Field Guide for our "Menominee Adventure"

Field conference of the Michigan Earth Science Teachers Association
With assistance of Wisconsin Society of Science Teachers
August 2-5, 2021

Iron Mountain, Michigan - out to Crystal Falls, Escanaba, Stephenson, NE Wisconsin

Guidebook written and compiled by Dave Chapman[1], John Luczaj[2], Chuck Schepke[3], and Peter Voice[4]

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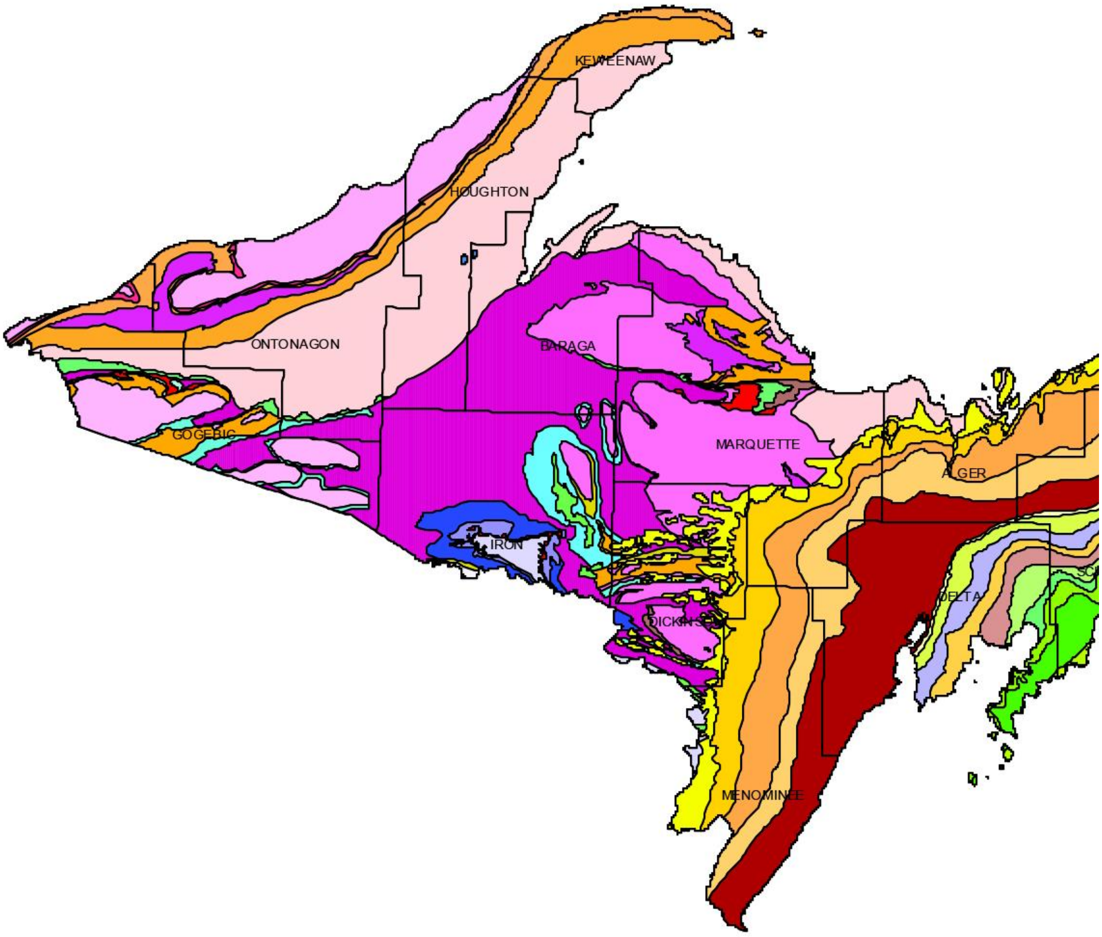


Errata and Other Notes

1. Paper copies of the guidebook erroneously mis-named the Wisconsin Society of Science Teachers as the Wisconsin Science Teachers Association.
2. By a quirk of confusion – the order of stops 2 and 3 were flipped when preparing the guidebook. We recommend that if you plan on recreating parts of this trip that you go to stop 3 first, then go to stop 2. Also note that by September, 2021, Kelly's Rock Shop will have moved locations to downtown Norway.
3. Please note that stops 4, 5 and 18 **require permission from the owners to access**.
4. On page 5, Groveland Mine Road actually intersects M-69 twice – turn right onto the first intersection with Groveland Mine Road.
5. On page 21, the first line of directions ("Drive to Aquila….) erroneously has Turn left onto US-41 (which would send you north instead of south). The direction should be "Turn right onto US-41".
6. On page 22, Pap Jim's Pizza should be Papa Jim's Pizza.
7. The appendices include two publications on Michigan Kimberlites – those publications were not included in this digital version of the document for copyright reasons. They are available to download by the public at:

Cannon and Mudrey, 1981, USGS Circular 842 https://pubs.er.usgs.gov/publication/cir842

Waggoner, 2018, Institute on Lake Superior Geology Annual Meeting Field Trip Guidebook https://digitalcollections.lakeheadu.ca/exhibits/show/ilsg/item/2942 (scroll down to the second document – the Waggoner guidebook chapter starts on pg. 44)

Schedule for Menominee Adventure

Time Stop #

Monday, Aug 2, 2021

[Note for Aug 2nd through the morning of Aug 5th – all times are in CST]

8:30-8:45 Meet at shopping center parking lot: turn south from US-2 at Tractor Supply Company drive (1860 S. Stephenson Ave, Iron Mountain); go to SW corner. Checking in, get group assignment, and drive to east on US-2 to Vulcan, Mi.

9:20 1a Group A goes on **Iron Mountain Iron Mine Tour** (W 4852 US-2 Vulcan, Mi - north side of road with big miner statue)

1b Group B goes to **Kelly's Rock Shop** (W 4789 US-2, Vulcan, Mi - south side of road) When done, go across US-2 to Iron Mountain Iron Mine to visit rock shop.

9:55 Group B starts tour; Group A checks out Mine Shop, then goes across street to Kelly's Rock Shop (W 4789 US-2, Vulcan, Mi)

Stops 1, 3, 4 and 5 – Various locations where the **Vulcan Iron Formation** was mined historically. The Vulcan Iron Formation is the major iron ore in the Menominee-Crystal Falls Range. Iron formation or banded iron formation is a type of chemical sedimentary rock that formed from the precipitation of iron-rich bands followed by silica-rich bands. The iron-rich bands likely started out as some type of iron hydroxide or oxyhydroxide (goethite, limonite, etc.) precursor mineral that has altered over time into iron oxide minerals like hematite or magnetite. Typically, this set of banding is characterized by gray iron-rich bands and red silica-rich bands. The silica has finely dispersed iron mixed within it – forming the variety of silica called Jasper. If other iron minerals are present (iron carbonates, iron silicates, iron sulfides), then the color pattern of the banding may be different.

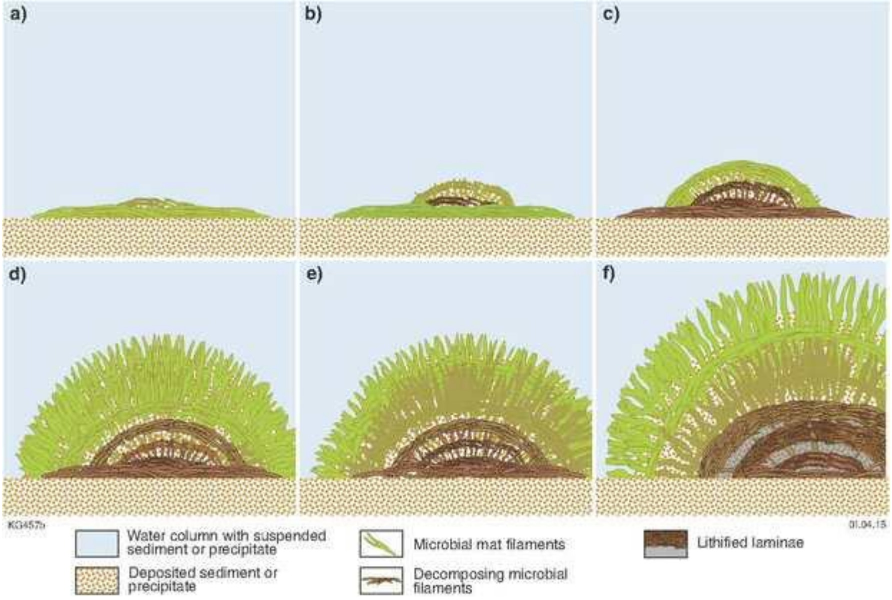
The early Earth's atmosphere was a reducing atmosphere rich in sulfur dioxide and carbon dioxide. The evolution of cyanobacteria (which may have occurred as far back as 3.8 billion years ago) led to a change in atmospheric chemistry, as these photosynthetic bacteria take in carbon dioxide as their carbon source and release oxygen gas as a waste product. By the time the Lake Superior iron formations were precipitated, this process of atmospheric conversion had progressed quite far.

~11:00 2 Both groups when finished drive west on US-2 to **Fumee Falls Park** (north side of road (45.8057N 87.978Wnear Quinnesec)
Observe falls, then climb stairs and note stromatolites in rocks along the walk to the right. [5 min stop]

Stop 2 – Fumee Falls

Fumee Creek flows over an outcrop of the Randville Dolomite just east of the town of Quinnesec along U.S. 2. The Randville Dolomite is named for outcrops of dolomite near the town of Randville north of Iron Mountain. The Randville Dolomite was deposited around the margins of a shallow tropical sea that covered part of the western Upper Peninsula roughly 2.2 billion years ago. The dolomite is technically a dolomite marble as it has been metamorphosed – but the degree of metamorphism is fairly low (chlorite-grade) which allowed the preservation of sedimentary structures like stromatolites.

Stromatolites are a bio-sedimentary structure formed by microbial mats. Most ancient stromatolites are thought to have been grown by cyanobacteria microbial mats – though the few modern stromatolites exhibit consortia of cyanobacteria, other types of bacteria (including various types of sulfate reducers, methanogens, etc. that live in the interior of the structure) and eukaryotic organisms (primarily diatoms). Microbial mats develop at a range of water depths as long as the sea floor is within the photic zone (as the cyanobacteria are photosynthetic and need sunlight to survive) – some even form in the intertidal zone on beaches. The microbial mat has a felt-like texture from the fibrous colonies of cyanobacteria and is also sticky from the secretions of mucous by the microbes. Sediments can be deposited on top of the mat and are cemented to it with the mucous – sedimentation can be due to storm events (more irregular) or tidal activity (more regular). As the microbes need sunlight to survive, they will glide on the mucous to reform the mat at the surface. In modern stromatolites, the organic mucous acts as a binding agent – but this is further enhanced by the chemical microenvironments created by other types of bacteria living in the interior of the stromatolite in more anaerobic portions which then favor cementation via mineral precipitation. This process of mat burial, mat reformation, cementation repeats many times to form a layered structure – the stromatolite.



Model of stromatolite growth (from http://www.dmp.wa.gov.au/Stromatolites-and-other-evidence-1666.aspx).

If the initial mat was composed of isolated clumps, the stromatolite that develops over time is dome-shaped. Domes can coalesce together to form laterally-linked hemispheroidal stromatolites. If the mat was more continuous, then the stromatolites will have sheet-like morphologies. Many paleontologists think that the morphology of a stromatolite might be related to environmental conditions (wave energy, water depth, turbidity); other paleontologists (primarily from the Soviet-block countries) thought that there was some relationship between morphology and geologic time (that stromatolite morphotypes might be index fossils).

Stromatolites are relatively rare in modern oceans – with a few localities around the world where we see them usually being characterized by inclement conditions. At Shark Bay in western Australia, stromatolites are found in hypersaline waters that prevent the grazing of animals like snails and echinoids that would graze on the cyanobacteria if they could live in these waters. Stromatolites are found in tidal channels in the Exuma Cays of the Bahamas – in this case, the water currents are thought to be too fast for the grazing animals to attach to the stromatolites to graze. In the geologic record, stromatolites become much less common starting in the Cambrian – and it is thought that the evolution of grazing animals kept microbial mats from growing to the point where stromatolites develop. Further evidence for this, is that we see resurgence of stromatolites in the early recovery period after each of the major mass extinction events.

References:

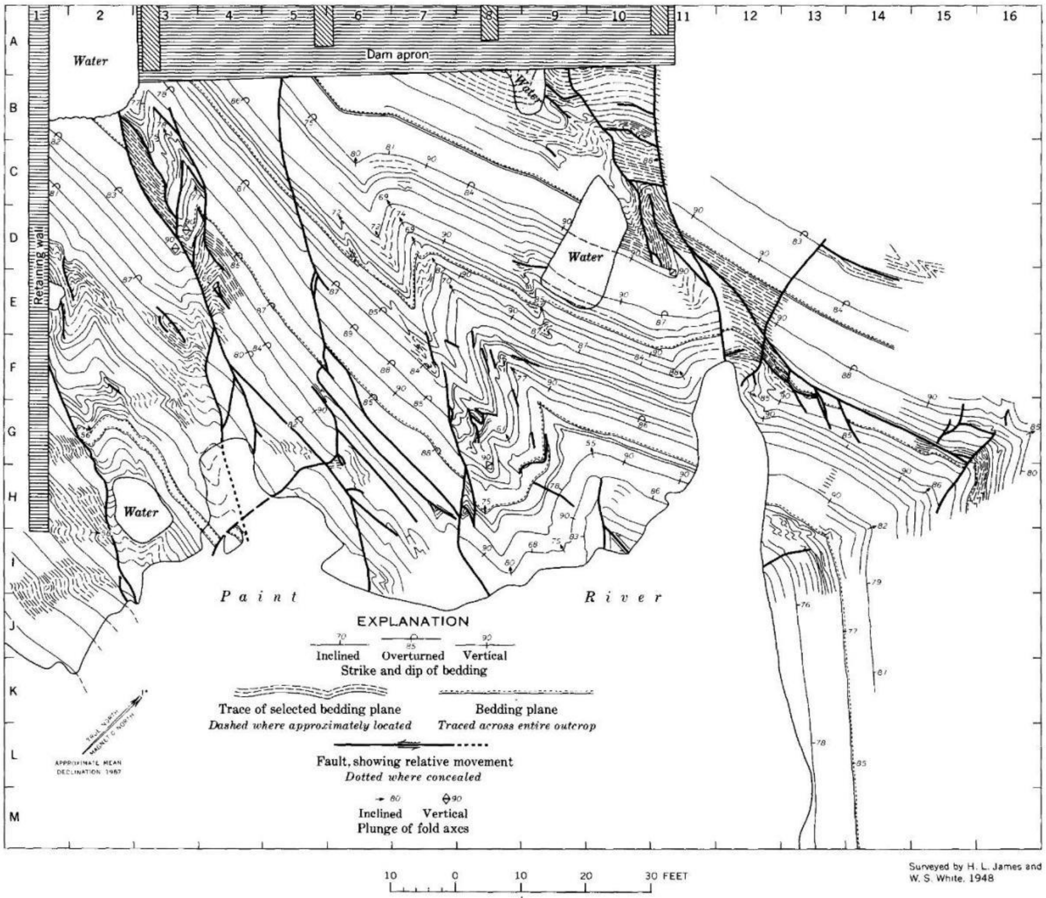
Bekkar, A., Karhu, J.A., and Kaufman, A.J., 2006, Carbon isotope record for the onset of the Lomagundi carbon isotope excursion in the Great Lakes area, North America, Precambrian Research, 148:145-180.

Logan, B.W., Rezak, R., and Ginsburg, R.N., 1964, Classification and Environmental Significance of Algal Stromatolites, The Journal of Geology, 72(1):68-83.

Reid, R.P., Macintyre, I.G., Browne, K.M., Steneck, R.S., and Miller, T., 1995, Modern marine stromatolites in the Exuma Cays, Bahamas: Uncommonly Common, Facies. 33:1-17.
Sousaari, E.P., et al., 2016, New multi-scale perspectives on the Stromatolites of Shark Bay, Western Australia, Scientific Reports, 6, paper 20557, 13 p.
Wohlbaugh, N., and Mancuso, J.J., 1990, Depositional and diagenetic history of the Big Cusp Algal Dolomite, Kona Formation, Marquette Range, Michigan, The Compass, 67(2):84-93.

~11:08		When done at Fumee Falls, continue driving west on US-2 to Norway. Turn north on Main Street. [Note passing Strawberry Lake, collapse site of Argon Mine https://www.mindat.org/loc-123846.html] Continue 0.6 miles to 16th Ave/Pine Creek Road and turn left. Continue to Pearney Lane/District 5 Road and turn left. Then turn left onto Summit Drive (veering to right side of water tower) and stop.
	3	**Norway Mine Tailings Pile**: opportunity to collect samples of iron bearing rock. [5 minutes stop]
11:25		Drive to pick up your own lunch at fast food stops in Iron Mountain on way west.
12:15		Meet along US 2 on north side of Iron Mountain at parking lot of Antoine Room/ Recreation Lane (1555 N. Stephenson Ave., Iron Mountain) Drive to Bacco Quarry taking US-2 north and west toward Crystal Falls (20 minutes) Turn left on 424 Road (note Split Rock Site on right side east of US-2 at turn) and right away park in front of gate to Bacco Quarry.
12:35	4	**Bacco Quarry** (formerly Boone Mine) Here you will find Iron formation and slate, along with beautiful folds in quarry walls. (30 minutes) Can collect.
1:05		Drive west on 424 Road into Alpha, where 424 becomes Main Street. At roundabout, go halfway around and continue on Main Street going west. Turn right (north) onto 7th Ave. which becomes Tobin-Alpha Road. Go 2.1 miles along Tobin-Alpha Road and turn left into driveway 478 (5 min)
1:10	5	**Dunn Mine** - split into two groups: Group A view quarry and learn history of site Group B walks to tailings pile: can collect. Halfway through the two groups switch. (25 + 25 min)
2:10		Drive to Crystal Falls: From Dunn property turn left onto Topin-Alpha Road, back to US-2/US-141. Turn right onto US-2. When in Crystal Falls, turn left onto N 6th St. (Note: S 6th St. Is just ahead on right, followed closely by US-2 taking a sharp job to south) Follow N 6th St., turn right onto Fairbanks Rd and cross bridge over Paint River. Park in Veterans Park on left (10 min drive) Consider gas and bathroom stop if needed in town (10 min)
2:35	6	**Crystal Falls Hydroelectric Plant** - Outcrop of Riverton Iron Formation (Paint River Group) at foot of dam. Note intense folding (15 min.)

Stop 6 – The Crystal Falls Hydroelectric Plant outcrop allows us one more look at the Vulcan Iron Formation. In this case, we can see the intense folding of the unit has produced chevron-folds. Chevron folds have a sharp V-shaped hinge. The sketch below shows the detailed structural deformation that has altered these rocks.



Sketch of the bedding planes (lighter lines) and structural deformation in the outcrop at the Hydroelectric Dam (From James et al. 1968).

References

James, H.L., Dutton, C.E., Pettijohn, F.J., and Wier, K.L., 1968, Geology and ore deposits of the Iron River-Crystal Falls district, Iron County, Michigan, U.S. Geological Survey Professional Paper, v. 570, 134 p.

2:50 Drive to Lake Ellen Kimberlite: Backtrack to US-2. Follow US-2 around jog to south after 6th St. Turn left onto E. Superior Ave/M69 to east. Turn left onto Way Dam Road (see sign for Resort at the intersection- about 9 miles from dam) Continue straight onto Channing Road (Way Dam Rd turns left.) At 6.2 miles turn left at Phelan Rd, right across from "bump" sign. [Phelan road is after Channing Rd takes a right angle turn to east.] At stop sign (junction of Phelan and Davis roads) turn left onto Phelan and continue 0.3 miles. Pull into two-track on right. Walk along two-track up hill to site. (25 min)

3:15 7 **Lake Ellen Kimberlite** - hike in, hear explanation and collect micro-crystals; panning with Cullen Laughlin-Yurs. (45 min) Can collect here.

Here you can see minerals including pyrope garnet (tiny, bright red/pink), ilmenite (black, bladed crystals), and a green mica-like mineral. Xenoliths of Ordovician carbonate rocks can also be found.

The is one of only two formations of Jurassic age found in Michigan.

The appendix to this guide has an in-depth article about this site.

Here are some other references about the site:

https://pubs.er.usgs.gov/publication/ofr83156

https://www.mindat.org/loc-28944.html

https://scholarworks.wmich.edu/cgi/viewcontent.cgi?article=2242&context=masters_theses

4:00		Drive to Groveland Mine: Return to M98 and turn left or east. Follow M69 3.5 miles to junction with south M95 and turn south. Just over 5 miles, when M69 separates to left, follow it. Follow M-69 just over 7 miles to Groveland Mine Road and turn right - onto two track road. (You can see tailings piles ahead on right.) Follow 2 track around bend and downhill. Park near paired mounds. (15 min drive)
4:15	8	**Groveland Mine** - Divide into two groups. Can collect here. *Group A explore* Groveland pegmatites and tailings; quartz, muscovite, feldspar (especially potassium feldspar), black schorl (tourmaline), beryl (sickly yellow green in color) Group B explore formation on ground with Peter Voice. Halfway the two groups switch. (20 + 20 min)

Stop 8 Groveland Mine Pegmatite

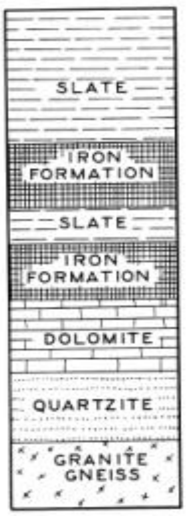
The Groveland Mine site actually had two major zones of activity. West of our stop is the tailing pile and pit of the Groveland Mine where they mined the Vulcan Iron Formation historically. This was one of the last active iron mines in Crystal Falls-Menominee Range and was the only mine in this trend where the taconite pelletization process was used to concentrate lower-grade ore into more useable higher quality product ready for the smelters. The current owners do not want people wandering onto the iron mine site – but have given permission for groups to explore the second part of the site – the Groveland Pegmatite. Pegmatites are coarse-grained igneous rocks thought to have formed in fluid-rich magmas with a low number of nucleation sites for crystal growth – this allowed crystals in the melt to grow significantly larger than is normal. The Groveland Pegmatite is a felsic or granitic pegmatite – so you will see many of the same minerals as in a typical granite – quartz, potassium feldspar, plagioclase feldspar, muscovite, biotite, etc. You will also see some of the accessory minerals at this site (Beryl, Schorl, etc. – these minerals are less common). The Groveland Pegmatite was also mined historically – it was used to make the rock dust in shingles.

Here are mindat's pages for the site and mine:
https://www.mindat.org/loc-125434.html
https://www.mindat.org/loc-11628.html

5:00		Drive back to Iron Mountain: Take M69 west, then left onto M95. Take M95 back to Iron Mountain. (~30 min)
6:00		**Dinner:** announcements, raffle, and couple short presentations (Antoine Room, 1555 N. Stephenson Ave., Iron Mountain - where we met at 12:15 in morning) (1 1/2 hour)

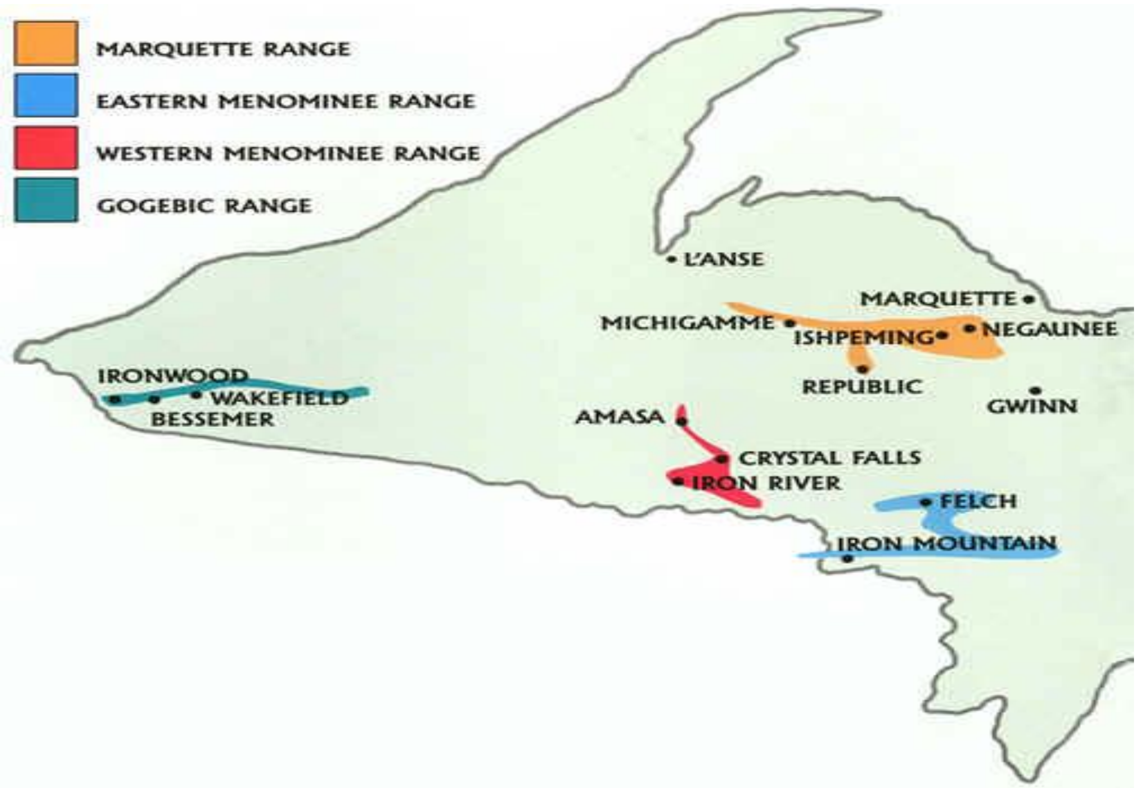
Iron Mining - A Short Summary for this Region

Iron ore deposits are in three of four areas in the Precambrian rocks of the western UP. The map below outlines the locations of Michigan's major iron ranges. These iron ranges are the roots of middle Precambrian mountains that where developed in the Penokean Orogeny 1.88 to 1.83 billion years ago (for more detail, please check your free Stephen Kessler book "4 Billion Years of Geologic History in the Great Lakes Region", Chapter 6).[1] Of the six principal iron ranges, or areas, in the United States of these Precambrian deposits, three are located primarily in Michigan: the Marquette Range, all of which is found within the state, and the Menominee and Gogebic ranges which are in extend from both Michigan and into Wisconsin. "Approximately 40 miles long and 3-10 miles wide, the Marquette Range stretches across the UP from the city of Marquette to a few miles south of L'Anse on the Keweenaw Bay. The Gogebic Range lies partly in Michigan and partly in Wisconsin. It is divided by the Montreal River, a short stream that flows

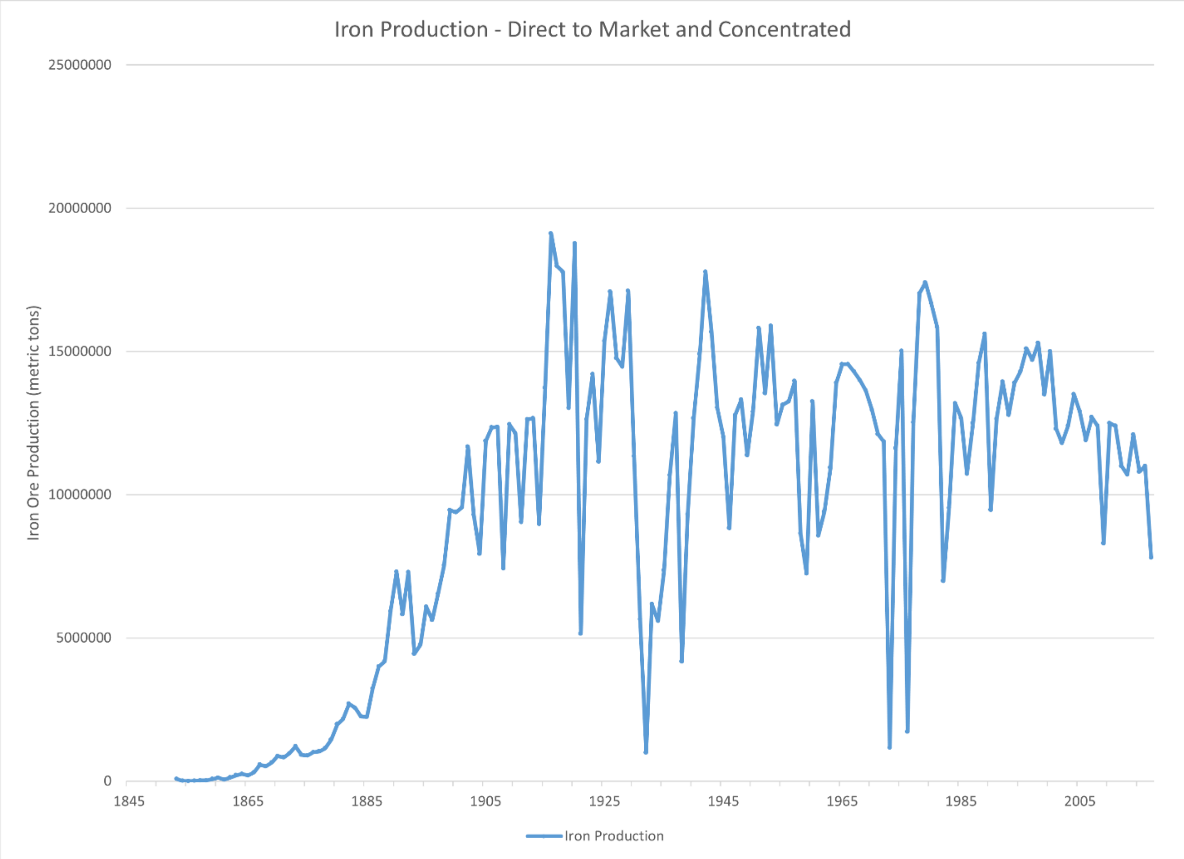


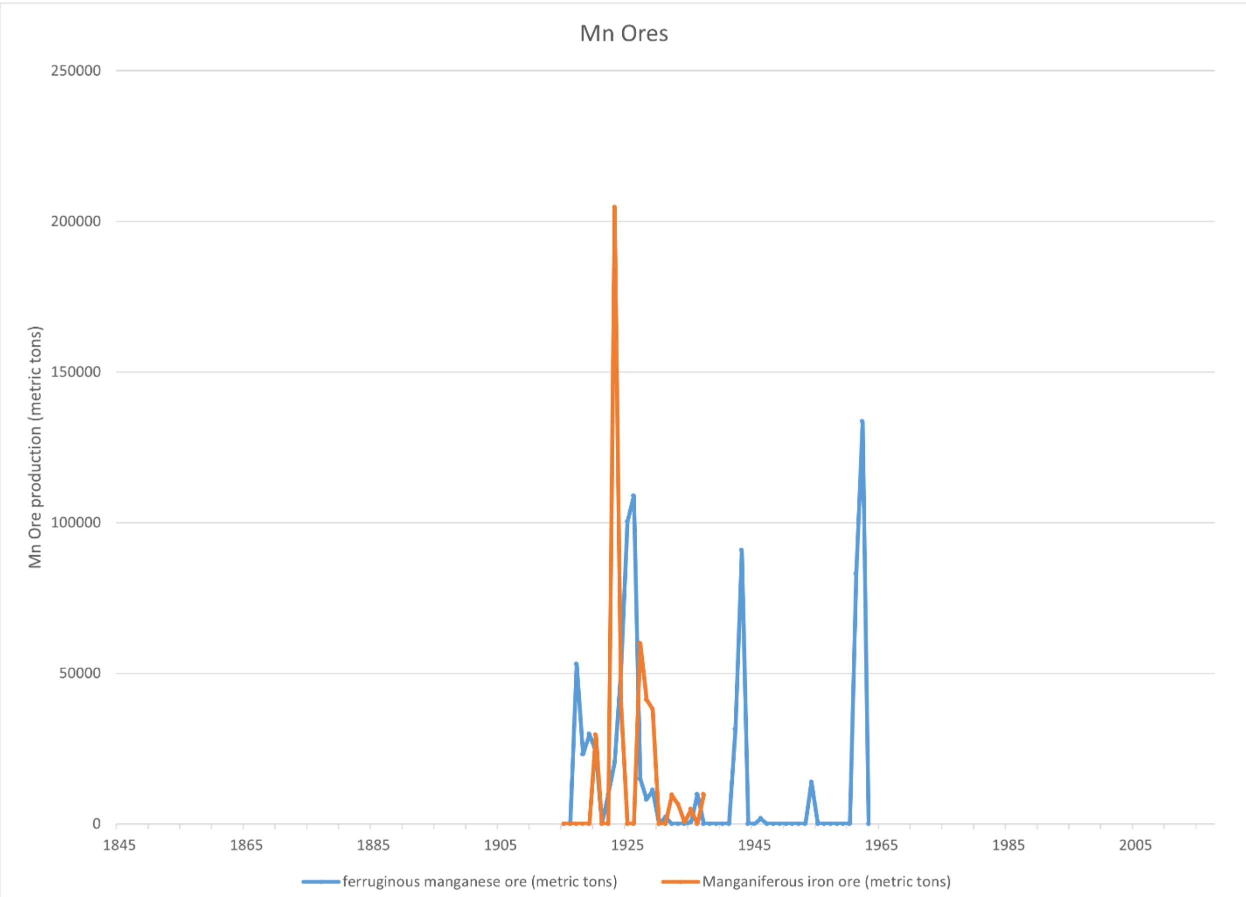
into Lake Superior about 25 miles east of Ashland, WI. This range extends almost 80 miles between Atkins Lake in Wisconsin and Lake Gogebic in Michigan; the Michigan section is approximately 25 miles long and stretches from the state boundary at Ironwood to a point slightly west of Lake Gogebic. The greater portion of the Menominee Range lies in the state of Michigan and includes the towns of Iron Mountain, Norway, and Vulcan. Main iron deposits in this range extend in an east and west direction, north of Iron Mountain".[2]

The Menominee Range is divided into two parts. The Eastern Menominee Range located near the towns of Iron Mountain, Norway, and Waucedah, Michigan was discovered in 1845. The Western Menominee Range located near the towns of Crystal Falls and Iron River, Michigan, was discovered in 1851. ***Unlike the mines (mostly large open pits) on the Marquette Range, the steeply dipping iron formation caused most of the mines on the Menominee Range to go underground from the start***. Major Mines on the Eastern Menominee Iron Ranges include the Penn Mines - Vulcan Mine; Pewabic Mines; Chapin Mine; Aragon Mine; and Groveland Mine.[3] A generalized geological column of the east Menominee Range is pictured to the right. The formation has been highly faulted and somewhat folded, which we will see evidence of on a field trip stops. Most of the ore mined came from the lower member of the iron formation.[4] Iron ore production is primarily in the Vulcan Iron Formation in the Iron Mountain region – this is equivalent to the Negaunee Iron Formation in the Marquette region – and both units are thought to be about 1.875 billion years old.

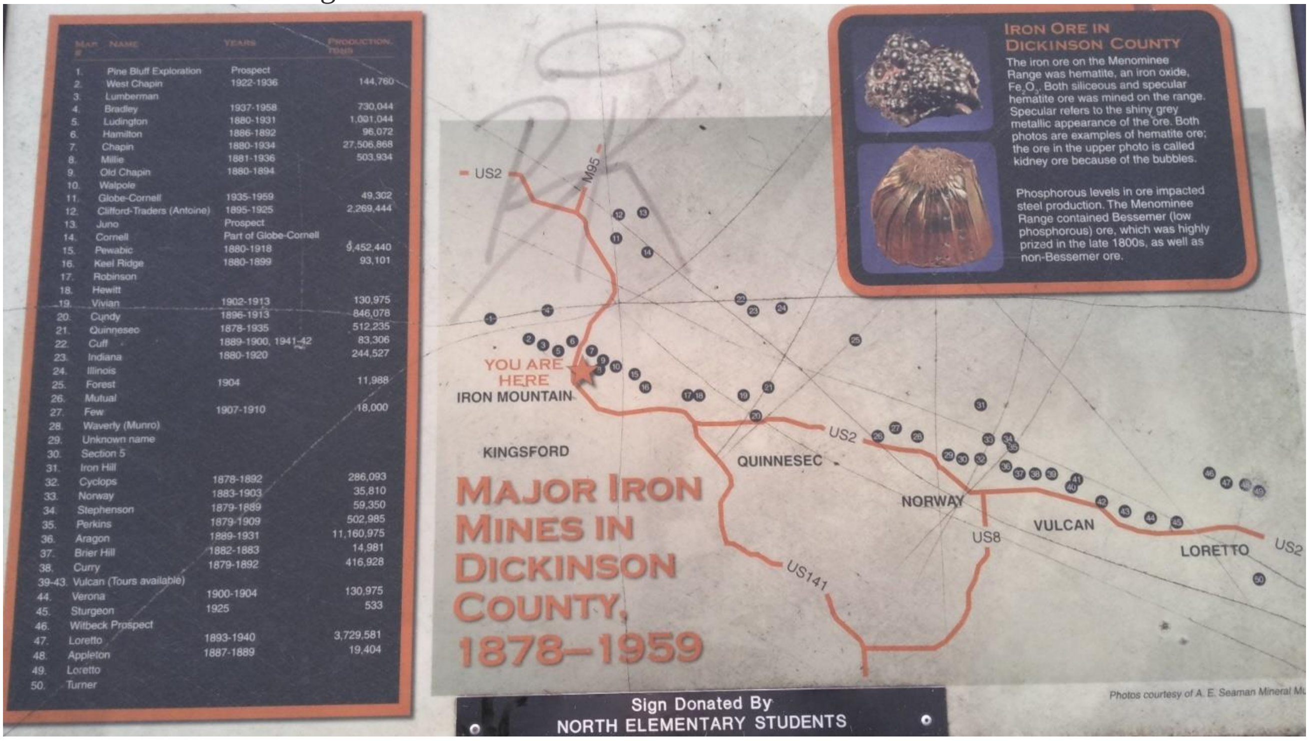


Iron ore was produced from the Menominee range primarily from high-purity direct to market ores – these ores were formed from leaching of material from the formation and concentrating hematite and magnetite in fractures and faults running through the rock. The Groveland Mine was one of several mines that piloted the taconite pelletization process which allowed them to mine lower quality ore and concentrate it to produce higher quality pellets. Some portions of the Menominee Range iron deposits were enriched in Manganese (Mn). These ores were slightly more valuable – as Mn added to steel during the refining process makes steel stronger. Cumulative production of iron ore in Michigan was 1.54 billion metric tons through 2017 and 1.3 million metric tons of manganese-enriched ore through 1962 [1 metric ton = 1.1 US tons][5].





These mines produced ore from 1880 up to 1940. At our Rock Raffle/Game night and the observational astronomy evening at Millie Mine Lookout Hill at and bat hibernaculum (which at its base is the old Chapin Quarry), there is a viewing display with a map of all the known mines in the Eastern Menominee Range.



Sources

1. Kessler, Stephen. **4 Billion Years of Geologic History in the Great Lakes Region**. Chapter 6. University of Michigan Press, 2019.
2. **Iron Mining**: Where and Why? https://project.geo.msu.edu/geogmich/iron.html.
3. **A Brief History of Mining in Michigan's Marquette and Menominee Iron Ranges https://www.mininghistoryassociation.org/Meetings/Michigan2019/History%20of%20Mining%20in%20the%20UP%20PDF%20v02%20%20IG12.pdf**
4. **MICHIGAN IRON MINES.** https://www.michigan.gov/documents/deq/NSFE_304650_7.pdf
5. Voice, P. and Harrison, W. 2016, Michigan Natural Resources Production Statistics: Resources for Teachers, MESTA Annual Meeting Presentation handouts (https://www.researchgate.net/publication/305991569_Michigan_Natural_Resources_Production_Statistics_Resources_for_Teachers).

Precambrian History of Michigan – a Brief Outline

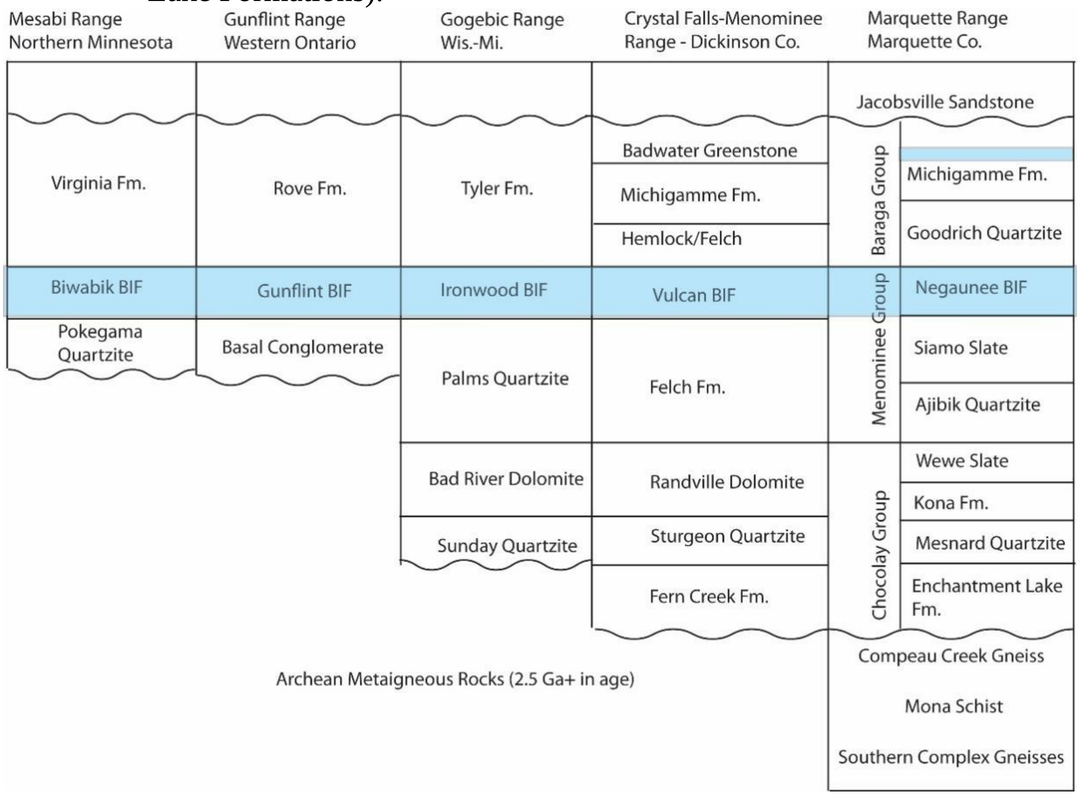
Pre-2.5 billion years ago – Amalgamation of the Superior Province through accretion of granite-greenstone terranes forming the basement rocks in the western Upper Peninsula. During the Archaean Eon, the Earth's crust was hotter – and more buoyant, so subduction likely did not occur. Instead, basaltic crust (later metamorphosed to greenstone) was pinched up between granitic arcs to form the cores of the microcontinents that merged together to form the Superior Province. These rocks are present near the surface away from the iron ranges (and are present at depth below the iron ranges). In areas west of Marquette, for example, pillow lavas representing the ancient seafloor basalt can be observed in several outcrops.

2.5 billion years ago – the Kenoran Orogeny occurred – this is an earlier phase that included the collision of the Superior Province with the Wyoming-Hearne blocks, and Karelia (a portion of what is now Finland and Russia). All three terranes have gabbro dikes that are the same age and have identical chemistry – suggesting that they were once together and the same magma source intruded the dikes across them.

Between 2.5 and 2.2 billion years ago – rifting occurred, breaking the Wyoming-Hearne and Karelia blocks from the margin of the Superior Province. Over this span, the margin of the Superior Province transitions into a passive margin

a. Approximately 2.3 billion years ago, the Earth entered a severe cooling period – the Paleoproterozoic glaciations. Michigan was near the equator (based on paleomagnetic data)

– but had evidence of continental scale glacial deposits (the Fern Creek and Enchantment Lake Formations).



Paleoproterozoic rocks of the Western Upper Peninsula and neighboring regions (redrawn from Ojakangas, 1994).

b. Following deglaciation, sediments of the Chocolay Group were deposited in Michigan. In the Iron Mountain region these include the Sturgeon Quartzite (not observed on trip) and the Randville Dolomite (stop 2). These are passive margin deposits of sandstone, shale and dolostone now metamorphosed – they can be difficult to define in the field because these units record changing sea levels characterized by changing lithologies. The Randville Dolomite and the stratigraphically equivalent Kona Dolomite (Marquette Range) are notable for their large stromatolites.

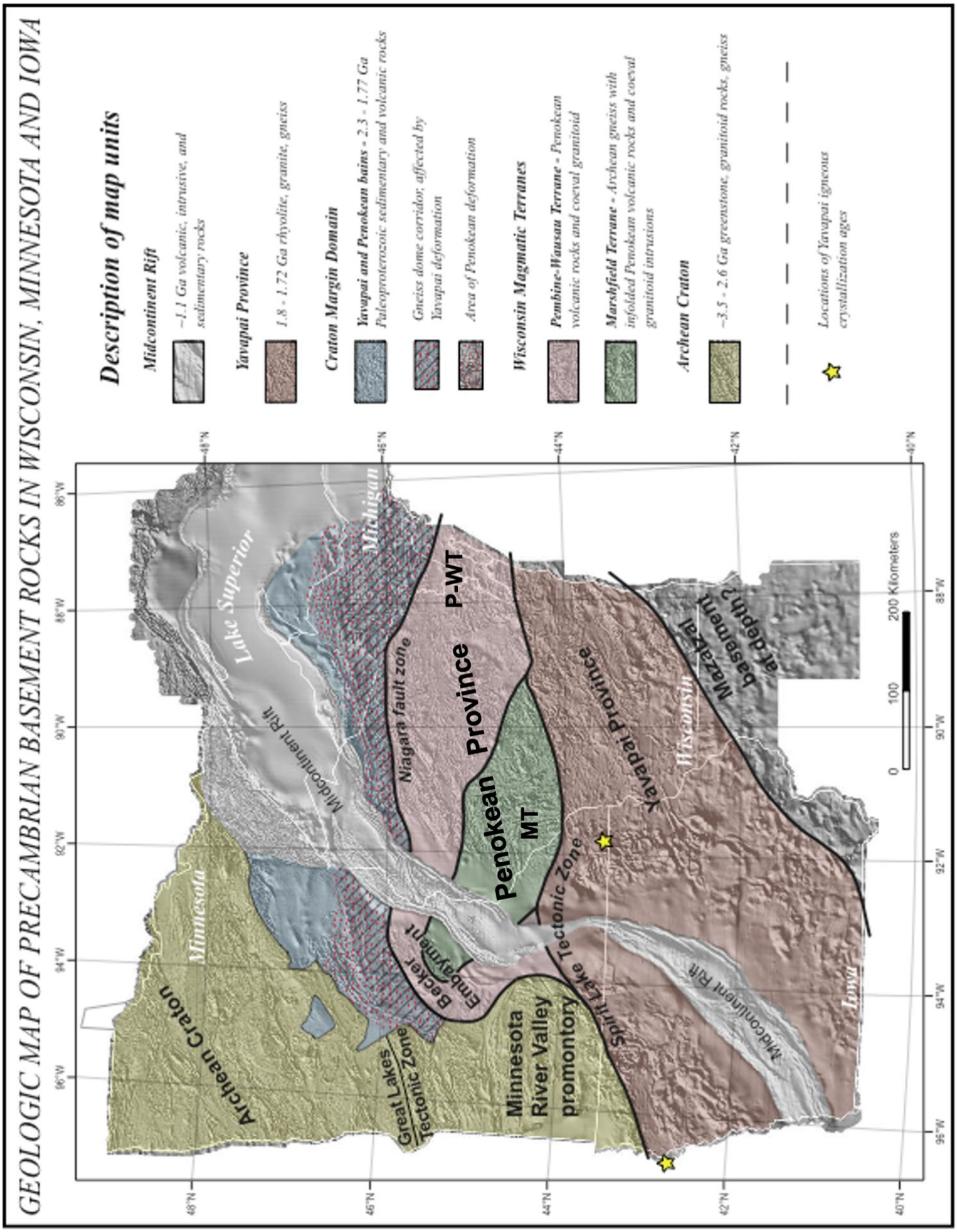
Between 1.88 and 1.83 billion years ago. **PENOKEAN OROGENY -** as the Pembine-Wausau terrane is brought closer to the Superior Province by the subduction of the intervening oceanic crust, basins develop in the western Upper Peninsula through subsidence. Subduction occurs to the south under the approaching island arc, which is why there are no major igneous intrusions in Michigan during this time. Sediment accumulates in these basins – including the slate and quartzite of the Felch Formation (and in the Marquette range – the Ajibik Quartzite and Siamo Slate) of the Menominee Group. The last phase of the foreland basin sequence is characterized by the deposition of iron formation – the Vulcan Iron Formation (equivalent to the Negaunee Iron Formation of the Marquette Range). To the south, the iron formations grade laterally into volcanic rocks of about 1.875 billion years old. The Niagara Fault Zone develops in the suture between the Pembine-Wausau Terrane and the Superior Province.
During the later stages of this orogeny, the Marshfield Terrane collided with the margin of the Pembine-Wausau Terrane – the compressional stresses translated through the crust down-warping the foreland basins a second time. These basins filled with a second generation of deeper water clastic sediments and iron formation of the Michigamme Formation of the Baraga Group. Intrusions related to this collisional system likely metamorphosed the overlying country rock including the iron ranges (with later overprints from subsequent orogenies).
Between 1.76 and 1.63 billion years ago – a series of later orogenies occur on the margin of North America (Yavapai-Mazatzal-Central Plains orogenies) accreting a large swath of crust from New

Mexico to the Lower Peninsula of Michigan to North America. These orogenies also likely caused reactivation of some of the faults, circulation of metamorphic/hydrothermal fluids, and alteration of the rocks in the Lake Superior region, and are responsible for forming the southern half of Wisconsin. The Baraboo sandstones were deposited in the period between these two orogenies and were later folded by the Mazatzal Orogeny.

1.6 -1.2 billion years ago – relatively quiet phase for the Superior region – One notable exception occurs just south of the field trip area in central and northeastern Wisconsin. Several plutons and a giant batholith of granite and related rocks (syenite, anorthosite) formed in this region around 1.5 billion years ago. The Wausau syenite complex and the Wolf River batholith are interpreted to be anorogenic rocks produced by the rapid uplift and erosion of the mountain ranges, causing decompression melting.

1.2-1.0 billion years ago – North America experienced a failed rifting event in the Great Lakes region. The opening of the Keweenawan rift came close to breaking the continent apart. The rift valley created was slowed filled with a sequence of basaltic lava flows and clastic sediments of the Keweenawan Supergroup. Away from the rift valley, gabbro intrusions cross-cut older rocks (a. they are not metamorphosed and b. they age date to this interval of time). Native Copper deposits were likely emplaced during and shortly after rifting due to hydrothermal circulation of groundwaters that leached metals out of basalt and concentrated them in fractures and other porosity in other rocks in the region. The Jacobsville Sandstone fills in the top of the rift and then spreads out laterally as a regional sandstone found over much of the region.

1.0 to 0.52 billion years ago – relatively quiet period of weathering and erosion of the Keweenawan and pre-Keweenawan mountains in this region



From: NICE (Northern Interior Continental Evolution) Working Group
D.K. Holm, R. Anderson, T.J. Boerboom, W.F. Cannon, V. Chandler, M. Jirsa, J. Miller, D.A. Schneider, K.J. Schulz, W.R. Van Schmus, 2007, Reinterpretation of Paleoproterozoic accretionary boundaries of the north-central United States based on a new aeromagnetic-geologic compilation. *Precambrian Research*, v. 157, p. 71-79.

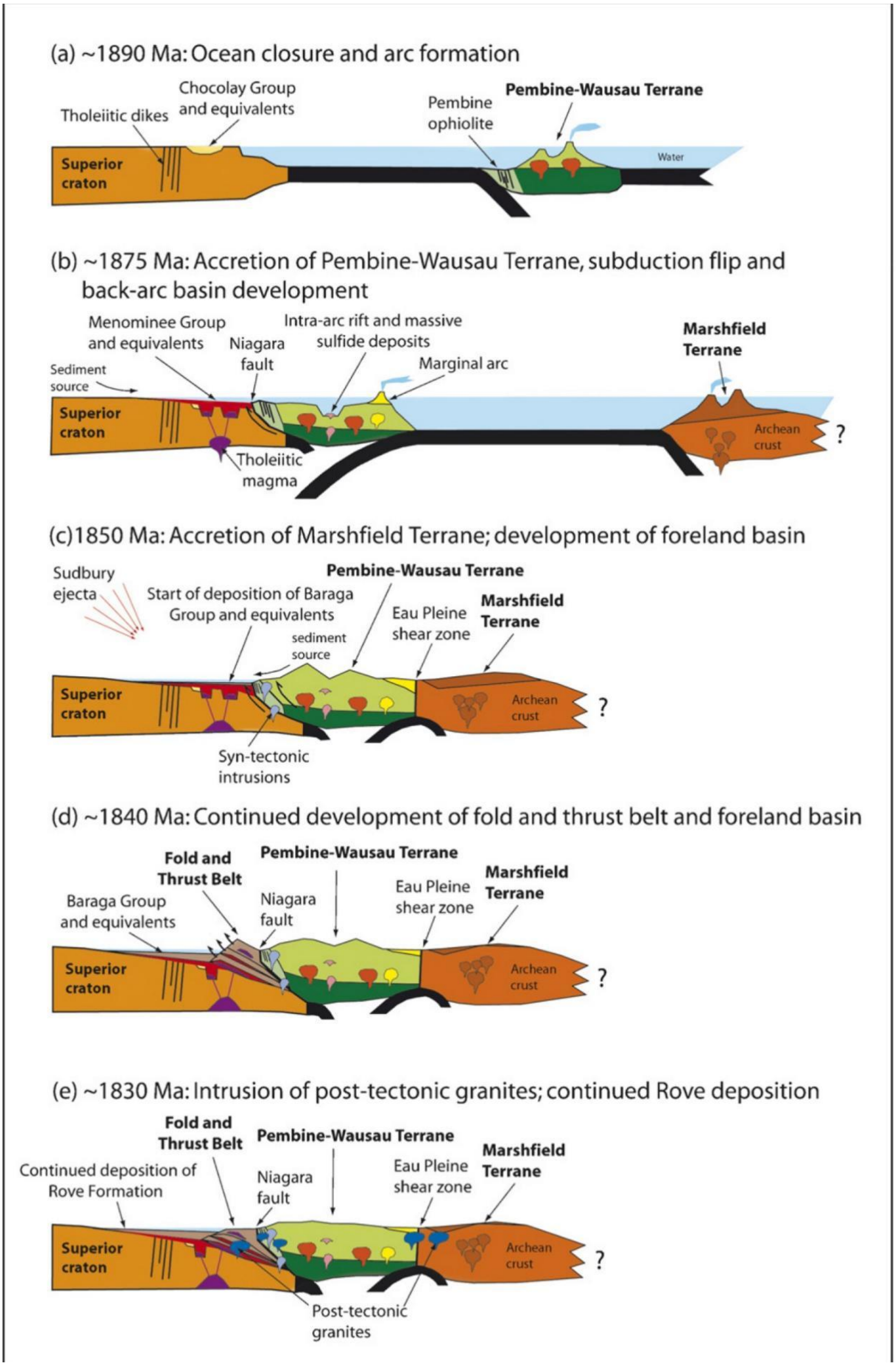
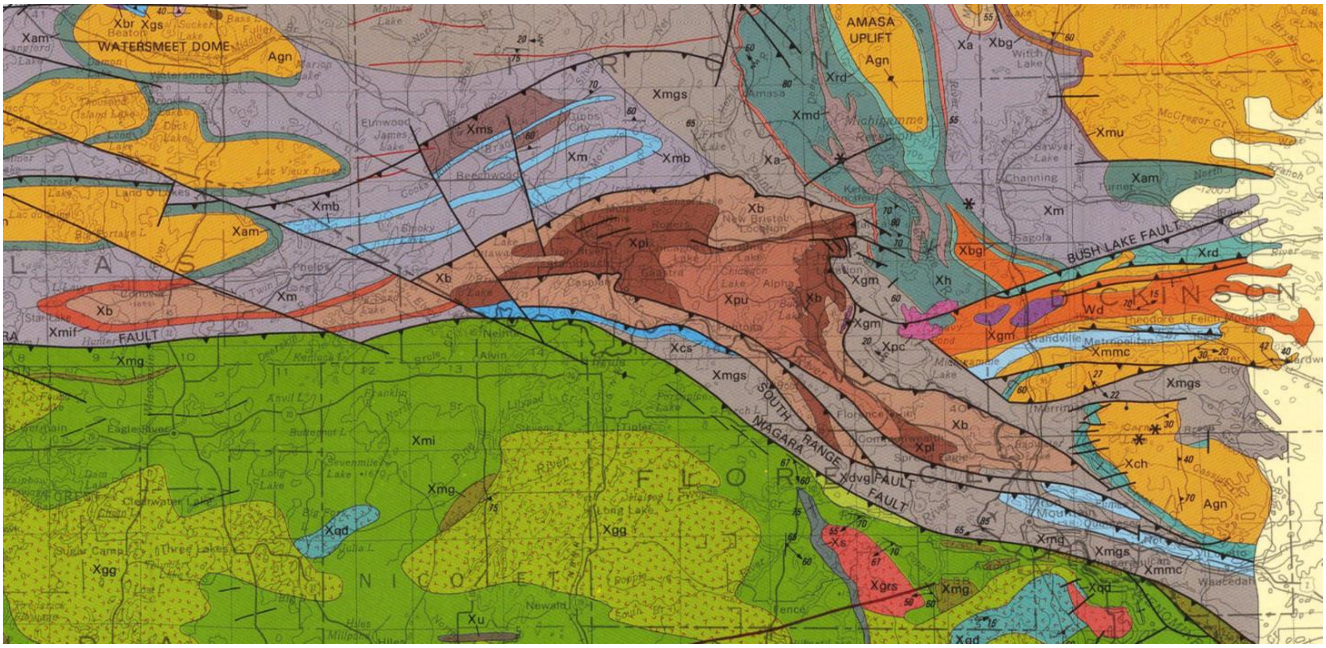
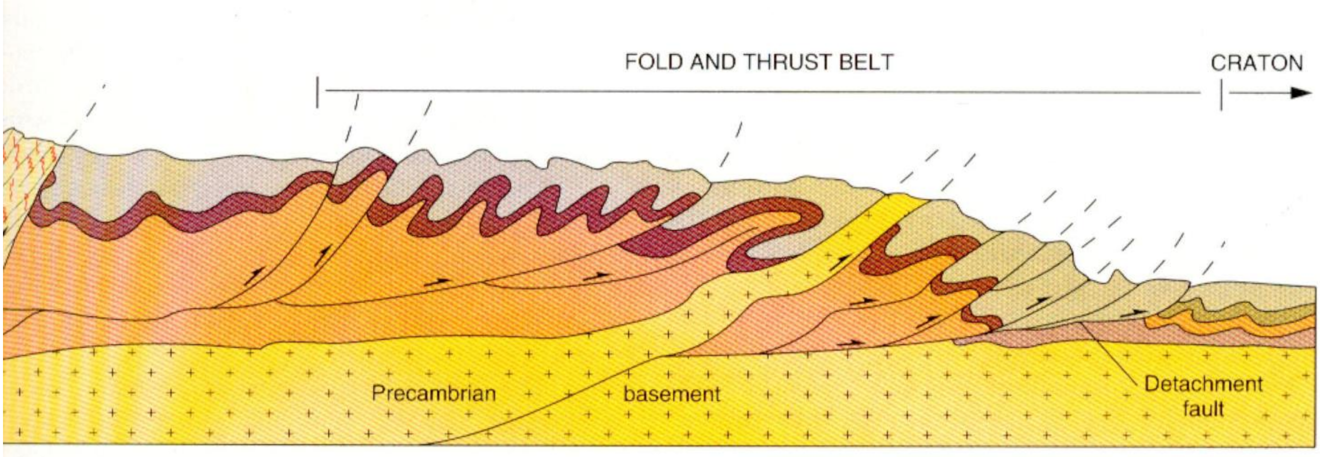
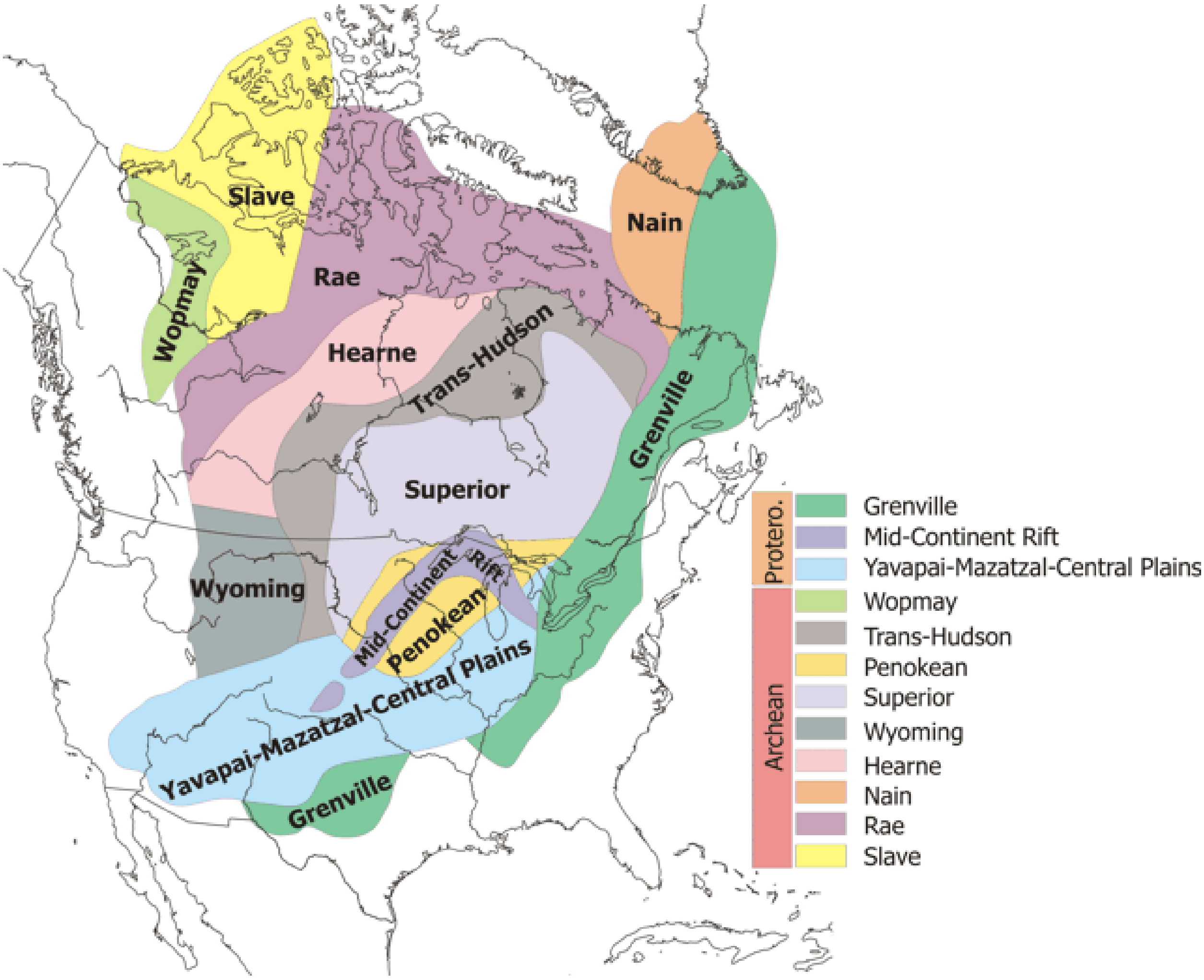


Plate Model for the Penokean Orogeny (after Schulz and Cannon, 2007).



Geologic Map (above) showing the thrust faults and folds north of the Niagara Fault Zone, which is the suture between the Superior Craton (Archean age) and the Pembine-Wausau Terrane (Proterozoic). The teeth (triangles) are on the overriding block. Map from Simms (1992). See cross section below of a generic fold-and-thrust belt.





Simplified terrane map of North America – showing the major provinces that make up the core of the continent. The Penokean block represents the Pembine-Wausau Terrane. From: http://profharwood.x10host.com/GEOL102/Study/Proteroz.htm (who redrew it from Whitmeyer and Karlstrom, 2007). More recent work has shown that this map extends the Penokean block too far to the south and east.

Approximately 500 to 440 million years ago, the Taconic Orogeny occurred – stresses propagated through crust causing down-warping of crust in what is now the Lower Peninsula, forming the initial sag of the Michigan Basin. The Upper Ordovician shales that make up the floor of Green Bay and are exposed in the Stonington Peninsula were deposited from erosion of the Taconic Mountains.
Between 520 and 310 million years ago, deposition of a series of sediments filling the Michigan Basin (Cambrian through Pennsylvanian periods). Shaly intervals in the Devonian are related to the Acadian Orogeny. These thicker shale layers were preferentially eroded from the Lake Michigan and Lake Huron basins during the Pleistocene glaciations.
Between 310 and 160 million years ago, no sedimentary record in Michigan – likely a period of weathering and erosion forming an unconformity. Kimberlites in the western central Upper Peninsula have fission track ages that suggest that they had been emplaced before 180 million years ago. In the Lower Peninsula around 160 million years ago, deposition of the Ionia Sandstone.
160 million years ago to ~30,000 years ago – no known record in Michigan – second phase of weathering and erosion in a terrestrial environment. During the Pleistocene, the most recent ice age occurred – in Michigan glacial sediments appear to correspond to the last phase of retreat of the Laurentide ice sheet and date between 30,000 and 10,000 years ago.
Modern times – modification of glacial sediments by soil formation, wind and fluvial activity has reshaped the deglaciated landscape since the ice melted away.

References

Ojakangas, R. W., 1994, Sedimentology and Provenance of the Early Paleoproterozoic Michigamme Formation and Goodrich Quartzite, Northern Michigan – Regional Stratigraphic Implications and Suggested Correlations: U.S. Geological Survey Bulletin, v. 1904-R, 31 p.
Schulz, K.J., and Cannon, W.F., 2007, The Penokean orogeny in the Lake Superior region, Precambrian Research, 157:4-25.
Whitmeyer, S.J. and Karlstrom, K.E., 2007., Tectonic model for the Proterozoic growth of North America, Geosphere, 3(4):220-259.

Tuesday, Aug 3

8:15 Meet at shopping center lot same as Aug 2

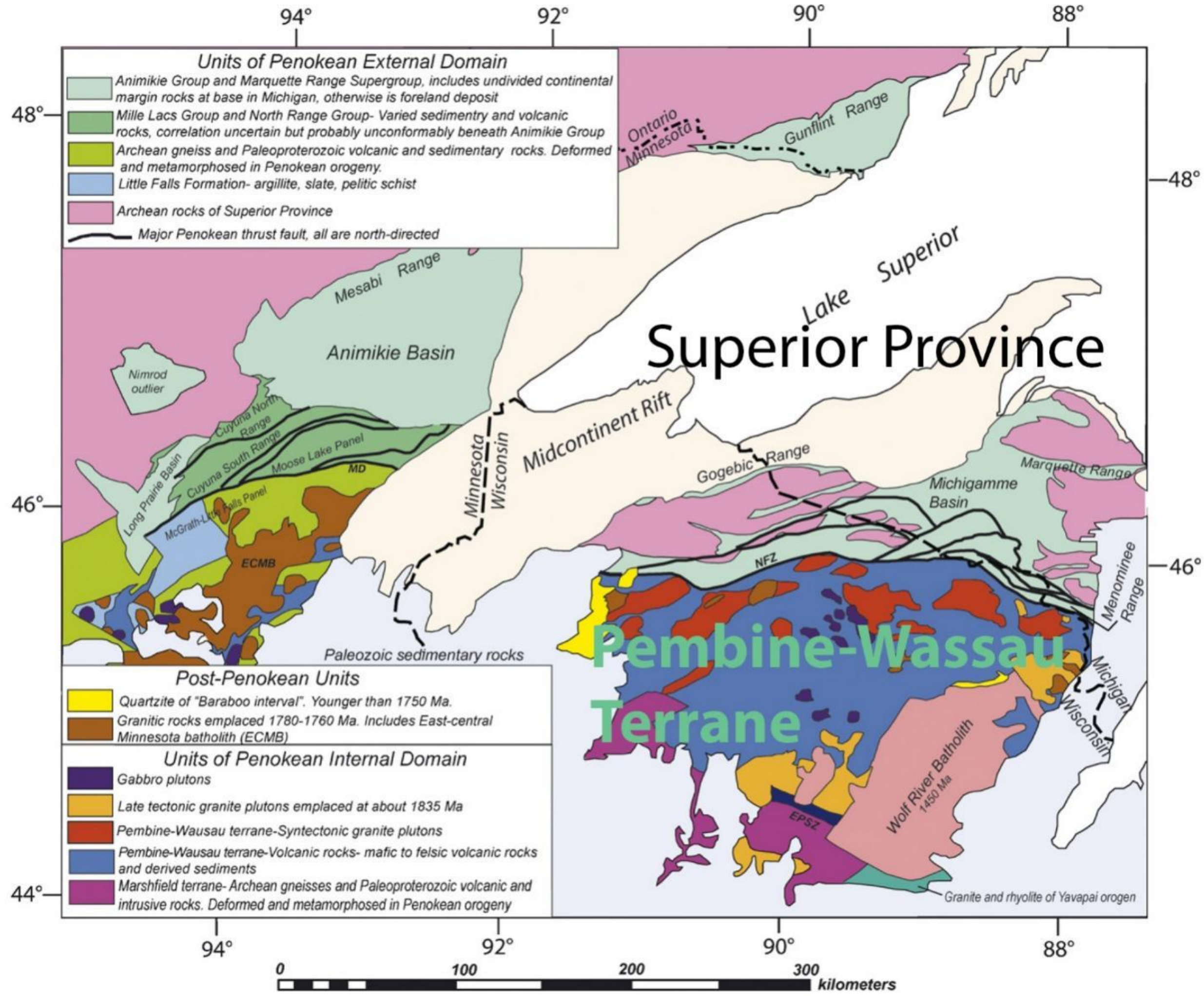
Group A (those going on raft trip)

Travel east on US-2 toward Norway. Turn right onto South 141 and then in Niagara veer left to stay on 141. (You will see a park at junctions with an artificial waterfall.) 1.2 miles turn right onto Maple St. Park along the road. Carefully walk across 141 to viewing site on Menominee River.

8:30 9 **Penokean Overlook**: Here you can see the Niagara Suture Zone. The ridge on the opposite side of the river is a sill (metagabbro) intruded along the contact between the Superior Province rocks (to the north) and the Pembine-Wausau terrane (ridge to the south on other side of 141).

Stop 9 – Scenic view at Niagara

At this site, we can see the scars of an ancient collision that occurred sometime between 1,890 and 1,830 million years ago. Much of the history of North America during the Precambrian consists of a series of collisional events that slowly built North America's core outward. The Upper Peninsula is located on the southern margin of one of these continental blocks that accreted to North America – the Superior Province or Superior Craton which extends north to Hudson Bay. At the town of Niagara, we are standing near the suture zone between the Superior province and the Pembine-Wausau Terrane. The Pembine-Wausau Terrane includes portions of central Minnesota and northern Wisconsin (now separated by the younger Mid-Continent Rift which cross cuts these terranes). These collisions were part of the Penokean Orogeny – and occurred in two major phases: collision of the Pembine-Wausau Terrane with the Superior Province, followed by the collision of the Marshfield terrane shortly thereafter. In the map below (from Schulz and Cannon, 2007), the Superior province is in pink and green, while the Pembine-Wausau and Marshfield terranes are the colorful swaths to the south.



Some symptoms of this collision:

1. These collisions caused deformation of the rocks of the margin of the Superior Province – deforming the rock with a series of folds, fractures and faults. Some of this stress was translated into the interior of the Superior Province deforming rocks in the Marquette iron range as well.
2. The stresses also caused down-warping of the crust in several places – this subsidence developed a foreland basin across the western Upper Peninsula and northern Minnesota. This basin will fill up with deep water sediments of the Michigamme Formation. That sediment is shed from the mountains that grew during this continent-continent collision.
3. Intrusions and volcanism due to the subduction of the intervening oceanic crust between the 2 micro-plates. We will see signs of this volcanism in Wisconsin in the Pembine-Wausau terrane. Several large intrusions have been identified in the western Upper Peninsula in the subsurface using geophysical tools – surrounding these domes are metamorphic halos that show decreasing metamorphic grade away from the domes in the surrounding country rock. There are also several generations of gabbro dikes and sills in the region – some date to the Penokean Orogeny, while others are younger and related to the Keweenawan Mid-Continent rift system.
4. There may be a component of fluid circulation that occurred during this deformation that pushed metal-rich fluids into rocks emplacing some of the ore deposits of the western Upper Peninsula.

At the scenic viewing area on the Menominee River, we are standing near this suture zone (the Niagara Fault Zone), which is just on the north side of these bluffs. Looking north across the river, the ridge of rock is made up of Superior Province rocks. If we turn and look to the south, the wooded ridge on the other side is the Pembine-Wausau Terrane.

References:

Schulz, K.J., and Cannon, W.F., 2007, The Penokean orogeny in the Lake Superior region, Precambrian Research, 157:4-25.

Group A Continued

8:40	Drive to Wildman facility: Get back to 141 by continuing on Maple St to Ridge St; turn left. Next block, turn left on Birch St and then right onto 141 to southeast. Continue to the intersection of East 8 (which heads toward Norway, Mi). Take East 8 north, then turn right on Old 8 Road to east. At 0.4 miles as the road curves to the right, take Bomber Road to the left. The facility is at the bottom of the hill. (N 22200 Bomber Road, Niagara, Wi). 54151)
8:45	Arrive at **Wildman Adventure Resort** - check in at building to east of restaurant.
9:00	Rafting trip

Group B (not rafting) - see options below
Time your choices so that you make it to Stop 9 by 11:50. (See directions above with Group A to site in Niagara, Wisconsin.)

Alternative Activities for those not going on the Piers Gorge Rafting Trip

Cornish Pump & Mine Museum - largest steam-driven pumping engine ever build in the United States and one of the largest in the world; a Michigan Civil Engineering Landmark. In addition to the mammoth engine, this museum also displays extensive underground mining equipment and a gift shop. Open 9-5 M-Sat, noon -4 Sundays.
Admission: adults $5; seniors $ 4.50; students (10-18) $3
Two blocks west of US 2 on Kent Street.

View rest of group rafting through **Piers Gorge** (a place we will be visiting as a group later). Just off US 8 south of Norway.

Revisit **Kelly's Rock Shop** - in Vulcan across the U.S. 2 from Iron Mountain Mine Tour

Millie Mine Bat Viewing Area - covered mine shaft providing one of the largest bat hibernation locations in U.S.; also dramatic view of Iron Mountain. From US 2, take Third Street or Park Street to the top of ridge in Iron Mountain. (Astronomy will be here one night.)

Miners Memorial Park - at corner of US-2 and Third Ave (on road to Bat Viewing Area).

Norway Spring - US 2 just west of Norway. Well formed in 1903 with 1,094 foot shaft drilled in search of iron ore.

Iron Mountain City Park - enclosed deer pen, dog park, picnic tables, hiking, lots of recreation opportunities. From US 2, take West A street until it dead ends at park.

Pine Mountain Ski Jump - one of the world's highest artificial ski jump. Located off US 2/141 on Pine Mountain Road.

Michigan Welcome Center - open 9-5 at 618 S. Stephenson Ave (US 2) in Iron Mountain.

Riverside Park, north Niagara, Wi - several trail loops; many easy, one expert trail. Washington Ave off US-141.

Quiver Falls (Wisconsin) - volcanic basalts, purported to have pillow lavas. Take US-141 south of US-2 then route R to the east all the way to the Menominee River. If you go, there will be a $5 daily fee. Keep the car tag because we will use it in the afternoon at two other falls.

Shopping of course is an option: Swedish/Scandia House in Norway, Iron Mountain Mine shop in Vulcan, Crispigna's Italian Market in Iron Mountain, etc.

Wild Rivers Interpretive Center (Florence, Wisconsin) - array of exhibits about mining, logging, thriving rural Wisconsin. Open 8-4 Mon-Friday at 5628 Forestry Dr, Florence, WI; about 14 miles west of Iron Mountain on US-2.

But don't forget to rejoin the group for significant rock exploration and lunch starting at 11:45 am. [see schedule]

Group B continued

11:50 9 **Penokean Overlook**: Here you can see the Niagara Suture Zone. The ridge on the opposite side of the river is a sill (metagabbro) intruded along the contact between the Superior Province rocks (to the north) and the Pembine-Wausau terrane (ridge to the south on other side of 141). Read information on previous page about stop 9. After 5 minutes stop, head back to 141 by continuing on Maple St to Ridge St and turn left. Next block turn left on Birch St and then right onto 141.

12:00 **Both groups** drive to **roadside park on Highway 141** just east of Niagara Overlook (and for those coming from rafting trip, drive west on Highway 8, then northeast on Highway 141 to park.)

12:05 After two groups meet, drive east on Highway 141 to Highway 8, then east 0.9 miles on Highway 8 to rock outcrop on side of road.

12:10 10 **Roadside rock outcrop (45.7471, -87.9367)**: sheared metavolcanics metamorphosed to chlorite grade; andesite; quartz veins, some showing signs of folding. In the set of outcrops the far east one has beautiful cross-cutting relationships and xenoliths. Note that rocks are glacially polished. (15 min)

Stop 10 – Roadcut on U.S. Highway 8. (45.7471, -87.9367)

This locality shows a spectacular example of cross-cutting relationships in the igneous rocks of the Pembine-Wausau Terrane. The darker metavolcanic rocks (chlorite grade) are intruded by granite. To the south along Highway 141, a similar exposure between the Quinnesec Volcanics and the Spikehorn Creek Granite helps to understand the precise ages of deformation in the area. The Spikehorn Granite in the area is undeformed, and must therefore have been emplaced ***after*** the deformation associated with the collision between the island arc and the continent margin. The rock was dated at 1835 ± 6 million years ago (Ma). Collision of the Pembine-Wausau Terrane is therefore constrained to have occurred ***before*** 1835 Ma. (Modified from LaBerge, 1984). Glacial polish can also be seen.

12:35 Drive north on Highway 8 to Marion Park (just before Norway, Mi)

12:40 **Miners Lunch at Marion Park** (40 minutes)

1:20 Drive south on Highway 8 to Piers Gorge Road (Piers Gorge Scenic Area sign at turn). Travel west on road which transitions to gravel. Continue straight to parking area. **This is a State Recreations Area - and each car will need a Recreation Passport or day pass (with forms and drop box at parking lot if needed).**

1:30 11 **Piers Gorge Park**: **(45.75812, -87.94310)** take path to river where there are foliated mica schists. [Note that if wet the outcrops are slick.] Along the path we will also examine a histosol, an organic-rich wetland soil. (30 min)

Stop 11 – Piers Gorge on Highway 8. (45.75812, -87.94310)
The area exposed is a branch of the Niagara Fault Zone. LaBerge (1984) interpreted the bedrock as foliated basaltic greenstone, but the area we will visit appears to be a muscovite schist or phyllite. The exposures along the trail to the gorge are dipping near vertically. At water level, pothole structures can be also be observed here.

About a mile north of here, the Michigamme Formation slates/graywackes are exposed, and dolomite, iron-formation, and quartzite crop out about 2 miles north of here (LaBerge, 1984).

2:00		Drive to Long Slide Falls: backtrack to Highway 8 and turn right. In 2.4 miles turn left onto S141/W8. In 3.2 miles turn left onto Morgan Park Rd. Veer right to stay on Morgan Park Rd at junction with Spike Horn Rd. Turn onto Long Slide Falls Drive and park. [45.68333, -87.9333W] **The site has a $5 county park day use fee. Pay at the fee station, place permit in car, and save for later in the day.** (25 min)
2:25	12	**Long Slide Falls (45.6838, -87.9325)**: waterfall flows over metavolcanics. [View from top or take a steep gravel path, moderately rigorous to lower viewing area] (30 minutes)

Stop 12 – Long Slide Falls County Park. (45.6838, -87.9325)
The rocks exposed here are part of the Quinnesec Formation of the Pembine-Wausau Terrane. The Quinnesec Formation is comprised of metamorphosed basalts, basaltic andesite and other related pyroclastic rocks.

2:55		Drive to Dave's Falls: Turn left out of Falls site onto Morgan Park Rd. When back at 141 turn left and continue south until you see the sign for Dave's Falls. [45.49611N, 87.98861W; State Road 141, Amberg, Wi 54102] Turn right onto County Park Rd to parking area. (25 min)
3:20	13	**Dave's Falls**: The Pike river flows over coarse-grained granite (to granite pegmatite). **This site also requires $5 day use pass. If you kept the pass from Long Slide Falls it works here as well.** (30 min)
3:50		Drive back to 141 and then north all the way to US-2. Take US-2 west to Iron Mountain and the empty parking lot across street from Home Depot [Home Depot address is W 8141 US-2, Iron Mountain -- but parking lot is across the street.](40 min)
4:30	14	Explore and interpret **rock outcrop** at parking lot site - recount big picture geology and view strata. You can collect (20 min)

Stop 14 – One more look at the Vulcan Iron Formation

This flavor of the Vulcan Iron Formation is a little bit darker in color – which may suggest that some of the iron minerals are pyrite or that some organic matter (as graphite) is present dispersed through the rock. It is also interbedded with slate. It likely was deposited in deeper, lower-energy water that was below the chemocline. The Precambrian seas were likely chemically stratified – with an oxygen-rich upper water layer, a transitional zone (the chemocline) and a deeper low-oxygen layer. In the lower oxygen bottom waters, minerals like pyrite or organic matter could accumulate.

One interesting feature at this site is that some of the iron formation layers are characterized by quartz sand grains. Sand is a bit unusual in these lower-energy environments – one model might be that these were deposited from turbidity currents that carried sediment from shallower water environments to this site.

4:50 Done for the day (except for astronomy session)

Astronomy viewing at Millie Mine Bat Hibernaculum [400 N3799 Park Ave, Iron Mountain; take Park Ave north from US-2 or Third St east from US-2] Starting when dark.
If sky conditions not good, star party will be offered Aug. 4.

Wednesday, Aug 4

8:00 Meet at vacant shopping center lot same as Aug 2. Depart for Pemene Falls
Drive east on US-2, then southeast on 141 through Niagara, Wi. Continue south on 141 (and 8) through Pembine to County Road Z. turn east on Z and continue into Michigan (where it becomes G-18/ 374). Immediately across the Menominee River look for a gravel road (labeled on Google maps as W-2 Rd/State Rd) and turn left. Travel north on gravel road until you see signs for Pemene falls on the left. Turn into drive to falls and reach parking lot in ~1/10th mile. (40+ min drive)

8:45 15 **Pemene Falls (45.59411, -87.77570)**: It is a rough trail down to riverbank, though not as steep as Long Slide Falls. Rocks at river a slick when wet. Here you will find meta- rhyolite, a dark purple rock with medium grained quartz phenocrysts. (45 min)

Stop 15: Pemene Formation at Pemene Falls on the Menominee River (45.59411, -87.77570)
Rhyolite of the Pemene Formation is exposed along the bank of the Menominee River at Pemene Falls. The rocks are dark gray to reddish-gray, and contain a few feldspar phenocrysts (mostly euhedral to subhedral albite). Some phenocrysts of blue quartz are also present locally. Microspherules of radial intergrowths of quartz and albite are also present. This phase of the Pemene probably represents the devitrified interior portion of a rhyolite flow.

In areas to the west, Pemene rhyolite lava flows show internal gradations from massive microspherulitic rhyolite at their centers to flow-banded rhyolite and autobreccia & hyaloclastite carapaces. This suggests that the Pemene rhyolite flows were deposted subaqueously. Locally, felsic dikes are found cutting the rhyolite. (from Schulz and LaBerge, 2003)

9:30 Drive back down gravel road to G-18 and turn left or east. At 3.2 miles continue past the junction with M577 another 0.8 miles and stop at the top of the hill.

16 **Drumlin road cut on County Road G-18** : Unique opportunity shows interior of a drumlin is primarily till.
In this case it contains clasts of Prairie du Chien carbonates (tan dolomite) and Silurian carbonates (gray carbonates with molds of brachiopods). Till is made up of a mix of clay, sand, and gravel and represents the melting of stagnant glacial ice. Sediment frozen into the ice is released during melting and accumulates in place as a jumbled, unsorted mess. Later on a readvance of glacial ice likely re-shaped the local landscape, streamlining the glacial till deposits into tear-drop shaped hills that we call drumlins. (5 min)
Drive on G-18 to east. In 1.6 miles you will pass the Carney Fen Natural Area (and Shakey River) - another place were histosols can be observed. Next stop will be 4 miles ahead. You will start passing through a major drumlin field when you see Little Cedar River and farmland. G-18 will take two 90 degree turns. After second turn at sop of ridge pull over to shoulder overlooking farm.

17 **Drumlin in profile on County Road G-18 (45.5873, -87.5903):** On south side of road the drumlin is oriented NE-SW direction, same as Green Bay glacial lobe. Note rock piles which farmer has set aside during plowing. They are likely derived from till of the drumlin. (5 min)

Stops 16 and 17: Drumlin Field of Menominee County, MI

In this part of the Upper Peninsula, there is a spectacular drumlin field of Menominee County, Michigan. It is a well-developed, but poorly known drumlin field of the Green Bay Lobe that formed about 12,000 years ago. The southwest-oriented drumlines are made of compact, loamy glacial till that are produced beneath a glacier during its flow by a variety of processes. In this area, agricultural fields and houses are typically located on the drumlins, and many of the areas between drumlins are wetlands (specifically fens, like the Carney Fen Natural Area, which we will pass through).

Drive to Aquila Core Storage Facility: Continue on G-18 to east to Carney (~1.9 miles). Turn left onto US-41 and travel ~3 miles south to Bagley. Look for Aquila Resource Building (boxy warehouse building) just south of town on right side of road. Sign is nearly horizontal on ground in from of building.

10:30 18a **Aquila Core Storage Facility** - safety induction and project update (50 min)

11:20 Tour warehouse, learn about core processing, logging, and study (1 hour)

12:20 Drive to Erickson Park: Proceed south on US-41 to Stephenson. Just as you reach town, turn right on River Road (also Old US-41 and C.R. 354) Cross over the river and turn into the park on the left. [N 305 Riverside Drive, Stephenson, Mi 49887] Go to small pavilion.

12:30 **Lunch at Stephenson's Erickson Park** - small pavilion (35 min)

1:05 Drive to Back Forty Area: Aquila staff will lead us to mine site.

1:30 18b **Back Forty Mine Site**; divide into two groups (1 hour)

Group 1 - Walking tour of cultural sites, wetlands, esker, Gossan outcrop

Group 2 - Geology overview; water monitoring program

2:30 Groups switch places (1 hour)

3:30 Concluding Q & A (30 min)

4:00 Drive back to Iron Mountain: Take C.R. 356 north to Chalk Hill Rd (become CR. K and turn left over Menominee River into Wisconsin. Take K back to US-141. Turn north on 141 and take it all the way back to US-2. (~ 1 hour)

5:30-7:30 Judy Ruddock's rock party with pizza and prizes. It will be held at Lake Antoine Park: On the north side of Iron Mountain from US-2 take Lake Antoine Road (also 398) around Lake Antoine to the park which is on the east end of the Lake. [N3393 Lake Antoine Road]

Thursday, Aug 5

9:00 Meet at same shopping center lot as Aug 2, 3, 4

- drive to Kingsley North. Take US-2 east to Norway, Mi. Turn north at Brown St. Kingsley North is at end of Brown St on the right. [910 Brown St, Norway, Mi 49870] (10 minute drive)

9:15 Tour **Kingsley North**: a world leader in lapidary supplies and more. Can purchase raw rock materials, geology publications, tools; etc. (30 minutes)

9:45 Drive back to US-2, then east toward Escanaba.

check out drumlin along U.S. 2 between Powers and Wilson

[change to Eastern time zone for remainder of day.]

In Escanaba where US-2 turns north continue straight through downtown on

		Ludington St. Just as it curves to the south take Beaumier Way to the left. Loop around the drive until you reach the Delta County Historical Society building - with lighthouse next to parking lot. [16 Beaumier Way, Escanaba, Mi 49829; 906-789- 6790]
12:00 11:45?		**Delta County Historical Society** (40 min) - presentation on transportation history related to Menominee Range ore - presentation by Sea Grant about Great Lakes issues and resources
12:40		Get **lunch** in Escanaba on your own from places back on Ludington St or on US-2 to the north. (1 hour)
1:40		Drive to Stonington fossil site: Take US-2 north out of town up through Rapid River. As US-2 curves south, turn left just past Pap Jim's Pizza Place onto
C.R.		
		513. About 10 miles south you will drive up onto a small rise. This is the more resistant limestone cap, the upper Stonington Formation (Ogontz Member). In the field on the left side of the road you will see pieces of the Orgontz. Continue about 1 more mile you will see a sign for Lakewood Cemetery. Park along the access road to the cemetery and carefully walk across to outcrop on east side of road (~25 in)
2:05	19	**Stonington fossil outcrop**: This rock is the Bay de Noc Member of the Stonington Formation. It is composed of shale with interbedded limestone beds, which are more resistant. Many Upper Ordovician fossils are found here: brachiopods, trilobite fragments, snails, bivalves, etc. You can collect (30 min)

Stop 19: Stonington Formation Outcrop

Location: On C.R. 513 across from Lakewood Cemetery (N45°45.811', W86°58.569')

The Stonington Formation consists of interbedded shale, shaley limestone, argillaceous limestone, and limestone – in all cases, it is characterized by a fine-grained matrix surrounding a wide variety of fossils. The layering ranges from laminated (very thin – mm-thick) to wavy-bedded and nodular layers (a few cm thick). The fossils present are dominated by invertebrate fossils that include brachiopods, bryozoans, mollusks (bivalves and gastropods), trilobites, some corals (both tabulate and rugose corals), small ammonoids, and crinoids. The fossils range from complete fossils in their growth positions to a variety of randomly organized clasts (broken pieces).

The fine-grained nature and high amounts of clay suggest that this formation was deposited in deeper, lower-energy waters – where the sediment was deposited by suspension settling (the slow rain of sediment from the upper water column to the sea bottom). The interbedded limestones often have more broken up material – which suggests higher energy conditions during their deposition – these are interpreted as storm deposits. Storm waves are felt in deeper water than fair weather waves – and can stir up the sea floor and concentrate coarser-grained sediments including fossil grains. The faunal composition suggests a marine fauna.

The clay content coming into the system is likely from the shedding of sediments from the new Taconic Mountains that were rising to the south (at the time – now these mountains are east of us – a portion of the Appalachian Mountains) due to the collision of the Taconic Island Arc. Most of the sediment shed off the rising mountains was into the Appalachian Basin of Pennsylvania and eastern Ohio – but finer-grained sediments (silt and clay) could have been transported into the adjacent Michigan Basin.

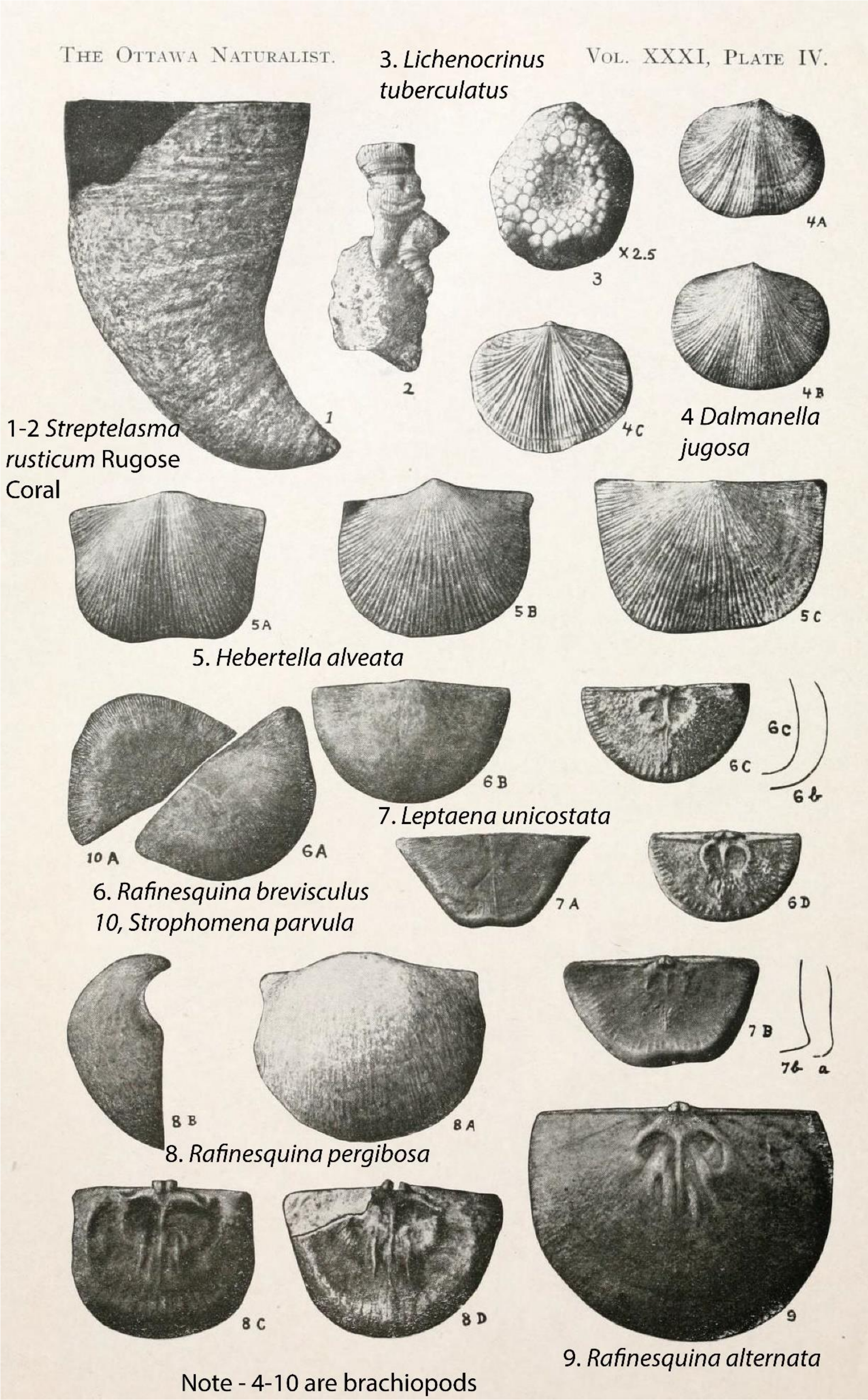
One special note in terms of the fauna – you will see some dark-colored chunks of material. Many of these are fragments of the large trilobite *Isotelus* and are likely cast-off molts. Trilobites are arthropods – arthropods molt or shed their exoskeleton at different stages in their life in order to grow larger. It is actually rare to find complete trilobites – when you do find one, it is an individual that actually died.

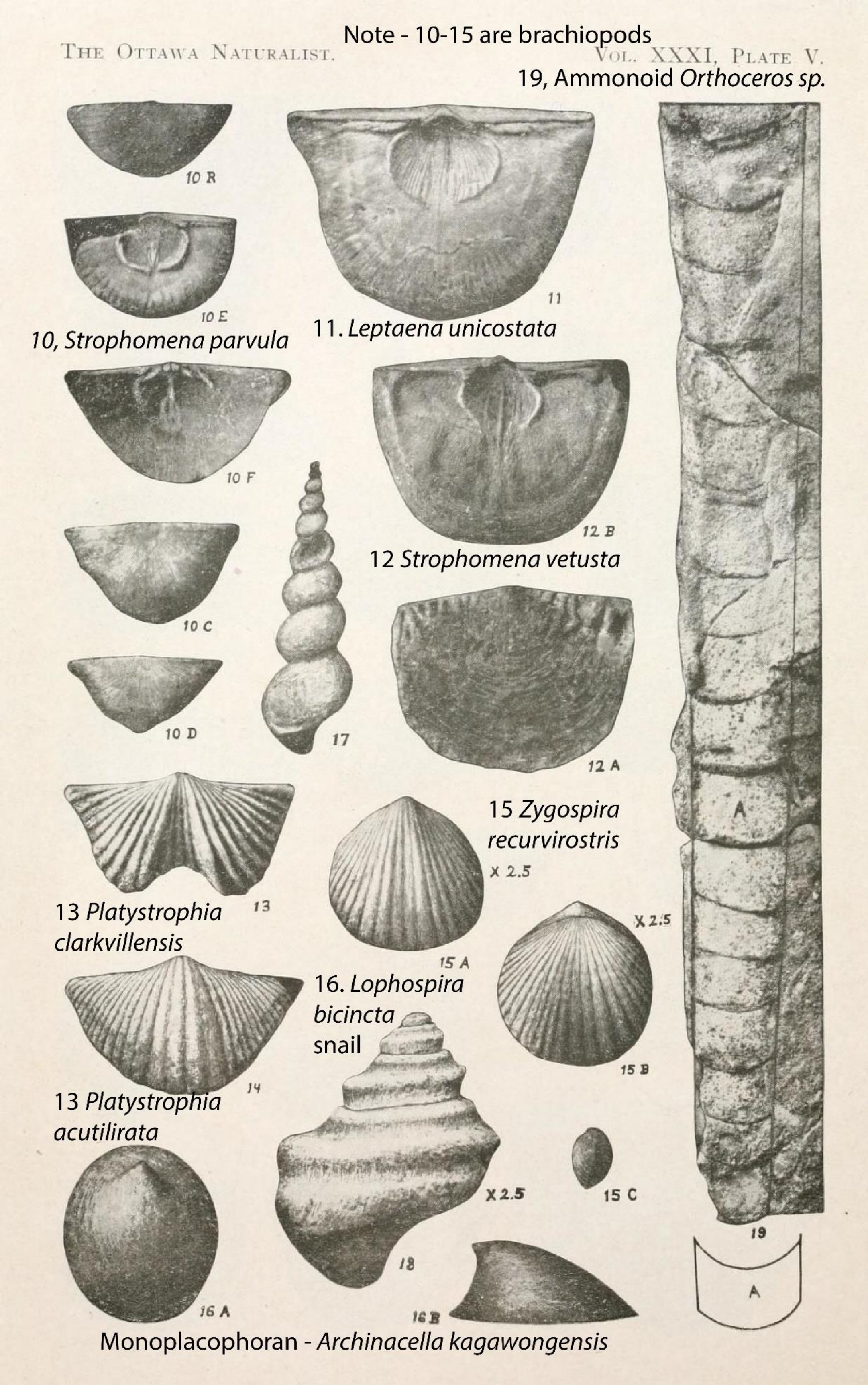
The next couple pages show sketches of fossils found on the Stonington Peninsula by Dr. Foerste (1917 and 1918) in the early 20th century – you can use these as a key to determining what species of fossils you have found.

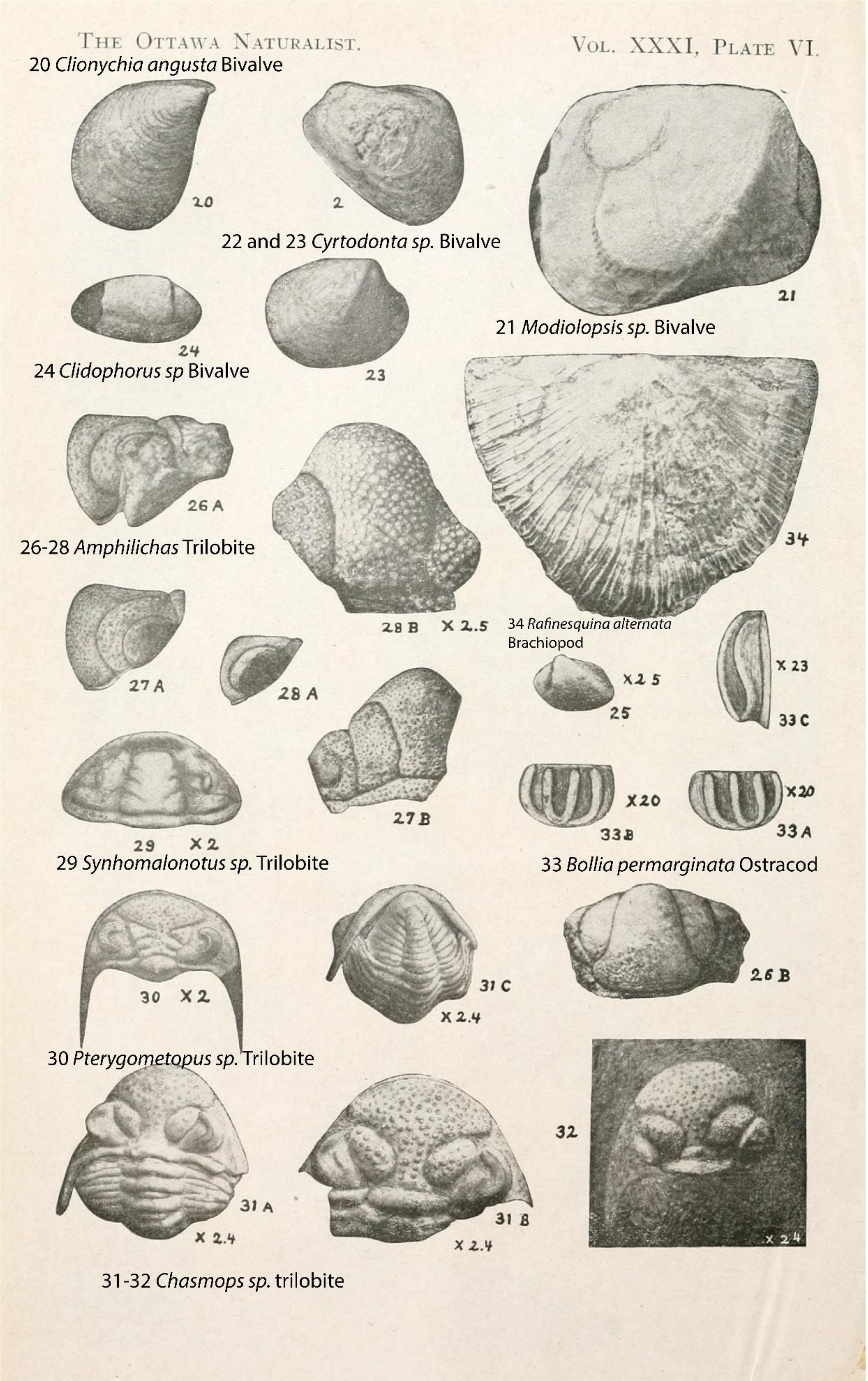
References:

Plates are sourced from: Foerste, A.F., 1917, The Richmond Faunas of Little Bay de Noquette, in Northern Michigan, The Ottawa Naturalist, 31(9):97-103, and 1918, The Ottawa Naturalist, 31(10):121-127.

Voice, P and Harrison, W.B., 2014, Paleozoic Geology of the Central Upper Peninsula of Michigan, Michigan Basin Geological Society and Michigan Geological Survey Guidebook, 111 p.


THE OTTAWA NATURALIST.
VOL. XXXI, PLATE IV.
3. *Lichenocrinus tuberculatus*
X 2.5
1-2 *Streptelasma rusticum* Rugose Coral
4 *Dalmanella jugosa*
5. *Hebertella alveata*
7. *Leptaena unicostata*
6. *Rafinesquina brevisculus*
10, *Strophomena parvula*
8. *Rafinesquina pergibosa*
9. *Rafinesquina alternata*
Note - 4-10 are brachiopods


Note - 10-15 are brachiopods
THE OTTAWA NATURALIST.
VOL. XXXI, PLATE V.
19, Ammonoid *Orthoceros sp.*
10 B
10 E
10, *Strophomena parvula*
11
11. *Leptaena unicostata*
10 F
12 B
12 *Strophomena vetusta*
10 C
10 D
17
12 A
15 *Zygospira recurvirostris*
X 2.5
13
13 *Platystrophia clarkvillensis*
X 2.5
15 A
16. *Lophospira bicincta* snail
15 B
14
13 *Platystrophia acutilirata*
X 2.5
15 C
19
A
18
A
16 A
16 B
Monoplacophoran - *Archinacella kagawongensis*



2:35 Drive to Rapid River Falls: Back track to US-2 and turn left. In 3.2 miles at Rapid City, turn right onto US-41. Go 7 miles north and look for picnic sign (on right side of road). Turn left onto Road I-389 (also called S15) and go round the bend to the right, cross the bridge over Rapid River, and head west to Rapid

		River Falls Park. Pull into the park on the left after Rapid River Lodge. (~20 min)
2:55	20	**Rapid River Falls:** Water here flows over Trenton Limestone (Middle Ordovician) in a series of ledges. Weathering loosens rock along bedding planes, giving this waterfall more of a step-like pattern. This limestone is poorly fossilized, and there is no collecting here. (20 min) At this point we will say goodbye to all and wish you safe travels.

Stop 20: Rapid River Falls:
Location: Rapid River Falls Park (N46°0.1348', W86°58.936')
Rapid River Falls flows over an Ordovician-aged limestone called the Trenton Formation – it is a little bit older than the Stonington Formation that we saw at stop 19 but has some of the same species of fossils that we observed there. The Trenton Formation is dominated by limestone and dolomite with minor interbedded clay-rich seams. Many of these clay-rich seams have been interpreted as ash beds and are linked to volcanic eruptions of the Taconic Island Arc. The Taconic Island Arc collided with North America during the Ordovician and was one of the early stages in the construction of the Appalachian Mountains.
Like the Stonington Formation, the Trenton was likely deposited in a lower energy setting – but with less clay coming into the system suggesting that the main phase of the Taconic Orogeny (collision of the Taconic Island Arc with eastern North America) had not occurred yet.
One thing to note at this site, is the style of weathering of the limestones. You will notice that the waterfall has a stair-like profile – at this location the bedding planes are nearly horizontal and form the treads of the stairs. This style of weathering requires that the rock already be weakened with a series of regular joints (fractures) along which failure can occur, spalling off blocks of rock. The process is called plucking or quarrying (Whipple et al., 2000).
Whipple, K.X., Hancock, G.S., Anderson, R.S. 2000, River incision into bedrock: Mechanics and relative efficacy of plucking, abrasion, and cavitation, Bulletin of the Geological Society of America, 112(3): 490-503.

Appendices

The Michigan Basin

The Michigan Basin is a circular intracratonic basin. Intracratonic means that the structure is in the interior of the continent. Most tectonic stresses act on the margins of continents – convergence due to subduction of oceanic crust, collisions as continental blocks are brought together, or sliding past one another along transform faults. Some of the compressional stresses can be translated through the crust into the interior – causing gentle warping of the crust. Down-warped crust can form the nucleus of a basin – and later sedimentation can load the crust more causing further subsidence. The Taconic orogeny likely initiated basin formation – this orogeny was due to the collision of an island arc with eastern North America during the Ordovician. Hamblin (1958) showed that paleocurrent indicators like crossbedding and ripple mark in Cambrian sediments (the Munising Formation) show flow directions away from the center of the Lower Peninsula and Ordovician sediments (the Au Train or Hermansville Formation) have flow directions towards the center. Water should flow towards lower topography – suggesting that by the Ordovician the basin had formed.
In the Upper Peninsula, the Paleozoic sedimentary units range from Cambrian to Devonian in age. The units dip towards the center of the Lower Peninsula. We will see several units as either outcrops or as clasts in younger sediments during our travel through the Upper Peninsula.
If you start your journey at the Mackinaw Bridge, the southern footings are in the Bois Blanc Formation. Crossing the bridge, you will then drive over the St. Ignace Dolomite and the outcrops right just north of the bridge are in the Mackinac Breccia. The Mackinac Breccia represents a collapse feature – where early Devonian caves collapsed and the rubble created formed the Breccia. As you follow US 2 West, you will cross over a series of stratigraphic units that are progressively older in age.

Between St. Ignace and Brevort you will drive over the Upper Silurian Point Aux Chênes Shales and the Lower Devonian Mackinac Breccia. Just west of Brevort, you will cross over onto the Niagaran Escarpment – a resistant ridge of rock cored by the Engadine Formation. Between Brevort and Ensign, you will drive over the rest of the Silurian rocks. After Ensign, you will cross over onto Ordovician-aged rocks. Between Hermansville and Vulcan, we will cross over the Ordovician-Cambrian boundary – in this part of Michigan, the Cambrian Munising formation has a patchy distribution due to erosion and we will see clasts of the Munising Formation at some stops. The base of the Munising Formation is characterized by a basal conglomerate – with clasts of the Precambrian rocks embedded in a matrix of sandstone.

A variety of resources are found in the Paleozoic rocks of the central and eastern Upper Peninsula. There are several large quarries in the Silurian rocks that mine crushed rock for aggregate or cement production (Port Inland, Cedarville, Drummond Island Quarry as well as a bunch of historic quarries). Near Rexton, high purity limestones are mined for flux. Historically gypsum was mined from the Pointe Aux Chênes Shale near St. Ignace and from the Cataract Group near Isabella. Dimension and ornamental stone are mined from the Big Hill Dolomite on the Stonington Peninsula. The Munising Formation has been prospected for glass sands, industrial sands, and hydraulic fracturing sands. A very significant resource hosted in these rocks is groundwater – which provides drinking water as well as water for local industry and agriculture. Hydrocarbon exploration has been done – but currently none of the Paleozoic rocks in the Upper Peninsula have been considered productive.

Generalized Stratigraphy of the Paleozoic rocks of the Upper Peninsula