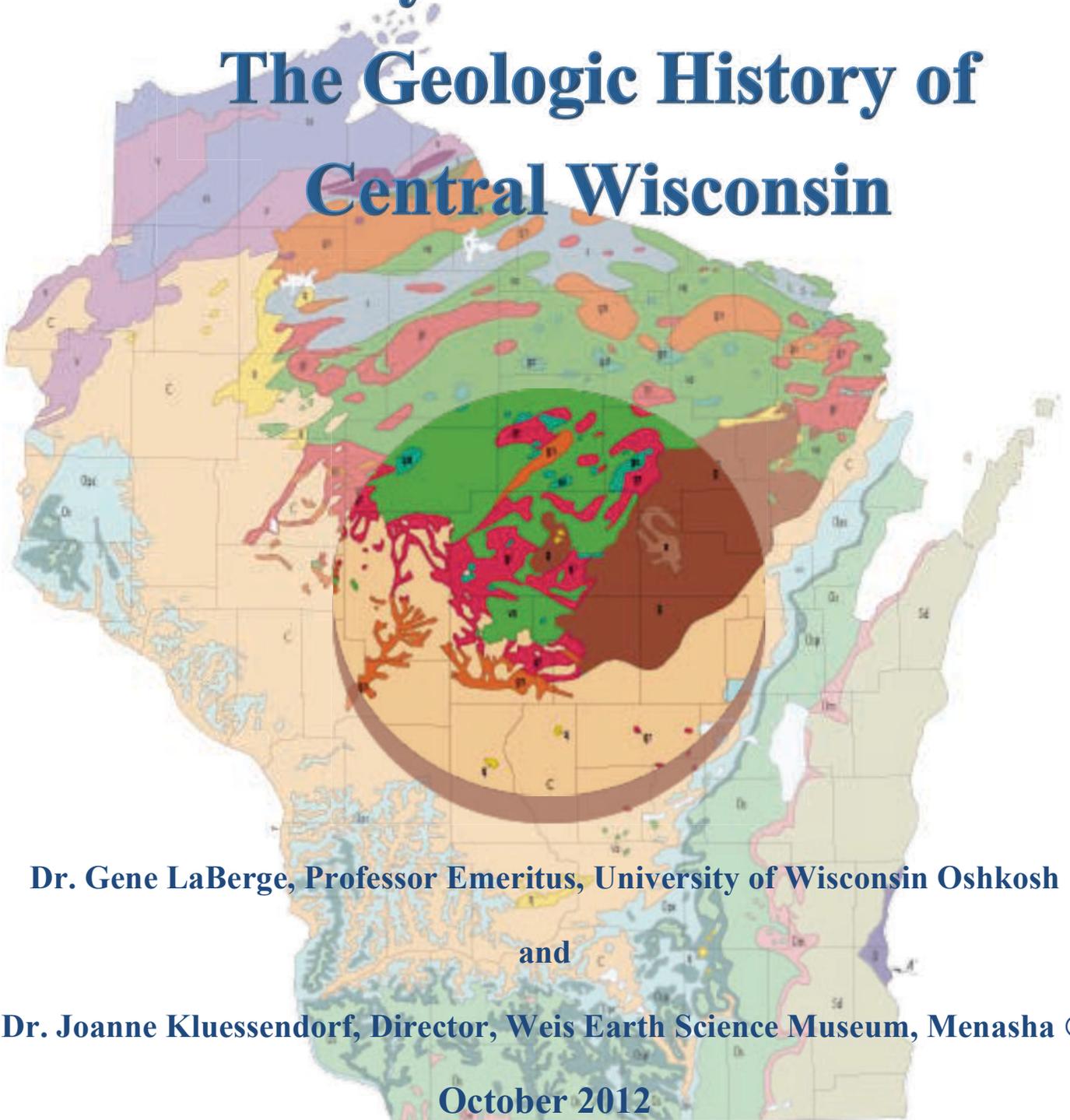


A Story Written in Stone: The Geologic History of Central Wisconsin



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and

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Introduction

The history of our Earth is recorded in its rocks — a story written in stone. The rock outcrops and boulders that we find along roads and rivers and in woods and fields provide clues about the significant changes that have taken place over time and reveal what a different place our planet, and Wisconsin, was in the ancient past.

Rocks in central Wisconsin are some of the oldest rocks in the state — almost 3 billion years old! In fact, they are some of the oldest rocks exposed in the U. S. During this vast amount of time, the geologic processes — shifting tectonic plates, mountain building, volcanic eruptions, changing sea levels — that make our planet work were busy shaping the continents and our state.

This booklet showcases some of the fascinating geologic features that we can see in the rocks, right in our own backyard — the stories we can find written in stone.

Mountain Building & Rock Bands

About 2.8 billion years ago, during the Archean Eon of Earth’s history, a mountain range formed in central Wisconsin. (Yes, there were mountains in Wisconsin — in different places and at different times!)

During periods of mountain building, pre-existing rocks are subjected to high temperatures and pressures, which cause folding and faulting and heat the rocks nearly to melting. As a result, mineral composition and rock texture are changed, or metamorphosed.

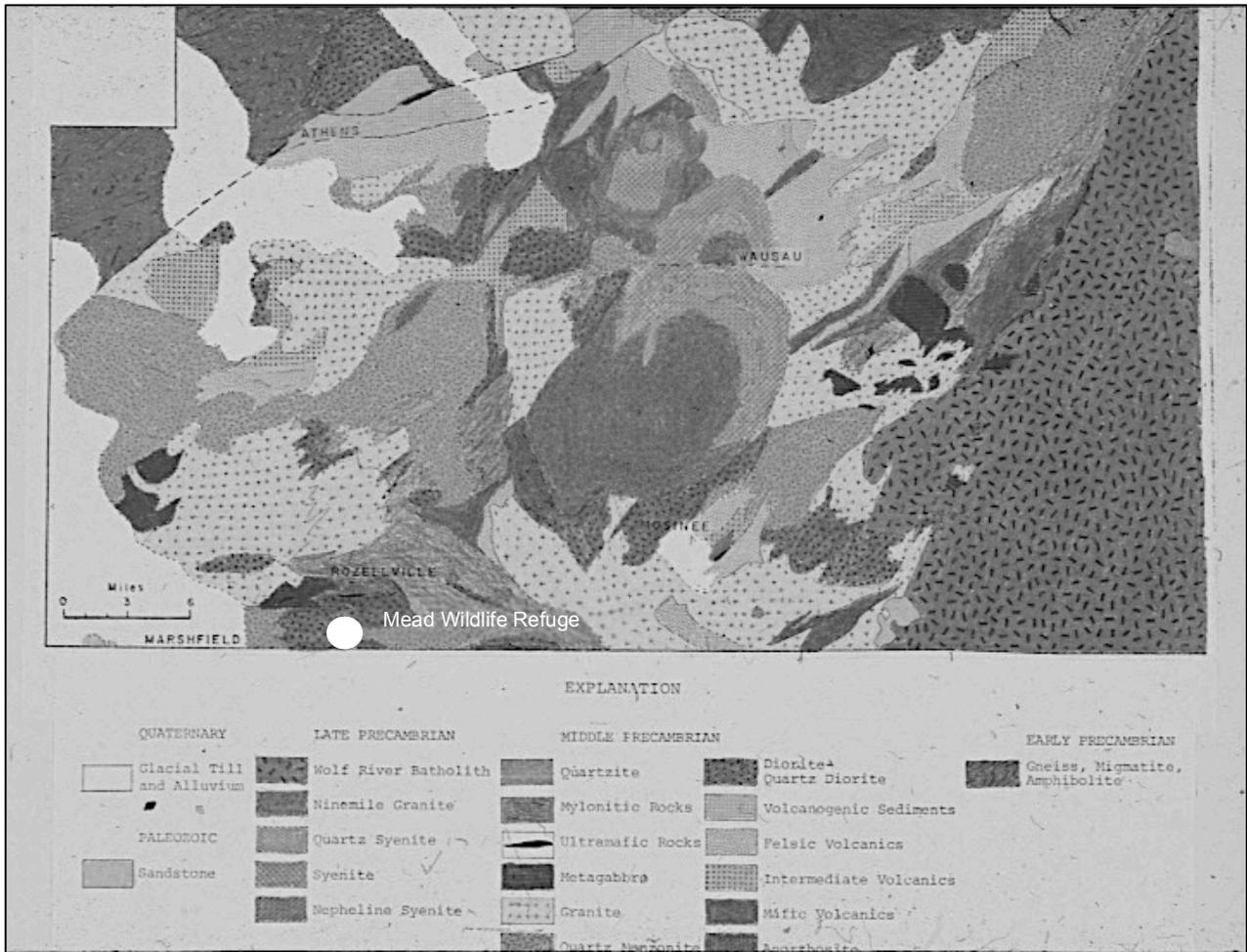


Bands of minerals in gneiss from Eau Plaine river valley.

In central Wisconsin, the coarse-grained metamorphic rock *gneiss* (pronounced “nice”) formed. The term may come from an old German word meaning “bright” or “sparkling.” Gneiss is characterized by the

separation of its component minerals, such as white quartz, pink feldspar and sparkly mica, producing light and dark bands in the rock.

Over the next 800 million years, this mountain range was mostly weathered away, but you can still see some remnants exposed at the Lake DuBay dam on the Wisconsin River, along new Highway 10 West from Stevens Point, in small outcrops along Wild Creek near the Little Eau Pleine River, and along the Black River in the Neillsville-Black River Falls area. Gneiss rocks also are common south of the Eau Pleine River valley.



Geological map of Marathon County showing distribution of the various rocks and their relationship to one another. Geologic maps are essential in determining the age relationship of the rocks in the area.

Map by LaBerge and Myer (1983).

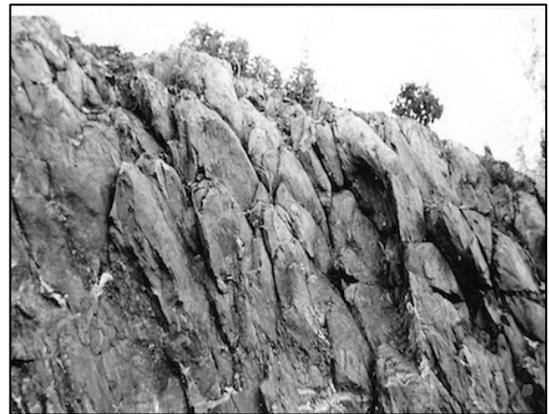
Pillow Lava

When we think of rocks, we don't usually think of pillows — at least not the soft, fluffy ones. But some rocks are called *pillow lava* because of the pillow- or sac-like shape they have, which formed in a very special way. Composed of the magnesium- and iron-rich igneous rock *greenstone*, pillow lava did not erupt from any common volcano! Instead, the greenstone oozed up as basalt lava onto the ocean floor from cracks formed in the Earth's crust where tectonic plates move apart. In fact, the ocean floor throughout the world is composed mainly of basalt with pillow structures, formed when molten basalt rises to the surface from deep inside Earth's mantle. As it reaches the surface and meets with seawater, the lava cools rapidly and forms a "skin" that causes "lava tubes" or pillow-like structures to form. The skin of the lava tubes and pillows commonly cracks, allowing lava to leak out and form additional pillows, which may pile up and drape over one another. This process happens over and over again until the supply of lava is exhausted. Pillows range from less than a foot to at least ten feet across, and the skin typically weathers to a different color than the interior.

The pillow lava in the Black River Falls area are Archean age, about 2.6 billion years old. Greenstone can be seen along Cunningham Creek in Jackson County.



Outcrop of basaltic pillow lava from the Archean ocean floor. The pillows are about two feet across.



Outcrop showing numerous overlapping pillow lava structures, which are somewhat stretched and deformed vertically.

From 1969-1986, iron ore was mined northeast of Black River Falls in Jackson County. This iron deposit originated about 2.6 billion years ago during the Archean. It is a banded iron formation composed of *jaspilite*, a rock that contains jasper (red chert) and bluish or silvery hematite (iron ore), some of which is shiny "specular" hematite. The jaspilite was folded and faulted, but not metamorphosed. The mine site, now water filled, has been reclaimed, and is now managed by the Jackson County Forestry and Parks Department as the Wazee Lake Recreation Area.



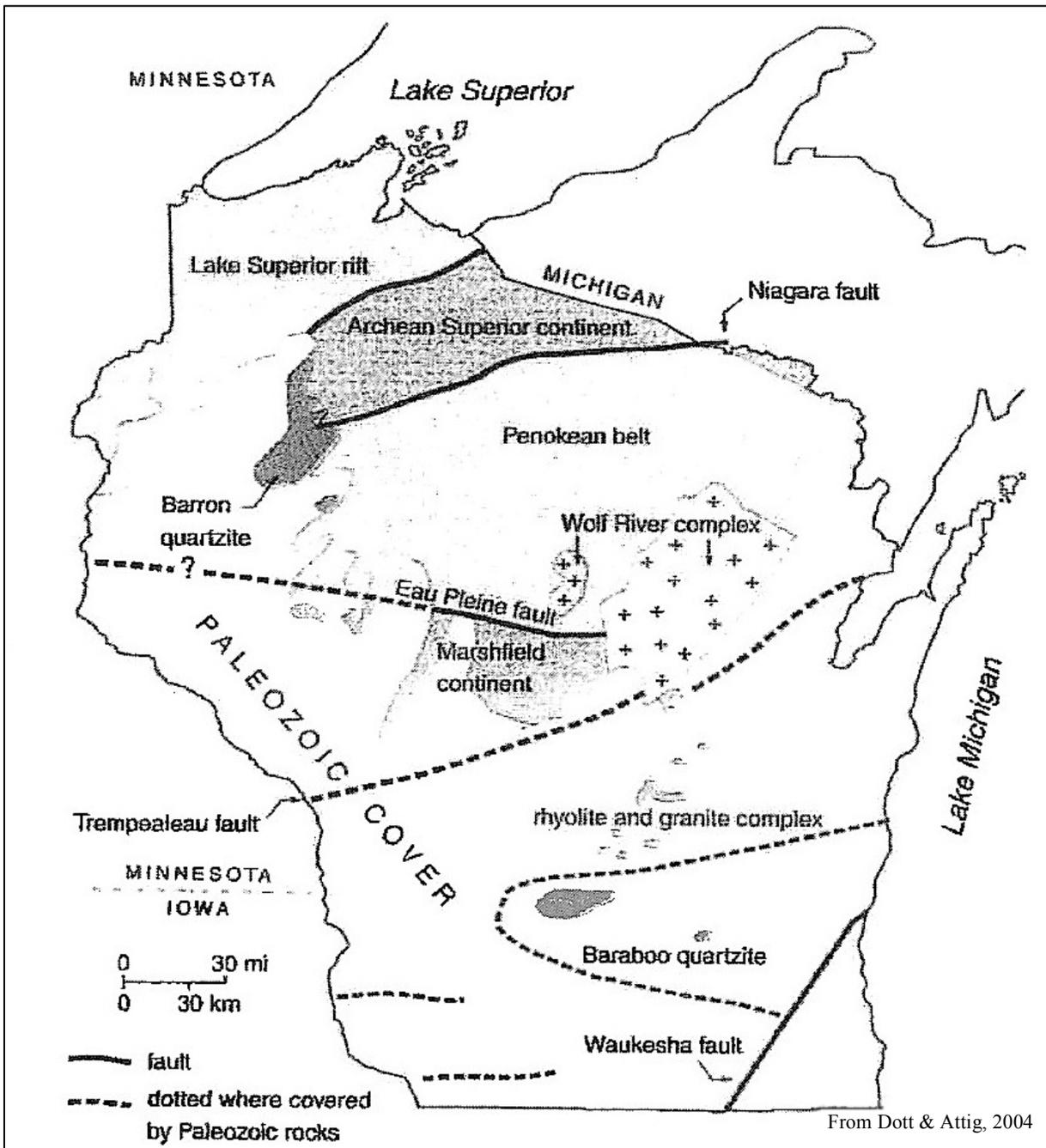
Cut and polished specimen of jaspilite showing bands of iron-rich hematite (light color) and jasper (dark color).



Wazee Lake Recreation Area showing reclaimed open pit mine.

Photo by Jackson County Forestry & Parks Department

The combination of gneiss, greenstone and iron formation is typical of ancient Archean continents throughout the world. In central Wisconsin, these rock types formed a landmass called the Marshfield Continent, a small part of the Canadian Shield that composed the core of the North American continent. The Marshfield Continent underwent erosion for nearly 800 million years, exposing the gneisses in the roots of an ancient mountain range.



Generalized geologic map showing distribution of Precambrian rocks. The Archean age rocks (shown in light gray hatch texture) are present in the “Superior continent” in northern Wisconsin and in the “Marshfield continent” in central Wisconsin.

More Ocean Floor Rocks

Following another very long period of erosion, the next event in the rock record in central Wisconsin consists of rocks that formed on the ocean floor, with pillow lavas much like those that formed in the older Archean time. In addition to pillow basalt, ocean floor crust contains several other rocks. Cracks called *dikes*, which form in the basaltic crust, may be filled with molten basalt that cools more slowly and forms a coarse-grained, dark-colored intrusive igneous rock called *gabbro*. The addition of seawater caused the gabbro to be altered to water-bearing minerals, and converted to metagabbro. Dikes in the pillow lavas may also be filled with blocks of the green-colored rock *dunite*, which is composed of the magnesium-rich mineral olivine. As in gabbro, the addition of seawater altered the olivine to the water-bearing fibrous minerals talc or serpentine, or both.

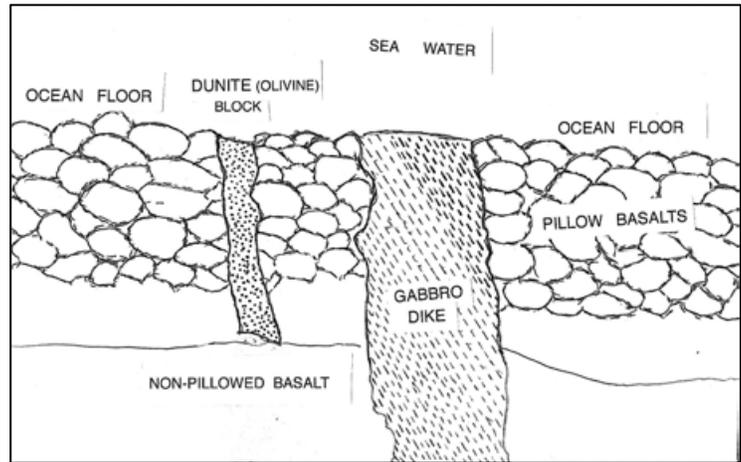


Diagram of ancient ocean floor showing pillow lava that has been disrupted by dikes of gabbro and dunite.

Greenstone (pillow lavas), metagabbro, talc, and serpentine are all present along the Eau Pleine valley, indicating that these rocks originated on an ancient ocean floor. An exposure of the Milladore talc occurs in the Mead Wildlife Refuge.

Violent Volcanoes

Violent volcanoes are also a part of Wisconsin's ancient past. They formed around this same time as a northbound

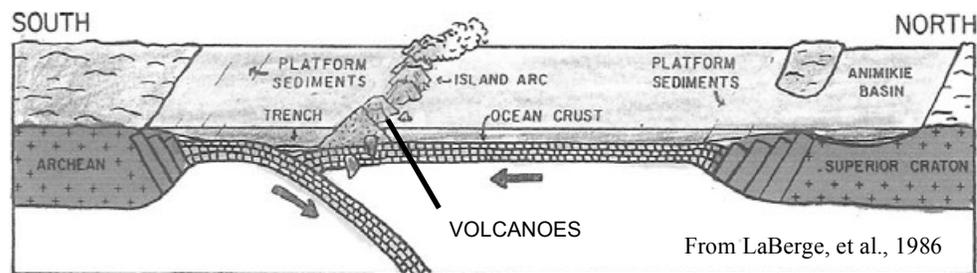
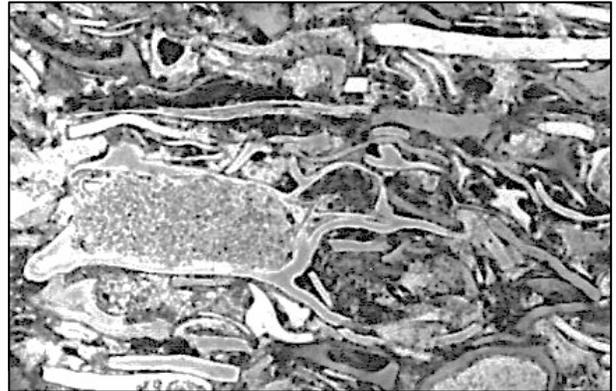


Diagram of tectonic plates showing subduction and associated volcanic eruptions.

tectonic plate was carried down, or subducted, into Earth's hot mantle. Here the old rocks were heated and began to melt. Some of this melted rock, or magma, rose to the Earth's surface in explosive volcanic

eruptions. These volcanoes produced a chain, or arc, of volcanic islands, like the modern Aleutian Islands of Alaska. The violent, explosive eruptions produced fragmental volcanic rocks. These eruptions resulted in deposition of the fine-grained extrusive igneous rocks *rhyolite* and *andesite*. Both of these rocks contain an abundance of silica, which gives the rocks a high viscosity. This means that these lavas are more explosive and slower moving (like molasses) than the more fluid basalt lavas that are typical of volcanoes on Hawaii. Rhyolite and andesite are common throughout Marathon County and elsewhere in north-central Wisconsin.

As the water-rich rhyolite magma neared the surface, the water began to boil, converting the magma into a froth of bubbles with rhyolite glass walls. The bubbles explode during the eruption and form a cloud of steam and “volcanic ash” of broken glass walls of bubbles.



Explosive rhyolite eruptions also shatter rock that formed from earlier eruptions, forming huge masses of rock fragments ranging in size from dust to blocks larger than houses. This produces rocks with visible fragments.

These are common in Marathon County.

Following the most eruptive phase of eruption, rhyolite lava may ooze out of the volcano, forming “banded” rhyolite, such as this near Rib Falls.



Great Granite

Not all of the magma produced by the subducted tectonic plate made it to the surface in volcanoes. About 1.8 billion years ago, some of the magma formed *granite*, which is made of the same minerals (mostly quartz and potassium feldspar) as rhyolite. Granite contains larger crystals than rhyolite because it cooled more slowly below the Earth's surface, while rhyolite cooled rapidly in an erupting volcano at the surface.

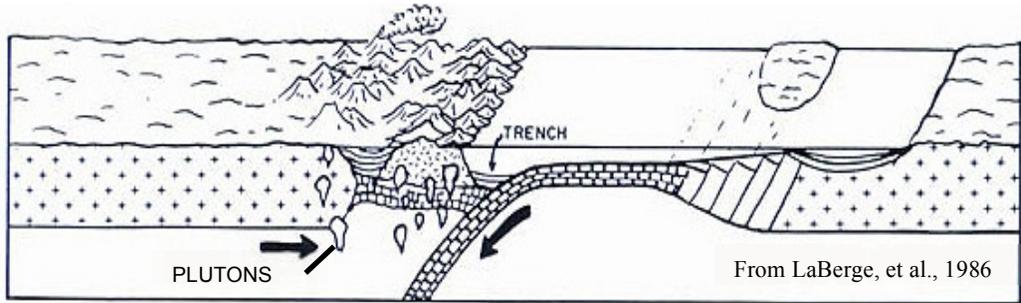


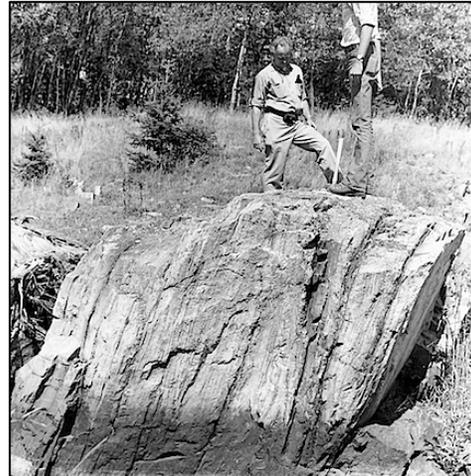
Diagram showing tectonic plates and location of granite plutons.

This is why granite has a coarse-grained texture that allows us to identify the different minerals in it but rhyolite is so fine grained that it is difficult to see its crystals with the naked eye.

Through strong movements of Earth's crust and long periods of erosion, some of these granite masses, called *plutons*, made their way to the surface. At one time, there were probably many volcanoes overlying them, but they have been eroded away. This granite, which can be red, pink or gray in color, can be seen throughout Marathon, Portage, Wood and Clark counties. The deep red-colored granite quarried north of Wausau has been named the official state rock of Wisconsin.



Granite quarry near Wausau.



Mylonite exposed near town of Milan,
southwest of Athens.

The area where this tectonic plate was subducted was a zone of unimaginable pressure. Such intense pressure can produce distinctive rock textures, such as the fine-grained “streaky” metamorphic rock called *mylonite*. Some of the features include flattened, or stretched, fragments in volcanic rocks and boulders that are smeared or folded.

These special rock textures are clues to the presence of major fault zones, or cracks in Earth’s crust. Almost TWO BILLION YEARS after it formed, the deformation in this fault zone formed the site for the Eau Pleine River Valley to develop. The following photos illustrate the sequential effects caused by such intense pressure along the extent of a major fault zone near Stratford.



This top photo shows pre-existing, relatively undeformed conglomerate containing white quartzite boulders that still have their round shape.

This middle photo shows that the quartzite and other boulders have been flattened greatly by pressures along the fault.



This lowest photo shows that the quartzite boulders, which are still white, have been flattened, folded and smeared by movement and pressure along the fault zone.

More Mountains

As time went on, the volcanic island chain and the large continent to the north had been moving toward

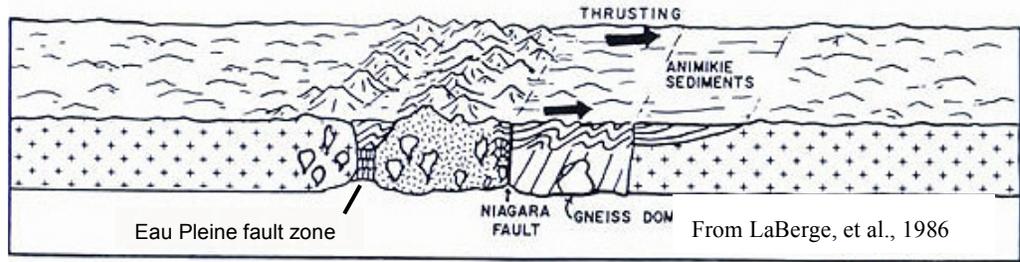


Diagram of tectonic plates showing the collision that produced the Penokean Mountains.

each other slowly — only a few inches per year. But about 1.8 billion years ago, they finally collided. This collision, which occurred along the Niagara Fault Zone and the Eau Pleine Fault Zone, caused intense deformation such as folding, faulting, metamorphism, thrusting and uplift of the rocks. The result was a new mountain chain known as the Penokean Mountains.

This high mountain range, which may have rivaled the modern Alps in height and grandeur, was oriented more or less east-west across what are now Minnesota, Wisconsin and Michigan. The Mead Wildlife Refuge is located on the southern edge of where this mountain range was located. The rise of the

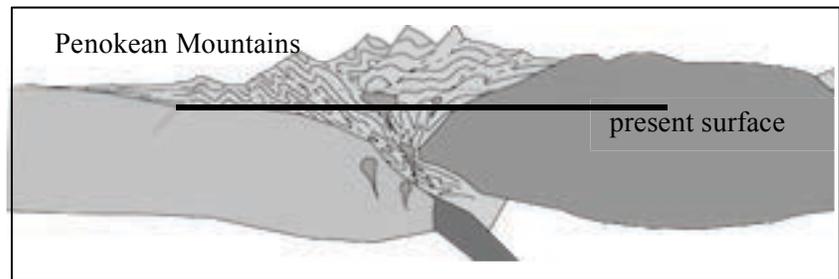


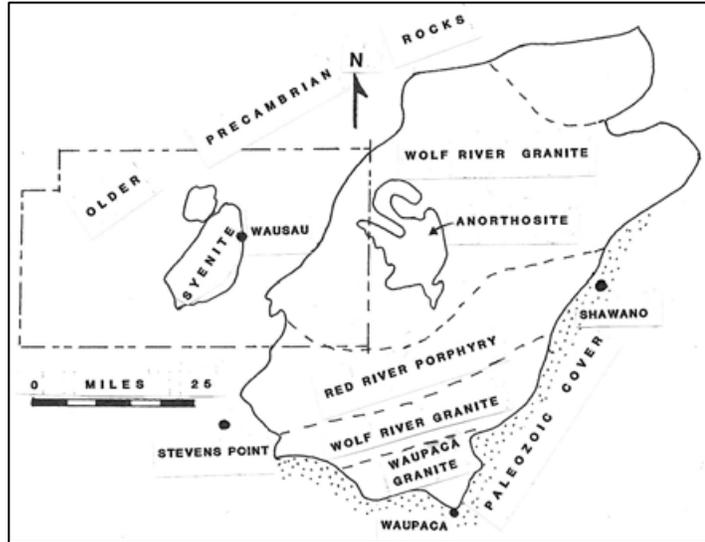
Diagram showing Penokean Mountains were mostly removed by erosion down to present ground surface. From Dott and Attig, 2004.

Penokean Mountains was a major event in the formation of the North American continent, and it coincided with a worldwide period of mountain building and continent formation.

Over the next 350 million years, streams, weather and wind wore down the Penokean Mountains. Without a protective cover of land plants, the mountains were eroded down to a gently rolling landscape with little relief. Erosion left behind thick layers of sedimentary rocks, particularly sandstone, dolomite and shale. The quartzite at Rib Mountain, Baraboo, Barrons and elsewhere, which is metamorphosed sandstone, is a remnant of these sediments. The sedimentary rocks were deposited between 1.8 and 1.6 billion years ago, at which time they were they were deformed during yet another mountain-building event.

Wolf River Batholith

The next geological event in central Wisconsin began about 1.5 billion years ago, when there was an intrusion of even more granite and related coarse-grained igneous rocks than ever before. When Earth's crust becomes over-thickened during mountain building, the deeply rooted rocks can become heated to melting and produce bodies of granitic magma. These granite bodies, which are called *batholiths*, are larger than plutons.



These formed the Wolf River Batholith, a combination of many granite plutons coalesced into a gigantic mass of magma that worked its way up into Earth's crust.

Map of location and extent of the 1.5 billion year old Wolf River Batholith, which was unusual in that its intrusion did NOT cause deformation of surrounding rocks. From LaBerge, 1994.

Covering more than 1300 square miles, the Wolf River Batholith extends across much of central and northeastern Wisconsin, stretching from the town of Mountain in Oconto County southwestward to the northeast corner of Marathon County, passing just east of Eau Claire Dells, then southwestward to Stevens Point. There the boundary turns east to Waupaca, where the batholith is covered by much younger rocks, before it returns to the Mountain area.

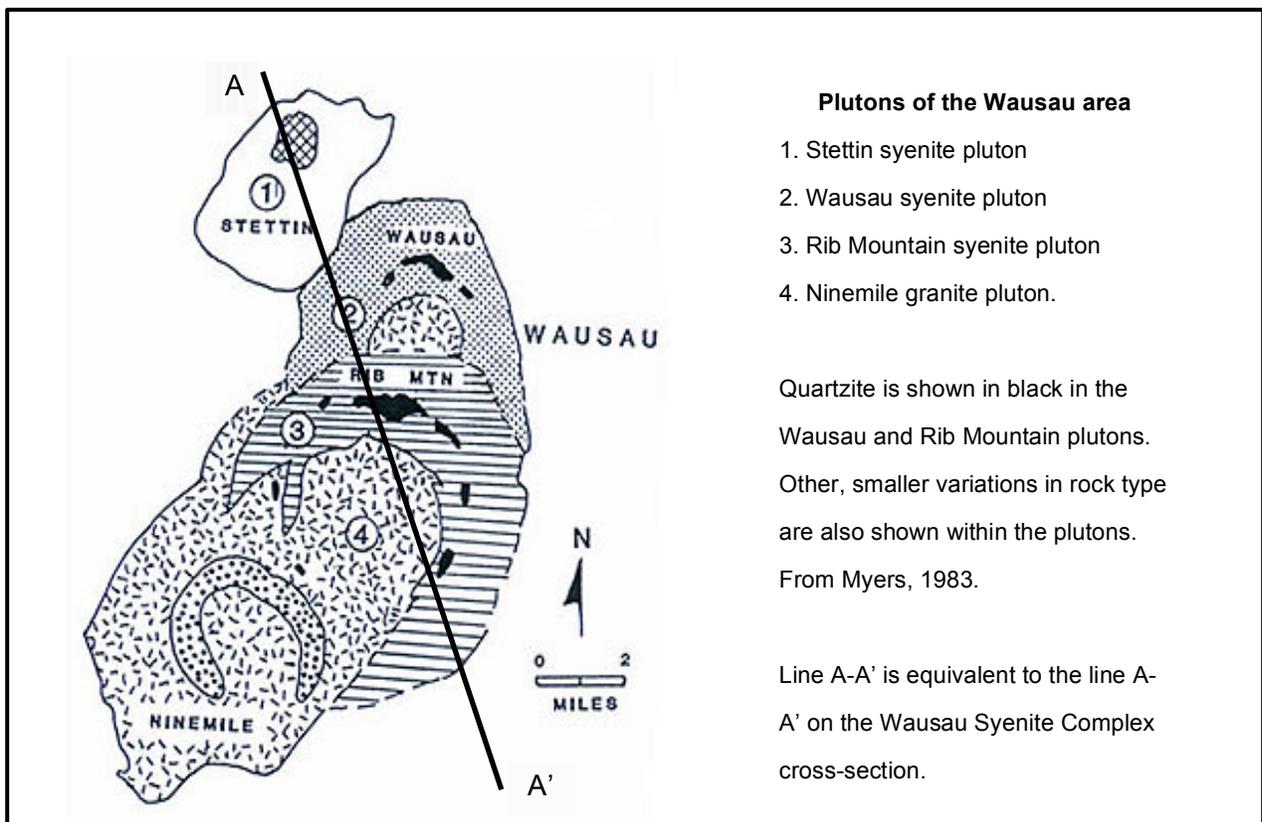
Coarse-grained granite outcrop of the Wolf River Batholith located in a pasture southeast of Wausau. The parallel grooves are caused by weathering along fractures (joints) in the rock.

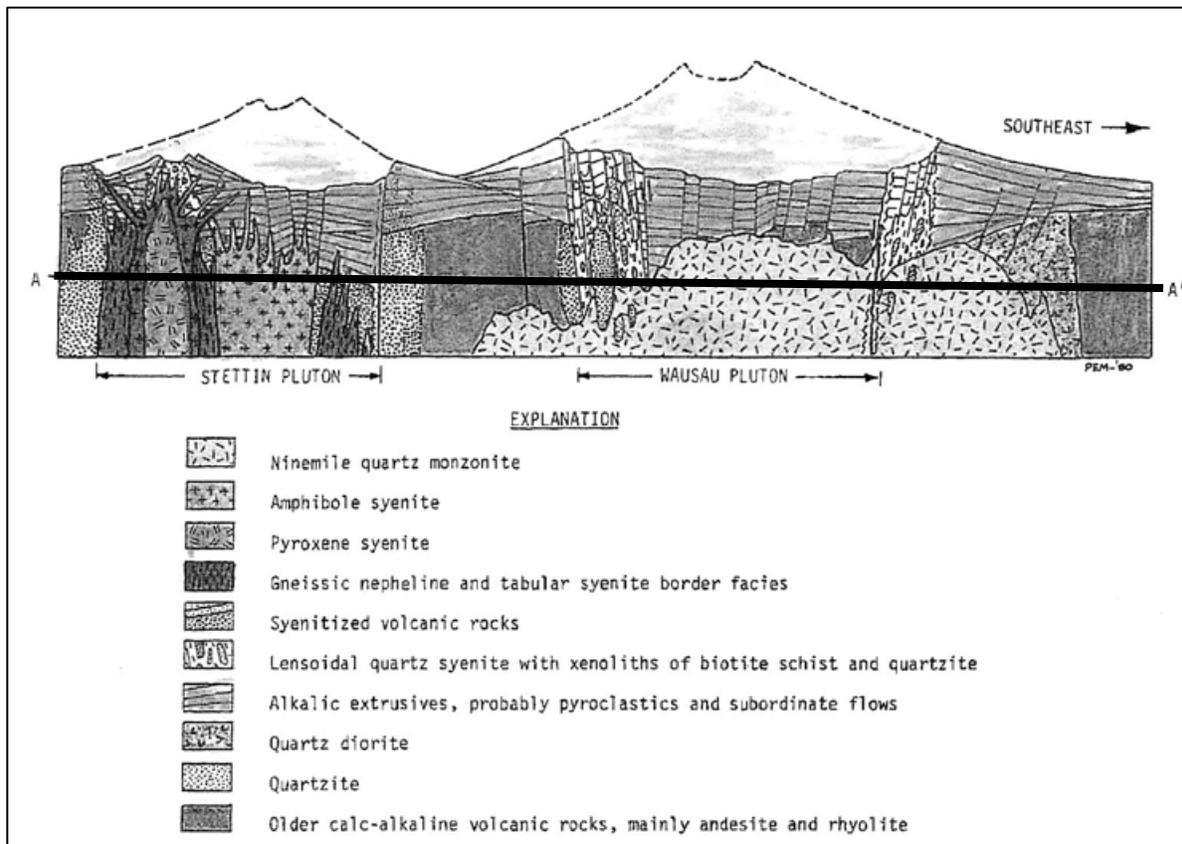


No Quartz and Quartzite

About 50 million years after the Wolf River Batholith was emplaced, a series of four small plutons were intruded into older rocks of the Penokean Mountains, just west of Wausau. Called the Wausau Syenite Complex, these were composed of granite or *syenite*, an uncommon intrusive igneous rock that contains no quartz. Syenite, which cooled slowly, is a coarse-grained rock composed of predominantly of sodium and potassium feldspars. These intrusions were probably part of the roots of volcanoes that had been eroded away.

In contrast to popular belief, Rib Mountain is NOT a volcanic peak. Instead, Rib Mountain, as well as nearby Mosinee Hill and Hardwood Hill, are composed of blocks of quartzite, which is metamorphosed sandstone. These gigantic quartzite blocks are embedded in the syenite plutons. The quartzite, which is more resistant to erosion than the syenite, forms hills that stand hundreds of feet above the surrounding countryside.



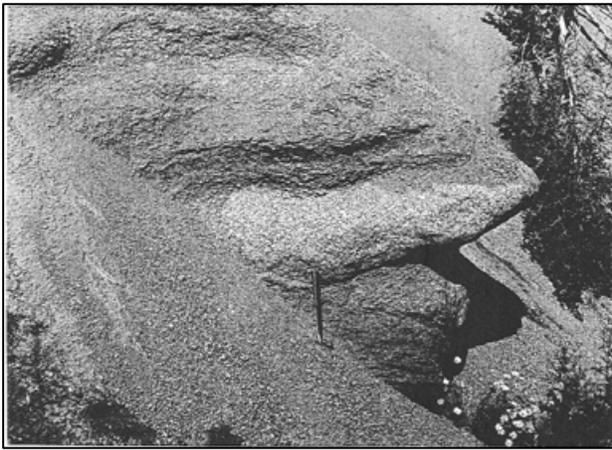


Cross-section of the Wausau Syenite Complex. Several intrusions are interpreted to be “roots” of volcanoes. Volcanic rocks along the Wisconsin River just north of Wausau are considered remnants of volcanic rocks that formed on the surface above the granitic rocks now exposed. Diagram also shows that quartzite on Rib Mountain and elsewhere in the syenite complex formed after the Penokean Mountains and before the Wausau Syenite Complex. The line A—A' represents the present land surface and is the same as line A-A' in figure of Plutons of the Wausau area. From Myers, 1983.

Rotten Granite

Granite south of Rib Mountain, named the Ninemile Granite after the Ninemile Swamp, contains a large amount of decomposed granite called *grus* (pronounced “grooz”). The Ninemile Granite may have formed very close to the Earth’s surface, possibly intruding pre-existing volcanic rocks. After cooling, a long period of erosion and weathering took place. This caused the granite to become fragmented, but not chemically altered. This process happens to some coarsely crystallized granite. This rotten granite is now exposed and used for road aggregate.

“Rotten granite,” or *grus*, pit in the Ninemile Granite south of Rib Mountain, which contains crumbly, rust colored feldspar and quartz.



Rounded masses of solid, unaltered granite show that the *grus* formed by exfoliation, meaning that the granite just fell apart by decomposition.

“Missing” Rocks

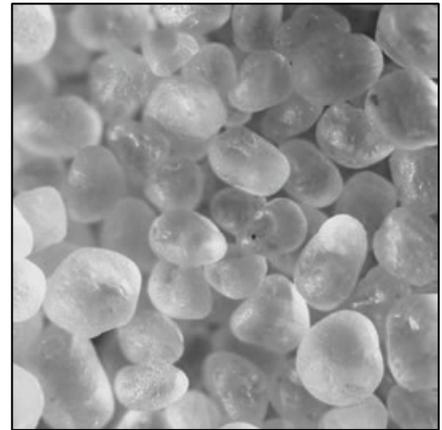
About 1.5 billion years ago, after intrusion of the Wolf River Batholith and the Wausau Syenite Complex, another long period of erosion took place, possibly as long as 500 million years. Judging from deposits in neighboring states, it is likely that many hundreds of feet of basalt lava flooded across Wisconsin. These deposits are the source of the rich copper deposits that were mined in the Keweenaw Peninsula of Michigan for more than 100 years. The widespread presence of basaltic dikes in northern and central Wisconsin, including dikes that cut across the Ninemile Pluton, suggests they were “feeders” for lava flows on the surface, which may have been a mile or more in thickness. Almost nothing of these lava flows remains in Wisconsin, however, following nearly a billion years’ worth of erosion!

Shallow Seas and Special Sand

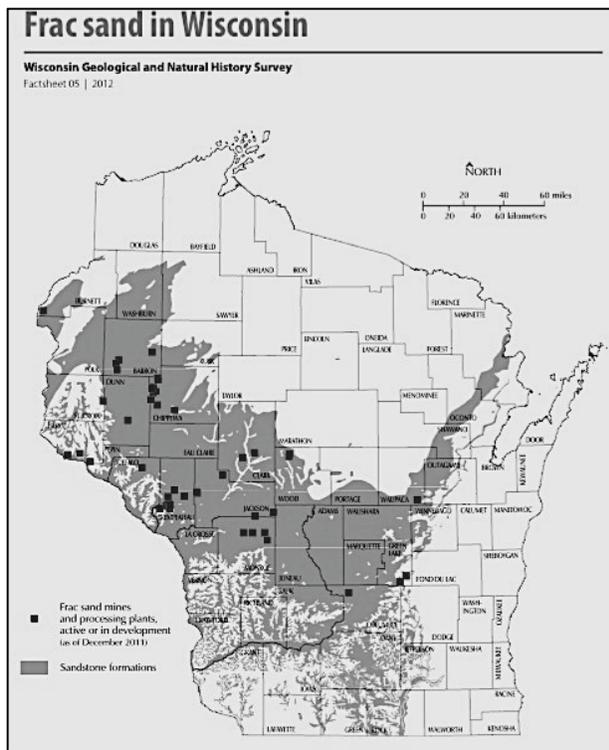
Throughout most of the Precambrian, ocean waters advanced and retreated numerous times across the ancient North American continent, including Wisconsin. At the close of the Precambrian, the continent was located near the equator, the climate was very warm, and this region had been eroded to a broad, flat plain.

With the beginning of the Paleozoic Era about 570 million years ago, the ocean slowly began to cover the region once again. As waves eroded the barren landscape, which was dominated by quartz-rich rocks like granite and quartzite, hundreds of feet of sand were deposited. With subsequent sea level advance and retreat, these sands and other sedimentary rocks were eroded and re-deposited many times over the next 200 million years or so.

These ancient sand deposits are now an important natural resource mined in west-central Wisconsin. They are not your typical sandbox-variety sands. Because these sands had been reworked and re-deposited so many times, they are composed mainly of pure quartz grains, and these grains have been smoothed and rounded into small



Close-up of spherical pure quartz frac sand showing porosity and permeability.



More than 70 frac sand mines were located in Wisconsin by mid-2012.

uniform spheres. Like so many marbles in a box, these spherical quartz sand grains don't pack closely together but leave open connected pores between them.

This special quality of our ancient sand is what makes it *frac sand*, which is so important to the oil and gas industry. In order to extract oil or natural gas, a mixture of sand, water and chemicals is injected into the deposit in order to fracture the rock. Frac sand moves into the fractures and holds them open, while the hydrocarbons can pass through the openings between the sand grains.

Life on Earth was nearly all marine, single-celled and microscopic until near the close of the Precambrian when the first multicellular life appeared. With the beginning of the Paleozoic, marine life became more diverse, abundant and widespread, and, over time, the ancestors of modern organisms evolved.



Painting *The Cambrian Sea* by Zdenek Burian, 1956.



Cambrian jellyfish on ripple-marked sandy shoreline near Mosinee, Marathon County. From Dott and Attig (2004).



Starfish (1 inch wide) in Ordovician age rocks at Mackville, Outagamie County. Photo by Sally LaBerge.



Some of the mammals that lived in North America during the last ice age.

The oceans covered our region for most of the first half of the Paleozoic Era. About 350 million years ago, however, the seas withdrew from the area for the last time. Wisconsin and the surrounding continent seems to have been dry land ever since.

Dinosaurs and, later, weird mammals likely roamed the Wisconsin landscape throughout this long time period, but we have not found their fossils. This isn't surprising given that the land would have been weathered and eroded throughout these many millions of years, destroying all evidence of the rocks that held their fossils.



Flat-lying Cambrian sandstone overlying Precambrian granite with foliation, Clark Co., WI

Ice Age Legacy

About 1.8 million years ago, Earth's climate cooled, creating vast continental ice sheets that advanced and retreated numerous times across the northern hemisphere. The ice sheets disappeared from the region about 10,000 years ago. This was the last of many ice ages that impacted Earth over its history.



Photo showing edge of the continental ice sheet in Baffin Island, Canada. The melting ice produces many streams flowing away from the end of the glacier.

Photo by Robert Baker.

The ice sheets, which were a mile or more thick, advanced slowly over the land. The underlying soil and rocks froze onto the glacial ice and were carried up to several hundred miles by the glaciers. When the ice melted, it dropped all the debris that was frozen into the glacier.

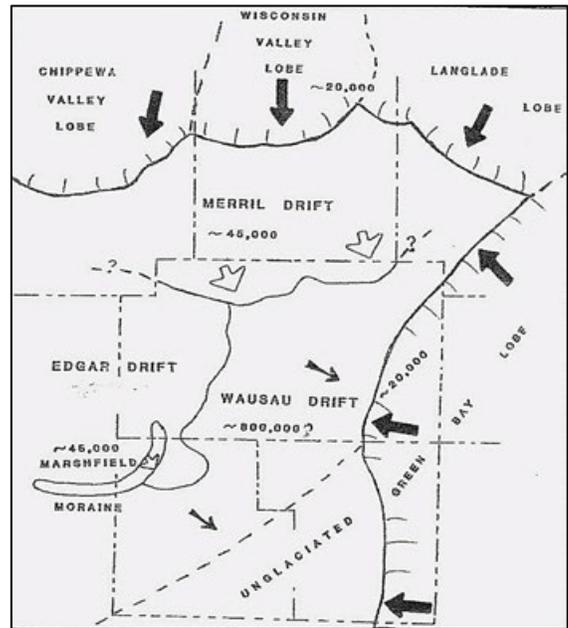
The southern part of Clark, Wood, and Portage counties is thought to never have been glaciated and is considered part of the *Driftless Area*, which has a well defined drainage pattern superimposed on the old Paleozoic rocks. The name "driftless" means there is no glacial material, or "drift" covering the older rocks.

At least five different continental glaciers left their mark on the landscapes of central Wisconsin. Much of central and eastern Marathon County was glaciated during an early glacial advance, possibly more than 800,000 years ago. Materials left by this glacier contain boulders from northern Minnesota as well as boulders of Rib Mountain quartzite, indicating the ice sheet was moving in a southeasterly direction. In western Marathon County, eastern Clark County and western Wood County, younger glacial material contains limestone cobbles that were probably transported from western Wisconsin by the ice. Boulders in glacial material in northern Marathon County, which has been dated as 40,800 years old, indicate that that ice sheet came out of the Lake Superior basin.

The youngest glacial deposits in central Wisconsin are represented by a series of “hummocky” ridges in the eastern part of Marathon and Portage Counties. These were produced by ice from the Green Bay Lobe that moved westward into the area between 18,000 to 10,000 years ago.

The Green Bay Lobe ice sheet covered a very wide area, which blocked the drainage of the Wisconsin River in the Portage area. Glacial Lake Wisconsin, a large lake was dammed up for several thousand years behind this blockage, north into Wood and Portage counties. When the blockage was removed as the ice sheet melted, the lake drained in a very short time. The picturesque Dells of the Wisconsin River were carved out of the sandstone bluffs by the rushing meltwater as it left the lake basin; the dells may have been produced in as little as a week or two of erosion by rushing water. The flat landscape throughout much of central Wisconsin is the remains of the old lakebed, and the sandstone mesas in Juneau and Monroe counties rising above this plain had been island in the glacial lake.

Water, which flowed from the melting ice sheets of the Green Bay Lobe and the Langlade Lobe located in the northeast



Ice lobes and glacial deposits in central Wisconsin. Arrows indicate direction of ice movement.

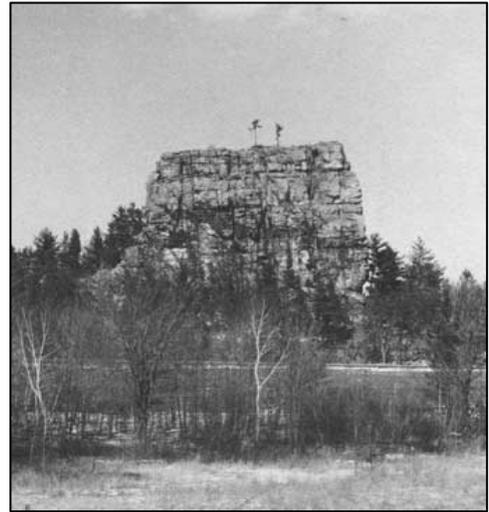


Sculptured sandstone bluffs along the Dells of the Wisconsin River formed by rapid draining of Glacial Lake Wisconsin.

corner of Marathon County, produced a broad flat sandy plain called Antigo Flats. This meltwater, at the headwaters of the Eau Claire River, formed the scenic Eau Claire Dells in northeastern Marathon County.



Precambrian igneous rocks were eroded by melting ice sheets, creating a canyon, or dell, along the Eau Claire River



Bee Bluff near Camp Douglas was an island in Glacial Lake Wisconsin. Photo by Wis. DNR

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Geological Time Scale for Central Wisconsin

	Eon	Era	Time	Events
PHANEROZOIC		CENOZOIC	2 million years ago	Last ice age
		MESOZOIC	65 million years ago	"age of dinosaurs"
		PALEOZOIC	250 million years ago 350 million years ago 570-350 million years ago	seas withdrew and long period of erosion begins shallow seas covered area much of the time
PRECAMBRIAN		PROTEROZOIC	1.1 billion years ago 1.45 billion years ago 1.5 billion years ago 1.63 billion years ago 1.76 billion years ago 1.87-1.85 billion years ago 1.89-1.85 billion years ago	erosion extensive basalt lava flows copper emplaced erosion Wausau Syenite Complex Wolf River Batholith erosion quartzites folded Penokean Mountains folded Lake Superior iron formation deposited Penokean Mountains formed & ocean crust subducted
		ARCHEAN	2.6-1.9 billion years ago 2.7-2.6 billion years ago 2.8-2.6 billion years ago 4.6 billion years ago	erosion iron formation deposited greenstone ocean crust & pillow lavas formed gneiss formed by mountain building origin of Earth