An Overview of the Geology of Central and Northeastern Wisconsin: The Story of Fire, Water, and Ice

Beth A. Johnson
University of Wisconsin-Fox Valley
Menasha, WI

73rd Annual Tri-State Geological Field Conference and Great Lakes Section – SEPM Fall Field Conference
Oct. 6-8, 2017

AN OVERVIEW OF THE GEOLOGY OF CENTRAL AND NORTHEASTERN WISCONSIN: THE STORY OF FIRE, WATER, AND ICE

Prepared for the 73rd Annual Tri-State Geological Field Conference and Great Lakes Section – SEPM Fall Field Conference

by Beth A. Johnson
Department of Geography and Geology
University of Wisconsin-Fox Valley
Menasha, WI

with contributions from Joanne Kluessendorf[1] and John Luczaj[2]

[1]Weis Earth Science Museum, Menasha, WI

[2]Department of Natural and Applied Sciences, University of Wisconsin-Green Bay, Green Bay, WI

October 6-8, 2017

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to take the time to thank everyone who was involved with helping to organize the 2017 Tri-State Geological Field Conference. Specifically, I would like to thank:

- The University of Wisconsin-Fox Valley for agreeing to host the conference

- The Office of Continuing Education for handling registrations

- The Weis Earth Science Museum for allowing the trip participants to visit

- The Geo-Adventurers Club of UW-Fox Valley for donating lunches and helping with trip logistics

- The Central Section of the National Association of Geoscience Teachers for co-sponsoring the field conference and donating funds to cover transportation and guidebook printing costs

- The Great Lakes Section of the Society for Sedimentary Geology (SEPM) for co-sponsoring the field conference

- Michels Materials for allowing us into their sites

- The Dunnett Family for allowing us into their site

- The City of Wautoma for allowing us to use their park and purposely delaying winterizing the restrooms just so our conference could use them

- Kobussen Buses Ltd. for agreeing yet again to take one of their pretty buses into places they were never designed to go all for the sake of geology

- Eric Carson of the Wisconsin Geological and Natural History Survey for being our guest speaker

- Don Mikulic for helping with fieldwork for the field conference

- Joanne Kluessendorf and John Luczaj for contributing to the guidebook

- UW-Fox Valley student volunteers for helping behind the scenes to make this conference happen

Most of all, I want to thank Joanne Kluessendorf of the Weis Earth Science Museum. She taught me everything that I needed in order to plan a field conference, took me out to potential

sites to consider, gave me materials from past conferences to use as reference, and helped with some of the fieldwork for this trip. This conference is as much her work as it is mine.

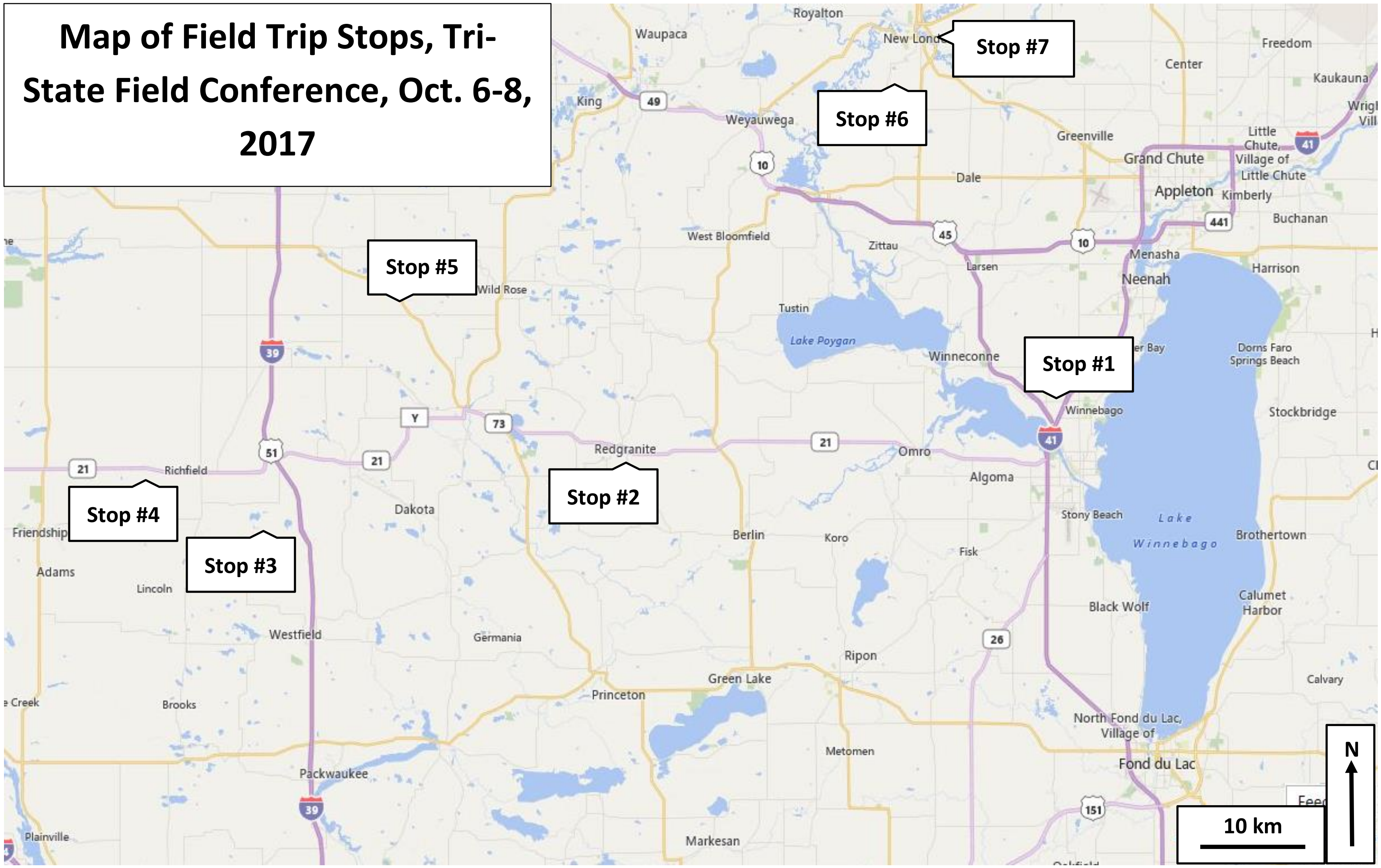
- Beth Johnson

ROAD LOG (Oct. 7 Stops Only)

Starting Point: University of Wisconsin-Fox Valley
1478 Midway Rd.
Menasha, WI 54952

Driving Directions	Distance (km)	Total Distance (km)
1) Turn right out of the UW-Fox Valley parking lot and drive west down Midway Rd	0.64	0.64
2) Turn right and drive north on Appleton Rd./WI Hwy. 47 North	0.48	1.12
3) Drive straight through first roundabout to stay on Appleton Rd.	0.14	1.26
4) Use the inner lane in the second roundabout to turn left to take the ramp to WI-441 S/US-10 W. Merge onto WI-441 S/US-10 W	0.47	1.73
5) Stay on US-10 W	9.9	11.63
6) Take the exit for Jackson St./WI Hwy. 76. Turn left off ramp to follow WI Hwy. 76 S	0.36	11.99
7) Follow WI Hwy. 76 S	11.83	23.82
8) Turn right to drive west on Cty. Hwy. GG. Go straight through the intersection with Cty. Hwy. T. **STOP 1: Devens Quarry** (4005 County Hwy. GG, Oshkosh)	4.46	28.28
9) Continue west on County Rd. GG. GG will become Hwy. 116 S at US-45. Continue to follow WI Hwy. 116 S through Winneconne and into Omro.	18.94	47.22
10) Go straight to follow WI Hwy. 21 W. Drive to Redgranite.	28.97	76.19
11) Turn right to go east on Division St. The parking area for the Redgranite Quarry Lake is on the left. **STOP 2: Redgranite Quarry Lake**	0.24	76.43
12) Drive west on Division St. back to WI Hwy. 21/County Rd. E/W. Bannerman Ave. Turn right onto Hwy. 21 W.	0.24	76.67
13) Continue on WI Hwy. 21 W. Drive through the cities of Wautoma and Coloma	38.94	115.61
14) In Coloma, turn left to go south on Cty. Hwy. CH. Go past Cty. Hwy CC. Turn right to go west on Dakota Drive (NOT Dakota Ave.!)	6.94	122.55
15) Drive to the end of Dakota Dr.	1.87	124.42
16) Turn left on 4th Rd. The entrance to the quarry is on the left. **STOP 3: Pockrandt Quarry**	0.17	124.59

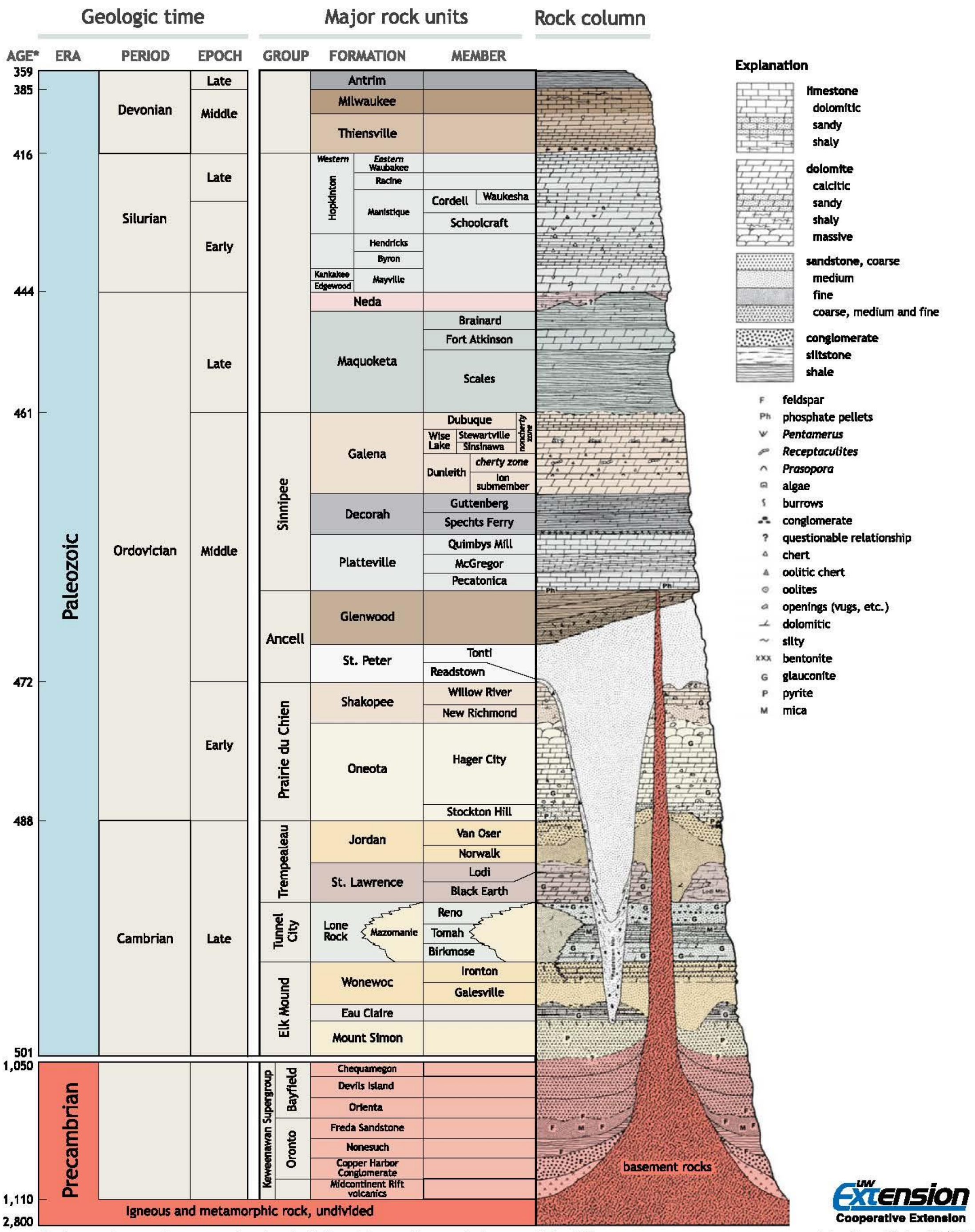
17) Drive north on 4th Rd. 4th Rd. becomes 4th Ave. Cross Cty. Hwy. CC. Stay on road until the intersection with Old Highway 21.	6.21	130.8
18) Turn left to go west on Old Highway 21.	0.16	130.96
19) Turn left to go west on WI Hwy. 21. Entrance to wayside is on the north (right) side of the highway. **STOP 4: Ship Rock Wayside**	10.57	141.53
20) Turn left out of the parking area to go east on WI Hwy. 21. Drive to intersection with Cty. Hwy. V	6.19	147.72
21) Drive north on Cty. Hwy. V to Cty. Hwy. C.	11.13	158.85
22) Turn right to go east on Cty. Hwy. C and drive to the intersection with Cty. Hwy. B	7.58	166.43
23) Turn left to go north on Cty. Hwy. B. Go past Cty. Hwy. O. Drive to the intersection with Aspen Ave.	6.50	172.93
24) Turn right to go east on Aspen Ave. Go past 11 Dr. The pit will be on the south side of the road on the right. **STOP 5: Meyer Sand and Gravel Pit** (W10003 Aspen Ave, Plainfield, WI)	5.24	178.17
25) Turn right from entrance of pit to drive east on Aspen Ave. to the intersection with WI Hwy. 73.	0.45	178.62
26) Turn left to go north on WI Hwy. 73 to intersection with Cty. Hwy. A.	2.63	181.25
27) Turn right to go north on Cty. Hwy. A. Keep following Cty. Rd. A east overall through Wild Rose and Saxeville. Just east of Saxeville, Cty. Hwy. A turns north as part of Cty. Hwy. E.	26.88	208.13
28) Follow Cty. Hwys. A and E north to the intersection where the two roads split.	4.10	212.23
29) Turn right to go east on Cty. Hwy. A.	8.57	220.80
30) Turn left to go north on WI Hwy. 29. Drive through west Bloomfield. Drive to intersection with US-10	8.77	229.57
31) Turn right to take the ramp toward US-10 E.	0.32	229.89
32) Follow US-10 E back to Appleton/Menasha. Follow the signs for UW-10 W (Appleton). US-10E will merge with WI Hwy. 441 N.	41.67	271.56
33) Turn right to take the Appleton Rd./WI Hwy 47 exit. Get in the right lane to turn right at the roundabout.	0.42	271.98
34) Turn right to go south on Appleton Rd./ WI Hwy. 47 S.	0.35	272.33
35) Turn left to go east on Midway Rd. UW-Fox Valley will be on the north (left) side of the road.	0.64	272.97



Map of the trip route. Stops #1-5 will be visited as part of the field conference on Saturday, Oct. 7. Stops #6-7 are part of the optional half-day car caravan on Sunday, Oct. 8. Please see the road log for the exact routes used for this trip. (http://Maps.Live.com)

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

Bedrock stratigraphic units in Wisconsin

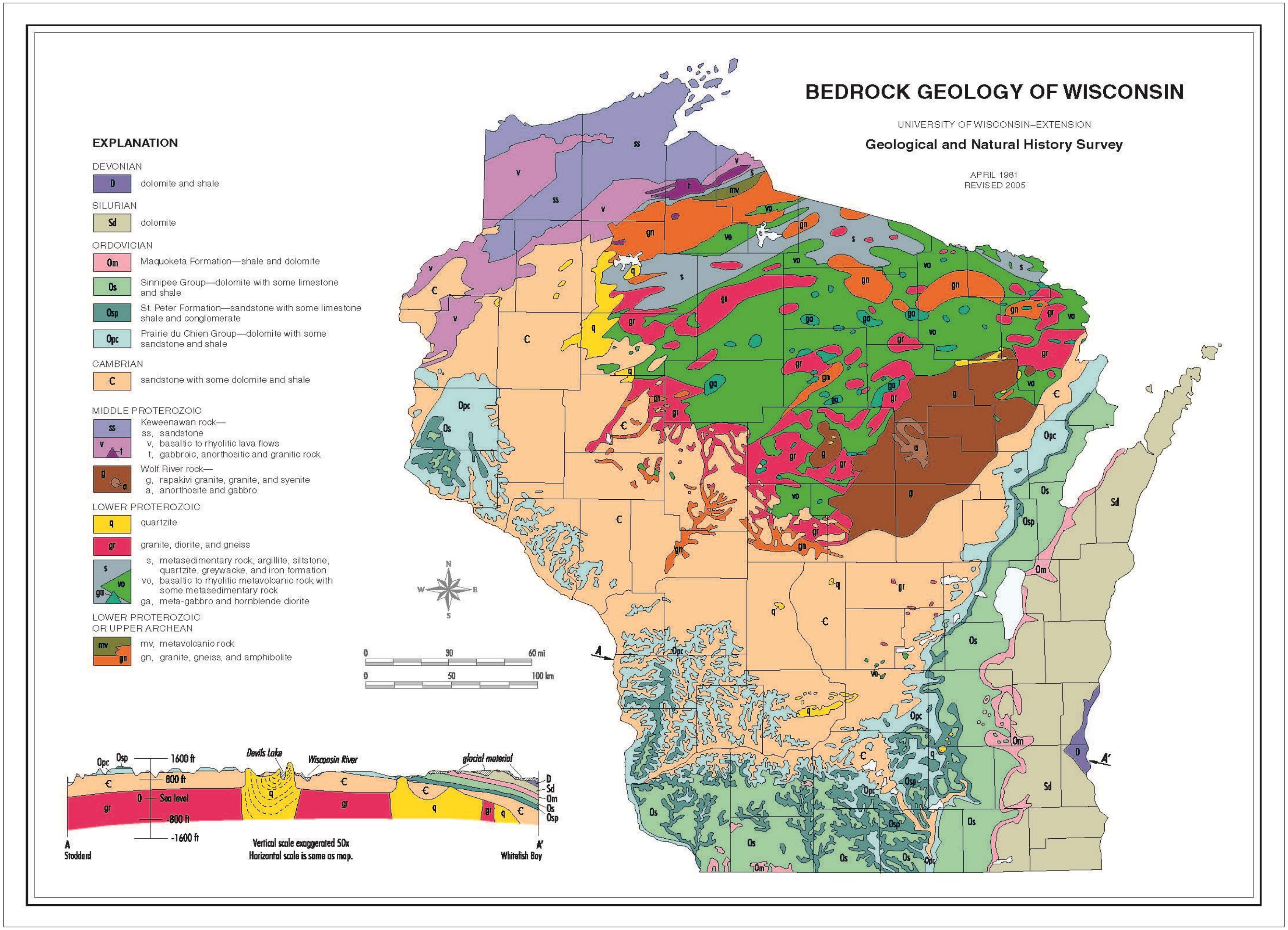


* Absolute age dates in million years are based on the Geological Society of America Geologic Time Scale, 2009.

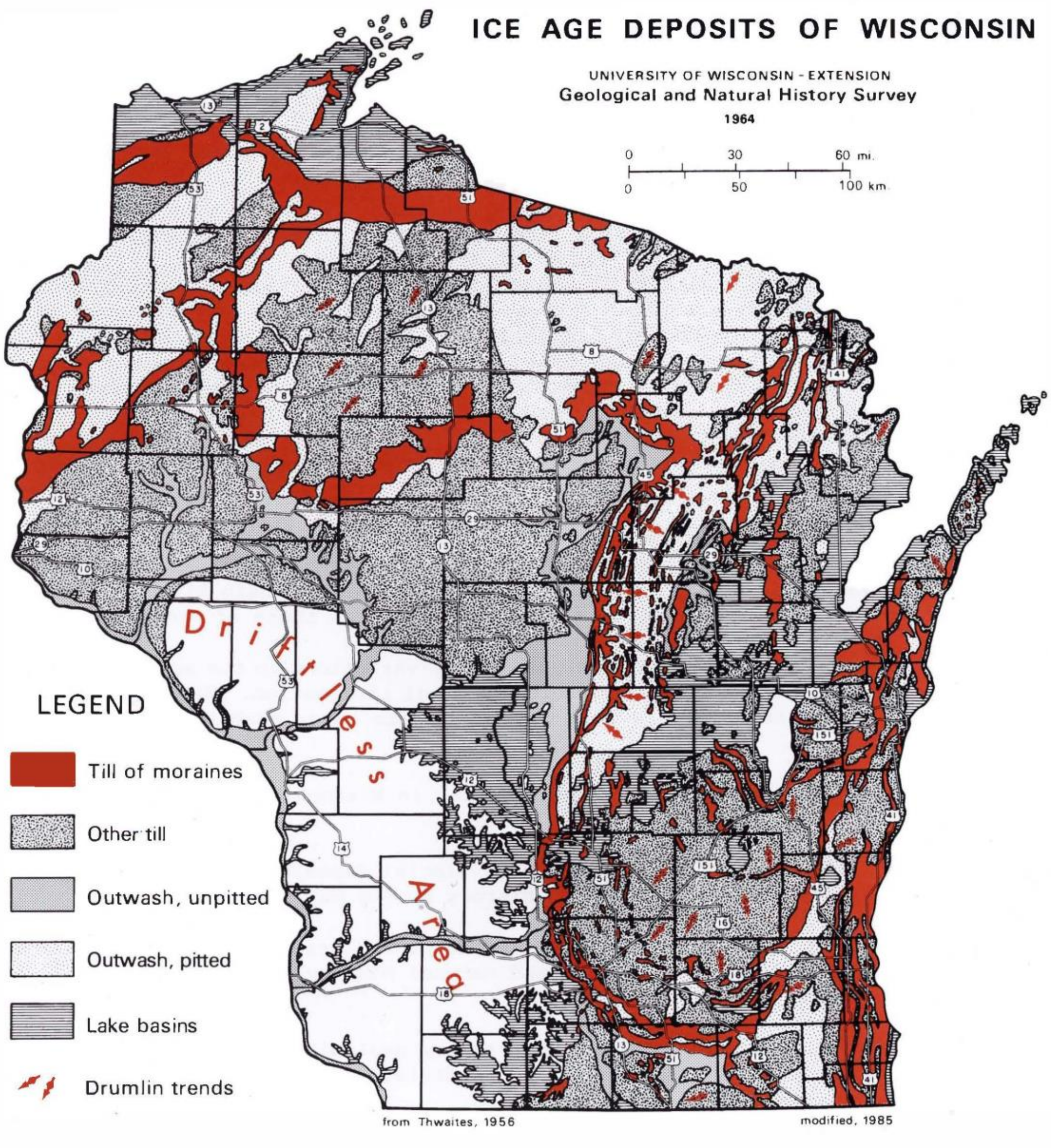
Modified from Ostrom, M.E., 1968, Paleozoic Stratigraphic Nomenclature for Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 8.

UW Extension Cooperative Extension
Educational Series 51 | 2011
ISSN: 1052-2115

Available for free download at https://wgnhs.uwex.edu/pubs/000200/



Available for free download at [*http://wgnhs.uwex.edu/pubs/m067/*](http://wgnhs.uwex.edu/pubs/m067/)



Available for free download at http://wgnhs.uwex.edu/pubs/m034/

STOP 1:
DEVENS QUARRY
By Joanne Kluessendorf and Beth A. Johnson

Site: Located on County Hwy. GG 1.23 km west of the intersection of County Hwy. T, near Oshkosh, WI

PLSS Location: W ½, NW ¼, Sec. 21, T19N, R16E

GPS Coordinates: 44° 6'24.14"N, 88°36'4.66"W

Note: This quarry is operated by Michels Materials and is next to the Vinland Quarry operated by Northeast Asphalt.

Bedrock: Water in the quarry precludes close examination of the rock walls, making it difficult to identify lithologies and fossil content definitively. It appears that only Ordovician strata are present. The lower unit visible in the wall may be the Middle Ordovician Glenwood Formation of the Ancell Group. Ranging from sandstone to mudstone, the Glenwood overlies the St. Peter Sandstone of the Ancell Group or directly on the erosional surface of the underlying Early Ordovician Prairie du Chien Group. Argillaceous material in the Glenwood can be green to greenish-blue to organic-rich and brown. The unconformity at the top of the Prairie du Chien represents prolonged emergence during which valleys, caves, sinkholes and other karst features developed, marking the top of the Sauk Megasequence.

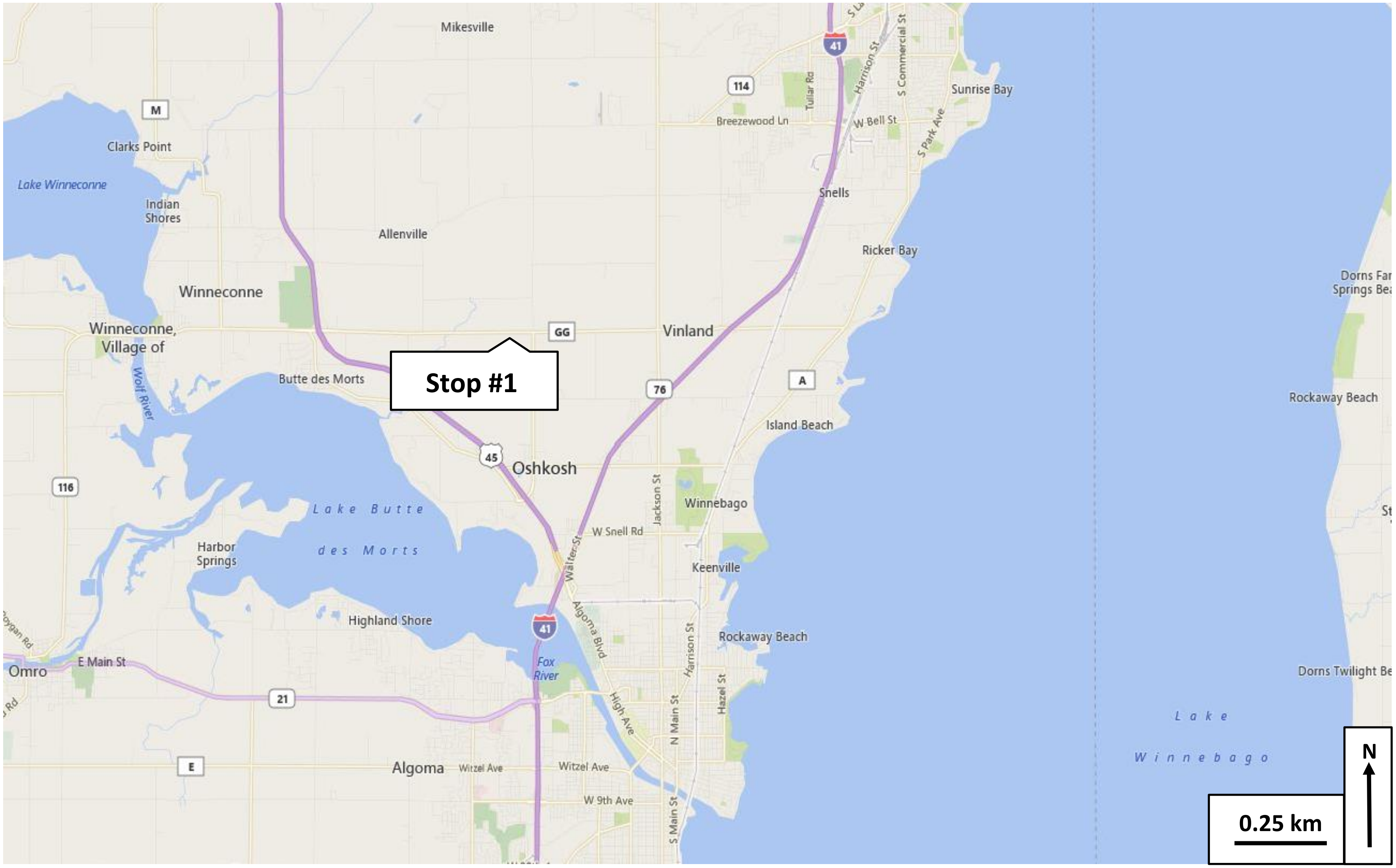


Figure 1: *Map of the site of Devens Quarry on County Hwy. GG 1.23 km west of County Hwy. T in Winnebago County. Please note that the site is directly adjacent to another quarry, so please check the signs carefully. (http://maps.live.com)*

Deposition of the St. Peter and Glenwood, where present, mark the transgression at the beginning of the Tippecanoe Megasequence. A minor regression occurred at the end of Glenwood deposition, producing a less pronounced unconformity, which is a sequence boundary (Figure 2).

Overlying the Glenwood is the Middle Ordovician Platteville Formation of the Sinnipee Group, likely represented by the basal Pecatonica Dolomite Member. Occurring in medium to thick beds of light brown dolomite, the Pecatonica generally has a very coarsely crystalline, "sugary" appearance. Much of the Pecatonica is planar laminate and fenestral porosity is present locally, indicating intertidal-supratidal environments (Figure 3).

Figure 2: *Upper part of west wall of the quarry. The two rock formations visible here are the Platteville Formation (mid-Ordovician) lying unconformably over the hypothesized Glenwood Formation (Middle Ordovician). The unconformity between the two is marked by a sharp contact. (Image credit: Beth A. Johnson.)*

Figure 3: *Fenestral porosity in dolomite from the Platteville Fm. Fenestral porosity is often the result of decaying organic matter in the soft sediments. (Image credit: Beth A. Johnson.)*

Although water restricted access to the rock face, there were few fossils observed in the units that could be studied. This is due in part to the intertidal-supratidal environments indicated by these units. However, limited evidence for some fossils has been found. Small segments of crinoid stems have been found *in situ* in the Platteville Formation in the west wall of the quarry. It is likely that these were fragments that washed into the site via waves or tides. Figure 4 shows one dolomite slab, likely from the Glenwood Formation that preserves a network of worm burrows. However, this was found separate from the outcrop.

Figure 4: *Worm burrows preserved in dolomite, possibly from the Glenwood Fm. (Image credit: Beth A. Johnson.)*

Figure 5: *Glacial diamicton in the southeast part of the quarry. Here, an erosional channel has cut down into older diamicton, the shape of which is marked by a stone line. Then, the channel was filled in by subsequent glacial advance. (Image credit: Beth A. Johnson.)*

Glacial Deposits: Although the glacial cover can be seen overlying the Ordovician bedrock on the quarry walls, it can be directly accessed in the southeast part of the quarry. Quarrying operations have resulted in a wealth of glacial boulders of varying lithologies, which have been collected in this section. Also, much of the glacial cover is exposed in outcrop here and much of that can be accessed on foot.

Glacial debris exposed here consists of diamicton carried by the Green Bay Lobe during the Wisconsin Episode Glaciation. The lower diamicton is brown (7 YR 5/3) silty clay loam. Clasts are abundant in this unit and, although several lithologies are present, the dominant lithology is carbonate and makes up an estimated 60-70% of visible clasts. A channel has been eroded into the unit, likely by a meltwater stream, which has been filled by younger glacial materials. The upper diamicton consists of reddish-brown {5 YR 4/4) silty clay. Clasts are less abundant in this unit compared to the one below and consist of more varied lithologies (e.g. carbonate, schist, granite). Although carbonate clasts are still abundant, they make up a smaller percentage of visible clasts (possibly 40-50%). Between these two units are scattered, discontinuous units of sand and/or silt, some of which display soft sediment deformation (Figure 6).

Although a more detailed analysis has not been undertaken due to time constraints, it is the initial hypothesis that the upper diamicton is the Kirby Lake Member of the Kewaunee Formation. This is supported by its 5 YR hue, its finer texture, and the lower percentage of carbonate in its clasts. If this is the case, then the maximum age of the unit would be 16,302 ± 428 cal. years (13,370 ± 90 ^{14}C yr. B.P.), but would have been deposited before the Two Creeks Forest Bed (13,100-14,600 cal. years or 11,200-14,600 ^{14}C yr. B.P.) (Syverson et al., 2011). However, the identity of the lower diamicton is still in question, in part due to a lack of data. Although the Horicon Member of the Holy Hill Formation is known to underlie the Kirby Lake Member in parts of Winnebago County, this member is known for having a sand content that is generally between 60-80% (Syverson et al., 2011), which is not something that is seen in the lower diamicton at this site. It was also noted by Syverson et al., though, that the sand content of this unit could vary considerably. Regardless, the 7.5 YR hue of the lower diamicton, the higher concentration of carbonate clasts, and the sharp contact between it and the upper diamicton compare favorably to the characteristics of the Horicon Member.

Figure 6: *Soft sediment deformation visible in fine sand deposit between the glacial diamictons in the southeast part of the quarry. Although only one fold is visible in this image, there were several others in the same fine sand body. (Image credit: Beth A. Johnson.)*

References

Syverson, K.M., Clayton, L., Attig, J.W., & Mickelson, D.M., eds. (2011). *Lexicon of Pleistocene Stratigraphic Units of Wisconsin.* Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

STOP 2:
REDGRANITE QUARRY LAKE
By Beth A. Johnson

Site: Located on Division Street just off of WI-21/W. Bannerman Ave. in Redgranite, WI.

PLSS Location: N ½, SE ¼, SW ¼, Sec. 8, T18N, R12E, Redgranite 7.5 Minute Quadrangle

GPS Coordinates: 44° 2'37.76"N, 89° 5'54.53"W

Note: Please pay close attention when working near the water's edge. Some parts of the lake terminate along the original, near-vertical quarry wall and can be dangerous.

Background: Wisconsin's state rock is red granite, famously a part of many important buildings in the state, including the Capitol Building in Madison. The granite that makes up a large part of the capitol came from the granite quarries in Waushara County, one of which is found in Redgranite, Wisconsin (Figure 1). Now inactive, these quarries fueled a widespread and important industry in the late 19th and early 20th century.

The land around today's city of Redgranite had been settled as farmland as early as 1849. The area was originally called Sand Prairie because crops could not easily be farmed in the thin, sandy soil that rested on granite. In particular, the land around the resident Theodore Chipman's trading post was very sandy, but contained several large boulders of mahogany-red granite. In 1889, six granite quarrymen from Berlin, Wisconsin came to Sand Prairie to investigate local granite exposures. They determined that the granite would suit their needs to make paving stones, so they purchased the land and started quarrying it under the name of the Berlin Granite Company. The quarry was an immediate success. The town's fortunes boomed for a second time in 1901, when the Chicago and Northwestern Railroad extended their Fond

Figure 1: *Map of the city of Redgranite and nearby Lohrville, both of which had active quarrying industries in the late 19th and early 20th centuries. The quarry sites for both locations can be identified on this map by the presence of the large quarry lakes that now occupy both sites. Redgranite Quarry Lake (labeled on the map) is a popular site for swimming. (http://maps.live.com)*

du Lac-Princeton line, adding a ten-mile spur to Redgranite in order to ship their paving stones to communities all over the United States. The community changed their name to Redgranite in 1904 to reflect their economic success. Many houses built at this time can still be found in the community can be easily identified by their foundation stones made from the local red granite (Redgranite, Wisconsin, n.d.).

The economic importance of the granite eventually led to scientific study and description. By 1898, Weidman had submitted his thesis on *A Contribution to the Geology of Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin* for his Ph.D. at the University of Wisconsin, where he detailed the geology and distribution of several granite outcrops in that part of the state, including what was termed "The Waushara Granite." In that same year, Buckley wrote his report on economic stone available in Wisconsin, its uses, and localities of extraction, paying attention to the uniformity of the stone and orientations of joints or rifts, all of which could potentially limit the dimensions of the building stones that were extracted (1898).

The heyday of the granite industry at Redgranite was the period from 1905-1918. Quarrymen and paving cutters from other parts of the United States as well as from various parts of Europe came to the area to work. Outside of Redgranite, quarries also mined the granite at Lohrville, West Point, and Glenrock. Unfortunately, the rise in the use of asphalt and concrete in paving spelled the end of the use of paving stones and the quarry closed in the 1920s (Redgranite, Wisconsin, n.d.). The six-acre quarry was allowed to fill with water to a depth of 163 feet and today is used for swimming, fishing, and recreational diving (WDNR).

Geology: Redgranite Quarry, along with other nearby quarries such as the Lohrville Quarry, Flynn's Quarry, and Spring Lake Quarry, are good examples of features described as Precambrian inliers in Wisconsin. These inliers are so called because they are small exposures of ancient rock, well beyond the margin of the Precambrian shield, that are surrounded by younger Paleozoic rock. Many inliers are small, less than a square kilometer of exposure, and were shaped and polished by advancing glaciers during the last glaciation. Most inliers are composed of quartzite, rhyolite, or granite and often contain intrusions (Schultz, 2004). These inliers are the result of the 1.76 Ga igneous event in Wisconsin. This event, part of the waning stages of the Penokean Orogeny 1.8 Ga, resulted in widespread rhyolite eruptions and granite intrusions (Paull and Paull, 1978; Dott and Attig, 2004).

The granite exposed in most of the Redgranite Quarry is similar in mineralogy and texture to that at the nearby Flynn's Quarry, located in a county park southwest of Lohrville, WI in Waushara County. Smith (1978) describes the mineralogy and texture of the sites as fine- to medium-grained granophyric granite, red in color, accompanied by examples of micropegmatitic and myrmeketic textures. The mineral composition of this granite is dominated by quartz and alkali feldspar, making up 90-98% of the rock, though subordinate minerals may include sphene, hornblende, muscovite, zircon, and biotite, the latter of which may have partially or completely altered to chlorite. All these taken together suggest shallow intrusion of the granite (Smith, 1978) approximately 1.76 Ga (Dott and Attig, 2004).

One major feature seen at this site is a large segment of a metabasalt dike, prominently exposed at the end of a peninsula jutting out from the south side of the lake (Figure 2). This dike is oriented at a bearing of 080° and corresponds to a similar dike exposed in the west wall of the quarry. Both are nearly vertical and stand out in relief from surrounding rock. The metabasalt is fine-grained and black to greenish-black. Smith (1978) describes the mineral composition seen in thin section as containing laths of plagioclase surrounding mats of epidote, clinozoisite, and iron oxide. Close inspection of the dike reveals a number of raised microdikes cutting through it, most filled with quartz and ranging between a few millimeters across up to 1 centimeter. Although this large dike dominates the site, there are other, smaller dikes located throughout the quarry (Figures 3 and 4). Many of these smaller dikes are only a few centimeters thick, stretch for only a meter or two, and display sharp contacts with the surrounding rock. Others demonstrate flow banding within a few centimeters of the dike contact. Lithologies present in additional dikes visible in the granite include quartz and pegmatite, with additional metabasalt dikes present as well.

Figure 2: *Metabasalt dike segment oriented 080°. The dike varies from 1 m wide at its east end at 2 m at its west end. The red arrow identifies another segment of the dike in the west wall of the quarry. There are other, smaller metabasalt dikes in the rock exposed along the south side of the site. (Image credit: Beth A. Johnson.)*

Figure 3: *Metabasalt dike located in the south side of the quarry, displaying a sharp contact between the dike material and the granite. (Image credit: Beth A. Johnson.)*

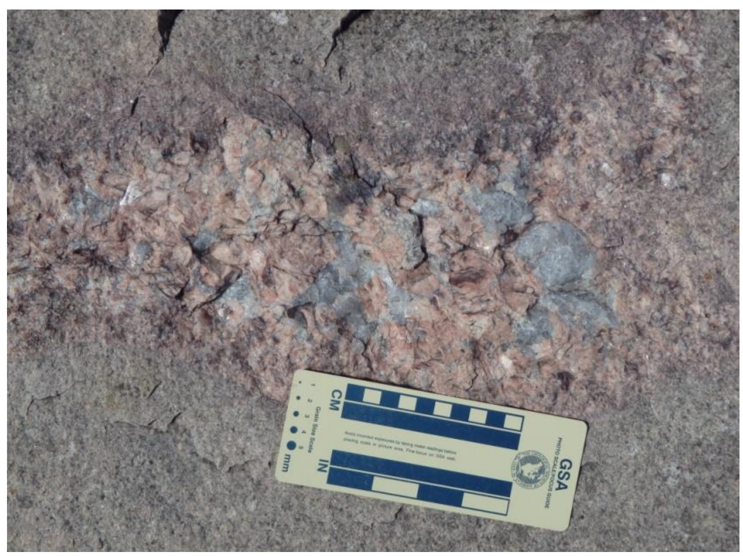


Figure 4: *Pegmatite dike in the south side of the site. (Image credit: Beth A. Johnson.)*

Other features of interest reflect the glacial history of the area. Much of Waushara County was covered by the Green Bay Lobe of the Laurentide Ice Sheet during the Wisconsin Episode Glaciation. As early as 25,000-30,000 cal. years ago, the terminus of the ice sheet was located at the Johnstown Moraine approximately 20 kilometers (12 miles) to the west, covering the region (Mickelson et al., 2011; Mickelson and Attig, 2017). Evidence that the glacial ice was in direct contact with the granite can be found on the west side of the site on natural rock exposures adjacent to the park lawn. There, small exposures of granite can be seen displaying glacial polish, striations, and concentric chatter marks (Figure 5). Chatter marks studied on the west side of the quarry have bearings of N82W (278°) and N56W (304°) whereas those exposed on the northwest side of the quarry had a bearing of N74W (286°). These bearings indicate an ice flow direction of west-northwest, which agrees with previously published data in Syverson et al. (2011).

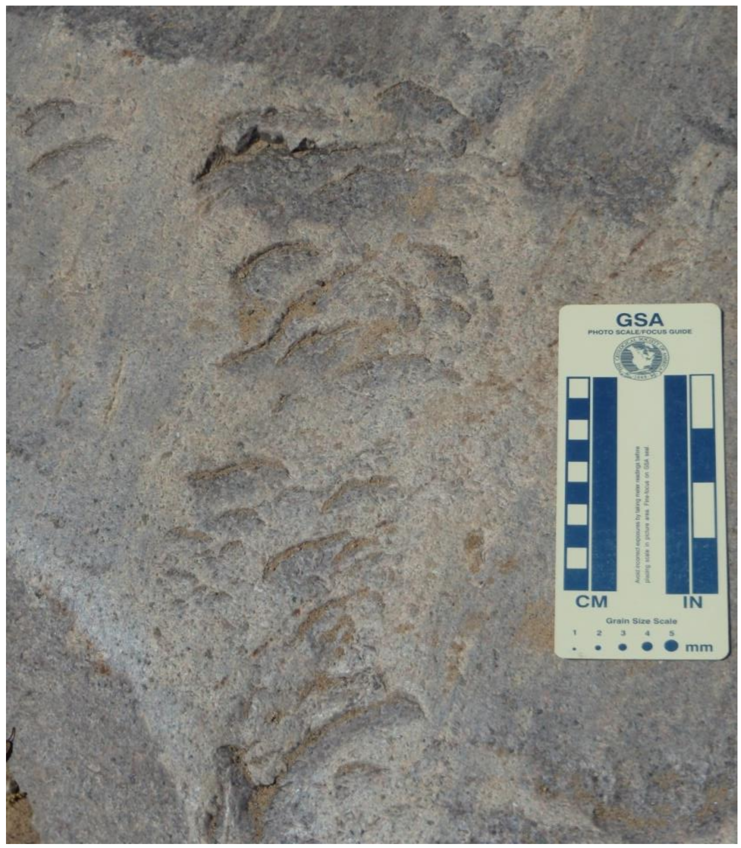


Figure 5: *Concentric chatter marks and glacial polish on an unquarried granite exposure on the west side of the quarry lake. (Image credit: Beth A. Johnson.)*

References

Buckley, E.R. (1898). *On the Building and Ornamental Stones of Wisconsin.* Wisconsin Geological and Natural History Survey, Bulletin IV, Economic Series No. 2, 544 p.

Dott, R.H. & Attig, J.W. (2004). *Roadside Geology of Wisconsin.* Missoula: Mountain Press Publishing, 345 p.

Mickelson, D.M., Maher Jr., L.J., & Simpson, S.L. (2011). *Geology of the Ice Age National Scenic Trail.* Madison: The University of Wisconsin Press, 395 p.

Mickelson, D.M. & Attig, J.W. (2017). *Laurentide Ice Sheet: Ice-Margin Positions in Wisconsin, 2nd Ed.* Wisconsin Geological and Natural History Survey Educational Series 56, 46 p.

Paull, R.K. & Paull, R.A. (1978). Geologic road log for a field excursion to Precambrian rhyolite and granite inliers of South-Central Wisconsin, *in* Smith, E.I., Paull, R.A., and Mudrey, M.G., eds., *Precambrian Inliers in South-Central Wisconsin*, Wisconsin Geological and Natural History Survey Field Trip Guidebook No. 2, 90 p.

Redgranite, Wisconsin (n.d.). www.redgranitewisconsin.com. Web. Accessed July 15, 2017.

Schultz, G.M. (2004). *Wisconsin's Foundations: A Review of the State's Geology and its Influence on Geography and Human Activity.* Madison: The University of Wisconsin Press, 211 p.

Smith, E.I. (1978). Granite and related intrusions at Flynn's Quarry County Park, *in* Smith, E.I., Paull, R.A., and Mudrey, M.G., eds., *Precambrian Inliers in South-Central Wisconsin*, Wisconsin Geological and Natural History Survey Field Trip Guidebook No. 2, 90 p.

Syverson, K.M., Clayton, L., Attig, J.W., & Mickelson, D.M., eds. (2011). *Lexicon of Pleistocene Stratigraphic Units of Wisconsin.* Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

Weidman, S. (1898). *A Contribution to the Geology of Pre-Cambrian Igneous Rocks of the Fox River Valley, Wisconsin.* University of Wisconsin Doctoral Thesis, 63 p.

Wisconsin Department of Natural Resources (WDNR) (n.d.). Redgranite Quarry Lake. www.dnr.wi.gov/lakes/. Web. Accessed July 15, 2017.

STOP 3:
POCKRANDT QUARRY,
GLOVER BLUFF IMPACT SITE
By Beth A. Johnson

Site: Pockrandt Quarry, currently leased by The Kraemer Company, is on 4th Rd. approximately 6 kilometers south of WI-21, near Westfield, WI.

PLSS Location: S ½, SW ¼, Sec. 3, T17N, R8E, Westfield West 7.5 Minute Quadrangle

GPS Coordinates: 43°58'5.19"N, 89°32'23.18"W

Note: THIS SITE IS PRIVATELY OWNED AND TRESSPASSERS ARE NOT TOLERATED! Please seek permission of the landowner before attempting to access the site.

Background: Glover Bluff has long been a challenging site for geologists to interpret.

This site was first described by W.C. Alden in 1918. In his descriptions of the disturbed strata, he hypothesized that glacial ice removed horizontal dolomite strata from the crest of the site's West Hill and dropped at the base of the western slope of the same hill (Figure 2) (Alden, 1918). A more systematic study was undertaken by F.T. Thwaites for his 1928 Master's Thesis from the University of Wisconsin and rewritten for publication by Ekern and Thwaites (1930). In this research, the varied dip directions of the exposed strata were attributed to the presence of a syncline and fault which may have been reactivated sometime between the Ordovician Period and the Pleistocene Epoch. Although their research did not include geophysical analysis, they suggest that "variations from normal magnetic attraction" may reveal a concealed structure (Ekern and Thwaites, 1930).

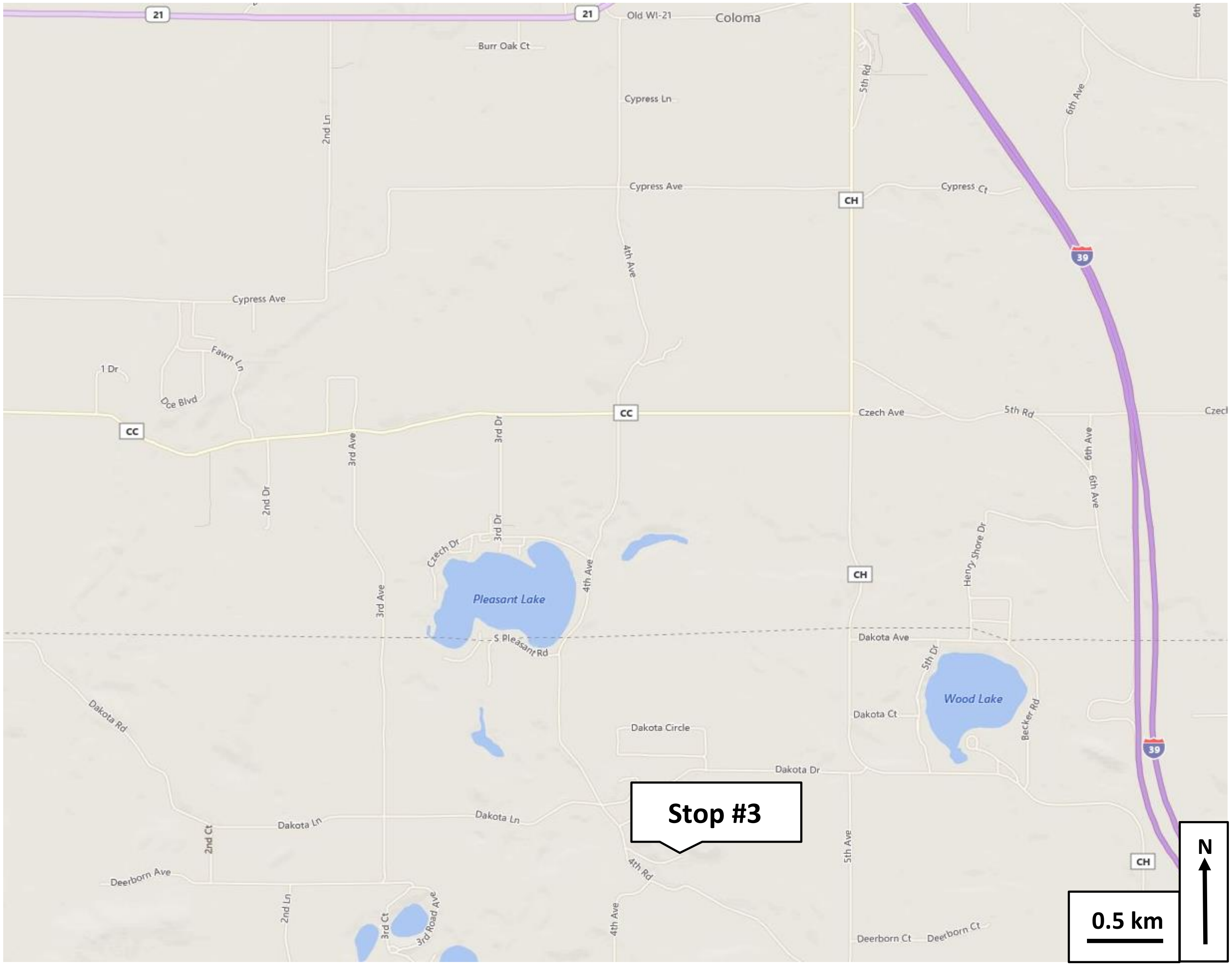


Figure 1: *Map of Pockrandt Quarry that has excavated into the Glover Bluff Impact Crater. The property itself is located in northwestern Marquette County. (http://maps.live.com)*

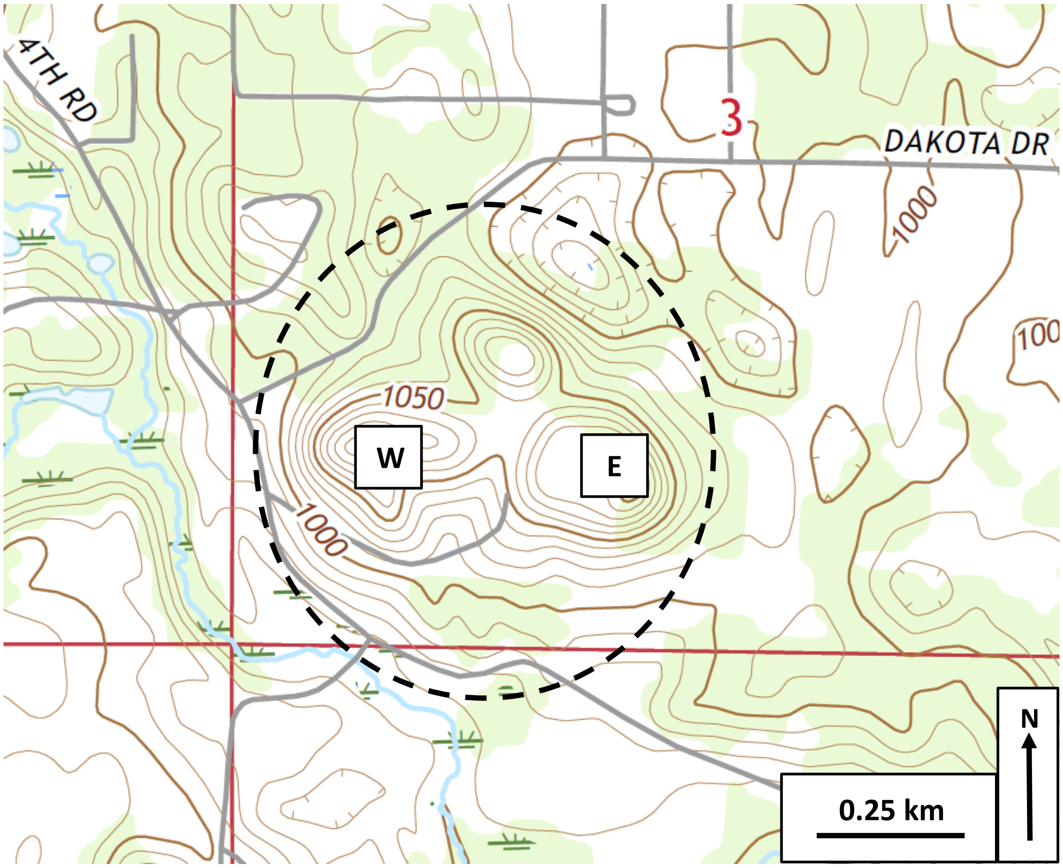


Figure 2*: Close-up of the Westfield West, WI 7.5 Minute Quadrangle Map (2016) showing the topography of Pockrandt Quarry and the surrounding landscape. The three hills described by early researchers are circled with a dashed line. The two modern quarry pits at this site are located in the West Hill (W) and East Hill (E), respectively. This guidebook will focus on the West Quarry in the West Hill.*

Geophysical analysis was finally undertaken here as part of Konen's 1956 Master's Thesis at the University of Wisconsin-Madison. Although localized gravity and magnetic anomalies were detected and these were associated with the center portion of the structure, Konen concluded that this was the result of graben faulting instead of the syncline proposed by Ekern and Thwaites. Today, quarrying has revealed the presence of a plunging syncline at this site, which is partially-exposed in the West Quarry.

Read (1983) was the first to report the discovery of shatter cones at Glover Bluff, thus establishing the site as one of meteorite impact. Subsequent investigation in the Ordovician-aged St. Peter Sandstone resulted in the discovery of impact bombs containing uncrystallized glass (Read, 1985), which suggested a date of impact around 460-470 million years ago and an estimated crater size of 10 km (United States Meteorite Impact Craters, n.d.). The minimum date of impact was provided by Earnst and Paulsen (2011). They studied changes in calcite grains located in the crater site and compared those to calcite grains found in the region as a result of the Alleghenian orogeny in the Late Paleozoic. Their conclusion was that the meteorite impact likely occurred prior to the Alleghenian orogeny (260 million years ago). In 2011, the Wiscah Geologic LLC completed a geologic evaluation of the site and interpreted that the geological float material found at the site was not glacial debris as has been concluded in 1930, but instead was ejecta from an extraterrestrial impact (Renard, 2011). Today, the size of the impact crater is estimated to be 8-10 km in diameter and the timing of the impact was refined to be 485-260 million years ago (Figure 3) (United States Meteorite Impact Craters, n.d.).

Figure 3: *The approximate location of the impact crater as mapped by United States Meteorite Impact Craters (http://impactcraters.us/glover_bluff_wisconsin). Although eroded and only partially exposed, the impact crater is estimated to be 8-10 km in diameter. Location of dashed line based on their data. (http://maps.live.com)*

__Figure 4:__ Northwest wall of West Quarry. Uppermost rocks in the wall are from the Ordovician System (Prairie du Chien Formation.) and transition to the Cambrian System (Jordan Sandstone) with depth. Some carbonate units toward the top of the exposure appear to steeply dip toward the viewer, which is opposite of the dip direction of the fold. (Marked with an arrow.) This may be evidence of disruption via impact. (Image credit: Beth A. Johnson.)

Geology: Quarrying activity at the site has resulted in two different pits, referred to as the West Quarry and East Quarry (Figure 3). For the purposes of this trip, all observations are confined to the West Pit.

The stratigraphy visible in the quarry consists of the Cambrian-aged Jordan Sandstone overlain by the Early Ordovician Prairie du Chien Formation (Figure 4). Both of these units are part of the Sauk Transgression during the Early Paleozoic. Subsequent reverse faulting and folding have deformed these units, creating a plunging fold sequence of an anticline and adjacent syncline. These folds are visible in the northwest wall of the West Quarry (Figure 5). Based on dipping layers exposed in the northeast wall, the fold appears to plunge at an angle of 10° in the direction of 308°. Evidence of faulting can be found in the form of slickensides. Slickensides have been found in pieces of carbonate rock in the lowest part of the West Quarry (Figure 6).

Shatter cones and impact breccia are both found in the West Quarry. Although not common, shatter cones can be found on pieces of Ordovician-aged dolomite (Figure 7). These structures are the result of high velocity impact and can be found at many known meteorite impact sites. The shatter cones in this dolomite are more susceptible to weathering and do not appear as detailed as those collected at other sites. The effects of the meteorite's impact on the underlying Cambrian sandstone was different than on the dolomite. Although much of the ejecta from both units was combined to create impact breccia, the immense heat associated with the impact also metamorphosed some of the sandstone, creating highly-crystalline quartzite in a variety of colors. Some quartzite displays flow structures as a result of the impact heating.

Figure 5 (Above): *Asymmetrical syncline in the northwest wall of the West Quarry. The syncline plunges at an angle of 10° in the direction of 308°.*

Figure 6 (Left): *Slickensides in a piece of carbonate rock.*

__Figure 7:__ Possible weathered shatter cones visible in carbonate rock, Ordovician in age. Because of the ease of dissolution of the carbonate, the shatter cones can often be weathered at this site and harder to identify. (Image credit: Beth A. Johnson.)

References

Alden, W.C. (1918). Quaternary geology of southeastern Wisconsin. U.S. Geological Survey Professional Paper 106, p. 207-208.

Dott, R.H. & Attig, J.W. (2004). *Roadside Geology of Wisconsin.* Missoula: Mountain Press Publishing, 345 p.

Ekern, G.L. and Thwaites, F.T. (1930). The Glover Bluff structure, a disturbed area in the Paleozoics of Wisconsin. *Transactions of the Wisconsin Academy of Science, Arts, and Letters*, *25*, p. 89-97.

Konen, K.H. (1956). Geophysical studies in south central Wisconsin. Unpublished Master's Thesis, University of Wisconsin, Madison, 44 p.

Read, W.F. (1983). Shatter cones at Glover Bluff, Wisconsin. *Meteoritics*, *18*, no. 3, p. 241-243.

Read, W.F. (1985). Impact bombs in Middle Ordovician marine sediments of southeastern Wisconsin. *Abstracts of the 16th Lunar and Planetary Science Conference*, p. 687-688.

Renard, G.M. (2011). Ejecta strata of recent origin have been identified in Central Wisconsin at Glover Bluff Impact Site. *Geological Society of America Abstracts with Programs, 43,* no.5, p. 306.

United States Meteorite Impact Craters (n.d.). Glover Bluff crater, Wisconsin. Accessed on June 30, 2017 at http://www.impactcraters.us/glover_bluff_wisconsin

STOP 4:
SHIP ROCK WAYSIDE
By John Luczaj and Beth A. Johnson

Site: Wayside on WI-21 approximately 13.3 km west of Coloma, WI.

PLSS Location: NE ¼, NW ¼, NW ¼, Sec. 21, T18N, R7E, Coloma SW 7.5 Minute Quadrangle

GPS Coordinates: 44°1'28.71"N, 89°40'30.11"W

Note: This wayside has a trail around the north side of the outcrop. Please note there are no restrooms at this location.

Overview: Examine the rocks here carefully. Look at them with a hand lens. Why might this particular portion of the Cambrian Sandstones be preserved, while areas surrounding Ship Rock are not? Does the outcrop have a preferred orientation?

Background: Several erosional hills known as "castellated mounds" have been recognized in Wisconsin for over a century (e.g., Martin, 1916). Most of these are composed of Cambrian sandstone that has been eroded over long periods of time during the Cenozoic Era. Dozens of these features, such as Roche-A-Cri State Park, Rabbit Rock, Ship Rock, Castle Rock, and others dot the landscape across south-central Wisconsin between Black River Falls, Wisconsin Dells, and Wisconsin Rapids. Dutch (2000) provides an online index of these features.

Dott and Attig (2004) interpret these sandstones as unfossiliferous river deposits formed during the early part of the Late Cambrian (just over 500 Ma). Castellated mounds in this part of the state are interpreted as the remnants of a once continuous sheet of Cambrian

Figure 1: Map of the Ship Rock Wayside on WI Hwy. 21 in Adams County. The parking area and formation are on the north side of the highway only. (http://maps.live.com)

sandstones that extended across the state. Fossiliferous marine strata with vertical tube-like burrows called *Skolithos* are present only in the upper parts of the highest buttes, such as Roche-A-Cri.

Ship Rock is one of the easternmost of the castellated mounds of central Wisconsin (Figures 1 and 2). It is an isolated pinnacle (or butte according to some authors) of Cambrian sandstone that rises about 100 feet above the surrounding terrain. The feature stands just west of the terminal moraine of the Green Bay Lobe near Coloma, Wisconsin. The delicate nature of this and several other castellated mounds requires that the glaciers did not cover these features. In fact, these features were formed by long periods of river erosion, followed by wave erosion in Glacial Lake Wisconsin during the Pleistocene.

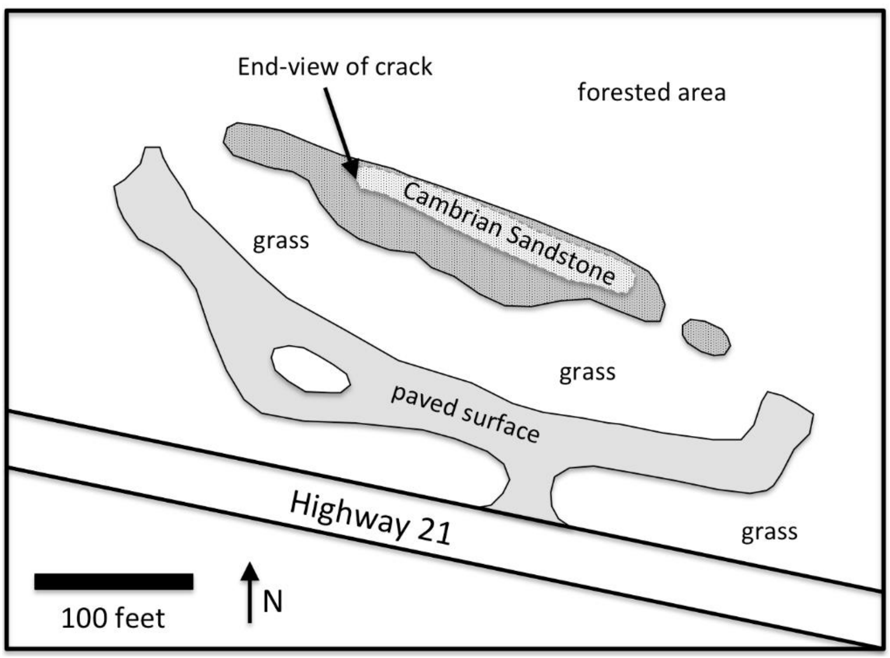


Figure 2. *Map of the Ship Rock Wayside. Stippled areas labeled as "Cambrian Sandstone" outline the area known as Ship Rock. Arrow shows location of large crack seen in the northwest end of the knife-edge pinnacle outcrop.*

Geology: An examination of water well construction reports reveals that the depth to bedrock in nearby wells is typically at least 85 to 115 feet below the surface, indicating that the true relief on this bedrock structure is likely about twice as high as what is exposed today at the surface. The exposed section of Cambrian sandstone is about 100 feet high and 250-300 feet long, but only about 30 feet wide, making this more of a “knife-edge” pinnacle than a “mound” or “butte”.

Several interesting observations can be made that prompt questions about Ship Rock.

1. Why is Ship Rock so linear, and why is it located at this specific place?

The long axis of Ship Rock trends at about 290°, which is similar to some of the northwest-trending structures in the Precambrian basement in northern Wisconsin, but little is known about the orientation of bedrock joints in this part of south central Wisconsin. One clue can be seen along the western side of the outcrop (Figure 3). Notice the prominent vertical cracks that run up the central axis of Ship Rock. Typically, fractured rock is weaker and more susceptible to weathering and erosion, but the castellated mounds are *more resistant* to erosion than the sandstone that once surrounded them. Roche-A-Cri butte also shows a major vertical crack that can be seen along the south side of the mound. Because the mineralogy of the sandstone is principally quartz, there must be something about the cementation of the rock that is variable.

Figure 3*. Prominent vertical cracks run up the central axis of Ship Rock. It is counter intuitive that vertical cracks would produce a resistant rock formation such as ship rock, but this fracture likely conducted silica-rich solutions that cemented the quartz sandstone on either side, making Ship Rock a more durable part of the bedrock that could withstand erosion. (Image credit: John Luczaj)*

Another clue can be seen by examining the outcrop during a bright sunny day. The sand grains in the outcrop glisten in the sunlight (you can see bright tiny reflections that only appear in one eye and not the other). These glistening grains are reflective surfaces of quartz crystals in the sandstone (Figure 4). The sandstone at this location is well cemented by quartz and was probably more resistant than the sandstone that once surrounded it that has been eroded. Precipitation of minerals is commonly observed near vertical fractures or faults that can conduct solutions capable of cementing bedrock. In the case of Ship Rock, the quartz cement near the vertical fracture system was more effective at holding the sandstone together than the fracture was at acting as a locus of weathering and erosion. In many parts of eastern Wisconsin, the Cambrian Sandstones are very poorly cemented, but areas near faults and fracture zones have sometimes resulted in poor well yields due to cementation by various minerals.

In fact, it is well documented that multiple episodes of diagenesis have affected the Paleozoic sedimentary rocks in Wisconsin (e.g., Luczaj et al., 2016). Some of these involved precipitation of quartz in sandstones and carbonate rocks in the region.

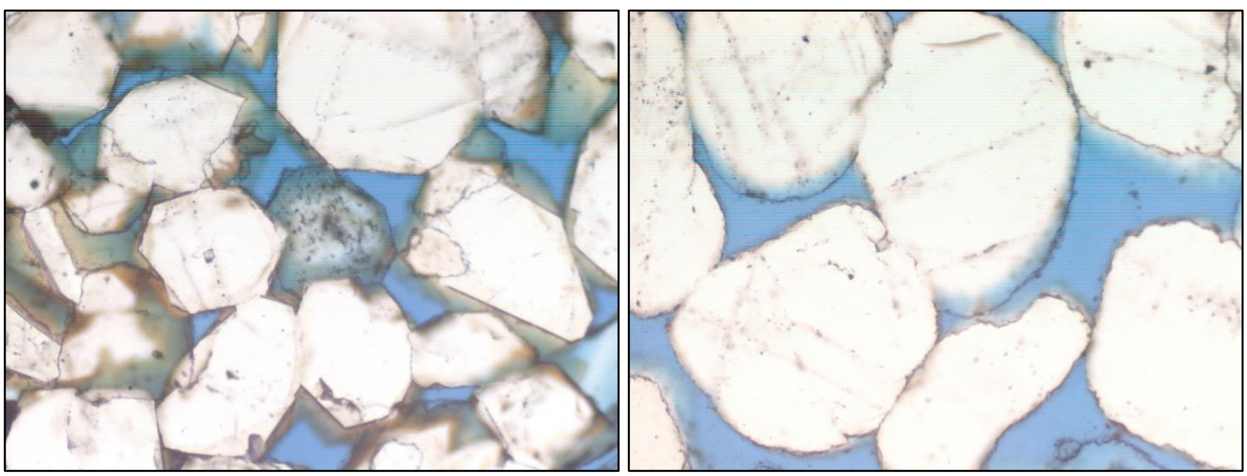


Figure 4. Left: *Thin section from near the fracture showing obvious euhedral quartz overgrowths on detrital quartz grains that serve as tiny mirrors for sunlight on broken rock surfaces. This results in a glistening effect on a sunny day.* ***Right:*** *Thin section from sample farther from fracture showing little quartz cementation. Images are courtesy of Tyler Hischke.*

2. What are the interesting patterns preserved in the rocks?

Several unrelated features are present that are worth noting. The main depositional features preserved are tabular and trough cross-stratification. This sedimentary structure was produced by water currents, likely those from river systems during the Late Cambrian as sea level encroached on the region (Dott and Attig, 2004).

The unusual pattern of depressions and ridges that can be seen on the vertical rock surfaces are a different story (Figure 5). These are the product of differential weathering, most likely due to areas of greater or lesser amounts of mineral cements in the rock. Poorly preserved areas are likely to undergo faster weathering, resulting in loss of sand grains from the surface of the outcrop.

Features that may be unfamiliar to beginning geologists are lichens and microbial growths that cover parts of the outcrop. Lichens are symbiotic growths of fungi and algae that thrive on many rock surfaces and produce green, orange, and black colonies.

Figure 5: *Differential weathering and cross-bedding in the basal sandstone units visible from the north side of the outcrop. (Image Credit: Beth Johnson)*

Questions for thought:

1. In which direction(s) does the cross-stratification indicate that currents were traveling? Does this make sense with where the uplands would be during the Late Cambrian Period?
2. What structures in the Precambrian basement might correspond to this fracture trend?

Surrounding Landscape: Glacial Lake Wisconsin formed as a result of the Green Bay Lobe advancing to its maximum position at the Johnstown Moraine 25,000-30,000 cal. years ago (Mickelson et al., 2011). The location of the moraine and the outwash deposits associated with it are approximately 8 km east of Ship Rock (Fig. 5). When the lobe reached its terminal extent, it blocked the eastward drainage of the modern-day Wisconsin River near Portage, WI, on the east end of the Baraboo Hills, causing the flow to back up and great a lake that covered 4,600 km^2 at its maximum extent with a depth of up to 46 m (150 ft.) (Schultz, 2004). Castellated mounds such as Ship Rock would have stood as islands in the massive lake, with smaller mounds submerged. Eventually, the lake filled to the level of the East Fork of the Black River on the northwestern edge of the lake and began to drain. Later, after the retreat of the Green Bay Lobe from the Johnstown Moraine and the opening of a lower drainage path around the east end of the Baraboo Hills, the lake was able to break through a fragile ice dam and drain catastrophically down the Wisconsin River, famously creating the Wisconsin Dells (Mickelson et al., 2011).

The area that was once covered by Lake Wisconsin is today known as the Central Sand Plain, so named for its relatively flat landscape and sandy soils. Sediment carried into the lake by stream drainage, outwash from the Green Bay Lobe, and even weathering of the castellated mounds by wave action resulted in nearly 100 m of sand and silt deposits (Dott and Attig, 2004). After drainage of the lake, some of the surface sands were blown into small dunes by prevailing winds, averaging between 1-3 m in height.

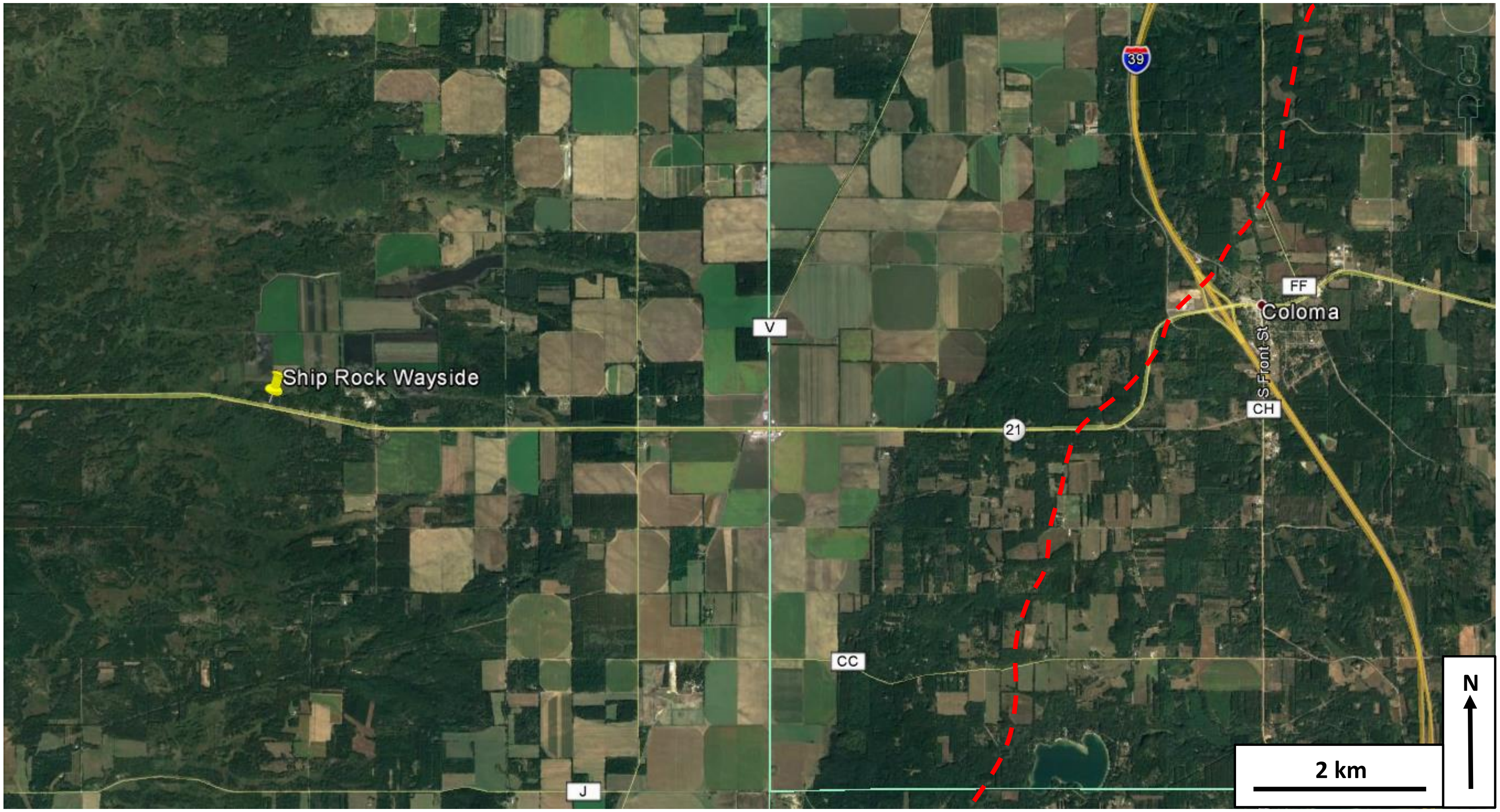


Figure 5: *Map of the Ship Rock Wayside, 13.3 km west of Coloma, WI in Adams County. The circular agricultural fields in this image are due to the use of center point irrigation and can be used to infer the presence of sandy soil. Much of the sandy soil visible here was deposited at the bottom of glacial Lake Wisconsin. Castellated mounts such as Ship Rock would have stood as islands in the lake. The location of the Johnstown Moraine is marked with a dashed red line. Outwash sands and gravel extend westward from the moraine until they intersect with the agricultural fields of the lake plain. (Google Earth)*

References

Dott, R.H. & Attig, J.W. (2004). *Roadside Geology of Wisconsin.* Missoula: Mountain Press Publishing, 345 p.

Dutch, S.I., 2000, Castellated Mounds of Central Wisconsin. Accessed on September 26, 2017. Available Online: https://www.uwgb.edu/dutchs/GeologyWisconsin/GEOSTOPS/CastMounds.HTM

Martin, L., 1916, The Physical Geography of Wisconsin. Wisconsin Geological and Natural History Survey, Madison, Wisconsin, 549 pages. Available Online: http://hdl.handle.net/2027/coo1.ark:/13960/t2g73z540

Mickelson, D.M., Maher Jr., L.J., & Simpson, S.L. (2011). *Geology of the Ice Age National Scenic Trail.* Madison: The University of Wisconsin Press, 395 p.

Luczaj, J.A., McIntire, M.J., Olson Hunt, M.J., 2016, Geochemical Characterization of Trace MVT Mineralization in Paleozoic Sedimentary Rocks of Northeastern Wisconsin, USA, Geosciences, v. 6, no. 2, 29 pages. doi:10.3390/geosciences6020029

Schultz, G.M. (2004). *Wisconsin's Foundations: A Review of the State's Geology and its Influence on Geography and Human Activity.* Madison: The University of Wisconsin Press, 211 p.

STOP 5:
MEYER SAND AND GRAVEL PIT
By Beth A. Johnson

Site: Aspen Ave. approximately 0.45 km west of WI-73, 11.3 km south of Plainfield, WI.

PLSS Location: NE ¼, NE ¼, NW ¼, Sec. 36, T19N, R9E, Plainfield 7.5 Minute Quadrangle

GPS Coordinates: 44°10'13.32"N, 89°22'48.08"W

Note: This pit is operated by Michels Materials.

Background: Meyer Sand and Gravel Pit is located between the Hancock and Almond moraines and exposes the thick blanket of outwash between (Figure 1). Tracing the Johnstown Moraine northward from Coloma, WI, the moraine splits into two separate landforms: the Hancock Moraine to the west and the Almond Moraine to the east. Meyer Pit is located just west of the Almond Moraine. All three moraines were deposited by the Green Bay Lobe during the Wisconsin Episode Glaciation, but according to Mickelson et al. (2011), the exact ages of the Hancock and Almond moraines are unclear. Spatially, it is reasonable to interpret that the Hancock Moraine is older than the Almond because it extended further west as it advanced. However, Mickelson et al. states that the till in the Hancock, Almond, and Johnstown Moraines is very similar and difficult to distinguish from each other save for their geographic locations (2011). The general age of the Horicon Member that makes up these features is poorly defined, with reported maximum ages varying between 26,000-20,000 cal. years and a minimum age predating the formation of the Two Creeks Forest Bed (approx.. 13,100-14,600 cal. yr B.P.)

Geology: Both moraines as well as the Johnstown Moraine contain sediments related to the Horicon Member of the Holy Hill Formation. The diamicton present in the moraines is very sandy, generally containing between 60-80% sand, and contains clasts of a variety of lithologies, with carbonate being in great abundance (Syverson et al., 2011). These clasts and sands were carried away from the glacial margin as outwash.

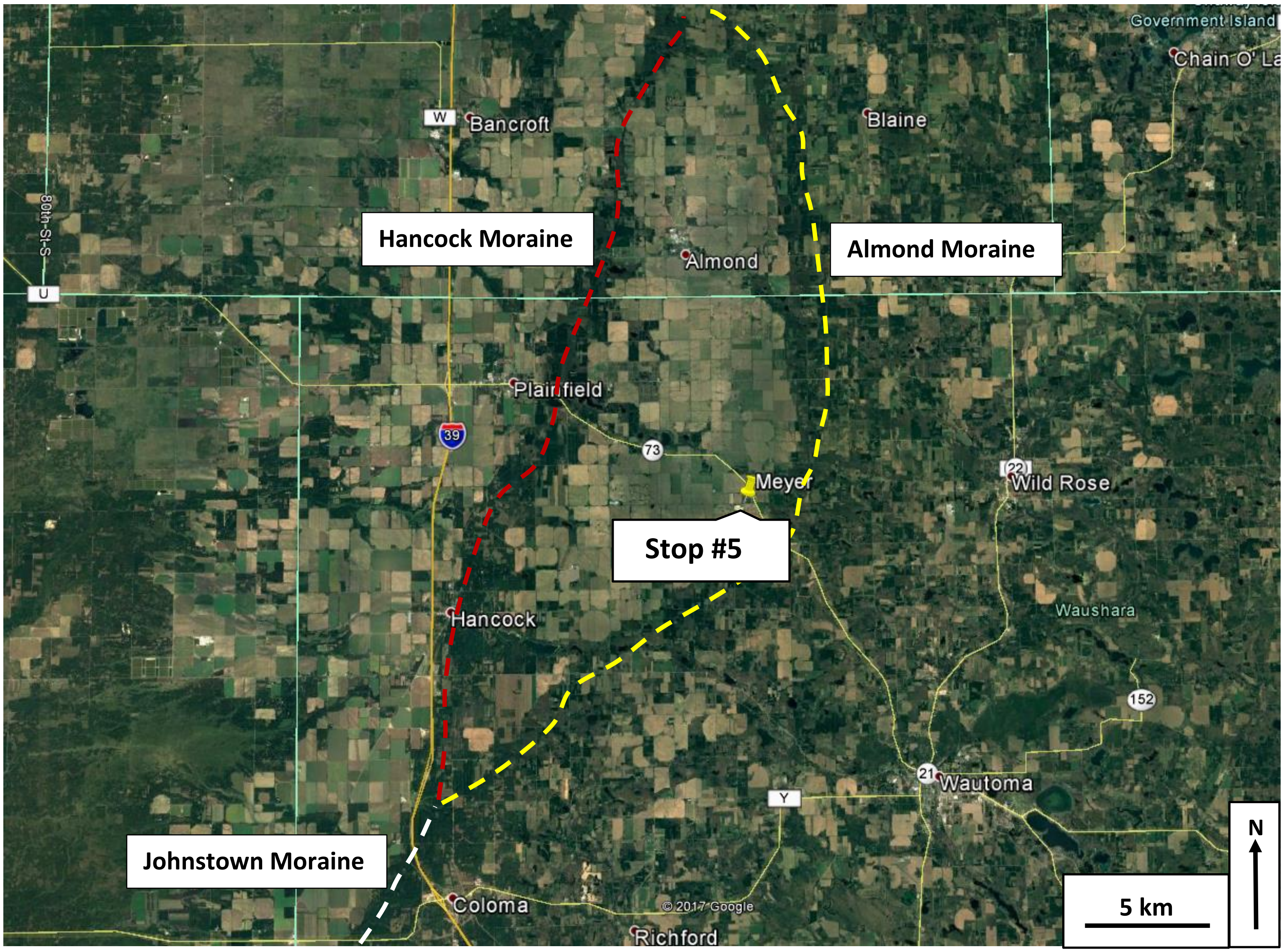


Figure 1*: Map of Meyer Sand and Gravel Pit on Aspen Ave. near Plainfield, WI. This site is in an outwash plain located between the Hancock and Almond Moraines. The approximate location of each of these moraines is marked with a dashed line. (Google Earth)*

The thickness of outwash currently exposed in Meyer Pit is in excess of 15 m. Clasts within the outwash vary in size from sand to boulders and contain a variety of lithologies (Figure 2). Although the quantity of carbonate is often used to distinguish between different glacial materials, it is worth taking the time to examine the lithologic diversity of materials, which include gneiss, schist, sandstone, greenstone, porphyritic rhyolite, breccia, basalt with glomeroporphyritic plagioclase laths, and several varieties of granite (including Wisconsin red granite, the state rock). Some of these lithologies can be used to trace the flow path of the Green Bay Lobe as it was moving from the north. For example, the basalt with glomeroporphyritic plagioclase laths (informally known as "daisy stone") is found both in the Keweenaw Peninsula of the Upper Peninsula of Michigan as well as the eastern part of Lake Superior. The Keweenaw would fall right in the flowpath of the Green Bay Lobe.

Figure 2: *Boulder pile in Meyer Pit that shows the diverse lithology found in the outwash. Common lithologies include carbonates, granites, schists, sandstones, and rhyolites. The field book is 19 cm tall and 11.5 cm wide for scale. (Image credit: Beth A. Johnson.)*

***Figure 3:** A cobble of basalt with glomeroporphyritic laths of plagioclase feldspar. This type of basalt is found in the central part of the Keweenaw Peninsula and around the eastern part of Lake Superior, indicating a possible flow path for the glacial ice (Image credit: Beth A. Johnson.)*

The landscape around the sand and gravel pit is reflective of the underlying outwash. The agricultural fields surrounding the site contain very sandy soil and irrigation systems are common. West of the intersection of 11th Dr. and Aspen Ave., the land surface is very flat, so much so that both the Hancock and Almond moraines are visible in the distance. East of that intersection, closer to the site of Meyer Pit, the land surface has a few small rises no more than 1-2 m in height. These rises are sand dunes created from outwash sand reshaped by prevailing winds.

References

Mickelson, D.M., Maher Jr., L.J., & Simpson, S.L. (2011). *Geology of the Ice Age National Scenic Trail.* Madison: The University of Wisconsin Press, 395 p.

Syverson, K.M., Clayton, L., Attig, J.W., & Mickelson, D.M., eds. (2011). *Lexicon of Pleistocene Stratigraphic Units of Wisconsin.* Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

STOP 6 (SUNDAY – OPTIONAL):
CACTUS ROCK (POPPY'S ROCK STATE NATURAL AREA)
By Beth A. Johnson

Site: Bean City Road, 0.8 km (0.5 mi) north of the intersection with Manske Road, New London, WI

PLSS Location: SE ¼, NE ¼, Sec. 26, T22N, R14E, Readfield 7.5 Minute Quadrangle

GPS Coordinates: 44°21'8.42"N, 88°45'28.87"W

Note: This site is owned by Lawrence University. Please seek permission of the institution before attempting to access the site. If vandalism is observed, please contact Lawrence's Facilities Management staff. Also, as the granite has been polished by advancing glaciers, the surface of the pluton can be extremely slippery when wet, so use caution when accessing the site after rain.

Background: Cactus Rock (historically known as Poppy's Rock after a former landowner) is a Precambrian granitic outcrop that would be interesting in its own right for the geology is displays (Figure 1). However, this site is also the home of an unusual assemblage of plant species, which changes with exposure, inclination of the rock, and humus content. Bare rock species can include spikemoss and an assortment of lichens, crevice species can include prairie vegetation such as prairie coreopsis and wild white indigo, and areas with thick accumulations of humus can include tree species including cedar, big-tooth aspen, jack pine, and shagbark hickory, among others. This location was designated a State Natural Area in 1996 (Wisconsin State Natural Areas Program, n.d.).

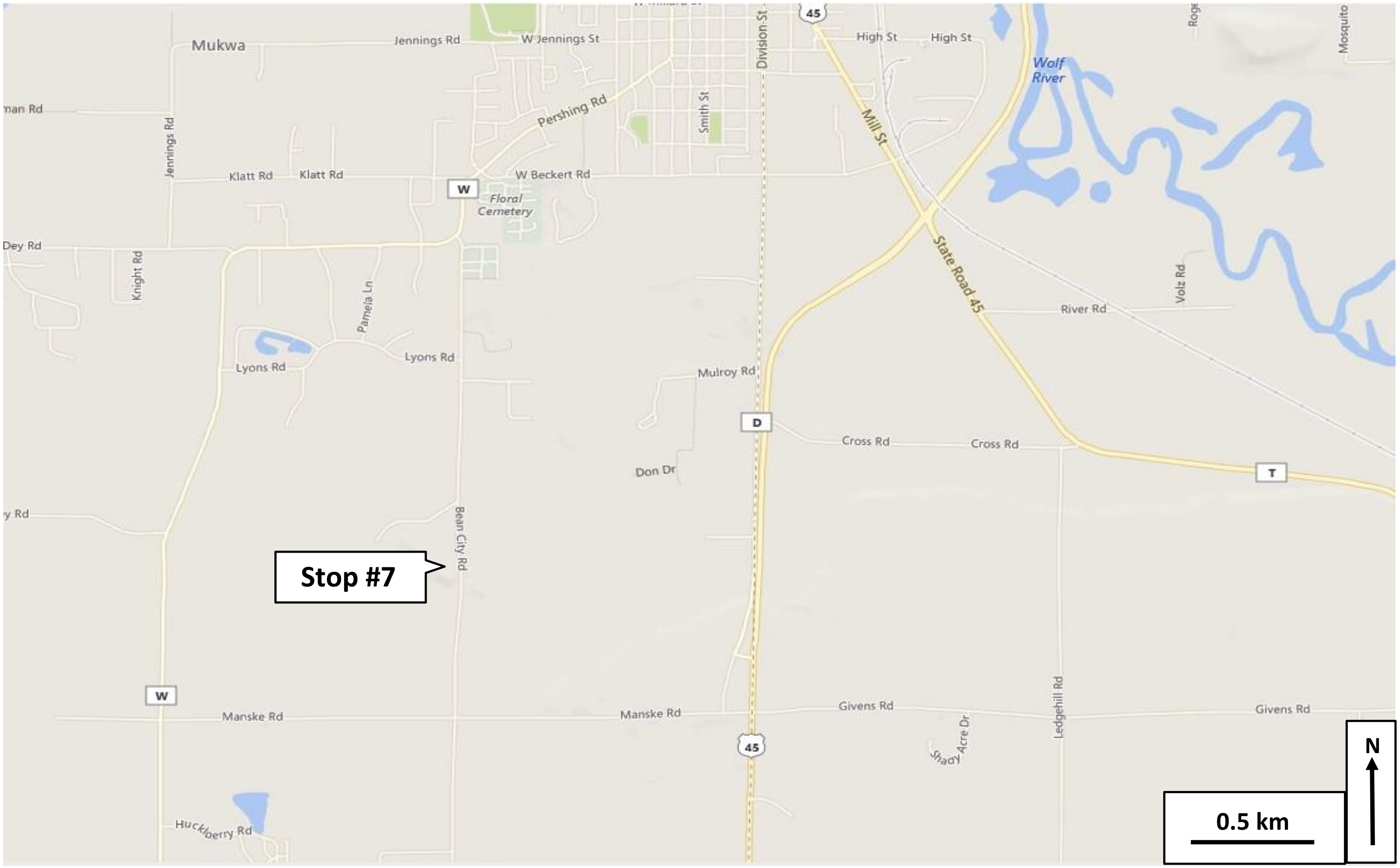


Figure 1: *Map of eastern Waupaca County and northwestern Outagamie County showing the location Cactus Rock (a.k.a. Poppy's Rock State Natural Area). There is a pullout visitors can use on the west side of Bean City Rd., approximately 0.8 km north of the intersection with Manske Rd. The site is south of New London, WI, shown at the top of the map. (http://maps.live.com)*

The reason the site's name has changed to Cactus Rock is because the site contains growths of the wild cactus *Optuna fragilis*, often found in mossy crevices near the top of the exposure (Figure 2). Also known as the Brittle Prickly-pear, *O. fragilis* is often found in locations with thin, dry soil over bedrock as well as in sand prairies. Although native to much of western North America, the cactus is also found in Upper Midwestern states such as Wisconsin, Illinois, Iowa, and Michigan as well as several Canadian provinces. It is listed as a Threatened Species in Wisconsin (Wisconsin Department of Natural Resources, n.d.).

Figure 2: *A small cluster of* Optuna fragilis *cacti in a crevice at the top of Cactus rock. (Image credit: Beth A. Johnson.)*

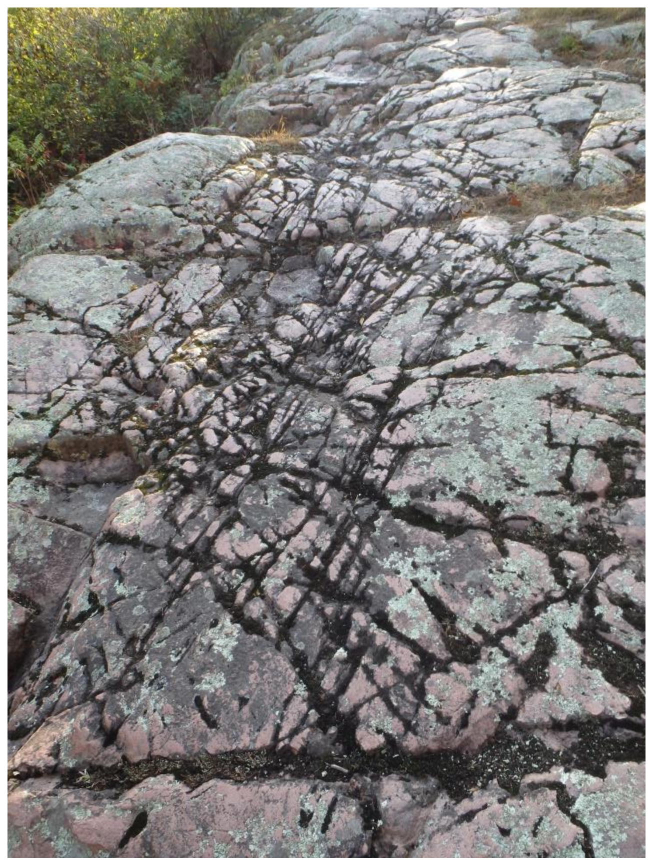
Geology: The outcrop at Cactus Rock is one of the Precambrian inliers found in central Wisconsin. This particular inlier is acknowledged as the easternmost Precambrian outcrop in east-central Wisconsin (Dutch, 2015). Likely part of the same suite of granitic and rhyolitic rocks emplaced 1.76 Ga near Redgranite, the dominant minerals composing this granite include quartz and alkali feldspar, with subordinate minerals including biotite, hornblende, muscovite, sphene, and zircon (Smith, 1978). Although heavily polished by glacial action, there are some places where fresh exposures of the granite can be seen. The majority of the minerals visible are alkali feldspar with smaller quantities of quartz. There is a long quartz dike approximately 2.5 meters long and up to 2.5 cm wide cutting through the eastern part of the exposure with a bearing of 090° stretching for 3 m (Figure 3) and at least one other smaller quartz dike can be found in lower exposures of granite along the path up from Bean City Rd. There are several other smaller quartz dikes near the top and east end of the pluton, many of which have been subsequently fractured and offset.

__Figure 3:__ A quartz dike cutting through the granite. The contact between the dike and the granite is sharp and distinct. One end of the dike has two boreholes from past research, not undertaken for this conference. (Image credit: Beth A. Johnson.)

Due to a combination of weathering and glacial erosion, the surface of the granite pluton is heavily jointed (Figure 3). Dutch observed that joints at the site fell into one of three main sets based on bearing: 30°, 115°, and 155°, with those following the bearing of 115° roughly parallel to the trend of the outcrop and possibly controlling the overall shape of the outcrop (2015). Joints often occur in clusters, with individual joints spaced only a few centimeters apart in an overall grouping that is only a few meters wide. Some joints show multiple minor offsets, some as much as 2-3 cm.

The Green Bay Lobe of the Laurentide Ice Sheet flowed over this area during the Wisconsin Episode Glaciation and the site would have been covered by several hundred feet of glacial ice when the lobe had reached its position at the Johnstown Moraine by 23,500 cal. years ago (Mickelson and Attig, 2017). The overall shape of the outcrop as well as features on the surface of the granite provide several pieces of evidence that not only show how the granite was shaped by the glacier, but provide data indicating the direction of ice flow. The topographic map in Figure 4 shows the overall shape of Cactus Rock and how the northeast slope has a long, gentle slope whereas the southwest slope has a shorter, steeper slope. This corresponds to the known axis of the Green Bay Lobe of 220°.

Figure 3: *View looking at the complex joint pattern on the east end of the Precambrian inlier. Weathering and the weight of overlying glacial ice has resulted in a heavily fractured body. (Image credit: Beth A. Johnson.)*



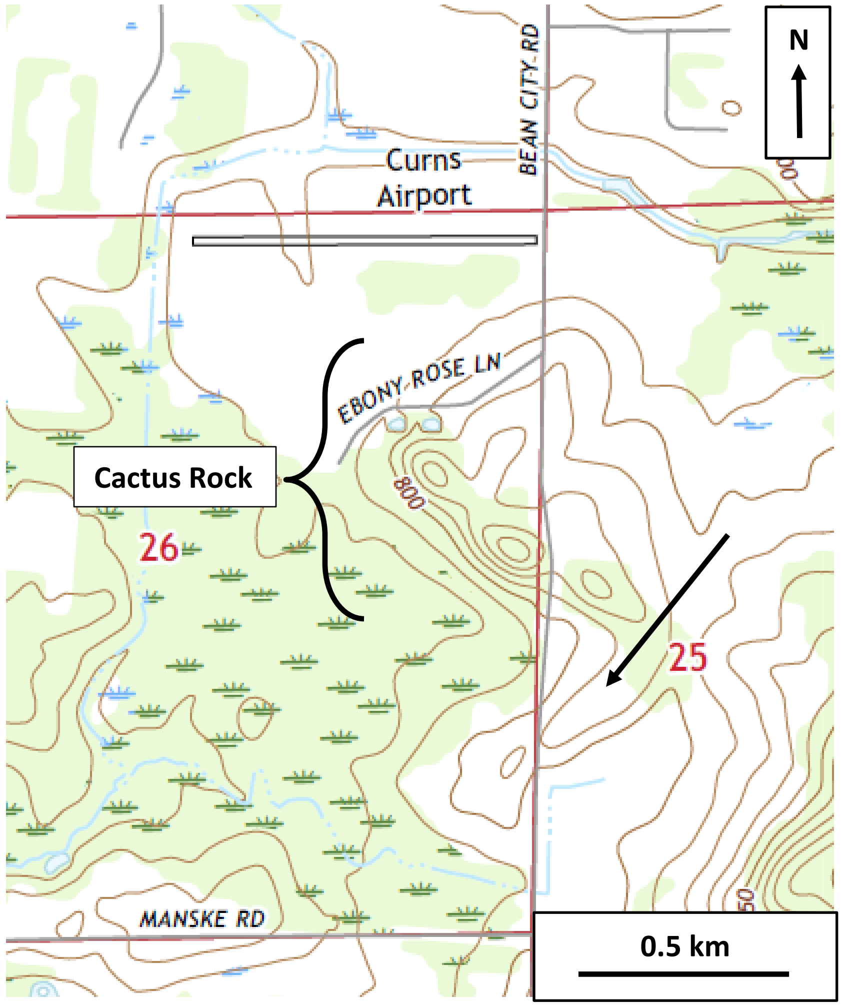


Figure 4: *Close-up of the Readfield, WI 7.5 Minute Quadrangle Map (2016) showing the topography of Cactus Rock and the surrounding landscape. As the Green Bay Lobe advanced during the Wisconsin Episode Glaciation, the overall direction of flow was 220°. This is reflected in the shape of the outcrop, which has a gentler northeast slope, pointing up-ice, and a steeper southwest slope, pointing down-ice. The arrow indicates a low-relief deposit of glacial debris, possibly deposited on the lee side of the outcrop as the base of the glacial ice was diverted around the obstruction. It is approximately 0.5 km long. The arrow is oriented to match the direction of glacial flow.*

Because of its bedrock composition, asymmetrical shape, and glacial erosion, Cactus Rock is a good example of a roche moutonnée. The northeast side of Cactus Rock (the stoss side) displays numerous examples of glacial polish, striations/grooves, and concentric chatter marks denoting multiple instances of glacial motion (Figures 5 and 6). The southwest side (the lee side) is slightly steeper, having been quarried while the basal ice was moving over and around the granite. And, with an elevation of approximately 10 m, it fits into Benn and Evans' size criteria of roches moutonnées ranging in size from 1 m to hundreds (1998).

The chatter marks in particular indicate multiple glacial flow directions at the site. Chatter marks visible at the east end of the exposure demonstrate two flow directions: 220° and 281° (Figure 5). Dutch (2015) hypothesizes these indicate different directions of movement show how the direction of ice flow in the Green Bay Lobe was changing over time. The earlier set of chatter marks (bearing 281°) formed when the lobe was expanding WNW from its central axis. The second set (bearing 220°) formed when the lobe had reached its full lateral extent and the direction of ice flow was largely along its long axis. These chatter marks have been determined to be concentric, with the ends of the crescent-shaped fracture pointing down-ice.

Figure 5: *Glacial polish and concentric chatter marks on exposed granite. The chatter marks at this location display two directions of glacial flow: 281° and 220°. Arrows next to the chatter marks have been added for clarity and to denote direction of flow. (Image credit: Beth A. Johnson.)*

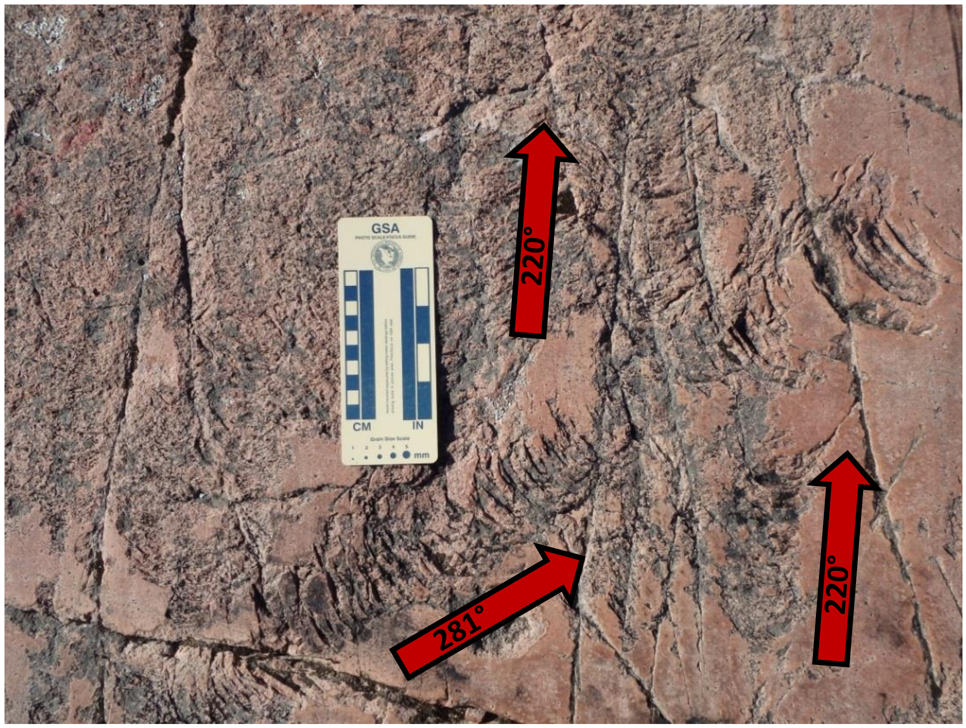


Figure 6: *Glacial polish and grooves on the upper part of the exposed Precambrian granite. Also visible are some concentric chatter marks just above the ruler in the image. The chatter marks at this location display glacial flow in the direction 220°. (Image credit: Beth A. Johnson.)*

References

Benn, D.I. & Evans, D.J.A. (1998). *Glaciers and Glaciation.* London: Arnold (Hodder Headline Group), 734 p.

Dutch, S. (2015). Cactus Rock. Originally created in 1999, revised in 2015. Accessed on Sept. 25, 2017 at https://www.uwgb.edu/dutchs/GeologyWisconsin/geostops/CACTROCK.HTM

Mickelson, D.M. & Attig, J.W. (2017). *Laurentide Ice Sheet: Ice-Margin Positions in Wisconsin, 2nd Ed.* Wisconsin Geological and Natural History Survey Educational Series 56, 46 p.

Smith, E.I. (1978). Granite and related intrusions at Flynn's Quarry County Park, *in* Smith, E.I., Paull, R.A., and Mudrey, M.G., eds., *Precambrian Inliers in South-Central Wisconsin*, Wisconsin Geological and Natural History Survey Field Trip Guidebook No. 2, 90 p.

Wisconsin Department of Natural Resources (n.d.). Brittle Prickly-pear (*Optuna fragilis*). Accessed on Sept. 25, 2017 at http://dnr.wi.gov/topic/EndangeredResources/Plants.asp?mode=detail&SpecCode=PDCAC0D0H0

Wisconsin State Natural Areas Program (n.d.) Poppy's Rock (No. 43). Accessed on Sept. 25, 2017 at http://dnr.wi.gov/topic/Lands/naturalareas/index.asp?SNA=43

STOP 7 (SUNDAY – OPTIONAL):
MOSQUITO HILL NATURE CENTER
By Beth A. Johnson

Site: Rogers Rd. off County Hwy. S, 1 km east of New London, WI

PLSS Location: SE ¼, Sec. 17, T22N, R15E, New London 7.5 Minute Quadrangle

GPS Coordinates: 44°22'52.17"N, 88°42'26.23"W

Note: The interpretive center at this site is open every day save for Mondays and Holidays and contains exhibits about the site's nature and history.

Background: Once quarried for dolomite to use for construction purposes and road fill, Mosquito Hill is now the site of a popular nature center with trails leading around and up the hill as well as along a restored prairie and down to the floodplain of the Wolf River (Figure 1). It is also a great place to take introductory geology students for field trips to see a variety of geological features in one small area, including sedimentary rocks, igneous rocks, mass wasting, and an oxbow lake.

Geology: Mosquito Hill is one of several erosional hills in eastern Waupaca and northwestern Outagamie counties, locally described as mesas, which can be seen dotting the landscape. These mesas generally consist of Cambrian sandstone covered with a resistant dolomite caprock. The mesas have been streamlined by glacial action when the Green Bay Lobe flowed through the region during the Wisconsin Episode Glaciation.

Figure 1: *Map of northwestern Outagamie County showing the location of Mosquito Hill Nature Center. The property the nature center sits on is along the Wolf River Floodplain and includes an oxbow lake that was formerly a meander loop of the Wolf River. The nature center is east of New London, WI, shown on the left side of the map. (http://maps.live.com)*

Figure 2: *Cambrian sandstone from Jordan Formation exposed along the north side of Mosquito Hill at the switchback in the Overlook Trail. No fossils or sedimentary structures are evident in the visible portions of the outcrop, though there is a high density of moss covering the exposure. (Image credit: Beth A. Johnson.)*

The base of Mosquito Hill consists of Cambrian-aged sandstone from the Van Oser Member of the Jordan Formation, deposited during the Sauk Transgression. This sandstone not well exposed along the trail, though one large outcrop is visible along the switchback of the Overlook Trail (Figure 2). Moving up-section, the sandstone gradationally changes over to sandy dolomite, followed by massive dolomite possibly related to the Hager City Member of the Oneota Formation (Prairie du Chien Group, early Ordovician) (Dutch, 2001).

Aside from the sandstone, the Overlook Trail has several features of geologist interest. Several boulders sit along the lower trail, most either granite or sandstone. They serve as useful educational tools for introductory geology students, giving them an opportunity to test their rock identification skills and use the presence of such rocks to hypothesize about what rock type may make up the local bedrock and, if the lithologies don't match, consider possible reasons why. Also present along the same section of trail are several pistol-gripped trees (Figure 3). These and the hummocky topography of the slope are useful visual aids for discussions about mass wasting processes.

__Figure 3:__ Pistol-gripped tree on the north side of Mosquito Hill on the Overlook Trail. Several younger trees in the same vicinity display this sign of creep and the slope in the area has a hummocky topography. (Image credit: Beth A. Johnson.)

Ordovician rocks become visible at the top of the Overlook Trail at the west end of Mosquito Hill (Figure 4). This large exposure, likely the remains of past quarrying, is approximately 10 m in height and contains layers of varying thickness and texture. Most of the lithology visible here is fine-grained dolomite, with occasional layers of coarse-grained sandy dolomite with visible cross-bedding. At least one instance of mudcracks has been discovered on the underside of an overhanging bed of fine-grained dolomite (Figure 5). However, the lithology of the early Ordovician in northeastern Wisconsin can be variable, something apparent near the top of this exposure. Looking toward the top of the exposure, more cross-bedding in a coarse-grained sedimentary rock can be seen. This layer can be accessed more directly by following the unit around to the south side of Mosquito Hill, still following the Overlook Trail. There, the trail rises up so that the layer in question is at approximately eye-level. Close observation reveals that these cross-beds are contained in a layer of coarse quartz sandstone (Figure 6). As the layer reacts with hydrochloric acid, it is likely that a large portion of the sandstone's cement is calcite.

Figure 4: *Early Ordovician rocks exposed in a quarried face at the top of the Overlook Trail on the west end of Mosquito Hill. The primary lithology present is dolomite, but some of the layers are particularly sandy and contain sedimentary structures such as cross-bedding. (Image credit: Beth A. Johnson.)*

Figure 5: *Mudcracks on the underside of a fine-grained dolomite (Early Ordovician). (Image credit: Beth A. Johnson.)*

Figure 6: *Cross-bedded sandstone at the top of the Overlook Trail (southwest side) leading up Mosquito Hill, showing two directions of past streamflow (Early Ordovician). (Image credit: Beth A. Johnson.)*

One of the major rivers that flows through northeastern Wisconsin is the Wolf River. The headwaters of the Wolf River are found in Forest County in the northern highlands of Wisconsin and by the time it reaches the vicinity of Outagamie and Waupaca Counties, it has become a meandering stream. The *Mosquito Hill Nature Center Trail Guide* describes the Wolf as a pre-glacial stream that has always flowed toward the south, but may have originally been part of the Wisconsin River system instead of part of the Fox River system as it is today (2000).

Mosquito Hill is located along the Wolf River and contains part of the river's floodplain within the nature center's property. There are several trails that run both along and across the floodplain, the latter of which are often covered with high water in the spring and can remain underwater for as long as two months (*Mosquito Hill Nature Center Trail Guide*, 2000). One of these trails, the All Peoples Trail, leads down to a former meander loop of the Wolf River named Oxbow Pond. Oxbow Pond is completely cut off from the Wolf River, as seen in Figure 1. The oxbow lake has become very shallow over time, so much so that vegetation grows in the center of the former channel and penetrates the surface of the water. When standing on the observation platform, the water is clear enough to see to the bottom.

Figure 7: *Oxbow Pond, a former meander loop of the Wolf River that has become an oxbow lake. As the lake is in the process of silting up, much of the former channel is choked with grass and the depth to bottom is only a few feet. This particular location is at a platform along the nature center's All Peoples Trail. Part of the former floodplain is visible on the left. (Image credit: Beth A. Johnson.)*

References

Dutch, S. (2001). Mosquito Hill. Originally created in 1999, revised in 2001. Accessed on Sept. 29, 2017 at https://www.uwgb.edu/dutchs/GeologyWisconsin/geostops/MOSQHILL.HTM

Mosquito Hill Nature Center Trail Guide (2000). Prepared by Outagamie Nature Studies, Inc. in 1975, revised in 1982 and 2000.