamilton Hill. As early as 1861, Daniels commented that the beds exposed in the Sylvester Quarry, near Hamilton Hill, "seem to have been disturbed here, by some force which has thrown them into a series of low anticlinal ridges, having a direction a little south of east." Other early authors have made similar comments on these features described as ridges, or as described by Buckley, (1898) as "domes and basins, often having a very considerable elevation or depression." Daniels's comments suggest that he believed these features might have been structural in nature. In 1939, Shrock published an extensive description of these features in Mayville and Byron strata at numerous localities from Dodge County north to Door County as part of his classic paper on Wisconsin Silurian bioherms. He was uncertain what process built the Mayville and Byron mounds, as he found the mounds themselves to contain no fossils or sedimentary structures that would explain their formation. He did suggest that algae might have played a role in the building of some of these mounds, but thought it was more likely that those of the Hamilton area were formed by inorganic processes in which chemical conditions favored rapid precipitation of calcium carbonate in mounds of calcareous sands and ground up organic materials formed by waves and currents. He was less certain of an origin for other mounds found in "Byron" strata elsewhere, such as Chilton. More detailed studies of some of these mounds were undertaken in the late twentieth century (Soderman, 1962; Soderman and Carozzi, 1963; Brooks, 1978; Elger, 1979), which provided a better understanding of the origin of these mounds. Soderman (1962) found many of them to be algal in origin with the exception of that at Chilton, which he thought was a bioclastic bar. He strongly emphasized that these mounds "are entirely different from the classical Niagaran reefs of the Great Lakes area." Brooks (1978) and Elger (1979) also suggested that many of these mounds may be algal in origin, while pointing out the existence of a much larger buried "Mayville" bioherm at Hamilton Hill of unknown origin. This large mound forms the center of Hamilton Hill, controlling its topography as well as the depositional structure of the "Mayville" and Byron strata overlying the mound. The character of this buried mound is unknown, but it might not be algal in origin as there is a large "reef" exposed at Neda, to the south, at the base of the "Mayville" (Mikulic and Kluessendorf, 1983), which has a more normal-marine organic composition. Since the publication of Shrock's 1939 paper many authors have considered the "Mayville" and Byron mounds as early representatives of the more famous, but younger, Silurian reefs of the Great Lakes area. For example, Shaver, et al. (1978) considered some of these mounds to represent an early generation of those reefs, even though Soderman had pointed out that they are different types of structures. We agree with Soderman's opinion that these structures are not related in any way to the later reefs of the region, as they developed under different environmental conditions. Therefore, they do not represent an early generation of reef development in the region.

Figure 3-2. Mounding of Byron Dolomite strata (most pronounced behind talus). Note adjacent beds pinch out against the west side of the vuggy mound. Mound area.

Although the origin of the domes on the quarry floor here is unknown at present, there is mounding present in strata near the middle of the uppermost level along the north wall (Fig. 3-2). Here, thick-bedded, locally vuggy strata thicken from west to east, and near the middle of the wall, it becomes a mound approximately five feet high. Overlying beds pinch out against the side of the mound, indicating that it had depositional relief. This mound is very vuggy and rubbly; however, none of the vugs could be conclusively attributed to biomolds. Mounding dominates to the north whereas the laminites pinch out in that direction. In contrast, laminites dominate to the south and the mounded units disappear. It is likely, however, that the mounding is common to the north as the stripped bedrock surface above the north wall is extremely irregular and knobby. This surface has been glacially polished and striated locally. Striae trend north-south, and the polish is better developed toward the east, probably in relation to the presence of rock having a denser lithology in that area. The rock drops off dramatically at the east edge and the glacial polish becomes even more pronounced.

The surfaces of the domes exposed in the floor of this quarry are dotted by numerous stromatolitic structures (Fig. 3-3). These microbial structures have a low, ring-like appearance that is circular to elliptical in outline and from one to four feet in maximum diameter or length; the elliptical structures may have a preferred orientation. The stromatolites generally have a relief of half a foot or less around the outside edge; however, the center of each forms a depression. It is uncertain whether this depression results from a blister collapse of the stromatolites due to decay of organic material or because the rock in the center of these structures was selectively plucked during quarrying. Only one of these structures was seen to have a low hemispherical profile, with a domed center. The stromatolites are most numerous on the two domes nearest the northwest corner of the pit, which are the domes with the lowest relief. They are rare on domes with greatest relief, being present only on the lower portions of these.

A ripple-marked surface occurs at the small area of highest floor nearest the northwest corner of this pit, above the level of the domes (Fig. 3-3). The ripple marks are linear, trend northwest-southeast, and display uncommon bifurcation. Ripple troughs average one foot wide, with crests ranging from nine to fifteen inches in width and as much as six inches in height, although the crests may be somewhat flattened. The ripples are asymmetrical, having a steeper lee (downstream) side and gentle stoss (upstream) side, corresponding with the slope of that bedding plane, which dips to the southwest. Rare *Virgiana* brachiopods were found on this surface.

Figure 3-3. View from northwest corner of east quarry, Fond du Lac Stone Co., with ripple marked surface in foreground and low doming on quarry floor around the pick-up truck. Note the stromatolites scattered around the domed surface (dark spots on the light floor between ripples and trucks).

Just south of and slightly above the exposed ripple-marked surface are several bedding planes in the west wall that are covered with abundant "rods" displaying a packstone texture. They occur in laminites that are marked by pronounced laminoid fenestrae. Brooks (1978) found abundant rods in the west quarry at Fond du Lac Stone Company in beds from 2.5 inches to more than two feet thick. These rods are cylindrical, approximately a quarter inch long by about 1 to 3 mm in diameter. Most are randomly oriented, with some overlapping, although others are aligned parallel to one another. In some, the center is hollow or the cavity is filled with calcite. Some appear to be coated grains. Although Elger (1979) thought them to be calcareous algae, the rods closely resemble the fecal pellets of modern crustaceans.

The preservation of abundant laminites in the Byron indicates that the environment of deposition generally was restricted, precluding the activity of most grazing and burrowing organisms. The small brachiopods and leperditiid ostracodes that occur in some strata here are represented by high numbers of individuals but low biotic diversity, which is indicative of a stressed environment. Bioturbation is rare or absent through most of the section, further suggesting an inhospitable setting. Brooks (1978) discovered gypsum crystal laths in similar laminated strata in the west pit at Fond du Lac Stone, suggesting hypersaline conditions prevailed at times. Environmental restriction would be fostered by the fluctuating salinity and exposure in the upper intertidal to supratidal zones in a tidal flat setting. Modern intertidal flats, especially the upper intertidal-supratidal zones, are characterized by permanent microbial mat coverage, abundant decay gas structures, flat pebble intraclasts, and small domical stromatolites (Shinn, 1983). More hospitable, but short-lived, conditions, which may have supported habitation by an opportunistic biota such as the ostracodes, would have been available in tidal flat ponds, channels, and the lower intertidal zone. Evaporites are not common in the Byron, suggesting that a more humid climate may have prevailed.

Stone Industry at Hamilton Mound

The production of building stone and lime at Hamilton Mound dates back to at least the 1850s. Thomas J. Hale (1860, unpublished notes) mentioned "the famous quarry of Fond du Lac flagstone on the farm of Mr. Samuel Butler, " and Daniels (1861) noted "flag beds were quarried extensively at Mr. S. Sylvester's place." He described the strata here as being "unsurpassed in their adaptation for flagging…The quarries are free from water and may be worked for centuries…These flags are delivered in the city, or on the railroad five miles distant, at from five to six cents per foot, ready to lay down. About 60,000 square feet have been taken out of this quarry." Butler's quarry was located in the SE, NW, Section 10, just northwest of the intersection of Hwy. 175 and Co. Hwy. B, the site of the Western Lime & Cement Company Hamilton quarry today (Fig. 3-1). Sylvester's quarry was located just across the road to the east in the SW, NE, Section 10, the present site of the Buechel Stone Company quarry (Fig. 3-1). Some lime was burned at these properties, however, the main product was initially building stone, most of which was used in the Fond du Lac area. The production of building stone has remained an important industry in this area and, presently, three companies operate here, including Fond du Lac Stone, Buechel Stone Company, and the Oakfield Stone Company. In addition, building stone operations have been opened east of Hamilton Hill in Section 11, where Michels Materials Corporation and Rademann Stone & Landscaping now operate.

Lime later became an important product of the Hamilton Hill area. Most of it was produced from Hamilton Hill itself, probably from the "Mayville" beds. In the 1880s, the Hamilton Lime & Stone Company operated a lime plant in the NW, Section 10, with a siding to the Wisconsin Central Railroad. A. K. Hamilton, of Fond du Lac, was secretary-treasurer of the company and J. L Ketcham, of Milwaukee, was president. Interestingly, the location was then called Ketcham, not Hamilton. This lime plant became part of the Union Lime & Stone Company in 1902, and then Western Lime & Cement Company in 1921. Western Lime & Cement Company operated this site primarily as a lime operation until the 1930s. More recently, Fond du Lac Stone Company and Michels Materials Corporation produced crushed stone from this site through a lease with Western Lime Corporation.

Fond du Lac Stone started operations in the mid-1940s as a building stone quarry located southwest of the intersection of Co. Hwy. B and Hwy. 175 (NE, SW, Section 10, T14N, R17E). The building stone was largely quarried out from the pit west of Hwy. 175, and crushed stone from the "Mayville" was produced later. In 1997, Dan Homuth sold Fond du Lac Stone Company to Michels Materials, which now runs the quarry. The western pit is now used just for stone cutting and shipping operations. Most of the building stone now quarried at Fond du Lac Stone is extracted from two pits on the east side of Hwy. 175 (N1/2, SE, Section 10, T14N, R17E). The western of these pits is Stop 3 on this field trip. Of the two, this pit is the one that shows the greatest influence from the main "Mayville" mound located at the Western Lime & Cement property to the northwest.

STOP 4. MARBLEHEAD QUARRY

Location: Marblehead Quarry of the Western Lime Corporation, west side of Co. Hwy. V, NE, NE, Section 7, T14 N, R18E, Town of Eden, Fond du Lac County, Wisconsin.

Stop Leaders: Donald Mikulic and Joanne Kluessendorf

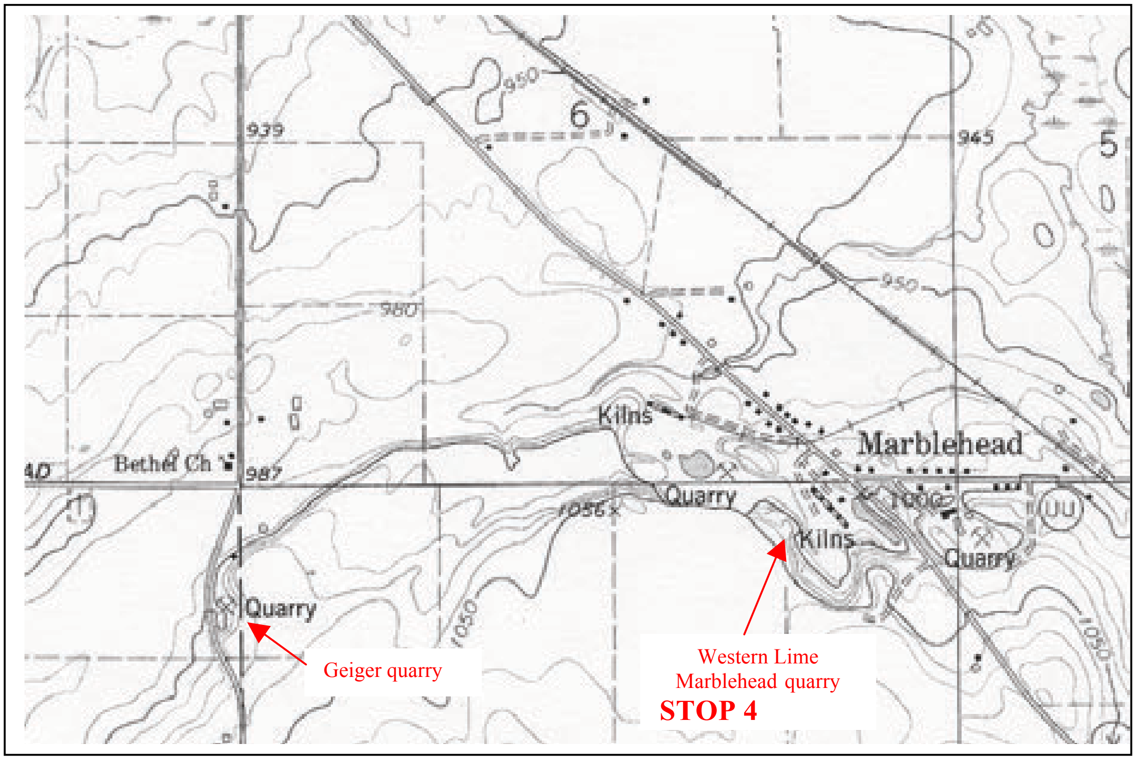


Figure 4-1. Marblehead Quarry (Stop 4) and Geiger Quarry

The Marblehead Quarry is located in a segment of the Niagara Escarpment that follows a discontinuous exposure from the Hamilton Hill area. This quarry provides a good exposure of the Lime Island equivalent *Virgiana* beds and most of the Byron Dolomite, covering much of the same section as at Rademann's Stone & Landscaping quarry near Hamilton Hill. The *Virgiana* beds of the Lime Island equivalent are a focus of this stop.

Brooks (1978) studied the Byron at this site. He found that, in general, the Byron was dominated by subtidal mudstones, mat-laminated mudstones and wackestones. He concluded that the upper part of the Byron mainly represents a rhythmic sequence of intertidal fenestral mudstones and subtidal ostracode wackestones, characterized by shoaling upwards cycles approximately four to five feet thick. He considered this very shallow setting to be penesaline based on the absence of evaporites, the presence of leperditiid ostracodes and the lack of biotic diversity. This part of the section also displays mudcracks as well as clay-filled cavities that may represent a karstified zone, suggesting that periods of emergence occurred during Byron deposition.

Section at Marblehead Quarry
Modified, in part, from Brooks (1978)

11 feet	Burnt Bluff. Dominantly very light gray, very finely crystalline, dense, even-textured, thin-bedded dolomite, which is laminated locally.
5.4 feet	Lime Island equivalent. Thick-bedded to massive, locally burrow-mottled, pale yellow, medium crystalline, granular dolomite and light brownish gray, finely crystalline, dense dolomite, containing common to abundant specimens of the brachiopod *Virgiana*.
16 feet	Light brown and pale yellow, fine to medium crystalline, granular, thick-bedded to massive dolomite that displays alternating zones of banding, burrow mottling and *Favosites* biomolds, occurring in cycles.
3.3 feet	Very light brown, fine to medium crystalline, thick-bedded to massive dolomite containing common to abundant *Virgiana* brachiopods in a packstone to rudstone texture underlies this.
3.3 feet	Byron Dolomite. Very light gray, very finely crystalline, even-textured, dense, laminated dolomite, displaying laminoid fenestrae, conchoidal fracture, and some reddish coloration. *Virgiana* zone near top.
15.8 feet	Greenish gray to light gray, dense, even-textured, very finely crystalline, thin- to medium-bedded dolomite, which may be laminated, with laminoid fenestrae, or contain ostracodes biomolds, alternating with very light brown, fine to medium crystalline, massive dolomite that contains ostracodes biomolds displaying a wackestone-packstone texture. The laminated strata commonly are ripple marked or mudcracked. These lithologies appear to be cyclic.
11.7 feet	Light gray, very finely crystalline dolomite with laminoid fenestrae, reddish coloration and scattered leperditiid ostracodes, interbedded with brown coarsely crystalline dolomite containing leperditiid ostracodes. Unit is capped by a dark gray hardground.
18.2 feet	Light brown to gray, very finely crystalline dolomite characterized by intraclast wackestone-packstone, scattered ostracodes, laminoid fenestrae, and reddish coloration.
6.8 feet	Light gray, finely to coarsely crystalline dolomite characterized by large vugs, some filled with dark gray illite clay
28 feet	Light gray, very finely to coarsely crystalline dolomite characterized by mat-laminated strata, commonly undulatory, with some rod wackestone-packstone and scattered zones of ostracodes

Virgiana Brachiopod Beds

Zones of *Virgiana* characterize the Lime Island at its type section in Michigan and in its equivalent in Wisconsin, where it overlies the Byron Dolomite. *Virgiana* also occurs at the top of the "Mayville Dolomite." Shrock (1930, unpublished notes) referred the pentamerid brachiopod bed at the top of the Marblehead Quarry to the Schoolcraft Dolomite, as did Brooks (1978) and others. It is now known that the brachiopods are *Virgiana barrandei* var. *major*, not *Pentamerus*, and the unit here is considered an equivalent of the Lime Island.

The *Virgiana* brachiopods at this and other localities in the area typically occur in deposits of common to abundant specimens displaying a packstone-rudstone texture. The specimens are overwhelmingly disarticulated, and the valves are randomly oriented, and, in places, are imbricated or telescoped. Generally, the individuals, which range from approximately one-half to more than two inches in length, are not sorted by size. Some of the deposits appear to be normally graded, however, either by size or abundance, with larger or more densely packed valves at the base. In some of these deposits, the *Virgiana* are associated with corals, especially the tabulate *Favosites,* which may be domal, discoidal or digitate. Commonly, the corals are fragmented or overturned.

Although the *Virgiana* and *Pentamerus* brachiopods seen at the stops on this field trip lived in a subtidal setting, the near monotaxic composition of the brachiopod fauna and low diversity of the biota in general suggests that living conditions were somewhat restricted. Certain features of these deposits (e.g., disarticulation, imbrication and telescoping of valves, grading of bioclasts, scoured basal contacts) indicate that many of specimens were deposited under higher energy conditions, including storms, although the mud-sized sediment fraction was not winnowed out completely in most cases.

Stone industry at Marblehead

The Niagara Escarpment in the Marblehead area has long been an important source of lime and building stone. The market for these products initially was centered in Fond du Lac, located only a few miles to the north. When railroads were built through the region during the late 1800s, however, some of the companies found it possible to ship their products to more distant markets, greatly expanding their business.

The early history of the Marblehead stone industry has not been recorded, but by the mid 1800s there were several quarries and lime kilns operating in the area. One of the oldest operations was located on the west end of the Escarpment, just across the Eden town line, in the Town of Byron. Quarries were located here (NE, NE, Section12, T14N, R17E; NW, NW, Section 7, T14N, R18E) in the 1860s. In 1873, Christian Geiger purchased the "old Oliver quarry" to produce lime and building stone (Western Historical Co., 1880) (Fig. 4-1). Under his ownership, it purportedly became the largest quarry in Fond du Lac County, shipping stone and lime to Illinois, Minnesota, and communities across Wisconsin. Geiger's business was successful through the 1890s, but it closed down in the early 1900s. Reasons for the closure are not known, but, in contrast with other nearby quarries, his site lacked direct rail access, and the added transportation costs may have made his products more expensive than his competition.

While Geiger's quarry on the Escarpment may have been sited too far from local rail lines for long term success, other local stone producers were better situated. Most notable was William Nast, who, in 1871, opened a quarry on his farm (S1/2, SW, Section 6, T14N, R18E), just east of the Geiger quarry, to produce lime and building stone. Nast sold some of his product to other settlers in the area, hauling the remainder by ox team to Fond du Lac. Although Nast was not much better sited than Geiger initially, in 1880, he purchased another kiln located a short distance to the east (SE, SE, Section 6, T14N, R18E). The Chicago and North Western Railroad crossed this property, and Nast had a short spur built across his land to connect his quarry to the rail line (McKenna, 1912). The new quarry was operated by his sons, August and William, as the Nast Brothers Lime & Stone Company (Fig. 4-2). Another farmer-turned-limeburner, Charles Mitchel, was located between the two Nast properties. Although he settled on his land in the 1840s, it is not known when Mitchel started in the lime business, but it remained a family operation during the late 1800s.

Fig. 4-2 Postcard view of Marblehead Quarry, looking north where present rotary kiln is located, ca. 1900.

Shrock (1930, unpublished notes) reported 19 active and abandoned lime kilns in the Marblehead area, indicating the importance of lime-burning here. In the early 1900s, several consolidations of the stone industry occurred in the Marblehead area, which reduced the number of lime operations to one. In 1902, the Union Lime Company was incorporated, combining the Ormsby Lime Company of Milwaukee, Cook & Brown Lime Company of Oshkosh, and the Marblehead Lime Company of Chicago, which then owned the Mitchel property (Fig. 4-3). In 1921, both the Nast Brothers Lime & Stone Company and the Union Lime Company became part of the Western Lime & Cement Company (now Western Lime Corporation). The property that both of these companies owned at Marblehead was combined into a single operation. The Nast family retained a prominent position in the new company, and they continue in the industry as sixth generation lime-burners today.

Throughout most of the twentieth century the main product of the Marblehead area quarries was lime. Until the 1980s, lime was burned in stone kilns at this site, at least eight of which are still standing. Presently, the main stone product produced at Marblehead continues to be lime

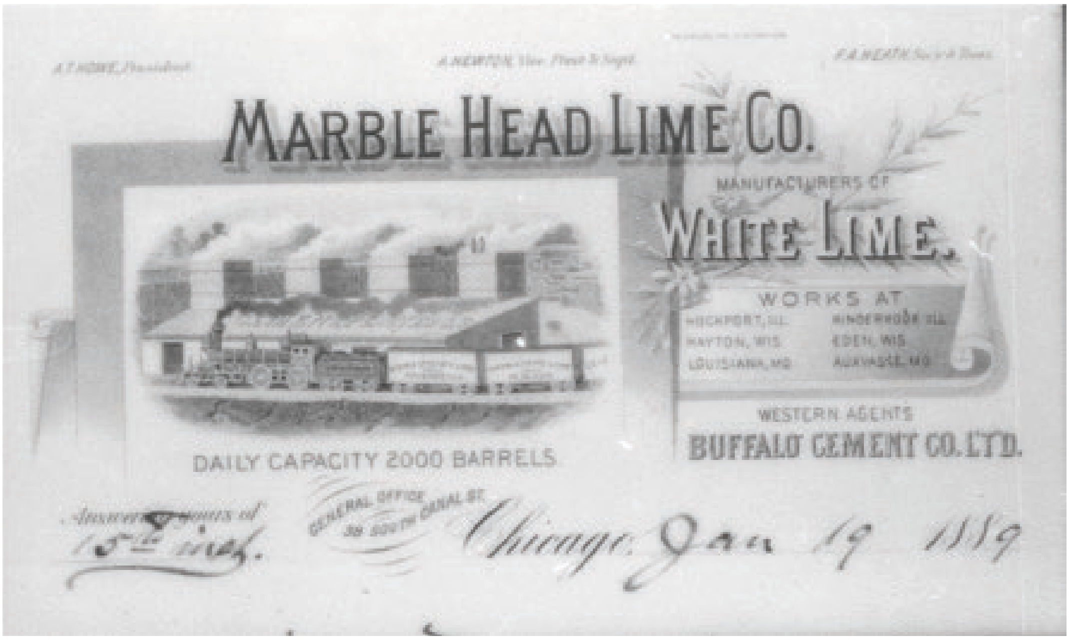


Figure 4-3. Letterhead of the Marblehead Lime Company, ca. 1880s.

produced by burning the Byron Dolomite in a rotary kiln. Initially, before the advent of portland cement, lime was needed for mortar in construction. Now, lime is required in the paper industry, helping to explain why so much lime was produced in the Lake Winnebago/Fox River region. The Lime Island equivalent beds had been used for lime in the past (Shrock, 1930, unpublished notes), but at this site, they were found to contain too many clay-filled vugs, which were difficult to separate out from the dolomite. The lower beds of the Byron are the same as those quarried for building stone around Hamilton Hill, and they are quarried for that purpose here, under lease by the Eden Stone Company, which also operates a quarry across Co. Hwy. V. The Lime Island equivalent beds and waste rock from the Byron are used to produce crushed stone by Michels Materials Corporation at Marblehead Quarry.

STOP 5. KIEKHAFER ROAD OVERLOOK OF LAKE WINNEBAGO

Location: SW, SE, Section 20, T16N, R18E, Fond du Lac County, Wisconsin

Stop Leaders: Tom Hooyer and Bill Mode

Standing on top of the Silurian Escarpment, looking westward, provides an opportunity to imagine what the landscape looked like when the Green Bay Lobe (GBL) of the Laurentide Ice Sheet was receding from its maximum extent and glacial Lake Oshkosh covered a large part of the Fox River lowland of east-central Wisconsin. From the Kiekhaefer Road overlook, Lake Winnebago, the largest inland lake in Wisconsin, can be viewed. The lake covers approximately 215 square miles and is 10 miles wide by nearly 30 miles long. The precursor to this lake, glacial Lake Oshkosh, was about 45 times larger (approximately 10,000 mi^2) and extended across 13 counties (see Stop 2, Fig. 2-4). Standing at this overlook 17,000 years ago, the lake would have spread out far to the horizon and the margin of the GBL would have loomed to the north. The lake would have most likely been littered with icebergs that were actively calving off the ice margin.

Closer inspection of the lake would have revealed that it drained southward into the lower Wisconsin River through an outlet located north of the city of Portage (Fig. 5-1a). This outlet, hereafter called the Portage outlet, was used for hundreds to thousands of years as the GBL receded slowly northward. This outlet (Fig. 5-2) now contains the modern-day, northward-flowing Fox River and is at an elevation of 790 feet above sea level (asl). The elevation of this outlet probably fluctuated as the water released from the lake incised and aggraded its riverbed with time. However, these fluctuations appear to have been minimal because abundant shoreline features, including bay mouth sandbars, beaches, and wave-washed surfaces, can be seen within the basin near the 790-foot level.

The most compelling evidence, however, for the existence of glacial Lake Oshkosh comes from thick sequences of lake sediment discovered in borrow pits (Fig. 5-3) and deep boreholes drilled into buried valleys within the lake basin (Fig. 5-4). These lake-sediment sequences usually comprise fine-grained sediment consisting of numerous silt and clay layers termed varves or couplets. Each couplet may represent one year of sediment deposition and is indicative of the depositional environment. For example, the coarser-grained silt usually is deposited within an open lake environment; the finer-grained clay settles out of the water column during the winter when the surface of the lake freezes. Some of the deep lake sediment sequences contain up to 1,500 couplets indicating an initially long-lived phase of glacial Lake Oshkosh

With continued recession of the GBL, lower outlets across the Door Peninsula were activated and glacial Lake Oshkosh drained to the Michigan Basin. The first of these northern outlets was through the Manitowoc River valley at 800 feet asl (Fig. 5-1b). Although this outlet elevation is 10 feet higher than the Portage outlet, it used to be about 50 feet lower due to isostatic depression of the Earth's surface that resulted from ice loading. Due to the lower outlet elevation, the areal extent of glacial Lake Oshkosh was dramatically reduced. As the GBL continued to recede northward, still lower outlets opened across the Door Peninsula, further reducing the area of the lake. These outlets, in order of decreasing elevation, include the Neshota River Valley at 765 feet asl (Fig. 5-1c), Kewaunee River valley at 685 feet asl (Fig. 5-1d), and Ahnapee River valley at 635 feet asl (Fig. 5-1e). A transect of the land-surface elevation across the crest of the Door Peninsula shows the low points from which glacial Lake Oshkosh drained (Fig. 5-1h).

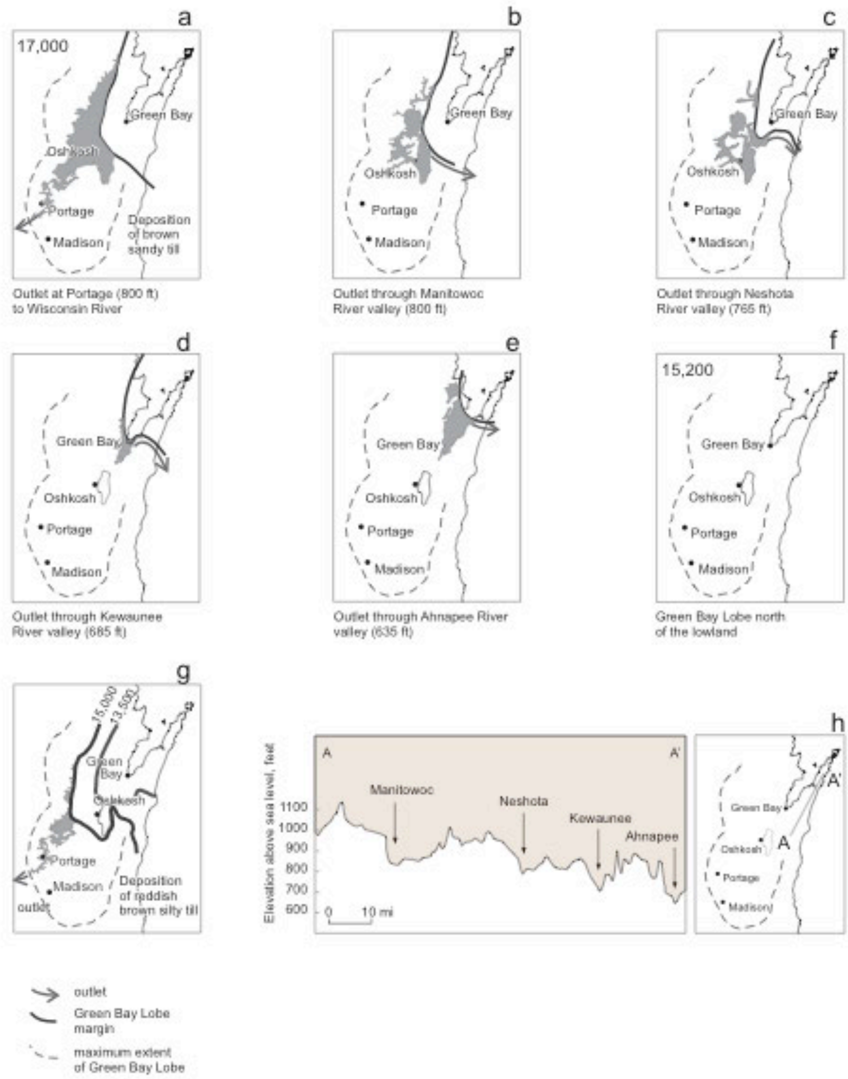


Figure 5-1. About 20,000 to 15,200 years ago, the Green Bay Lobe receded, opening a sequence of lower outlets to the east (a-f). The lobe readvanced to the central part of the lowland twice at about 15,000 and 13,500 years ago, resulting in reuse of the outlets (g). A profile of the land surface across the Door Peninsula shows the location and elevation of the eastern outlets of glacial Lake Oshkosh (h).

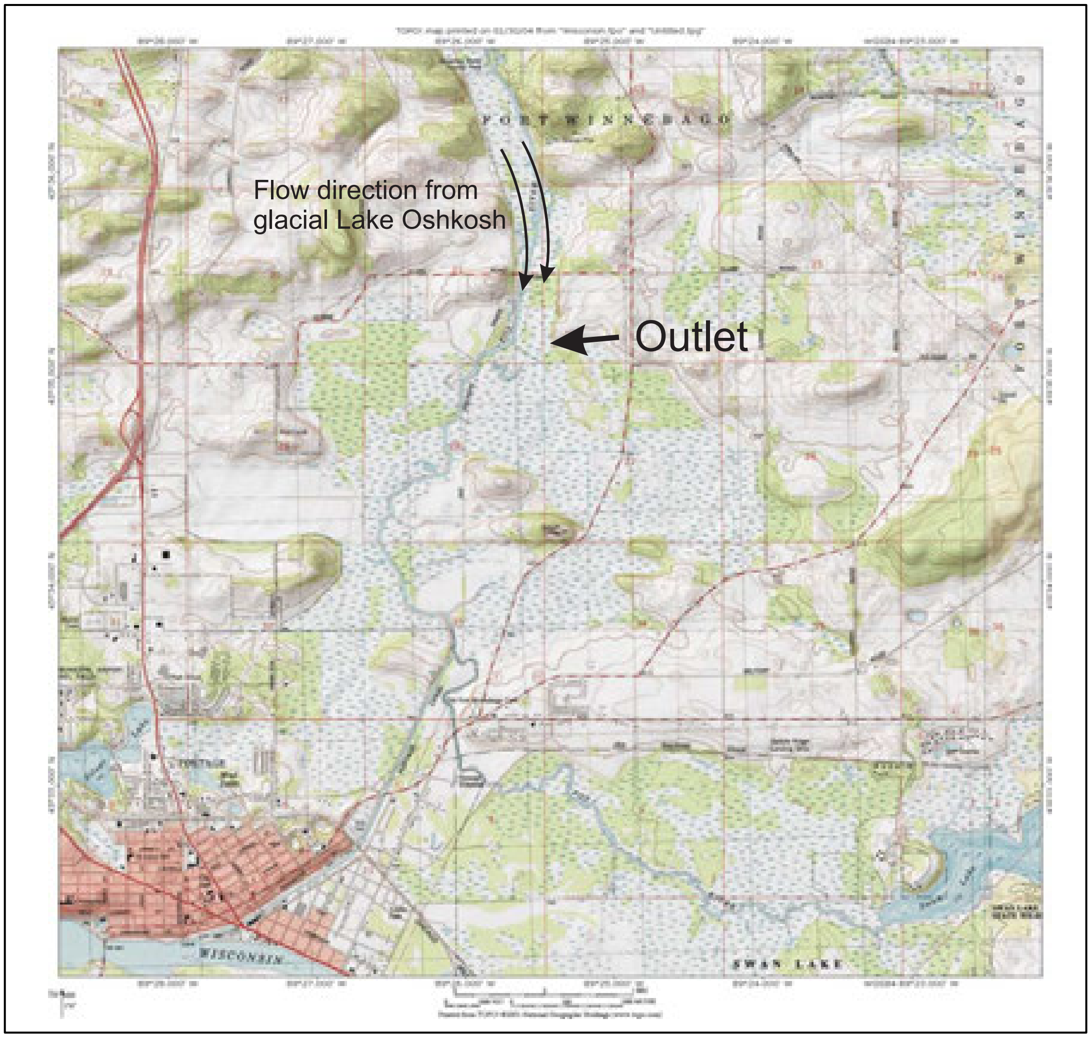


Figure 5-2. Shaded relief map showing the location of the Portage Outlet of glacial Lake Oshkosh.

The period of time that each of these lake phases existed is poorly known; however, they are thought to have been short-lived due to the lack of well-developed shoreline features at the elevation of the various outlets. In addition, assuming a relatively constant rate of ice marginal retreat, the proximity of these northern outlets to each other would mean that they were probably activated for a relatively short period of time (less than 100-200 years?).

When the GBL receded northward past Sturgeon Bay (Fig. 5-1f) around 15,200 years ago, glacial Lake Oshkosh ceased to exist because the water in Green Bay was then connected to the Michigan Basin and controlled by its outlets. There is limited evidence from radiocarbon age dates on wood that within a few hundred years (around 15,000 years ago) the GBL readvanced back into Wisconsin (Fig. 5-1g). Glacial Lake Oshkosh reformed as the lobe advanced over the northern outlets, reactivating the southern outlet at Portage. The GBL stabilized within the lake basin at the well-developed Eureka moraine that was observed in Stop 2 of this field trip. This moraine is unique in that it is composed almost entirely of reworked lake sediment that

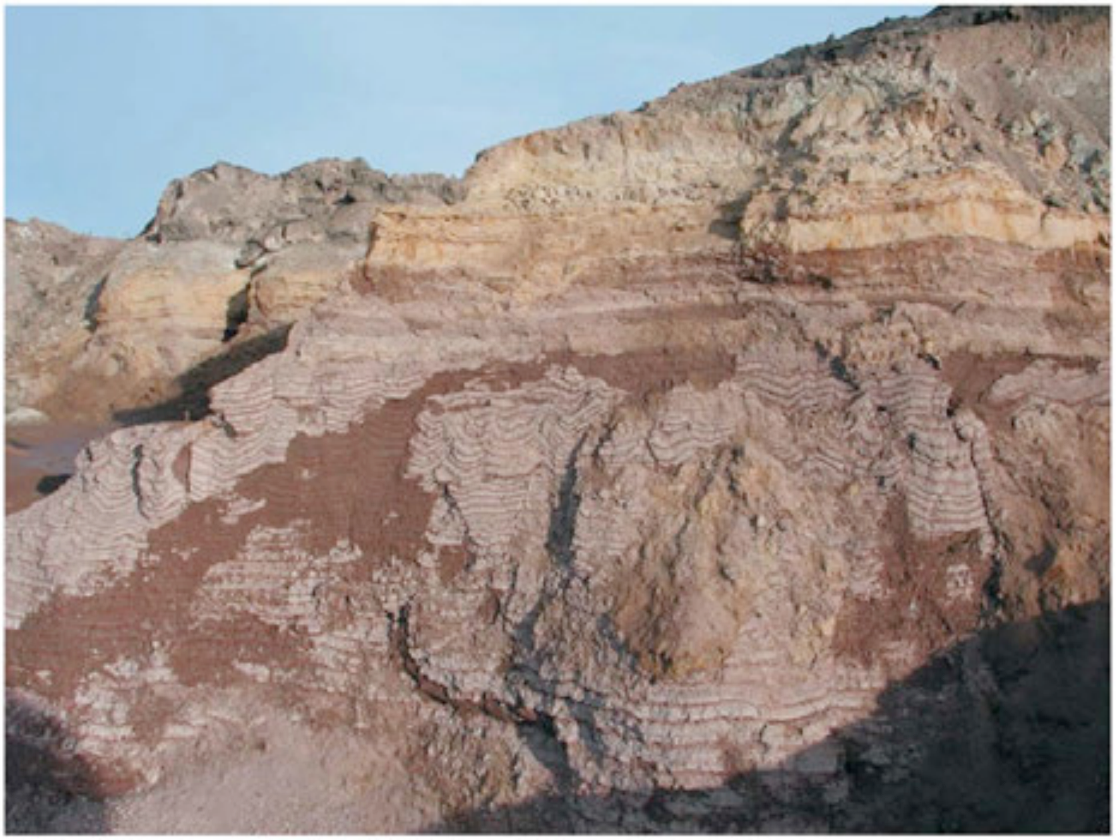


Figure 5-3. Photograph of a borrow-pit wall in the Fox River lowland showing a lake sediment sequence consisting of numerous laminated silt and clay layers (couplets). The pit wall is approximately 5 m high.

distinguishes it from its predecessors, which are primarily sandy and eroded directly from the underlying Cambrian sandstones and Ordovician dolomites.

With the retreat of the ice margin from the Eureka moraine, the lower outlets across the Door Peninsula were once again reactivated. There is abundant evidence that the ice receded relatively quickly out of the basin and a large part of northeast Wisconsin was covered in a boreal forest. Once again the GBL advanced into the basin, to a much lesser extent, reactivating glacial Lake Oshkosh. Buried forest beds along the Lake Michigan shoreline as well as organic material within the lake basin indicate that this occurred around 13,500 years ago. The terminal moraine of this advance is less well developed than the Eureka moraine, indicating that it stood at this position for a shorter period of time. By 13,000 years before present, the GBL had receded northward of the state line. Disintegration of the entire Laurentide Ice Sheet quickly followed due to a rapidly warming climate.

The chronology of the GBL and the evolution of glacial Lake Oshkosh since the last glacial maximum are complex because it involves two major readvances of the ice margin into east-central Wisconsin. On the bases of more than 50 radiocarbon dates of organic material, including tree and plant fragments, and optical simulated luminescence (OSL) dates on lake sediment, a reasonable chronology for east-central Wisconsin can be reconstructed (Fig. 5-5).

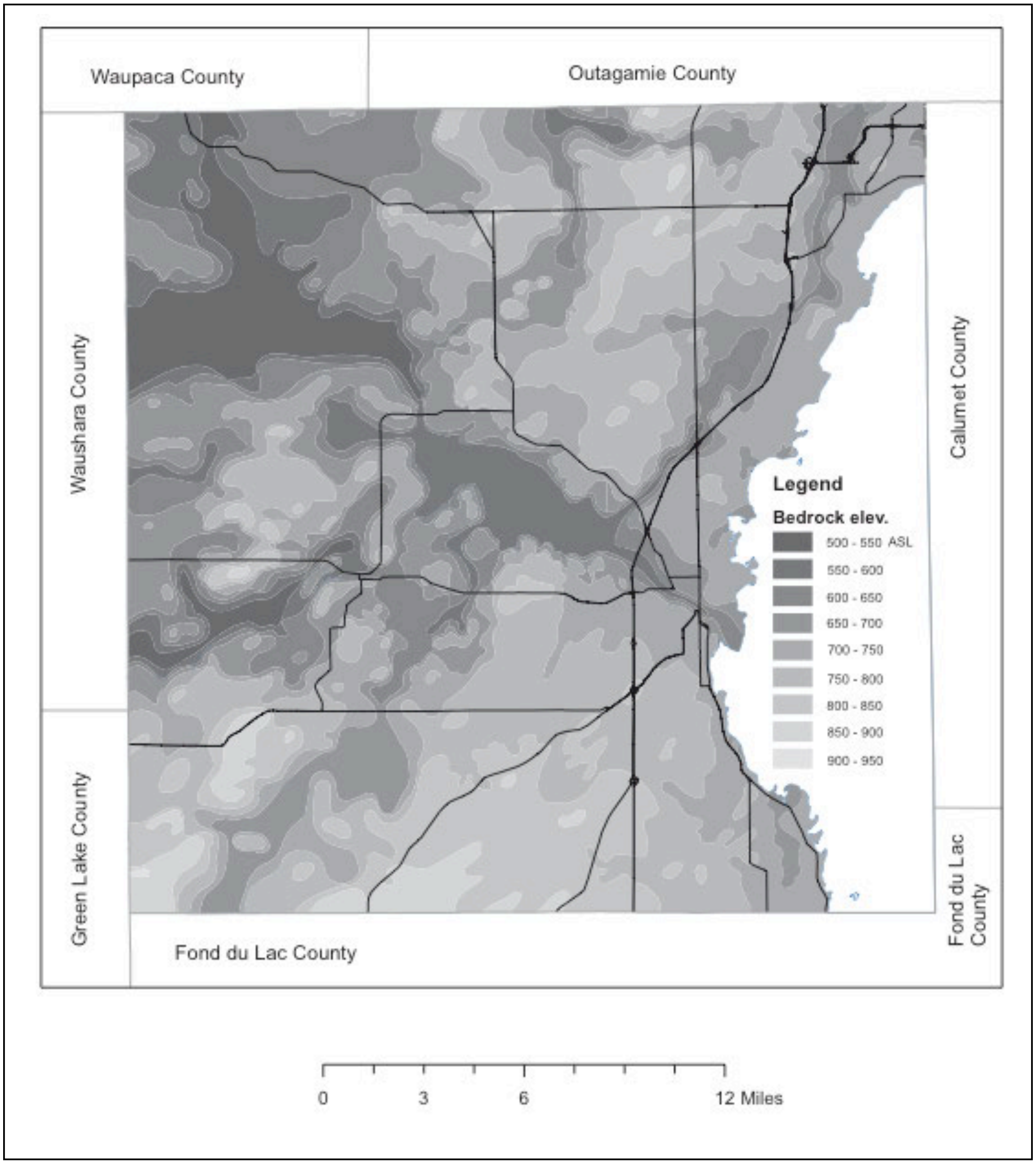


Figure 5-4. Bedrock elevation of Winnebago County showing the location of buried valleys (map courtesy of Bruce Brown, Wisconsin Geological and Natural History Survey).

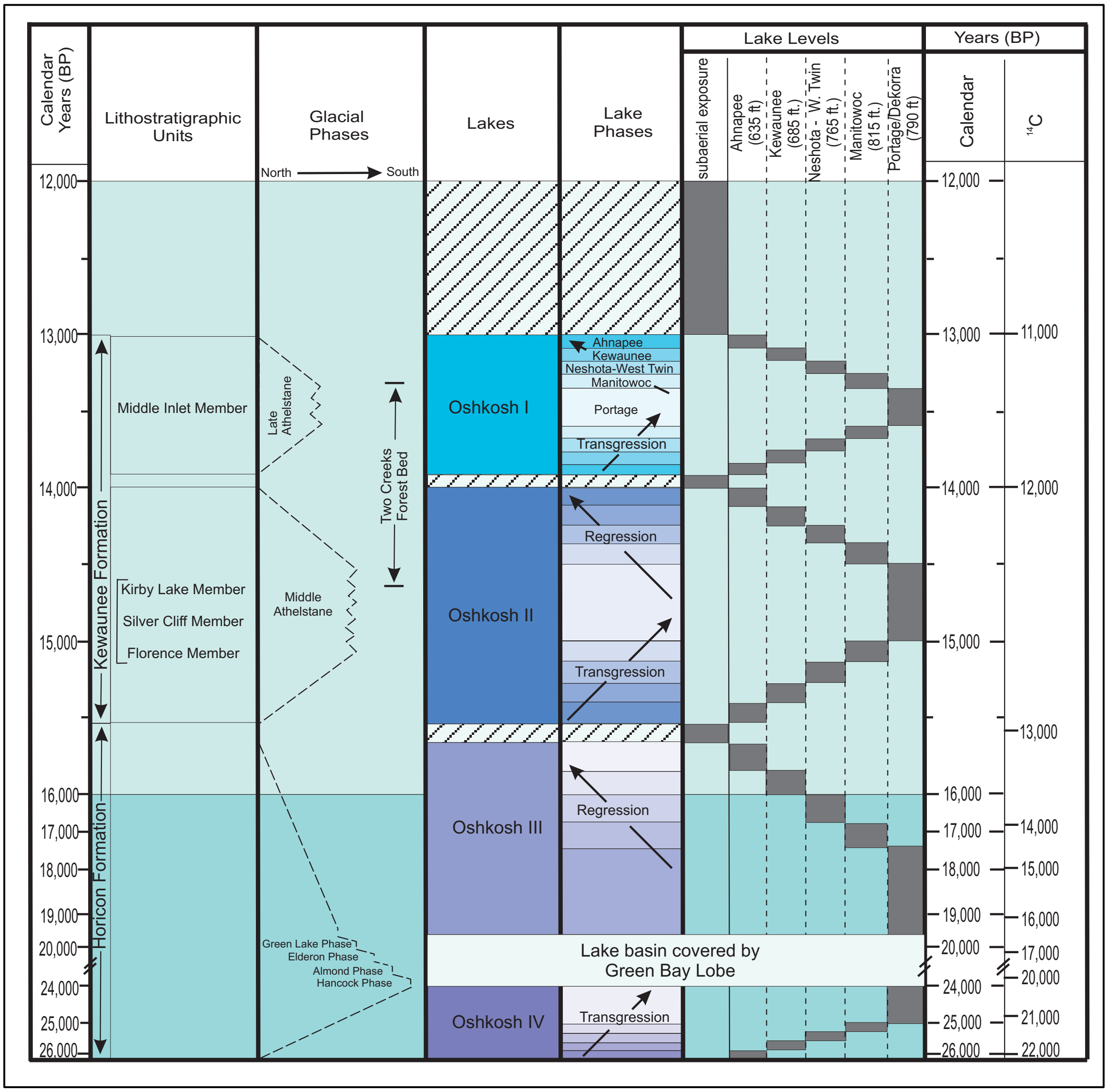


Figure 5-5. The chronology of glacial events in east-central Wisconsin during the most recent glaciation.

STOP 6. HIGH CLIFF STATE PARK

Location : SE; E1/2, SW; and S1/2, NE, Section 36, T19N, R18E, Town of Harrison, Calumet County, Wisconsin

Stop Leaders: Donald Mikulic and Joanne Kluessendorf

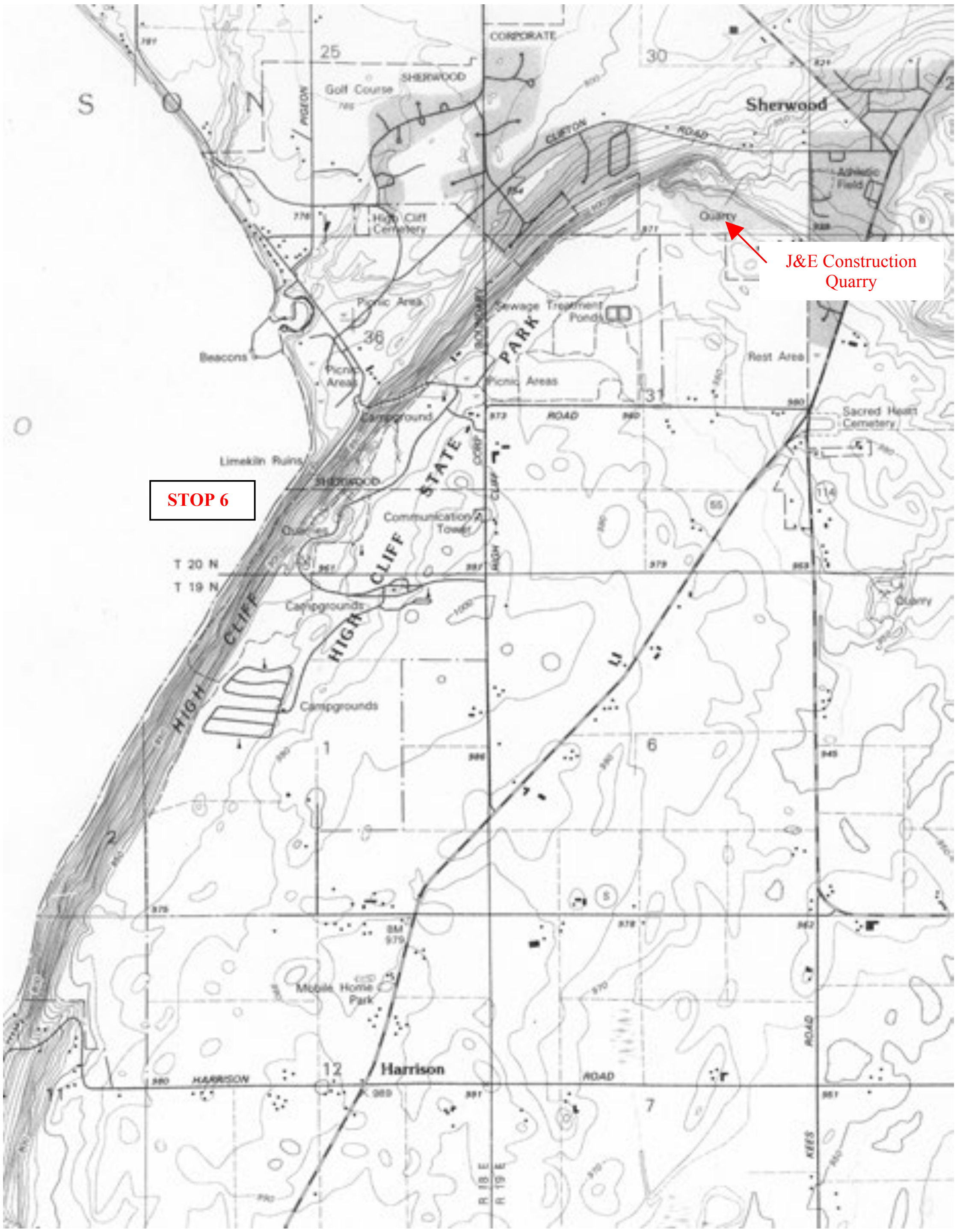


Figure 6-1. High Cliff State Park area (Stop 6)

The Niagara Escarpment rises more than 210 feet above the level of Lake Winnebago at High Cliff State Park. The lower 170 feet of the Escarpment is covered by talus, but probably consists of Maquoketa Shale. It forms a continuous bluff extending for about five miles, from the village of Sherwood south to Calumet County Park near Stockbridge. It is capped by about 40 feet of "Mayville Dolomite," which is well exposed in the cliff face and old quarries in the park (Kluessendorf and Mikulic, 1983). The presence of Maquoketa Shale causes the lower part of the Escarpment to form a readily-eroded, sloped front, whereas the Silurian dolomite creates a steep-faced front in its upper reaches.

Section at High Cliff State Park

Modified from Shrock (1930, unpublished notes) and Elger (1979)

8 feet	"Mayville Dolomite". Light brownish gray, finely crystalline dolomite containing silicified corals and stromatoporoids, at top of Escarpment.
20 feet	Cherty dolomite, containing possible anhydrite crystal molds in the lower 8 feet (Elger, 1979).
12 feet	Wilhelmi/Mosalem equivalent. Bluish gray, thinly laminated argillaceous dolomite
6 to 10 feet	Dark gray, argillaceous dolomite containing common *Chondrites* burrows. At the base of this unit are several inches of dark gray, very dense, finely laminated, argillaceous dolomite with scraps of carbonaceous material and flattened pyritic brachiopods.
46.5 feet	?Maquoketa Shale. Covered interval
15.6 feet	Maquoketa Shale. Gray, laminated shale, containing numerous white, calcareous bands
36.5 feet	Alternating series of slabby fossiliferous dolomitic limestone and gray shale.
23 feet	Gray shale
5.3 feet	Thin-bedded, impure fossiliferous dolomitic limestone
46.3 feet	Blue, conchoidally-fracturing shale
6 feet	Blue fissile shale containing limestone band with pyritized fossils, to lake level.

This is one of the few sites where the argillaceous basal Silurian is exposed. Although referred to the "Mayville Dolomite," these argillaceous strata are probably equivalent to the Mosalem/Wilhelmi formations of northeastern Iowa and northwestern Illinois and northeastern Illinois, respectively.

The contact between the Ordovician and Silurian strata is not well exposed at High Cliff, but it can be examined in the nearby J&E Construction Quarry in Sherwood (Fig. 6-1). Here, the contact is marked by a lag deposit containing shale clasts, phosphatic pebbles, and pyrite. Linguloid brachiopods are present just below the top of the Maquoketa Shale at this quarry.

Stone Industry at High Cliff

The history of the stone industry at High Cliff is the most interesting of any site in this region. Funk (1997) provided a history of both the stone industry and the community that grew up around it at this location. In 1859, Daniels (unpublished notes) recorded four lime kilns at "Clifton," as High Cliff was first named (Funk, 1997). Daniels (1861) reported that "Large quantities of lime and rough stone are taken from [Clifton], and some layers dress tolerably well, and have been used for caps and sills in the new College buildings [Lawrence University] at Appleton. The proximity of these quarries to the lake and the immense face exposed, renders their products very cheap." Initially, stone used to make lime and building stone was obtained from blocks of Silurian dolomite that had slid downslope to the bottom of the Escarpment. Funk (1997) reported that early settlers, such as August Fiedler, hauled limestone from the side of the hill to the lakeshore where it was picked up and taken by boat to cities on the west side of the lake, such as Oshkosh, to be burned in kilns there (Fig. 6-2). Chamberlin (1877) noted that rock from Clifton was also used at Appleton for flux in smelting Lake Superior iron ores. He noted that the "rock is obtained from the fallen masses on the slope below the cliff." Apparently, the Silurian cliff at the top of the Escarpment was not quarried to any significant extent at least until after Chamberlin's visit in the mid-1870s.

It is notable that, even though lime was burned at High Cliff, several companies apparently found it more economical to haul bulk stone by boat in the summer and sled in the winter across Lake Winnebago to burn in kilns at Oshkosh and Appleton (Fig. 6-2). J. A. Day and Company, of Oshkosh, used this method from at least 1864 until 1868, when the company was sold to Ossian Cook. Cook, along with R.C. Brown and F.E. Waite, established the Cook and Brown Company in 1874, which was incorporated as Cook and Brown Lime Company in 1878. This company supplied lime, brick and other building materials for the city of Oshkosh. Cook and Brown had brickyards at High Cliff and Stockbridge, on the east side of Lake Winnebago, and owned considerable land along the Escarpment around High Cliff from which it obtained rock for lime burning. Eventually, they built a lime kiln on the shore at High Cliff (Fig. 6-3) and opened a quarry at the top of the Escarpment to simplify operations and provide a better quality stone for lime burning. A railroad spur was built around 1890 to the "new" kilns higher on the Escarpment, the remnants of which can still be seen along the shaley slope of the Escarpment. In the 1870s until about 1906, John Kusche & Brothers also obtained rock from High Cliff and transported it across the lake to burn at their kiln in Oshkosh. C.M. Fisher and Company shipped rock to be burned in their lime kiln in Appleton during the 1870s. In 1878, this company was sold to Marsden and Company of Appleton, which operated it until the early 1900s. In 1902, Cook and Brown was combined with the Union Lime Company, and, in 1921, became part of the Western Lime & Cement Company. Western Lime ceased operating at High Cliff in 1956, and

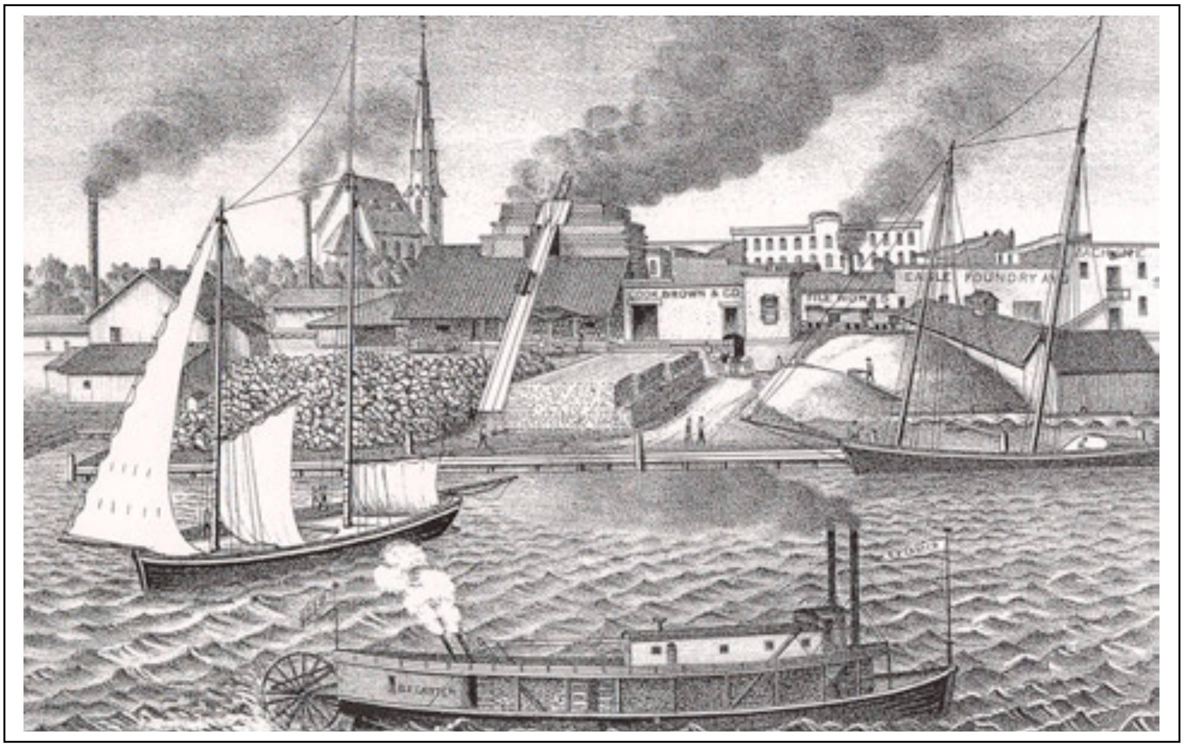


Figure 6-2. Lithograph of the Cook & Brown kiln and dock at Oshkosh, to which rock from High Cliff was shipped for processing, 1880. (From R. J. Harney. 1880. The history of Winnebago County, Wisconsin, and early history of the Northwest. Oshkosh, Allen Hicks Printing).

Figure 6-3. Lime kilns along lakeshore and farther up escarpment at High Cliff, ca. 1900.

sold their property to the State. High Cliff State Park was opened on the site in 1957.

Stone quarrying continues on the Escarpment in the vicinity of High Cliff, however. J&E Construction runs a crushed stone operation in the Silurian rocks at the north end of the Escarpment near Sherwood. Previously, the Frank brothers burned lime at this location as early as the 1870s, but there was little activity at the site throughout most of the late nineteenth and early twentieth centuries.

An important brick industry was also located along the Escarpment from High Cliff south to Stockbridge. Little is know about the beginnings of this industry, however, Daniels (1859, unpublished notes) stated that in 1859 there were four brick kilns along the lakeshore between Stockbridge and Clifton. Most of the brickyards obtained clay from the Maquoketa Shale in the lower part of the Escarpment, but the operation at Clifton used Quaternary lacustrine clay from glacial Lake Oshkosh excavated at the base of the Escarpment. In 1877, Chamberlin reported, "At Clifton, a yard producing 1,000,000 [bricks] per year, is owned by B.F. Carter, and one making 700,000 by H. Day & Co., of Oshkosh…Mr. B.F. Carter employs sixteen hands and uses steam power, with a Burnham machine. Nine men are employed at the yard of Day & Co. The crude material is in the form of beautiful laminated red clay and sand. The bricks are light colored, and are sold at $7 per thousand." The High Cliff brickyard closed down before 1900. Buckley (1898) described the brick operation at Stockbridge, where Cook & Brown made bricks until 1915. From then until about 1920, clay was taken across the lake to the Cook & Brown brickyard in Oshkosh (Meyer, 1973). In about 1920, all operations ceased at Stockbridge, and, in 1937, the property was sold to Calumet County for a park (Meyer, 1973).

STOP 7. LEDGE VIEW NATURE CENTER CAVES AND QUARRY

Location: Quarry in NW, NW, Section 30, T18N, R20E, just east of Co. Hwy. G, west of Ledge View Nature Center, about 2 miles south of Chilton, Calumet County, Wisconsin (Fig. 7-1).

Stop Leaders: Joanne Kluessendorf and Donald Mikulic

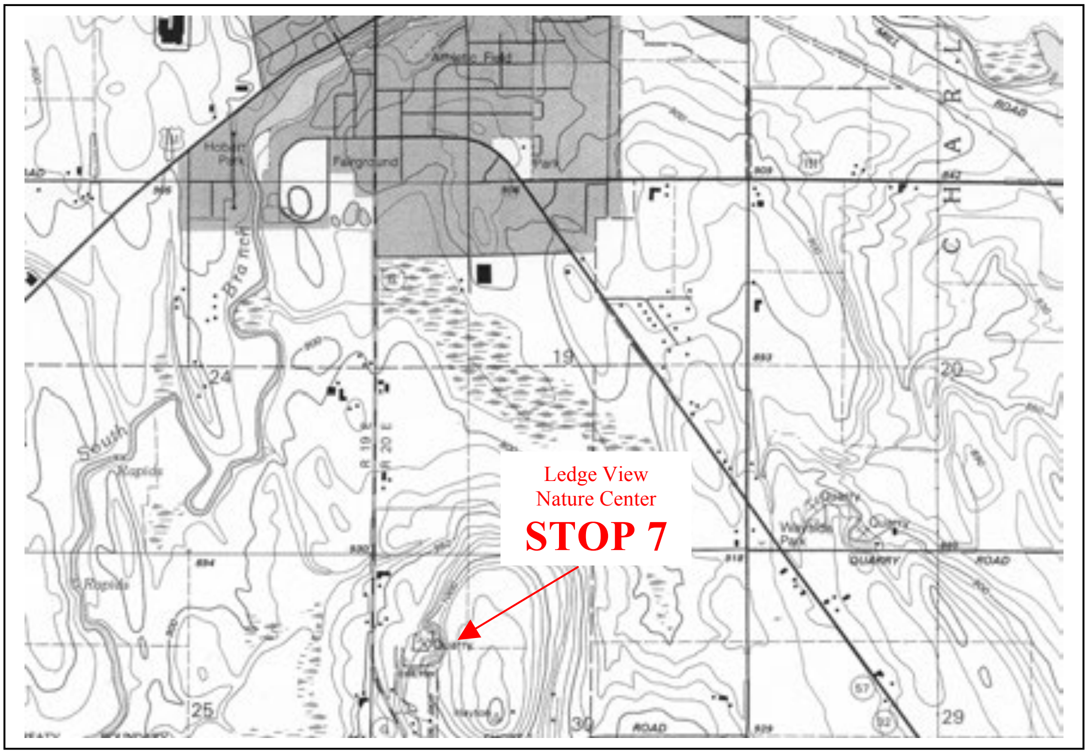


Figure 7-1. Quarry at Ledge View Nature Center

This small abandoned quarry on the west side of Ledge View Nature Center (Fig. 7-1) exposes the youngest Silurian rocks seen on this field trip, although they are still Early Silurian and much older than the Silurian rocks present to the east and southeast. Here, the Schoolcraft Member of the Manistique Formation (Middle-Late Aeronian), containing a brachiopod deposit, is present at the top of the quarry. Although superficially resembling the *Virgiana* deposits seen in the Lime Island equivalent elsewhere, this deposit comprises *Pentamerus*, a younger pentamerid brachiopod taxon.

Strata in the rest of the quarry belong to the Burnt Bluff Group, which is dominated by laminites. This unit is commonly misidentified as the Byron Dolomite (see Harris and Waldhuetter, 1998; Ehlers and Kesling, 1957, for examples of this). Bedding planes in these laminated strata commonly display ripple marks, rill marks, and mudcracks (Shrock, 1940). Small rounded domes as much as 10-20 feet in diameter with shallow intervening basins are scattered across the quarry floor (Shrock, 1940).

A variety of mudcracks can be seen on the floor of this small quarry. Of particular note, Shrock (1940) described some unusual rectangular forms, which he considered indicative of rapid subaerial desiccation (Fig. 7-2). Although fossils are very rare in the Burnt Bluff here, at last one orthoconic nautiloid cephalopod has been seen in these beds.

Section at the old county quarry on the west side of Ledge View Nature Center

5 feet	<u>Schoolcraft Member of Manistique Formation</u>. Brown, granular, laminated, massive dolomite with chert layers and nodules near the middle. Silicified and biomoldic corals and stromatoporoids are common in the lower one-third of the unit. Specimens of *Pentamerus* brachiopods are common to abundant in the upper part of the unit.
5 feet	<u>Burnt Bluff.</u> White to bluish gray, very finely crystalline, very dense, even-textured laminated, thin-bedded dolomite with conchoidal fracture.
20 feet	Light brown, medium crystalline, medium-bedded, rough textured dolomite occurs below this. There are some laminae and laminoid fenestrae as well as local vugs. The vugs comprise both coral biomolds and tubular burrows. The laminated and vuggy layers appear to be cyclic.
5 feet	Bluish gray, very dense, nonporous, even-textured, thin- to medium-bedded, laminated dolomite with a conchoidal fracture. There are ripple marks and mudcracks in this unit. About 31 inches above the base of this unit is a blackened microkarst surface

Stone Industry at Ledge View

The history of the stone industry at Ledge View is poorly known. This rural locality was never located near a railway or other important transportation route, and, given the limited local market, it is unlikely that much, if any, quarrying was done here during the nineteenth century. By 1922, the City of Chilton was operating a quarry in the west side of this hill to supply crushed stone for its municipal work. By 1935, Calumet County had opened an adjacent quarry south of the city's pit for the same purpose. Both operations seem to have been run intermittently and there is little recorded information about them after the 1930s. The Ledge View Nature Center acquired part of the quarry area, but some of the land is still owned by the county.

This site is interesting because it is an example of a publicly owned quarry. In the early twentieth century, the rapidly expanding road improvement programs required considerable amounts of crushed stone for aggregate, and some municipalities opened quarries to supply this material to meet their own needs. Only a few of these remained in operation for any significant amount of time, in part because of the objections of private quarry owners who viewed this as unfair competition.

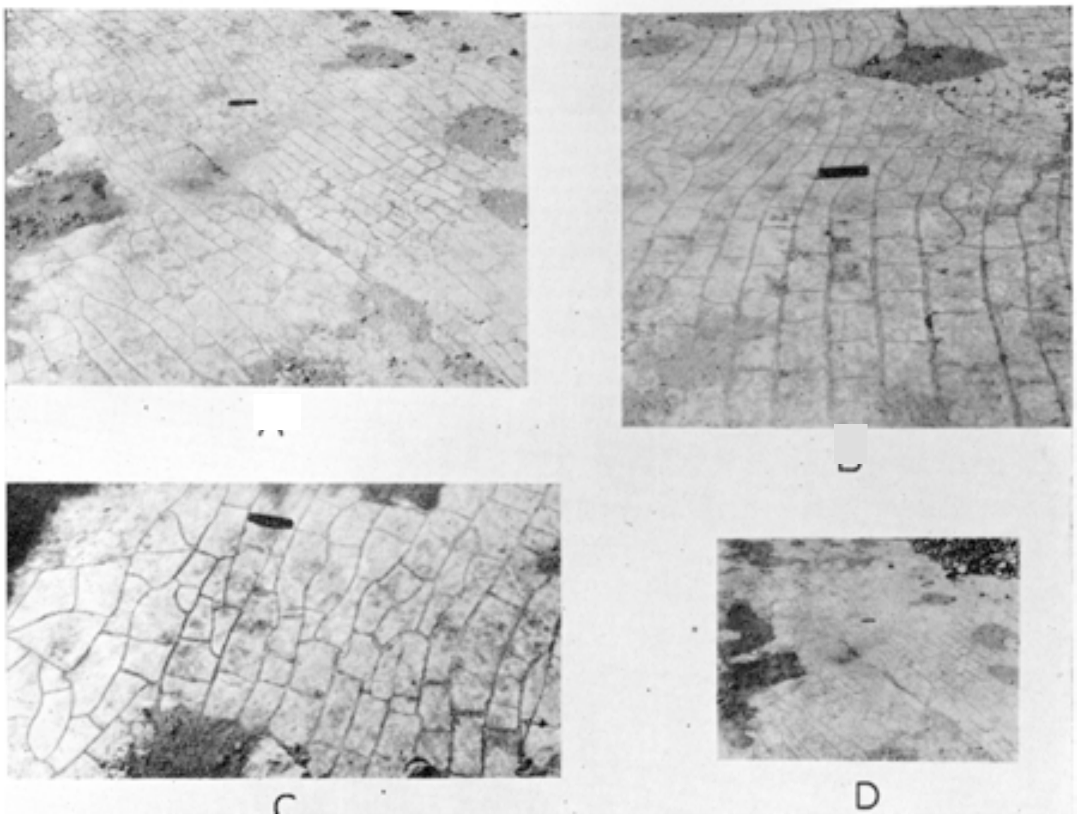


Figure 7-2 Rectangular mudcracks on the floor of the quarry at Ledge View Nature Center (from Shrock, 1940).

Caves at Ledge View

The slow dissolution of carbonate rocks by slightly acidic groundwater produces a variety of karst features, including caves and sinkholes. Basically, groundwater forms caves by slowly enlarging joints and bedding surfaces as it percolates downward into the rock. As dissolution continues, large underground chambers and cavities are created. If the roof of a chamber, or cave, collapses, a sinkhole results. Given enough time, the redeposition of carbonate minerals by groundwater will produce speleothems, such as stalactites and stalagmites, on the walls of caves.

The thinness of the dolomite bedrock, the glaciation of much of the area, and the periglacial effects of runoff, frost action, and subsequent erosion have all contributed to the paucity and small size of caves in Wisconsin (see Wisconsin Speleological Society website, www.caves.org).

Karst features are most characteristic of the Ordovician carbonate rocks in the southwestern corner of Wisconsin. Known as the Driftless Area, this area was not affected significantly by Quaternary glaciation. As a result, erosion and weathering have had a greater period of time to create karst features, and once formed they were not subsequently destroyed by glaciation. This is where most of the speleothems have developed and most of the commercial caves are located.

In contrast, caves, sinkholes and speleothems are not very common in the Silurian rocks of eastern Wisconsin. This region may have once sported as many caves as the Driftless Area, but Quaternary ice modified that pre-glacial topography. Consequently, most of the caves in this part of the state are chiefly solution-enlarged vertical joints in fractured bedrock, which formed during or since Quaternary glaciation. Many of these caves are filled with clay, sand and gravel that may have been deposited by the melting glaciers.

Some of the best-known caves in eastern Wisconsin are located at Ledge View Nature Center. Named for a nearby farmer, Montgomery Cave was the first to be discovered here, around the time of the Civil War. This cave is about 30 feet deep and nearly 230 feet in length. Montgomery Cave is a solution cave that formed when water enlarged a crack in the dolomite; this lifeline is still visible in the roof of the cave (Green, 2000). There is a room at the highest elevation in this cave as well as two other rooms at lower elevations. In the early twentieth century, this cave, which was owned by the Zimmermann rendering plant, had been stuffed with unprocessed animal carcasses (Rudy, 1998). Montgomery cave was opened to the public in 1981.

Carolyn's Cavern was uncovered by members of the Wisconsin Speleological Society in 1986. Located beneath a sinkhole, this cave is about 35 feet deep and has a passage more than 290 feet long. More than eight tons of mud and rock were removed from the cave's two rooms. This cave has the best-developed speleothems in the park, with cave coral, cave drapery, stalactites and flowstone (Green, 2000). Since its discovery, more rooms have been found and several passages have been connected to sinkholes in the area (Rudy, 1998).

Mother's Cave was discovered on Mother's Day in 1986 (Rudy, 1998). The opening to this cave occurs at the base of the rock ledge. This cave is more than 300 feet long and 33 feet deep, but some of the passageways are no more than 3 feet high. Mother's Cave is home to three species of bats (Green, 2000).

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