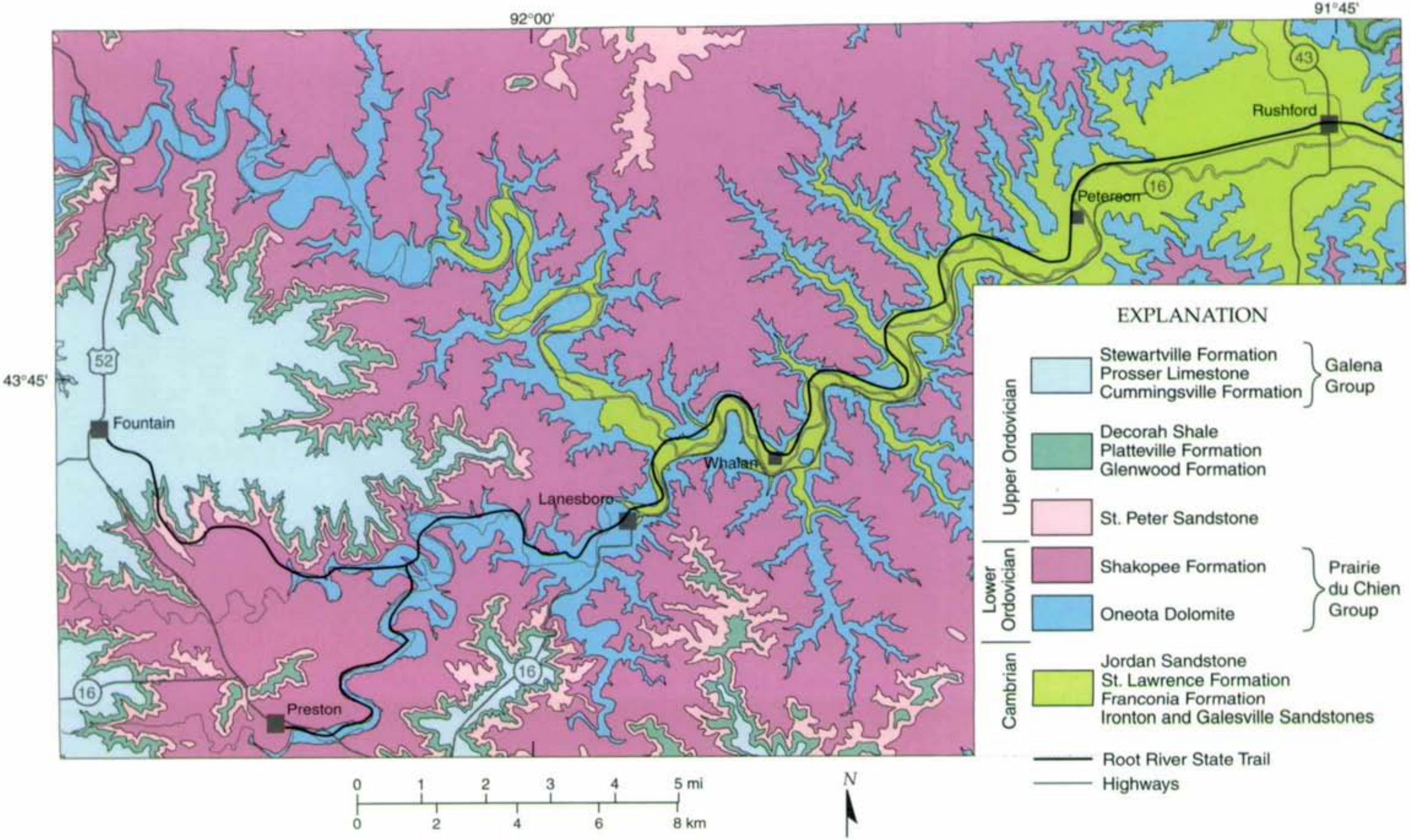
Minnesota Geological Survey Educational Series 10

Geology of the Root River State Trail Area, Southeastern Minnesota

by John H. Mossler

BEDROCK GEOLOGIC MAP OF THE ROOT RIVER STATE TRAIL AREA, SOUTHEASTERN MINNESOTA



GEOLOGY OF THE ROOT RIVER STATE TRAIL AREA, SOUTHEASTERN MINNESOTA

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Getting To The Root River State Trail

The Root River State Trail is a paved walking, bicycling, and cross-country skiing trail in southeastern Minnesota that currently extends from the town of Fountain through Lanesboro to Rushford, and farther east towards Houston. It is maintained by the Minnesota Department of Natural Resources, which operates a trail information center in Lanesboro. The Rushford Historical Society operates a trail rest area in Rushford. The trail is part of a planned network of trails throughout southeastern Minnesota, that will ultimately extend into Iowa and Wisconsin. This guide was developed for the Fountain to Rushford segment of the Root River State Trail, but the information will help you learn more about geologic features you see anywhere in southeastern Minnesota.

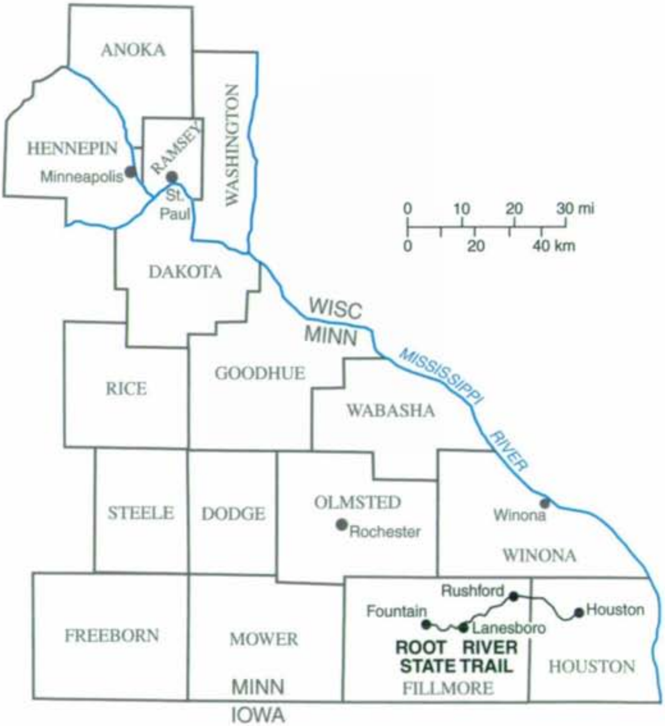


Figure 1. Location of Root River State Trail.

To get to the Root River State Trail from the Twin Cities, take US Highway 52 south to Rochester and Fountain. Alternatively, you can take U.S. Highway 61 south from the Twin Cities to Winona, and State Highway 43 from Winona to Rushford. Access to Houston and Rushford from the east is via State Highway 16, which parallels the trail between Houston and Lanesboro.

Introduction

The Root River State Trail (Fig. 1) traverses the unique landscape of Minnesota's 'Historic Bluff Country,' and provides us with a birds-eye-view into the processes that have been forming the rocks and the land surfaces in this part of Minnesota during the past 500 million years. Flat-lying layers of **limestone** and **dolostone** form high bluffs above narrow river valleys, such as the Root River valley. The limestone uplands are intensively farmed, but many of the fields contain pits or depressions, called **sinkholes**, that surface water drains into. The sinkholes are usually overgrown with burr oak, stinging nettle, woodbine, and wild cherry. The Root River has eroded a steep-sided valley into the layers of limestone and dolostone. At the base of the cliffs, water that drained into the sinkholes on the uplands emerges as springs, having traveled through passageways in the limestone and dolostone.

This booklet summarizes the history of the rocks that you see as you explore the Root River State Trail, and presents a field guide to features of geologic interest. The booklet is divided into four sections. At the start, in the **Background** section, the geology of Minnesota is briefly introduced, together with general geologic principles. In the **Geologic History** section, the geologic history of southeastern Minnesota is summarized. The Paleozoic (500-million year old) rocks are described first, then the Pleistocene (2 million to 10,000 years old) glacial deposits, and finally the modern-day (Holocene—younger than 10,000-years old) sediments. In the **Trail Guide** section the geologic features on or near the Root River State Trail between Fountain and Rushford are described, and their origins explained. The site numbers are keyed in to the trail map in the back pocket of this guide. The final **Further Information** section includes a glossary of some of the geologic terms, as well as suggestions for further reading. The first time a new geological term is used in the Background and Geologic History sections, it is written in bold face, and is explained in the glossary. The rock **stratigraphic** sequence for southeastern Minnesota is given on the outside back cover, and a simplified geologic map is presented on the inside front cover.

Readers who want to find out more about the general geology of southeastern Minnesota are referred to 'Minnesota's Geology,' 'Minnesota Underfoot,' 'The Geology of Whitewater State Park,' and 'North America and The Great Ice Age' (see Further Reading on p. 55 for complete citations). Detailed descriptions and discussion of the geology and hydrology of the region are presented in the Geologic Atlas of Fillmore County. Information on the history of the Lanesboro area can be found in articles by the Lanesboro Historical Preservation Society.

BACKGROUND

Minnesota Geology

The rocks and landscape of Minnesota record a complex history. The oldest **bedrock** in Minnesota records a history that goes back to at least 2.7 billion years (2,700 million years), and involves volcanoes, ocean islands, mountain chains, tropical beaches, tidal flats and ocean basins. The oldest rocks are exposed at the surface in northern Minnesota. In southeastern Minnesota they form the basement or underpinnings upon which 545 million-year old (Paleozoic) sediments were deposited. The Paleozoic sedimentary rocks are now overlain by **unconsolidated** earth materials (clay, sand, gravel and soil), also known as **surficial** deposits, that were largely transported and deposited by **glaciers** and their **outwash** streams during the past 2 million years. Most of the landscape we see today was carved or formed during the past 2 million years, although much of the bedrock and basement is among the oldest in North America (Fig. 2).

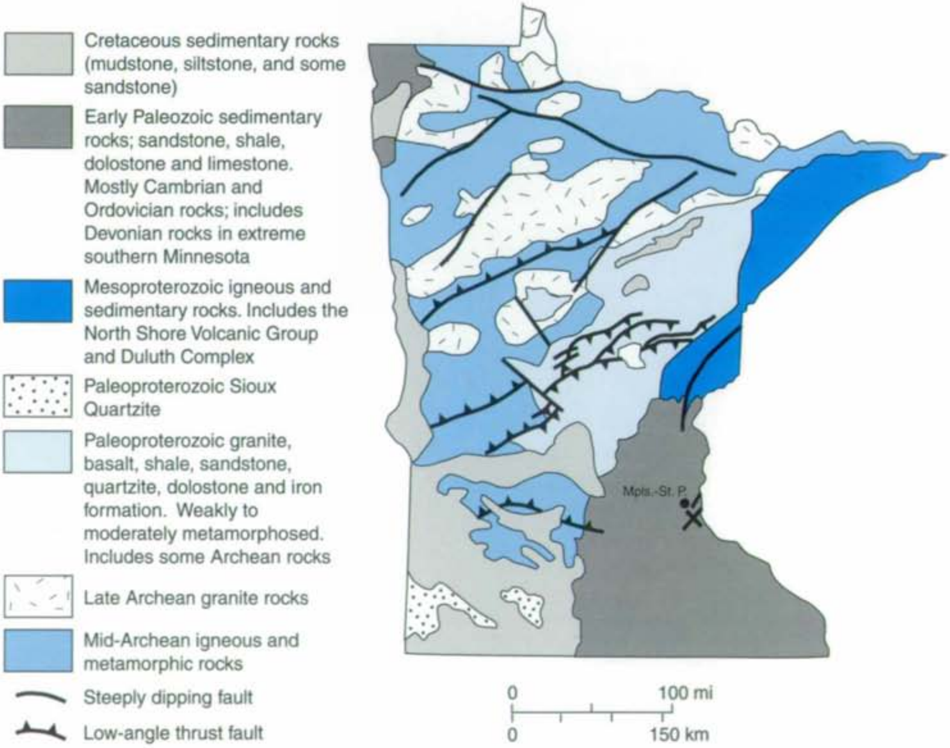


Figure 2. Simplified bedrock geology of Minnesota. Shows the bedrock or basement units that geologists interpret to underlie the surficial deposits that cover much of Minnesota's land surface.

Geologic Time and The Rock Record

Earth history spans 4.6 billion years (4,600 million years) from the time the planet formed to the present. We need to know the relative age of the rocks so that we can interpret the order of events associated with their origin. It is also important to know the absolute (exact) age of a rock unit. Geologists have established a geological time scale, with names for the different time periods (Fig. 3). These names are used in this booklet.

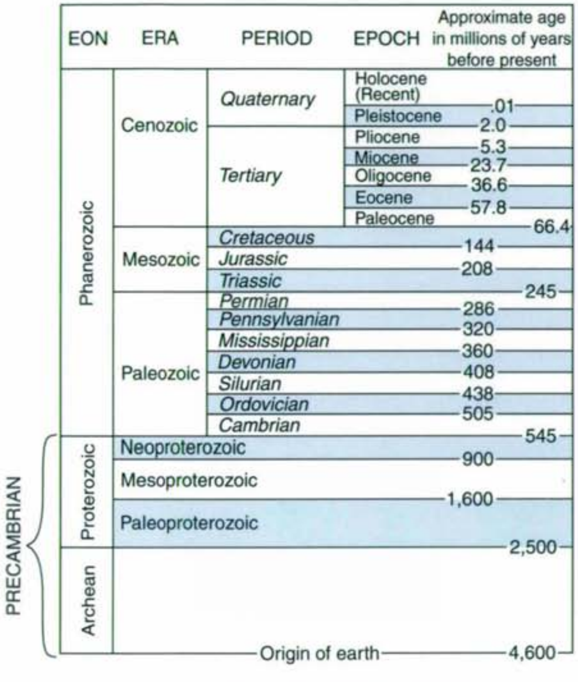


Figure 3. Geological time scale.

The relative age of a rock unit is usually determined in the field on the basis of geological principles such as the 'Law of Superposition' and the 'Principle of Original Horizontality' which together say that in sedimentary rocks the younger rocks lie on top of the older rocks, in approximately horizontal layers. For example, in the Root River area, unconsolidated Pleistocene glacial sediments overlie Paleozoic sedimentary rocks, and Ordovician sedimentary rocks overlie Cambrian sedimentary rocks. It is important to note, however, that the folding and tilting of rocks that results from **tectonic** activity can sometimes turn rock sequences upside down. This has happened in some places in northern Minnesota. Geologists always need to check features in sedimentary rocks to ensure that the sequence is facing up.

There is no continuous sedimentary record that represents all geologic time in any one place. The lost time intervals range in length from short time spans such as those recorded between storm events, to long breaks such as that between the Precambrian rocks and Pleistocene glacial till in northeastern Minnesota. The unconsolidated surficial sediments deposited by the glaciers and their outwash streams are currently being eroded from the land surface. Similar processes occurred during the past to produce **unconformities** (Fig. 4), which may represent hours, days, thousands, or millions of years of erosion. Unconformities can also represent periods when no sediments were deposited. Relatively short-lived interruptions in deposition are called diastems. Rock sequences below unconformities are sometimes warped or tilted before the sediments above are deposited; this produces an angular unconformity. Where the sediments below and above an unconformity are essentially parallel, sediments may have been removed to produce a disconformity. Alternatively, there may have been a time when no sediments were deposited (a paraconformity); there are numerous such unconformities within the Cambrian and Ordovician rocks exposed on or near the trail. The break or erosional surface may itself have considerable relief (the physical shape of the land surface), such as the unconformity between the Paleozoic rocks and the overlying Quaternary sediments along the trail.

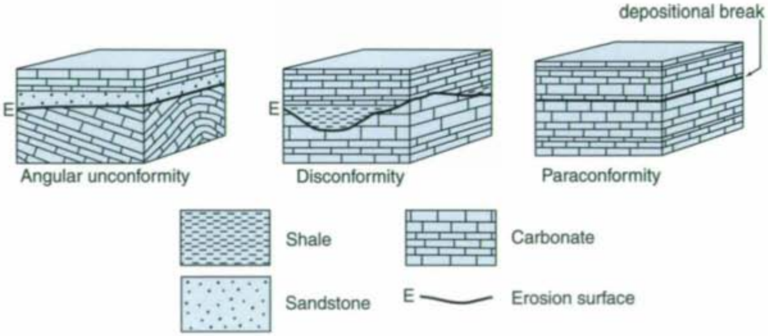


Figure 4. Different types of unconformities.

In order to decipher the geologic history of a large region, geologists need to correlate (or establish the time equivalence for) sequences of rock from different sites in that region. In smaller areas such as the Root River Valley, simple physical criteria such as grain size, composition, color and sedimentary features are used to identify individual beds, and correlate up and down or across the valley. This is called physical correlation or physical stratigraphy. Geologists usually establish a 'type section' or 'representative section' for a rock unit at a locality where the distinctive features of that unit are best observed. The rock unit is usually named for a geographic feature near the type section. For example the Jordan Sandstone was named for the town of Jordan, Minnesota. In order to establish correlations between sedimentary rock units over broader areas and between continents, **biostratigraphy** is typically used.

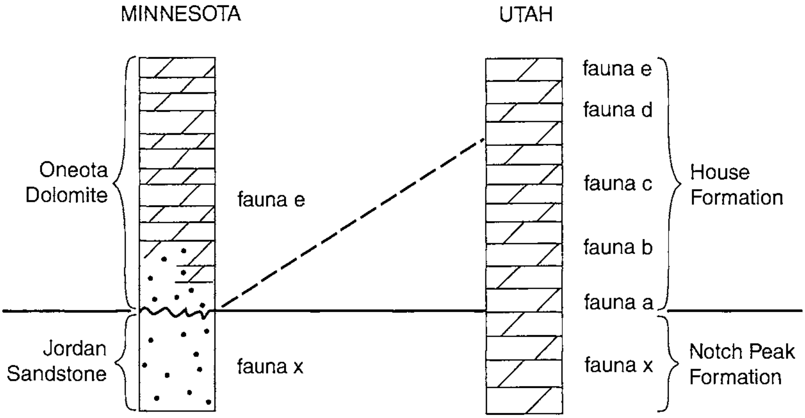


Figure 5. Illustration of the Ordovician-Cambrian rock sequences in Minnesota and Utah. The presence of faunas a, b, c, and d in the House Formation in Utah, and their absence from the Minnesota sequence confirms the presence of an unconformity at the base of the Oneota Dolomite in Minnesota.

Biostratigraphy uses fossils (the hard parts of ancient animals and plants that are often preserved in sedimentary rocks) to establish correlations. Because animals and plants have evolved with time, the changes in the features of individual fossils, and in the types of assemblages (groups of fossils) can be used by **paleontologists** to establish the relative age of rock sequences. In Minnesota the absence of several fossil assemblages that are present in a more complete, similar-aged sequence of rocks in Utah confirms the presence of an unconformity at the contact between the Jordan Sandstone and Oneota Dolomite (Fig. 5). In Utah the unconformity is represented by 500 ft of carbonate rock.

When the relative age of a rock unit is known, radiometric dating can be used to determine the 'numeric' age of a rock. **Minerals** in many of the rocks include elements such as uranium or potassium that have radioactive **isotopes** that decay at a known rate, and form daughter products. The amounts of the daughter product and of the parent isotope are determined by precise measurement on a mass spectrometer, and the numeric age can be calculated.

Geologic Processes and Rock Types

Nearly all of the rocks and unconsolidated sediments of southeastern Minnesota are of sedimentary origin. They formed at or near the earth's surface from particles of preexisting rocks or minerals. Most of the Paleozoic rocks are limestones or dolostones, which are sedimentary rocks made from calcium-, magnesium-, and iron-carbonate minerals, such as **calcite** or **dolomite.** The carbonate minerals are either the remains of organisms (plants or animals), or they were precipitated from seawater or groundwater. The basement on which these sediments were deposited includes rocks of the other two rock groups, igneous rocks and metamorphic rocks. Igneous rocks are made from molten rock (magma) that originally lay deep below the earth's surface. Volcanic rocks are igneous rocks that form when magma erupts from a volcano or other fissure on the earth's surface. Igneous rocks that cool and solidify beneath the earth's surface are called plutonic rocks. Metamorphic rocks form from preexisting rocks that are subjected to increases in temperature and pressure in the earth's crust. Igneous and metamorphic rocks are known to underlie southeastern Minnesota from drillhole data and **geophysical** surveys, but are not visible anywhere near the trail because they lie hundreds of feet beneath the land surface.

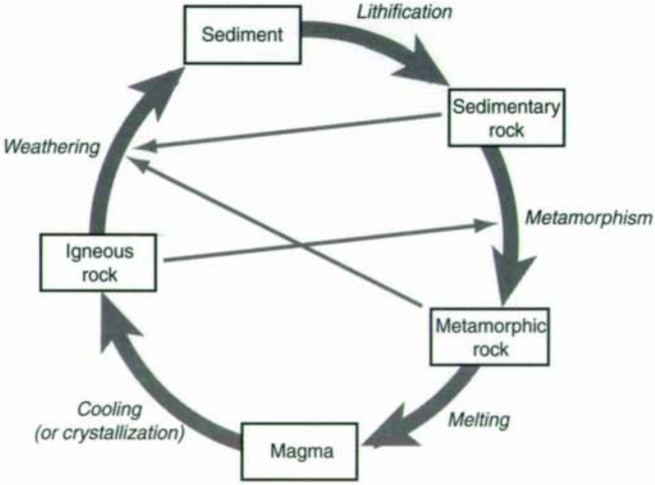


Figure 6. The rock cycle

The rock cycle explains relations between igneous, metamorphic and sedimentary rocks (Fig. 6). When magma (molten rock) solidifies it forms igneous rock, which many contain minerals such as pyroxene and hornblende that are stable at temperatures and pressures deep inside the earth. If the igneous rock is then exposed at the surface, it will be affected by weathering. Some minerals will be altered to clays by chemical weathering processes. Other minerals will be worn down (abraded) or broken up by physical and mechanical weathering. Plants also contribute to the weathering process. Tree roots often extend along fine cracks within rocks. As the roots grow the rocks fracture. When water freezes in cracks in the rocks, the increased volume of the ice causes the rocks to fracture. The results of all these processes are visible in rocks exposed on or near the trail.

The debris produced by weathering is transported by water or wind, and deposited as sediment in rivers and lakes, and ultimately in the ocean. When the sediment becomes **lithified**, it is called a sedimentary rock. The sedimentary rock may then be eroded to provide material for new sediments, or it may get buried and carried to greater depths within the earth's crust as a result of plate tectonics, where it is subjected to high temperatures and pressures, and becomes a metamorphic rock. Sedimentary or metamorphic rocks may be melted to form igneous rocks. Metamorphic rocks may be exposed at the surface due to uplift and erosion, and supply material for new sediments. The rock cycle continues endlessly, and not all rocks go through all the steps in the cycle.

Sediments are made up of particles derived from preexisting rocks ('clastic' grains). They may also contain the skeletons or remains of plant and animal organisms. The clastic grains can be fragments of igneous, sedimentary or metamorphic rock, or individual mineral grains (e.g.

CLASTIC SEDIMENTARY ROCKS

Size of Constituent Grains (diameter)	Unconsolidated Sediment Name	Sedimentary Rock Name	Metamorphosed Sediment Name
boulders (>256 mm)	conglomerate	conglomerate	
cobbles (64–256 mm)	(rounded clasts)	or	metaconglomerate
pebbles (4–64 mm)	breccia	breccia	
granules (2–4 mm)	(angular clasts)		
		sandstone	metasandstone
sand (63 microns–2 mm)	sand	arenite	
		psammite	
		siltstone	slate
silt (4–63 microns)	silt	mudstone	shale
		pelite	metapelite
clay (less than 4 microns)	clay	claystone	

CARBONATE SEDIMENTARY ROCKS

Dominant Mineral	Unconsolidated Sediment Name	Sedimentary Rock Name	Metamorphosed Rock Name
calcite ($CaCO_3$)	(depends on	limestone	
	grain size		marble
dolomite [$Ca, Mg (CO_3)_2$]	and type)	dolostone	

Table 1. Terminology used for clastic and carbonate sediments, sedimentary rocks, and their metamorphosed equivalents.

quartz, feldspar) that have survived the weathering process. Geologists name sediments and sedimentary rocks largely on the basis of the size of their grains (Table 1), although sedimentary rocks formed from the carbonate shells of marine organisms (or from carbonate minerals) are called limestone or dolostone, depending on the dominant carbonate mineral. New names are given to sedimentary rocks when they are metamorphosed.

Sedimentary layers are called beds. A bed may range from about half an inch thick to as thick as 6 feet. A bed will usually have a distinctive lower and upper boundary or surface. Some beds are distinctive because of their color, the size of the grains, the composition of the grains, the fossils within the sediment, or the sedimentary features of the bed, such as cross bedding (Fig. 7 and Fig. 34). A collection of similar beds is usually called a Formation (e.g. Shakopee Formation). Formations may be joined together into Groups (e.g. Prairie du Chien Group), or subdivided into Members (e.g. New Richmond Member). Some units are simply named for their constituent rock or mineral type, such as the Oneota Dolomite, the Decorah Shale and the St. Peter Sandstone, all of which have formational status.

As water or wind transport and deposit sediments, the sediments are often sorted to form graded beds. In a graded bed the coarsest particles are deposited by the fastest-moving current, and typically form the base of a bed. The finest particles such as silts and clays settle out from suspension as the current slows down. Cross beds are also present. They are beds that contain internal layering that is at an angle to the main bed boundary. Cross beds represent sediment deposited as ripples or sand dunes, which result from the movement of grains by winds, rivers, ocean storms or tidal currents. Ripples form on the top surface of the sediment when water (or wind) moves the grains to form an undulating surface. You may have noticed ripples forming on sandy lake beaches, and river or ocean beaches.

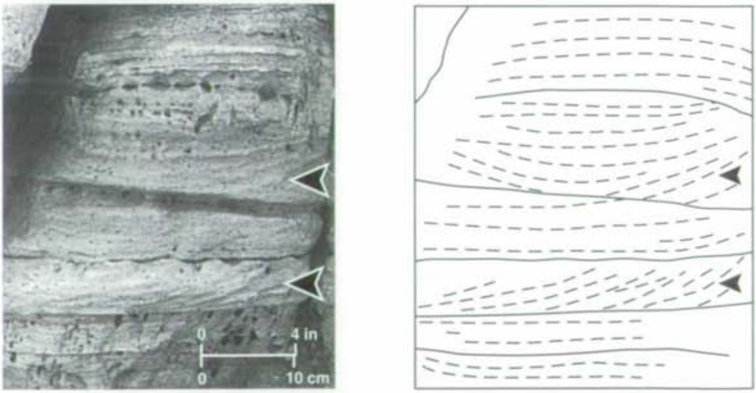


Figure 7. Photograph and line drawing of cross beds (arrowed) in the New Richmond Member of the Shakopee Formation. (site 9).

Plate Tectonics

Plate tectonics is the theory that says the surface of the earth is broken into plates that move. These tectonic plates move apart from each other at divergent plate boundaries to form ocean basins or rift basins, such as the basins in which the Proterozoic rocks of northern Minnesota formed. Plates collide with each other at convergent plate margins, and mountain ranges are formed, such as in the present-day Andes of South America. The Paleozoic rocks of the Upper Midwest record sedimentation in the middle of a continental plate, where tectonic activity was essentially limited to the slow subsidence of the 'basement.'

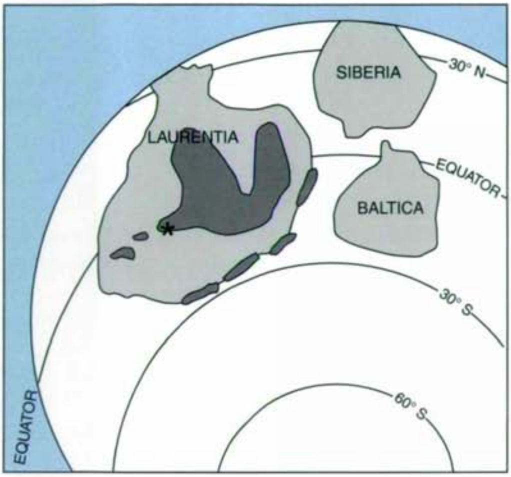


Figure 8. Paleogeographic sketch showing distribution of the continents Laurentia, Siberia and Baltica (light gray) in equatorial latitudes about 460–450 million years ago during the Middle Ordovician. The margins of Laurentia approximate the present United States and Canada. The dark gray area shows land above sea level. The star marks southeastern Minnesota.

Continents have changed their positions with respect to one another, the poles, and the equator. The Paleozoic sedimentary rocks along the trail were deposited at a time when the North American continent (Laurentia) lay in subtropical latitudes near the equator (Fig. 8). The margins of this ancient supercontinent have changed as a result of collisions with other continental fragments (such as Baltica), and their subsequent dispersal.

The changing positions of continents and ocean basins on the globe have had dramatic effects on the earth's climate. The continental glaciers that covered Minnesota and neighboring states during the Pleistocene resulted in part from the arrangement of continental land masses in high northern latitudes, which restricted circulation of oceanic currents and caused chilling of sea water in Arctic latitudes, contributing to the formation of high-latitude glaciers.

GEOLOGIC HISTORY OF SOUTHEASTERN MINNESOTA

Summary Geologic History

In southeastern Minnesota the oldest bedrock exposed at the surface is Paleozoic sedimentary rock, although geologists know from drill cores and geophysical surveys that the Paleozoic rocks are underlain by rocks formed during the Proterozoic. Unconsolidated sediments in the Root River region were deposited during the Quaternary (Fig. 9). The sedimentary bedrock in southeast Minnesota was laid down in extensive, shallow subtropical seas that covered the region between 545 and 360 million years ago, during the Cambrian, Ordovician, and Devonian Periods of the Paleozoic Era. The rocks exposed along the Root River State Trail were deposited during the earliest part of this interval, in the Cambrian and Ordovician Periods (between 545 and 444 million years ago). Between 360 and 300 million years ago sedimentary rocks may have been deposited in shallow marine waters in southeast Minnesota, but if so, they have long since been removed by erosion. Between 300 and 2 million years ago southeastern Minnesota probably lay above sea level, and the land surface was eroded by wind and water. Between 150 and 60 million years ago (part of the Jurassic and the Cretaceous periods, the age of the dinosaurs) the streams that flowed across the region drained westward into a succession of shallow seas that extended from the Gulf of Mexico to the Arctic. In southeast Minnesota thin sand and gravel deposits of questionable Cretaceous age are all that remain from this time interval. The only representative we know from the age of dinosaurs in Minnesota is part of a Hadrosaur vertebra from Crow Wing County. There is no sedimentary record here for the time period between the Late Cretaceous (90 my) and the Quaternary (2 my). This was a period of great mountain building in western North America. Most of the unconsolidated sediment that overlies the bedrock in the Root River region was deposited during the Quaternary period (the last 2 million years of geologic history). Continental glaciers extended southward across the region between 2 million and 10,000 years ago (during the Pleistocene Epoch). The continental glaciers receded and melted by about 10,000 years ago, when the Pleistocene 'Ice Age' ended, and the warmer Holocene Epoch began.

General Background: Southeastern Minnesota During the Paleozoic

During earliest Paleozoic time (545 million years ago) the North American continent lay near the equator in low subtropical latitudes, between 20 to 30 degrees north and south of the equator. The climate was

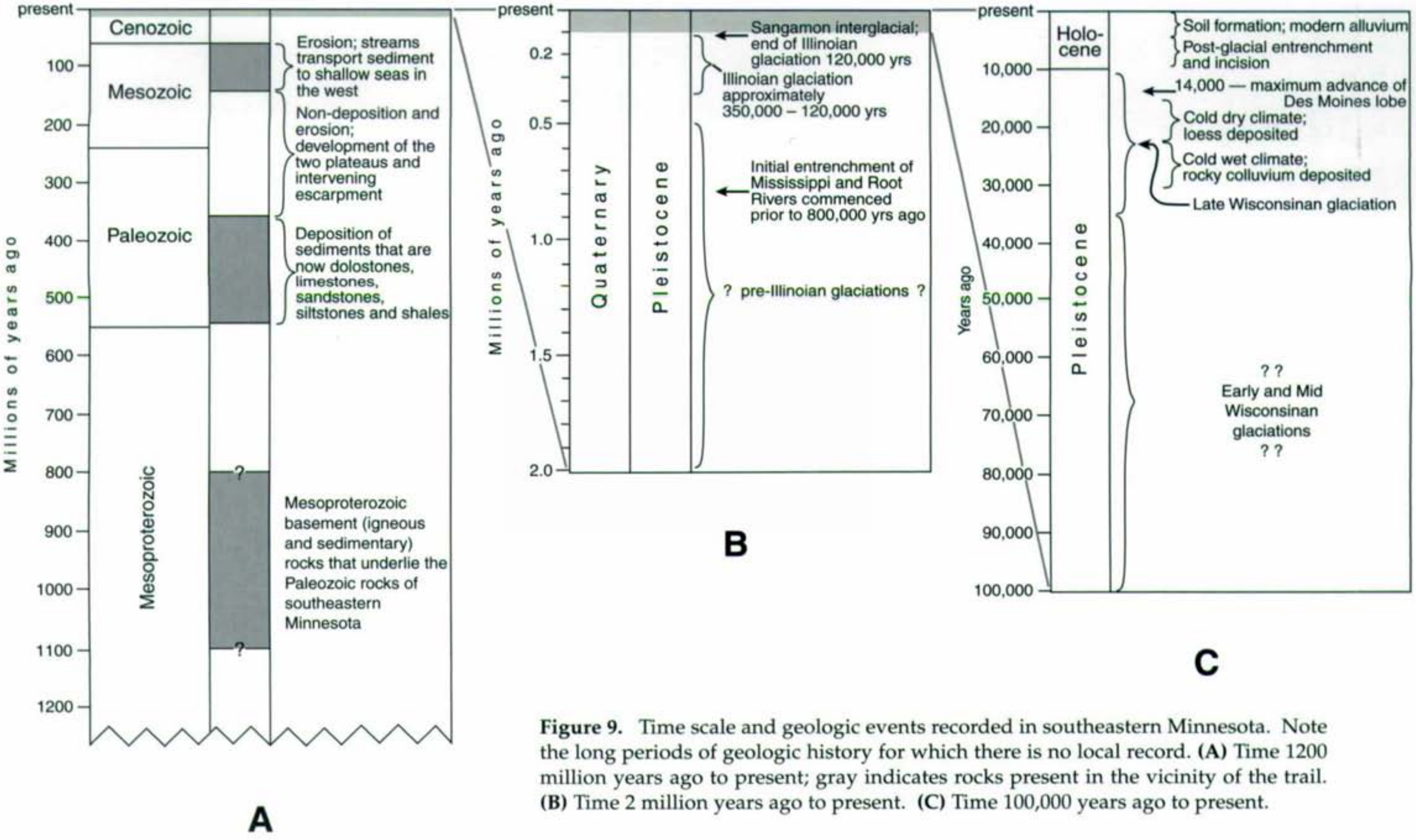


Figure 9. Time scale and geologic events recorded in southeastern Minnesota. Note the long periods of geologic history for which there is no local record. **(A)** Time 1200 million years ago to present; gray indicates rocks present in the vicinity of the trail. **(B)** Time 2 million years ago to present. **(C)** Time 100,000 years ago to present.

tropical, but the land was barren of vegetation because land plants had not yet evolved (except for some primitive forms such as algae, cyanobacteria, and fungi). Sea level began to rise about 540 million years ago, causing a broad shallow ocean to extend across the interior of North America and eventually cover most of the continent. Because the sea floor in Minnesota and throughout the central United States was very flat, relatively minor changes in sea level caused dramatic shifts in the location of the shoreline, which in time resulted in changes in the type of sediment deposited in any one place. Southern Minnesota and adjoining parts of Iowa and Wisconsin lay along the northern margin of this shallow sea and formed part of a large bay that lay between highlands formed of resistant igneous and metamorphic rocks (Fig. 10). These highlands included hills of Proterozoic quartzite in southwest Minnesota (the Pipestone area) and Baraboo, Wisconsin. The highlands also included Proterozoic basalts such as those now seen at Taylors Falls, Minnesota, which are part of the Precambrian igneous and metamorphic basement that extends into northern Wisconsin, where it forms the Wisconsin Dome.

Sediments accumulated in this shallow Paleozoic ocean during two main 'phases'; Late Cambrian to Early Ordovician and Middle to Late Ordovician. They were gradually lithified, and now range from less than

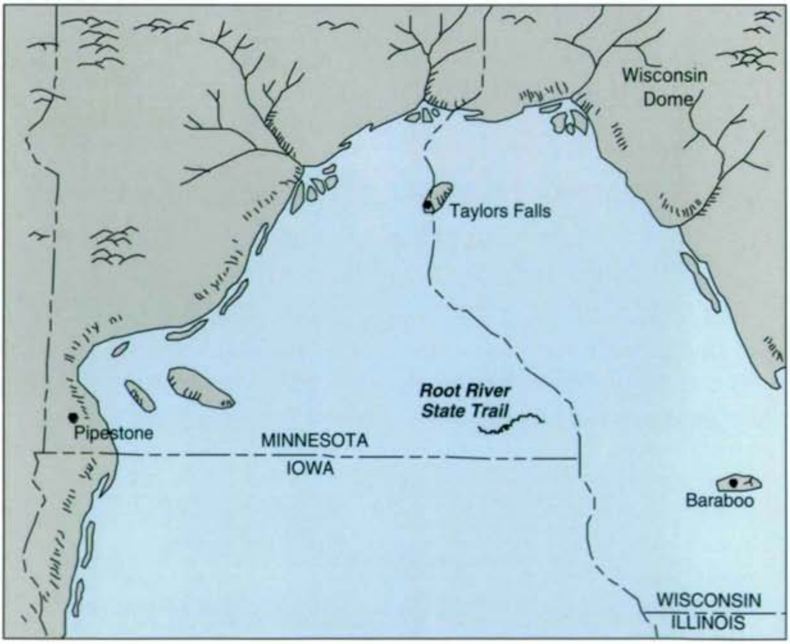


Figure 10. Paleogeographic map of southern Minnesota and adjacent areas during the early Paleozoic Era when a shallow sea covered most of North America. When sea level was much higher than shown on this figure, most of the state was covered with water. At other times when sea level was much lower, all of Minnesota was dry land.

100 ft to as much as 1200–1500 ft thick, but cover thousands of square miles. To envision what southern Minnesota looked like during their deposition in the Late Cambrian and Ordovician time, picture the sandy coast of the Gulf of Mexico but with a barren, mostly lifeless land surface. Erosion by wind was a much more important process at that time due to the absence of land plants. Intense wind action on land surfaces caused sand-sized particles to be worn down (abraded). The softer rock and mineral grains were destroyed, so that rounded quartz and feldspar grains were typically all that remained. Waves and currents sorted the sediments and deposited them so that the coarsest sand was laid down in the shallowest marine environment at the shoreface, where current and wave action is strongest.

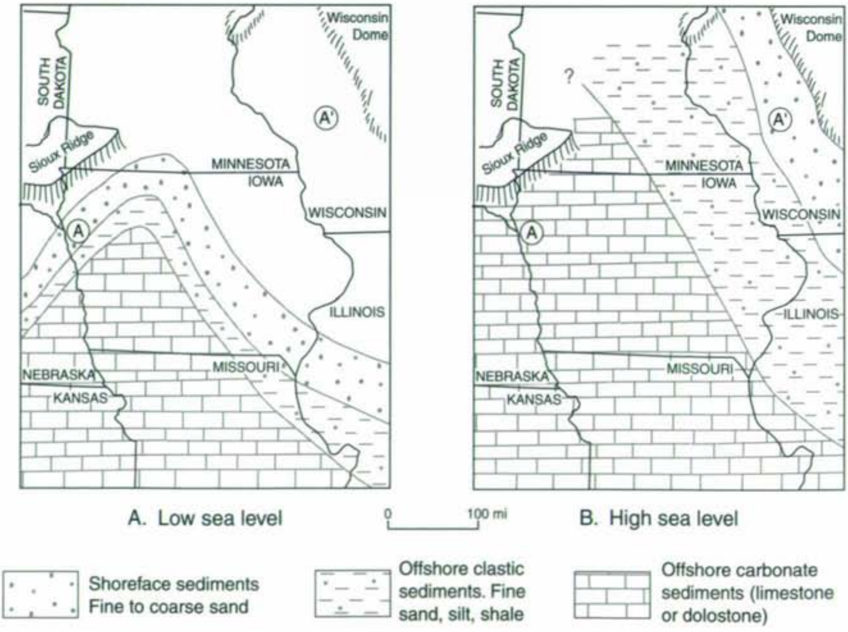
Figure 11. The St. Peter Sandstone is very soft, and easily eroded to form loose sand that is composed almost entirely of rounded quartz grains.

Very fine sand-, silt-, and clay-sized particles were generally deposited in deeper water farther from shore on the offshore shelf. The finest particles (fine silt and clay) settled from suspension in the deeper water hundreds of kilometers from shore. Areas farthest from land were dominated by carbonate material. These areas were simply too far from shore to receive significant quantities of land-derived sand, silt and clay. Carbonate sediments were also deposited in near-shore areas at times when source areas for clastic sediments were drowned by shallow seas, or were themselves blanketed by carbonate sediment.

Paleozoic sedimentary rocks are now exposed in numerous bluffs, road cuts, and quarries in southeast Minnesota. They include sandstone, siltstone, shale, dolostone, and limestone. Natural exposures of bedrock are called **outcrops.** Many of the sandstone beds, such as the St. Peter Sandstone, are very poorly **cemented** and erode easily to form loose sand (Fig. 11).

Late Cambrian to Early Ordovician Time Mount Simon Sandstone to Oneota Dolomite

The first sea to cover southeastern Minnesota during the Paleozoic Era spread northward through what is now Iowa about 545 million years ago. This sea extended across the midcontinent until about 480 million years ago, although there were short episodes when it withdrew from southeastern Minnesota into Iowa. The Cambrian Mt. Simon Sandstone is the oldest Paleozoic unit. There was an enormous volume of sediment available; **braided stream** and **braided delta** deposits make up the lower part of the Mount Simon Sandstone. The upper part of the Mt. Simon Sandstone was deposited on the shoreface associated with the advancing sea. The shoreface is the permanently flooded zone immediately seaward from the low water shoreline, over which beach sands and gravels actively oscillate with changing wave conditions. The Mount Simon Sandstone is overlain (in stratigraphic order) by: Eau Claire Formation, the Ironton and Galesville Sandstones, Franconia Formation, St. Lawrence Formation, Jordan Sandstone, Oneota Dolomite, and Shakopee Formation. The Ironton-Galesville Sandstone, Jordan Sandstone, and basal Oneota Dolomite were deposited when the sea level was low. Each time sea level was lowered, a succession of sand-rich shoreface deposits was left behind.



A. Low sea level

B. High sea level

Figure 12. Geographic positions of shoreface and offshore sediments deposited at times of (A) low sea level (B) and high sea level during the Cambrian and Ordovician geological periods. A–A' marks the line of section shown in Figure 13. Maps courtesy of Tony Runkel.

The New Richmond Sandstone at the base of the Shakopee Dolomite is the result of a minor drop in sea level during the Early Ordovician, toward the end of the overall rise in sea level (Fig. 13).

When the sea level was relatively high, the sandy shoreline lay toward the northeast on the higher ground of the Wisconsin dome (Figs. 12 and 13). At these times southeastern Minnesota was a large offshore shelf where clay, silt, and fine sand accumulated very slowly. The Eau Claire and Franconia Formations formed in this sort of setting. These sediments typically include glauconite (a dull green, earthy to granular, iron-rich mica mineral). Glauconite is an indicator of very slow sedimentation. Sediments deposited on the offshore shelf commonly contain the burrows of marine animals that feed on organic matter in the sediments. This burrowing disturbs the original bedding, so some of these rocks consist of thick sequences of mixed up sand, silt, and clay that contain the tracks and burrows (called 'trace fossils') made by the animals that churned up the original sediment. An entire branch of paleontology, called ichnology, is devoted to the study of trace fossils. The trace fossils in the Franconia Formation are *Planolites* (Fig. 14). On deeper parts of the offshore shelf, hundreds of miles from the shoreface, silt and clay sized particles and some carbonate grains settled slowly from suspension when sea level was high. The St. Lawrence Formation was deposited in such a setting. When

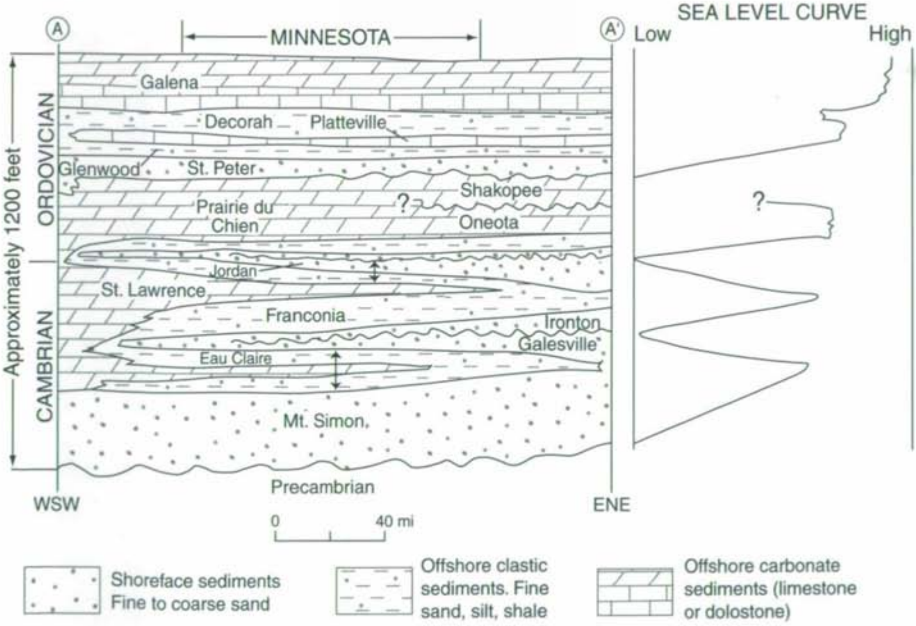


Figure 13. 'Restored' stratigraphic section for the Cambrian and Ordovician sedimentary rocks. The section runs WSW to ENE from northwestern Iowa, across southeastern Minnesota, and into west-central Wisconsin. A and A' correspond to the points marked in Figure 12. The sea level curve shows the changes in sea level associated with deposition of the different stratigraphic units. See Figure 12 for geographic distribution of units.

sea level was at its highest, carbonate sediments were deposited everywhere because the highlands that supplied the coarser, sand-sized sediment were covered with water; the Oneota Dolomite and the Shakopee Formation were deposited under these conditions. Parts of these units formed as tidal flats, which are tracts of land along the coast that are alternately covered then uncovered by the tide. Some beds in these units contain intraclasts, which are typically flat pebbles composed of tidal-flat carbonate mud or sand that dried out, broke into chunks, and got rolled around and redeposited by the tides as slightly rounded oblong pebbles.

The Oneota Dolomite and the Shakopee Formation contain stromatolites. Stromatolites are mounds which are built up by cyanobacteria, in which mud is trapped as the tide moves in and out (Fig. 15). The only place where stromatolites form in marine waters today is Shark Bay in Australia. Stromatolites have been found in some modern hard-water lakes, including some in Minnesota. Oolites are common in the Willow River Member of the Shakopee Formation, and present in the Oneota Dolomite. They are sand-sized round or oval grains that consist of a coating of whitish to pale gray carbonate cement that has grown around a nucleus, such as a bit of shell or a sand grain. Oolite beds are associated with thin beds of quartz sand that were deposited in agitated water in the nearshore zone. You may notice that ground water has sometimes dissolved the carbonate minerals forming the oolites in the Shakopee Formation, so that now only the material between the oolites remains, and the oolites are represented by voids. The final retreat of the Late Cambrian and Early Ordovician sea from the region is marked by the unconformity at the top of the Shakopee Formation beneath the St. Peter Sandstone, which may represent over 20 million years of erosion (site 8).

Figure 14. Trace fossil *Planolites* (arrowed) displays a criss-crossing tube-like form.

Figure 15. Stromatolites (arrowed) are domed features, present at sites 8 and 11.

Middle to Late Ordovician Time
St. Peter Sandstone to Maquoketa Formation

About 450 million years ago during the middle of the Ordovician, a second shallow sea spread across the region. This sea covered most of southeastern Minnesota for the remainder of the Ordovician. This was the most extensive sea to ever cover the North American continent. Compared to the Cambrian and Early Ordovician, sea level did not fluctuate much, and the shoreline did not move back and forth across the continental interior. This sea covered the entire region more or less continuously for the next 14 to 18 million years. The St. Peter Sandstone is the shoreface sandstone deposit that marks the initial spread of the sea across the region. The units overlying the St. Peter Sandstone are (in stratigraphic order): Glenwood Formation, Platteville Formation, Decorah Shale, Galena Group, Dubuque Formation, and Maquoketa Formation. These units are all dominated by carbonate sediments. Carbonate is much more common than it is in sediments deposited in the earlier Cambrian–Ordovician sea. The carbonate sediments were deposited in marine waters that contained a wide range of organisms, including numerous **invertebrate** animals such as mollusks, crinoids, bryozoans, and brachiopods whose skeletons contributed material to the sediments (Figs. 16 and 17).

The sediments deposited seaward of the shoreface were a mixture of very fine silt and clay nearer the shore (the Glenwood Formation and Decorah Shale), and calcareous oozes containing lenses of broken shells of organisms (such as the valves of brachiopods) farther from shore (Platteville Formation, the upper part of the Galena Group, and the Maquoketa Formation). The basal part of the Galena Group (the Cummingsville Member) and the upper part of Dubuque Formation are both composed of alternating beds of limestone and shale. They represent the zones where nearshore and farshore sediment interfingered. Sandstone and siltstone are much rarer in these Middle and Late Ordovician rocks than in the Cambrian rocks. Beds of volcanic ash, now altered to clay called bentonite, are present in the Middle to Late Ordovician rocks of the region, and form thin beds that are at most a few inches thick (Fig. 37). The volcanic ash was probably derived from volcanic centers in an active mountain chain forming on what is now the east coast of North America.

A large drop in sea level took place at the end of the Ordovician when large amounts of water from the world's oceans became bound up as ice in continental glaciers. This marked the end of the Middle and Late Ordovician sea. Marine water occasionally spread across parts of Iowa, northern Kansas, and Wisconsin during the ensuing Silurian Period. Small coral reefs flourished in shallow marine water throughout eastern and southern parts of the Midwest. It is possible that this Silurian sea extended

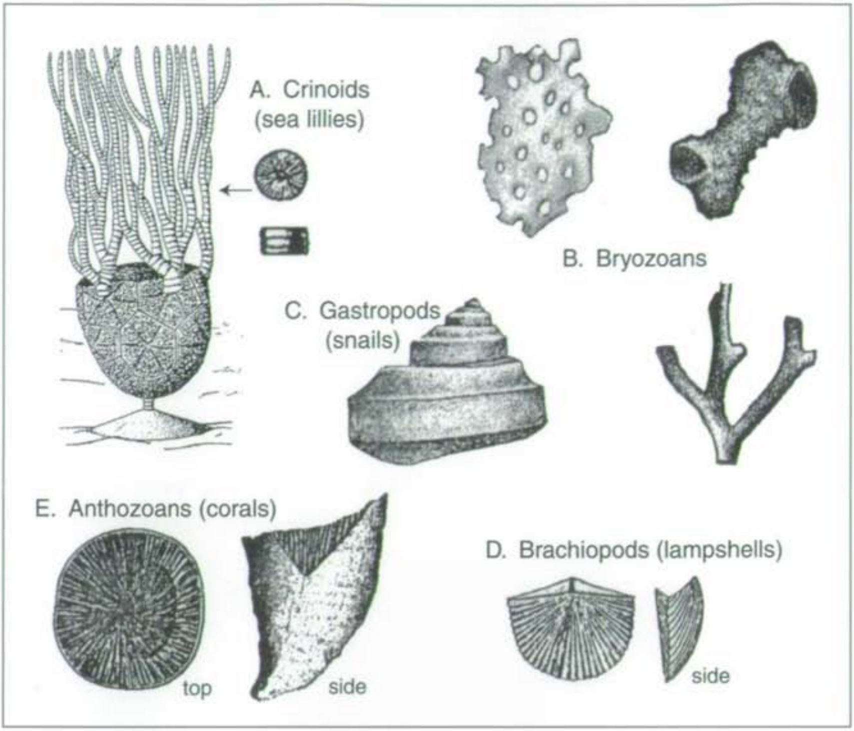


Figure 16. Five fossils common in the Middle and Late Ordovician Platteville Formation and Decorah Shale.

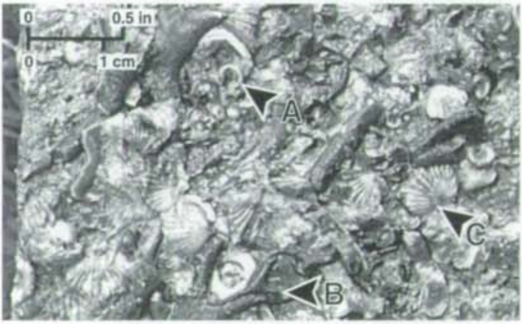


Figure 17. Slab of Decorah Shale showing:
(A) Crinoid stems
(B) Bryozoa
(C) Brachiopod fragment

into southern Minnesota, but if so, any traces of it were removed during a period of erosion (40 million years) which followed the Silurian. Shallow seas flooded the region periodically until the Late Devonian, about 360 million years ago. No rocks of Devonian age are exposed along the trail, although they are present farther to the southwest in Fillmore and Mower Counties; consequently, one may infer that the seas in which they formed extended across all of southeastern Minnesota. Where preserved, the Devonian rocks are mostly limestone and dolostone that formed in shallow subtropical seas (some as coral reefs) or in tidal flats along the shoreline.

Post-Devonian to Quaternary

Rock units that represent the remainder of the Paleozoic and early part of the Mesozoic Eras (the interval that lasted from 360 to 100 million years ago) are absent from southeast Minnesota. They are documented from as near as central Iowa, but if they were ever present in Minnesota they have since been eroded. Southeastern Minnesota lay above sea level, and the land surface was being denuded by weathering and erosion. About 100 million years ago, during the middle part of the Cretaceous Period, a vast shallow sea covered the western interior of North America (the Great Plains region) east of the rising Rocky Mountains, extending from the Gulf of Mexico to the Arctic. Shales, silts and carbonate sediments deposited in this sea are preserved in southwestern Minnesota. In southeastern Minnesota the only remains are patchy **alluvial** deposits of sand and gravel left by streams that crossed the region from the east to discharge their water into the sea that lay to the west. There is no sedimentary record in southeast Minnesota for the time period between 90 my and 2 my.

The thick sequences of Ordovician carbonate rock that underlie the region were (and still are) very susceptible to chemical weathering by the slightly acidic soil water, but were highly resistant to stream erosion. They can be divided into three sequences, which controlled the **geomorphic** development of the erosion surface that developed during the last part of the Cretaceous and the Tertiary Periods. The lower, older sequence is composed of the dolostones of the Prairie du Chien Group. The upper, younger sequence is composed of limestone and minor dolostone of the Galena Group and overlying units. These two sequences are separated by a relatively thin sequence that includes the St. Peter Sandstone, Glenwood Formation, Platteville Formation and Decorah Shale (Fig. 18). All these rock units are very flat lying. The sandstone and shale units are much softer and more easily eroded than the limestone and dolostone units.

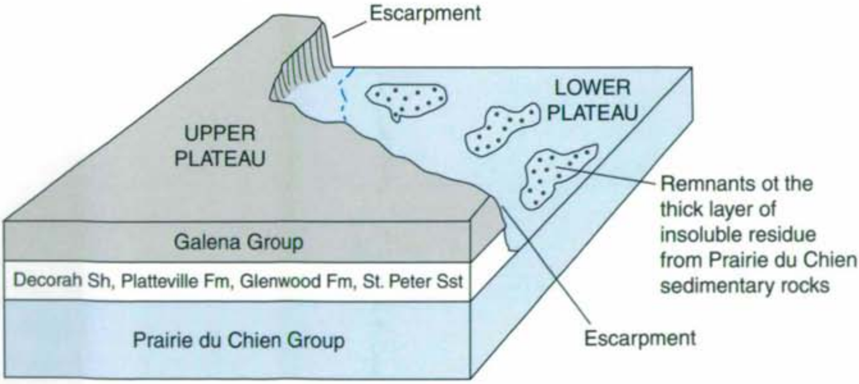


Figure 18. Block diagram showing development of the upper and lower plateaus, and the escarpment that separates them.

Consequently, at the start of the Quaternary the region essentially consisted of two plains or plateaus separated by a low northeast-facing **escarpment.** The surface of the upper plateau is the top of the Galena Group and overlying formations. The surface of the lower plateau is the top of the Prairie du Chien Group. Extensive post-Devonian to Quaternary erosion left a thick layer of sand, silt, clay and **chert**, as well as other insoluble matter mantling the lower plateau. Remains of this cherty and sandy iron-stained residuum still overlie the Prairie du Chien Group (Fig. 18).

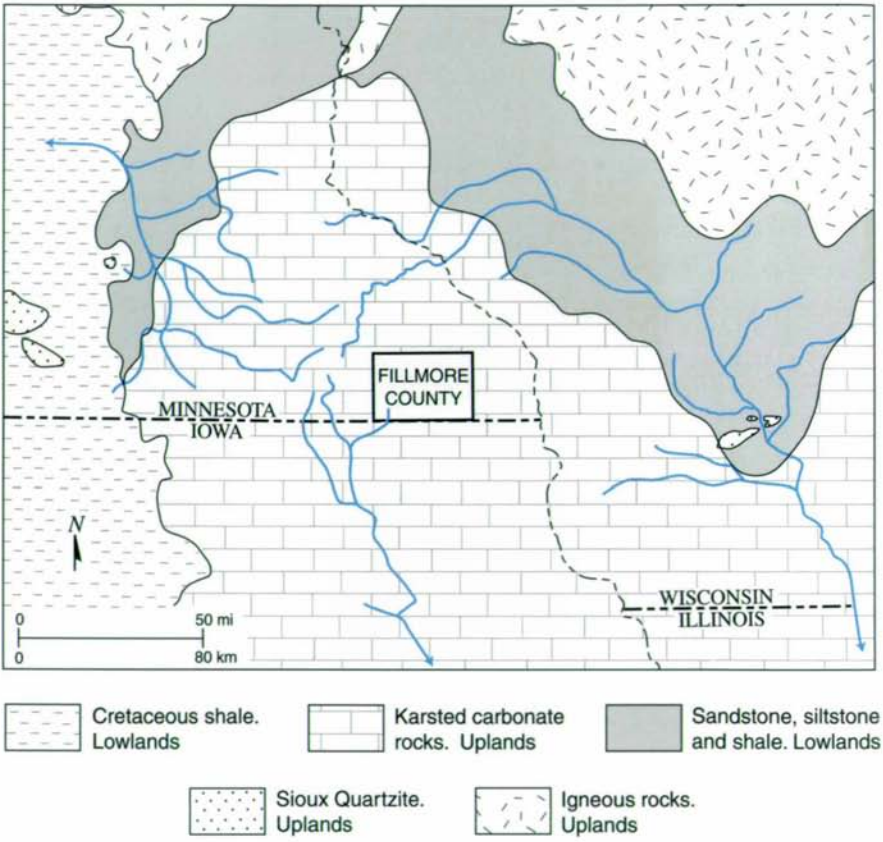


Figure 19. Inferred regional drainage pattern for southeastern Minnesota and adjoining region at the start of the Quaternary Period before continental glaciation altered the pattern.

Southeastern Minnesota During The Quaternary

At the beginning of Quaternary time, about 2 million years ago, the landscape was gently rolling with wide, shallow bedrock valleys carved into the bedrock plains and escarpment. The landscape was also mantled by weathered rock and soil. Some of the deep valleys of the present day that are eroded into the Paleozoic rocks apparently did not form until relatively late in Quaternary time, although geologists have interpreted the evidence in various ways. Geologists have identified broad, shallow, pre-Quaternary valleys beneath glacial deposits in western Fillmore and adjoining Mower County on the basis of drill-core data. South of a broad divide, streams within those valleys seemingly drained eastward into what is now the upper part of the Wisconsin River, or southward into Iowa to tributaries that emptied into a pre-Quaternary predecessor of the Mississippi (Fig. 19). Streams to the north and northwest of the divide may have drained northward into a predecessor of the Red River Valley, into a lowland corresponding to the present drainage basin of the Minnesota River. The present-day major streams, such as the upper Mississippi River, the Minnesota River, and the St. Croix River, or other major eastward-flowing tributaries, such as the Root River, probably didn't exist prior to the Quaternary. Much of the drainage in the Fillmore County area may have been underground through solution-enlarged fractures in the carbonate rocks.

Pleistocene Glaciation in Southeastern Minnesota

During the Pleistocene—the 'Great Ice Age'— enormous sheets of ice, known as **glaciers**, as much as 2 miles thick (similar to those now in Antarctica and Greenland) extended across northern Canada. Thinner ice lobes extended southward across much of the Upper Midwest. The names used for the two most recent glacial periods are Wisconsinan (25,000–12,000 yrs) and Illinoian (approximately 350,000–120,000 yrs). The interglacial period between them has been called the Sangamon. Both glaciations include numerous glacial advances and retreats. Glacial periods prior to the Illinoian used to be called the Kansan and Nebraskan, but these terms are no longer used. The term pre-Illinoian is used for glacial events that took place between 2 million and 500,000 yrs ago, prior to the Illinoian.

A lobe of one of the earliest continental glaciers extended across southeastern Minnesota between approximately 2,000,000 and 500,000 years before present (the 'pre-Illinoian' glaciation). It covered all of Minnesota except for the eastern fringe of Winona and Houston counties, just to the east of Fillmore County (Fig. 20). In Fillmore County, the local direction of ice flow was west to east; however, the main direction of ice movement was southward. This lobe probably extended as far as northern Missouri. As the ice advanced it scraped soil and rocks from the land surface, and transported boulders, gravel, sand, silt, and clay. When the ice melted, these materials were spread across the landscape as a thick layer of unsorted material (**till**). Some of this material was carried from the ice by meltwater (Fig. 21) in outwash streams, and deposited as sorted gravel, sand, and silt to form **outwash** plains or **valley trains**. Some of this material still remains as isolated patches on uplands in the Root River region. Deposits of both till and outwash are thicker and more continuous west of the trailhead at Fountain, where streams have not yet removed the Quaternary cover and cut into the landscape. The landscape in southeastern Minnesota looks very similar to that in southwestern Wisconsin, just across the Mississippi River. However, glaciers never extended across the small region of southwestern Wisconsin, which is termed the 'Driftless Area.' Southeastern Minnesota is not part of the 'Driftless Area.'

After the first major pre-Illinoian glaciation the Mississippi River probably became the master stream for the region. Meltwater from the receding ice excavated the Mississippi River Valley to depths of several hundred feet. Initially, meltwater flowed south along the front of the melting glacier, and cut a channel in the bedrock surface. It was this initial channel that determined the present course of the Upper Mississippi River (Figs. 20 and 21). After the Mississippi River eroded through dolostone of the Prairie du Chien Group and cut its valley in underlying soft Cambrian

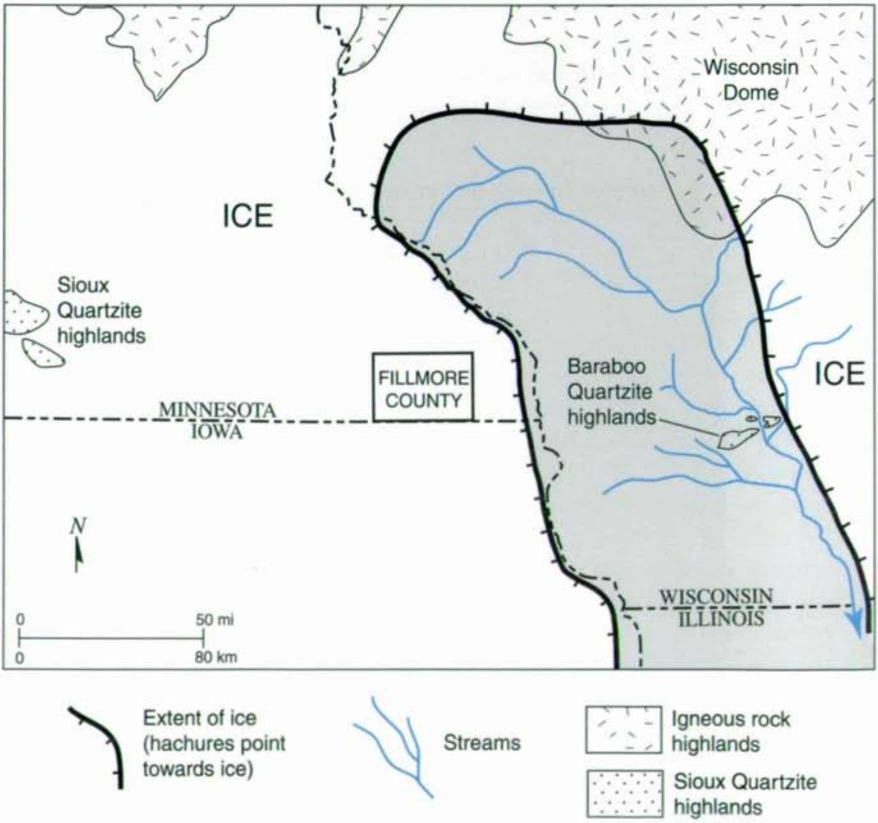


Figure 20. Southeastern Minnesota during maximum pre-Illinoian glaciation.

sandstone and siltstone, many of the east-draining tributaries to the Mississippi, such as the Root River, began to **incise** their valleys and extend their headwaters into the glacial sediment and **exhume** parts of the older, pre-Quaternary landscape.

Geologists estimate the initial **entrenchment** of the Root River valley commenced more than 800,000 years before present, after retreat of the earliest pre-Illinoian ice. After initial entrenchment, the Root River flowed along a bedrock surface that was much lower than present river level; it was more than 100 ft lower at Rushford, and 200 ft lower where it joins the Mississippi. This entrenchment was the result of the lowering of sea level (and **base level**), when vast quantities of water were trapped in continental glaciers, causing major streams such as the Mississippi River to incise their valleys. Tributary streams such as the Root River entrenched their valleys in response to the lowering of 'base level' in the Mississippi. When the ice melted to produce large volumes of meltwater, erosion was accelerated. Between 350,000 years and 120,000 years ago, during the Illinoian, **ice lobes** advanced southward, but none extended as far to the east or south as they did during the earliest pre-Illinoian glaciation.

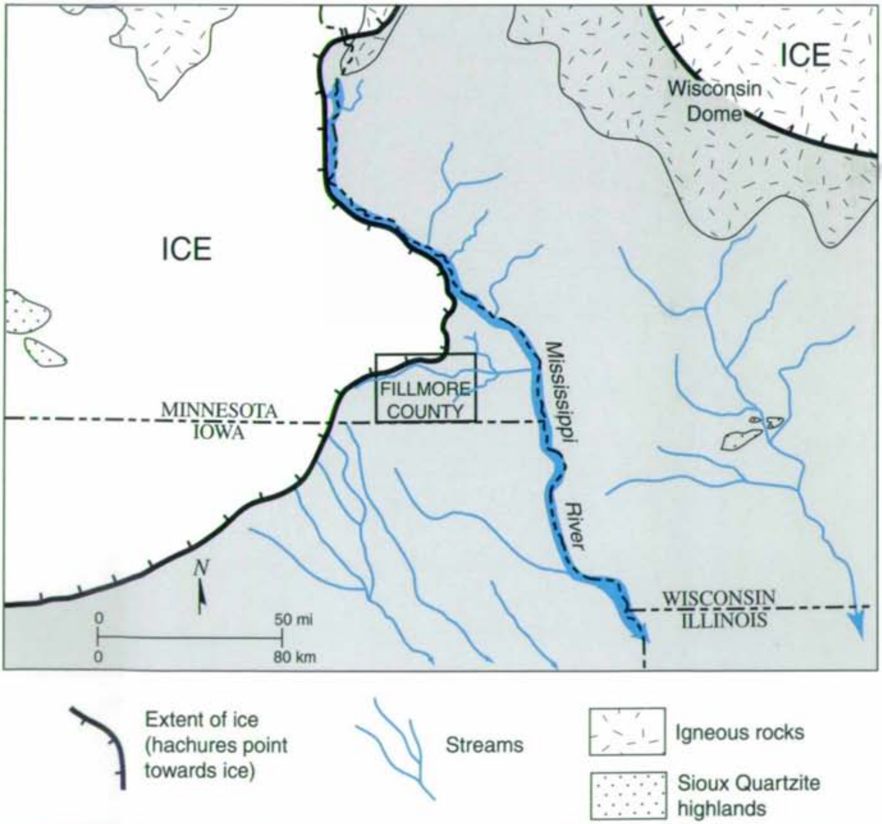


Figure 21. Southeastern Minnesota during retreat and melting of pre-Illinoian ice. Shows early development of the Mississippi drainage system.

During the Late Wisconsinan, about 25,000 years before present (Fig. 22) an ice lobe lay just to the west and north of the region. Regions near glaciers (**periglacial** regions) such as southeast Minnesota were subject to large amounts of erosion. Most of the subsoil was permanently frozen, and only the upper few feet thawed during the summer. Moisture was unable to percolate down into the permanently frozen subsoil, and the thawed surface layer became saturated with water. This led to **solifluction** or soil flow on slopes, which carried away soil. It also increased the amount of erosion that resulted from runoff and gullying. In southeast Minnesota this resulted in the deposition of large amounts of sand and gravel in the Mississippi River valley during the Late Wisconsinan (Fig. 23).

Ultimately the large amount of outwash filling the Mississippi River valley reduced the gradient of the Root River and other tributaries, and they ceased to transport the large quantities of locally derived sediment, and became choked with sediment derived from periglacial erosional processes. The sand and gravel deposits that fill valleys such as the Root

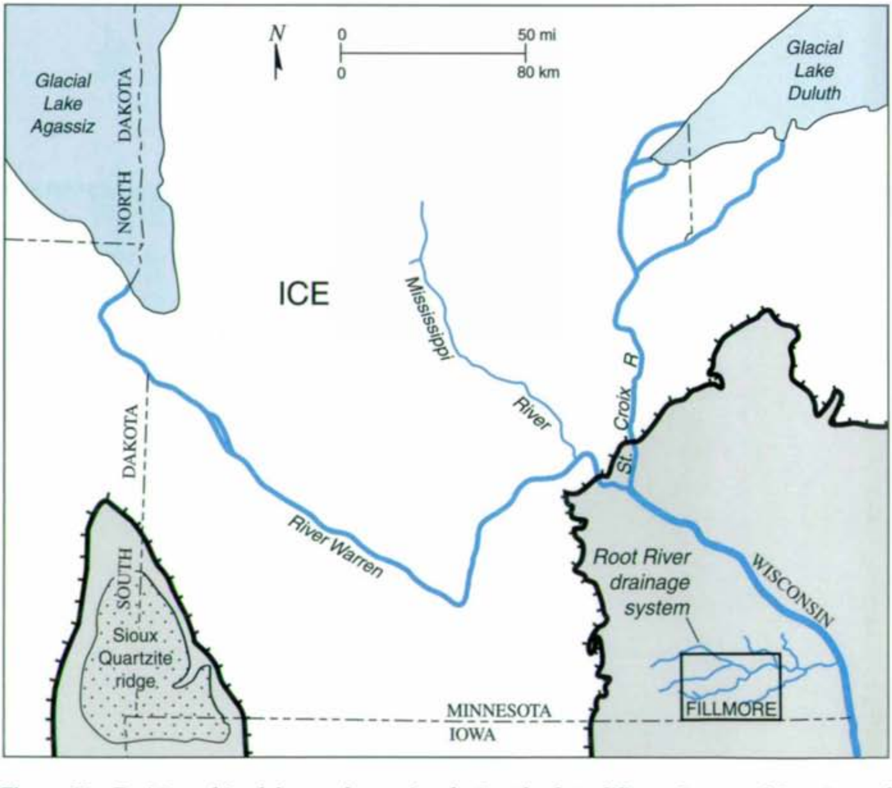


Figure 22. Position of ice lobes and margins during the Late Wisconsinan, and locations of subsequent glacial lakes and ice-melt drainageways. See Figure 23 for detail of southeastern Minnesota.

River valley are thus much younger than their rock floors. At the same time that valleys were filling with sand and gravel, windblown silt (**loess**) was deposited across the region. Some of the loess was derived from outwash aprons in front of the ice that dried out periodically and were subjected to wind erosion. However, most of the loess accumulated after the climate changed from cold and moist to cold and dry about 20,000 years ago. Deposition of loess ended about 12,000 years ago when growth of vegetation associated with the warming climate stopped wind erosion.

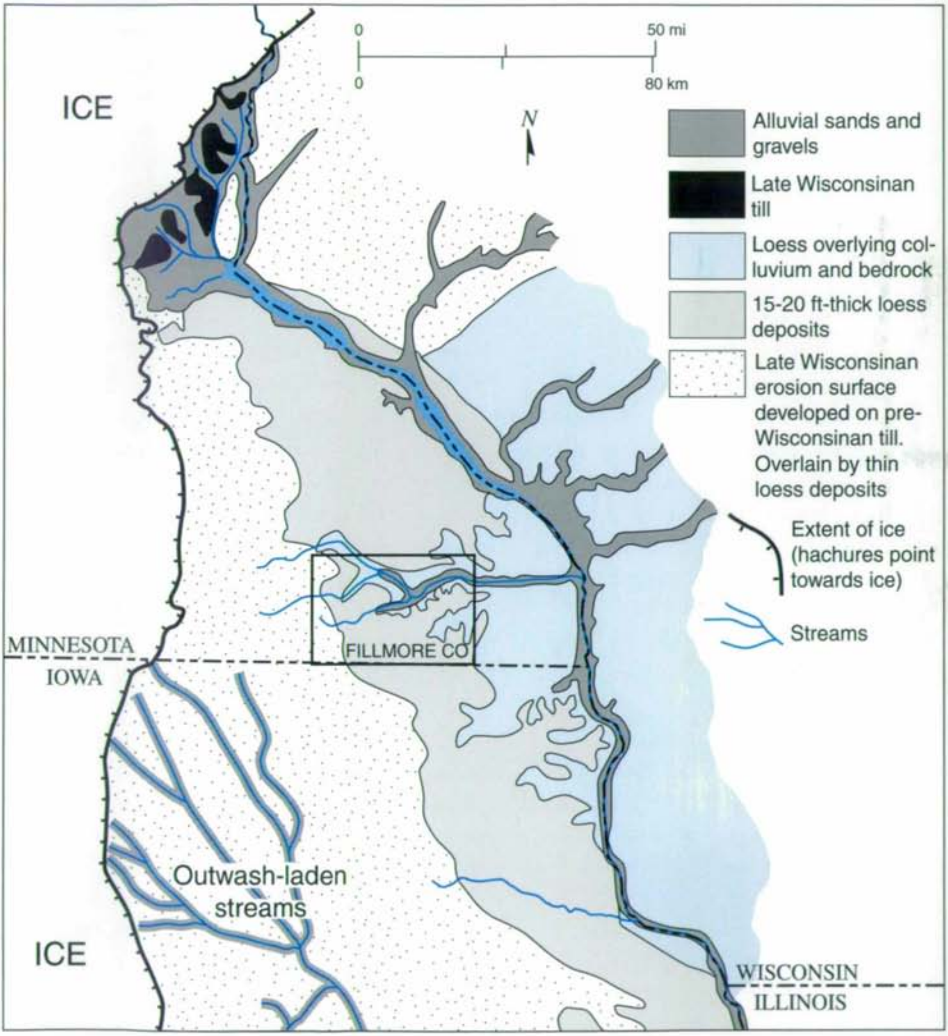


Figure 23. Distribution of Late Wisconsinan surficial sediments in southeastern Minnesota, northeastern Iowa and westernmost Wisconsin during the Late Wisconsinan glacial maximum, when ice did not reach southeastern Minnesota.

West of the Root River area erosion dominated the large region bordering the ice. On steep bedrock slopes, water percolated into cracks and joints, where it froze and expanded, widening the joints, and ultimately shattering the rock. The loose, angular blocks slid downslope and built up big piles of angular boulders (blocky colluvium) at the base of steeper slopes. Because this mechanical weathering took place concurrent with deposition of sand and gravel alluvium along stream valleys, the two deposits are commonly interbedded. Rainwater and meltwater removed loess from steeper hillsides and deposited it as silty **colluvium** along the Root River Valley. The coarse, bouldery colluvium is typically overlain by silty colluvium derived from loess. Trees and shrubs now cover most of the colluvium but it can be seen in exposures along recent road cuts and in steep ravines along the river bluffs.

The Holocene Landscape and Retreat of The Ice

The last continental ice sheet melted about 10,000 years before present. This event defines the boundary between the Pleistocene and Holocene. Loess was no longer deposited, and streams again started to cut down through the Pleistocene sand and gravel that choked the valleys. The streams typically did this in stages, leaving behind a series of **terraces**.

The downcutting streams, such as the Root River, were responding to entrenchment of the Mississippi River, which entrenched its valley when Lake Agassiz (an enormous glacial lake that extended across eastern North Dakota, northwestern Minnesota and southern Manitoba) drained through the Minnesota River into the Mississippi (Fig. 22). Glacial Lake Superior also drained into the Mississippi by way of the St. Croix River. Meltwater from these lakes picked up and removed sand and gravel from the river channels. At this time the floor of the Mississippi River channel was incised 150 feet into sediments deposited during the preceding Wisconsinan glaciation. The gradients of tributary streams such as the Root River were thus increased, accelerating their capacity to erode and transport sediments.

After the ice melted and the glacial lakes to the north had drained, rivers such as the Mississippi carried less water and lost much of their erosive power. Their valleys once again filled with sediment, this time with organic-rich silt. Along the Root Valley trail this has occurred mainly in the Rushford area. Smaller tributaries were affected by an additional valley filling episode that commenced during settlement of the region which started in the mid 19th century. Runoff from plowed fields carried large amounts of soil into the valleys, in places burying pre-settlement soil to depths of 7–8 feet.

Environmental Geology

Environmental geology is the application of geologic principles and knowledge to problems created by our occupancy and exploitation of the physical environment. One of the most important environmental issues in the region is the protection and maintenance of a clean, safe **groundwater** supply. The Shakopee Formation, Oneota Dolomite, and Jordan Formation together form an aquifer (a body of rock that stores and allows movement of economic quantities of water within it). The aquifer is called the Prairie du Chien—Jordan aquifer, and it supplies most of the household water used in southeast Minnesota.

Aquifers, Karst Terrains, and Ground-Water Contamination

When rain falls it either evaporates back into the atmosphere, gets taken up by plants, forms streams, or percolates into the ground. Water that has percolated into the ground and is stored and transported in the ground is called groundwater. The water table is the upper surface of a zone of saturation, below which the rocks or sediments are permanently saturated (full of groundwater). The shape of the water table below the land surface depends on the orientation of the geologic unit that contains the groundwater, as well as the shape of the land surface (the topography). The level of the water table fluctuates with the weather; high rainfall causes it to rise and a long drought causes it to fall. The permanently saturated zone beneath the water table is the source of water for wells. Where the water table intersects the land surface, a lake, river or swamp results. In southeastern Minnesota, the position of the water table is controlled by layers of **impermeable** rock beneath the **permeable** carbonate rock through which the groundwater has traveled. When the groundwater reaches these impermeable rocks it flows horizontally until it reaches the land surface, where it discharges as a spring or seep (Fig. 24). Rivers and major streams are recharged (supplied with groundwater) if they flow at or below the water table. Many of the small streams that flow only during periods of heavy rainfall are perched above the permanent water table and disappear after rain storms.

When rain water percolates through the soil it encounters decaying organic matter and becomes acidic. As this acidic water moves through the ground it dissolves soluble minerals such as calcite. The limestone units of the Galena Group that form the upper part of the plateau in southeast Minnesota are particularly susceptible to dissolution, because they are dominated by calcite. Mystery Cave to the southeast of the town of Spring Valley is formed within Galena Group limestone.

Landscapes that develop as a result of chemical dissolution of carbonate rocks are called **karst terrains** (Fig. 24). Sinkholes, such as those that characterize the uplands adjacent to and west of the Root River valley, form where **solution cavities** that have formed in fractures or along bedding planes in the rock lie close to the surface and become enlarged, so that overlying rock, sediment and soil collapse into the enlarged solution cavities to form depressions called sinkholes.

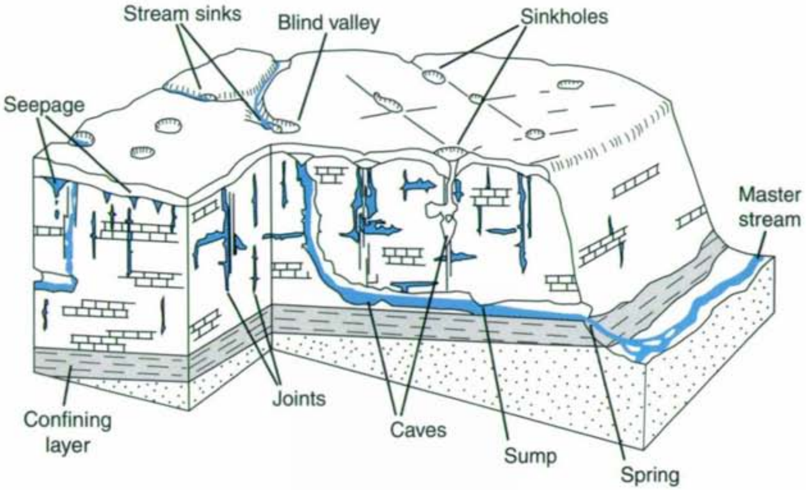


Figure 24. Karst drainage and related land forms. Surface drainage is diverted through sinkholes and stream sinks to underground where it flows along fractures and cavities in rock such as joints, returning to the surface later as springs. Modified from Lively and Balaban (1995).

Slow subsidence or catastrophic collapse associated with the development of a sinkhole can adversely affect any building or structure overlying a sinkhole. The placement of water storage structures can also induce the formation of sinkholes due to their weight, and because seepage of water from the structure can cause further dissolution of the limestone, as well as erosion of sediments overlying the solution cavity.

The dolostone and sandstone beds of the Prairie du Chien Group are less soluble than the calcite-dominated Galena Group sediments. Thus they do not contain nearly as many dissolution features. In the Root River region, water moves into the otherwise essentially impermeable Prairie du Chien Group through vertical fractures (**joints**) and along bedding planes, which form the network of conduits through which the ground water moves. As the groundwater moves, some solution takes place and conduits capable of carrying large underground streams form. In the Root River area water travels through bedrock of the Prairie du Chien Group and emerges as springs and seeps in the lower part of the Prairie du Chien and Jordan Sandstone. The Prairie du Chien Group and Jordan Sandstone form a regional aquifer (Fig. 26).

When groundwater moves through sediment or rock composed principally of insoluble grains, it must seep through the small interstices between the grains. This is a very slow process compared to the flow of water through fissures and caverns in carbonate rocks. The movement of groundwater through the small interstices between grains is a very effective way to filter suspended sediment and other impurities from the water. In contrast, sinkholes, caverns and crevices of karst terrains do not filter the water that is recharging the water table; therefore, areas underlain by carbonate rocks are very sensitive to pollution. Runoff from farm fields

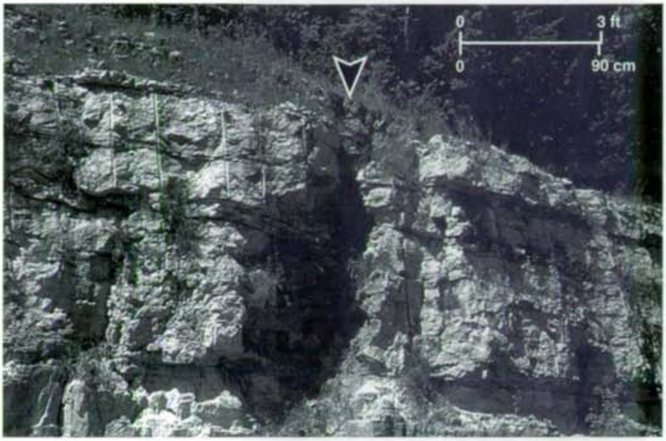


Figure 25. Enlarged solution cavity (arrowed) in Shakopee Formation dolostone is visible in the roadside outcrop at site 11. The vertical lines are drill holes used for blasting the rock when the road was widened.

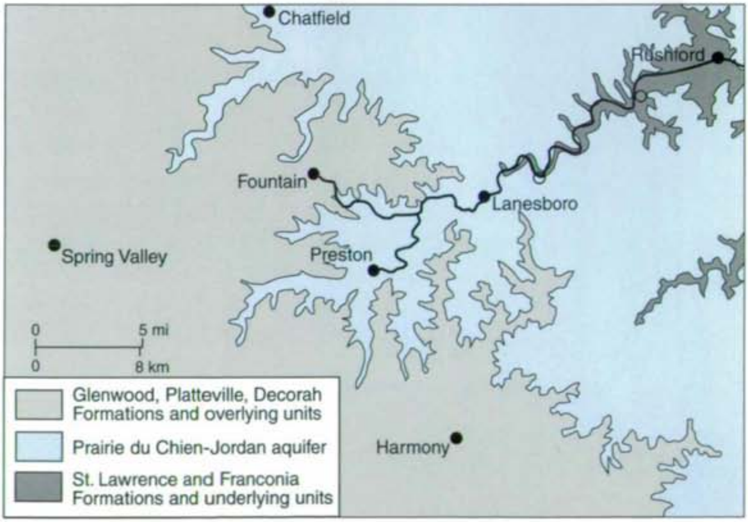


Figure 26. Simplified map of Fillmore County showing distribution of the Prairie-du-Chien-Jordan aquifer at the ground surface. Note that the aquifer extends westward beneath the overlying stratigraphic units. The black line linking the towns is the trail.

often contains sediment and agricultural chemicals or bacteria; it can reach the water table very quickly by flowing down sinkholes and through the underground waterways, to bypass nature's natural filtration system. The use of sinkholes as rubbish dumps (because they appear to be otherwise unusable plots of land) is also highly undesirable. Contaminated water can spread over large areas, and may remain within the aquifer indefinitely.

Rugged Landscapes and Light Loess Soils

The environmental sensitivity of southeastern Minnesota is further increased by its rugged topography and the light loess soils that cover the plateaus. Prior to European settlement, soil erosion was not a significant problem because thick sod adsorbed much of the rainfall and reduced the rate at which the water ran off the land surface. Intensive farming removed the sod cover, increased the speed of rainwater run off, and exposed the light loess soils to erosion. The lakes and marshes that act as reservoirs for rainwater storage in other parts of Minnesota are absent in southeast Minnesota. Rainwater here moves rapidly downslope through the carbonate bedrock; consequently, flooding is a problem for communities along the major streams in southeast Minnesota during periods of extremely heavy rainfall. Thick layers (7–8 feet) of silt eroded from fields on the uplands during heavy rainfall have been deposited near the mouths of tributaries along major stream valleys. These recently deposited sediments can be distinguished from pre-settlement sediments where they are separated by the original soil horizon. During the 1930's the methods of modern soil conservation (Fig. 27) were put into practice to combat soil erosion.

Figure 27. Aerial photograph shows use of contour ploughing to minimize soil erosion. Area shown is sloping area west of trail near site 8.

GUIDE TO SITES OF GEOLOGIC INTEREST ON OR NEAR THE ROOT RIVER STATE TRAIL

The site numbers refer to numbered locations on the trail map (in the pocket at the back of the booklet). As you travel from west to east on the trail you will be moving down the stratigraphic section—from younger to older rocks. Please refer to the regional stratigraphic column, which is presented on the back cover of the booklet. Please also note that some of the outcrops or exposures are on private property. Permission should be obtained from the landowners if you want to look at these outcrops. The trail is owned and maintained by the Department of Natural Resources, which encourages the enjoyment of our natural environment, but which prohibits the removal of rocks from the trail area. The Root River State Trail area is a prime habitat for the threatened timber rattlesnake.

Site 1. The city of Fountain is built on a plateau (a flat, upland region) underlain by horizontal bedrock strata of the Galena Group limestone and dolostone. Sedimentary rocks of the Galena Group are visible in a large active quarry owned by Mathy Construction Company, just northwest of Fountain (Fig. 28). The vertical orange-colored areas in the quarry walls are solution cavities in the Galena Limestone. The Galena Group is overlain by as much as 10 to 15 feet of loess that is well exposed around the periphery of the quarry. The loess was transported and deposited by winds blowing across unvegetated regions near glaciers that lay to the west during the late Pleistocene. Although glaciers advanced across the upland plateau of the Fountain area during the early Pleistocene and deposited till and associated glacial debris, most of these deposits were later removed by erosion.

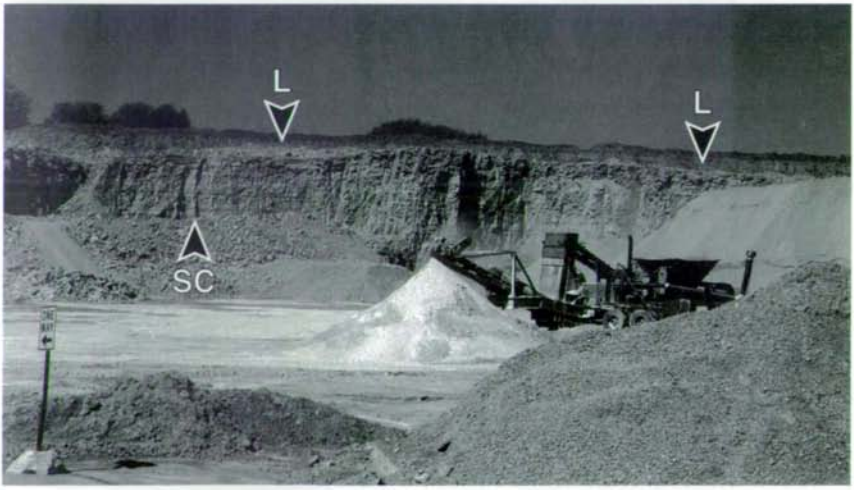


Figure 28. View of quarry in Galena Group sediments northwest of Fountain. The solution cavities (SC) and loess cap (L) are arrowed.

Figure 29. Aerial photograph showing sinkholes east of Fountain. The sinkholes are the darker, treed areas that dot the fields.

Site 2. Sinkholes like the ones seen here by the side of the trail pockmark the plateau surrounding Fountain (Figs. 29 and 30). Sinkholes form when slightly acidic surface water percolates down fractures in soluble rocks such as limestone and dolostone, and enlarges them by dissolving the rock to form a cavity. Eventually the soil and sediment overlying the cavity collapse into it, forming a sinkhole. Dye-trace studies show that water entering sinkholes near the trail is discharged from the Fountain springs northwest of the City of Fountain. The berm (low embankment) constructed around the sinkhole close to the trail was built to prevent contamination of ground water by sediment-laden rainwater from the fields that surround the sinkhole. The berm ensures that sediment suspended in the water settles out before the water enters the sinkhole.

Figure 30. Sinkholes near trail

Site 3. As the trail turns south just east of the Fountain Cemetery it begins to descend from the upper plateau down an escarpment to the lower plateau, which it eventually reaches at site 6. This escarpment is the relatively steep slope that separates the level land developed on Galena Group carbonate rocks from that of the Prairie du Chien Group, on which the lower plateau is developed. These two groups are separated by the soft, poorly resistant sandstone and shale beds of the Decorah, Platteville, and Glenwood Formations, and the St. Peter Sandstone. These softer units are easily eroded by running water. They are also more subject to mass wasting such as soil creep, talus creep, and slumping on oversteepened slopes. This sort of mass movement is especially well displayed in the Decorah Shale and in the shaley Cummingsville Formation (the basal unit of the Galena Group) where they are exposed in fresh road cuts on rural roads.

Site 4. Limestone that forms the basal part of the Galena Group crops out on private property to the east of the trail in the farmyard, and is exposed intermittently on the west side of the trail for about 1000 ft. Limestone was quarried near the farmyard during early settlement of the area, and burned in kilns for lime which was then used to make cement. The first geological survey of the area (Winchell, 1884) mentions this quarry and even then calls it old. Galena Group limestone at this locality contains distinct joints (prominent fractures that cut through the rock), and is thick-bedded.

Figure 31. A. Thin- and wavy-bedded dolomite of the McGregor Member overlies the sandy thicker-bedded dolomite of the Pecatonica Member of the Platteville Formation at site 5. **B.** Joints (arrowed, straight, vertical fractures) at site 5.

Site 5. Between this site and site 4 further up the escarpment, limestone of the Platteville Formation crops out discontinuously on the uphill side of the trail. At this locality an outcrop on the north side of the trail exposes the two basal members of the Platteville Formation. The thin- and wavy-bedded, medium-gray unit that is cut by prominent vertical, or near-vertical joints (Fig. 31A) is the McGregor Member. The underlying thicker bedded sandy dolomitic unit (Fig. 31B) is the Pecatonica Member of the Platteville Formation. If you examine the stratigraphic column on the back cover you will note that Decorah Shale (the unit which lies between the Galena Group and the Platteville Formation) does not crop out along the trail. This is because the Decorah Shale is soft and easily eroded. It is a clay-rich unit that retains any water that seeps into it; it also contains traces of phosphorous and potash minerals essential to plant growth. Therefore it is generally rapidly overgrown by grass and shrubs and is only rarely exposed in Fillmore County. Between this site and site 6, the St. Peter Sandstone forms poor outcrops in gullies northeast of the trail. You will also notice that the Glenwood Formation (which underlies the Platteville Formation and overlies the St. Peter Sandstone) does not crop out near the trail.

Site 6. St. Peter Sandstone forms the cliffs immediately to the north of the trail just to the west of the intersection with the gravel township road (Fig. 32). The St. Peter Sandstone is very soft and easily eroded ('friable') because there is no mineral cement between the sand grains; for this reason it has attracted a large amount of carved graffiti. The St. Peter Sandstone is a medium-grayish color on weathered surfaces, but has more striking whitish to yellow or slightly orange coloration where it has been recently excavated. The horizontal orange, yellow and red lines that are essentially parallel to bedding are probably liesegang bands, which are colored bands in the rock that result from precipitation and oxidation of a variety of minerals, probably due to changes in the level of the water table. The slightly greenish layers include a small amount of mud, and are probably an original depositional feature. This sandstone formed as a near-shore or beach sand at the margins of a shallow sea. If you pick up a handful of eroded sand from near the base of the cliff, you will notice that it is made up entirely of quartz grains (Fig. 11), which are all very rounded. The cliffs are topped by a discontinuous, thin, loess cover.

Figure 32. The St. Peter Sandstone at site 6 displays the characteristic bedding, liesegang bands, and friable nature (soft and poorly cemented). The cliffs are topped by a thin, discontinuous, loess cover.

Site 7. You have now descended to the lower plateau, the upper surface of which is dolostone and sandstone of the Shakopee Formation of the Lower Ordovician Prairie du Chien Group. The trail climbs very slightly over a low divide between two streams that are both tributaries to the more deeply incised Watson Creek. There are some vegetation-covered outcrops of the upper part of the Shakopee Formation next to the trail here.

Site 8. Between site 7 and this locality, the Lower Ordovician Shakopee Formation crops out in banks at a few places along the trail. At this site, on private property just north of the trail, the upper member (the Willow River Member) of the Shakopee Formation is exposed. It is medium gray on weathered surfaces, and the beds range from less than 1/8" thick to several inches thick. The dominant fossils in the Shakopee Formation are stromatolites which are usually dome-shaped, calcareous structures (Fig. 15). The Shakopee Formation also contains some gastropods (snails) that probably grazed on the stromatolites, and rare trilobites (which are an extinct relative of lobsters and crabs) that probably preyed on the snails. The Shakopee Formation also contains a lot of coarse, white, void-filling calcite crystals, and light gray chert lenses or nodules. The Shakopee Formation underlies the St. Peter Sandstone, and represents material deposited in the earlier (older) Late Cambrian to Early Ordovician sea that covered the region. The contact or bedding plane that separates the Shakopee Formation from the overlying St. Peter Sandstone represents an unconformity (a gap or break in the rock record) that spans 20 million years. During this time interval the region was above sea level and was subjected to erosion and therefore no record of it remains. The view to the south, where Watson Creek meanders through the valley-bottom pasture illustrates the formation of incised meanders and river terraces.

Site 9. At this site on the north side of the trail close to mile marker 5, the contact between the Willow River Member and the New Richmond Member of the Shakopee Formation is exposed. Rock columns of Shakopee Formation dolostone are present in this region. The columns formed where the more resistant carbonate rock (that included a greater amount of insoluble constituents such as silica and clay) was not dissolved by the acidic groundwater. These resistant carbonate rocks are often preserved as knobs or columnar outcrops where the surrounding material has been eroded. These erosional remnants of dolostone or limestone are common throughout Fillmore County, some forming such distinctive landmarks that they were named (Pulpit Rock, a landmark since the late 1800's is not far from the bicycle trail between Lanesboro and Isinours Junction).

Site 10. During railroad days (1860's to the 1970's) the Isinours rest stop was a switching site for trains going south to Preston and points east or west. It was the place where an extra locomotive was added to westbound trains going up the escarpment to Fountain. There was a hotel and some other buildings at Isinours at that time. The site is now occupied by a parking lot, picnic tables and restrooms for the trail.

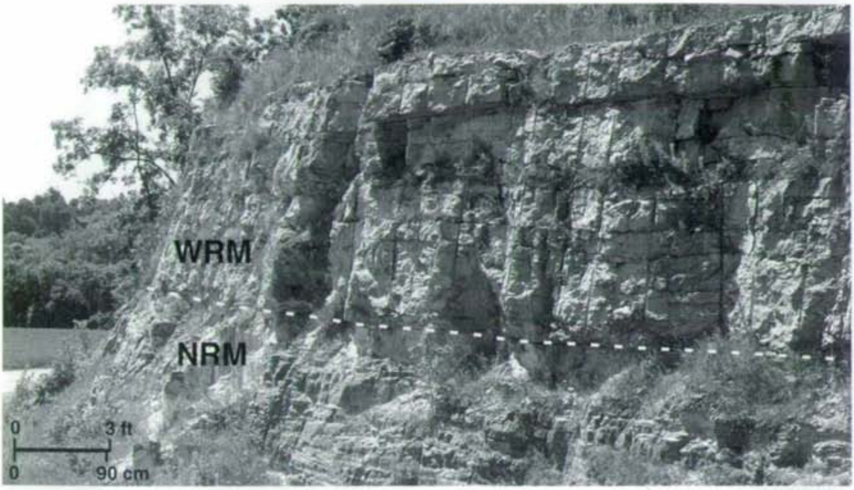


Figure 33. Road cut at site 11 exposes New Richmond Member (NRM) and overlying Willow River Member (WRM) of the Shakopee Formation.

Site 11. The road cut on County Road 17 immediately north of where the trail crosses provides excellent exposure of the New Richmond Member and the overlying Willow River Member of the Shakopee Formation. The friable sandstone at the base of the outcrop includes cross beds (Figs. 33 and 34) that were probably deposited by wind as sand dunes. The sharp contact between these sandstones and the overlying dolostones of the Willow River Member reflects the flooding of the region by a shallow sea that drowned the sand dunes. The dolostones include well-preserved stromatolites, some of which are dome-shaped (Fig. 15), and others of which form lenticular mounds. A 5- to 10-inch-thick bed of sandy dolostone containing intraclasts (Fig. 35) lies 8 ft below the top of the Willow River Member. The upper 8 ft of the member contains oolites and quartz sand that were deposited in high-energy conditions in a nearshore environment.

Site 12. This site is half-a-mile up County Road 17 from site 11, on the west side of the road. It is separated from site 11 by a grassy interval with no outcrop. The road cut exposes St. Peter Sandstone, Glenwood Formation, and Platteville Formation. The basal part of the St. Peter Sandstone is covered by vegetation and the contact between it and the underlying dolostone of the Willow River Member is not visible. The soft

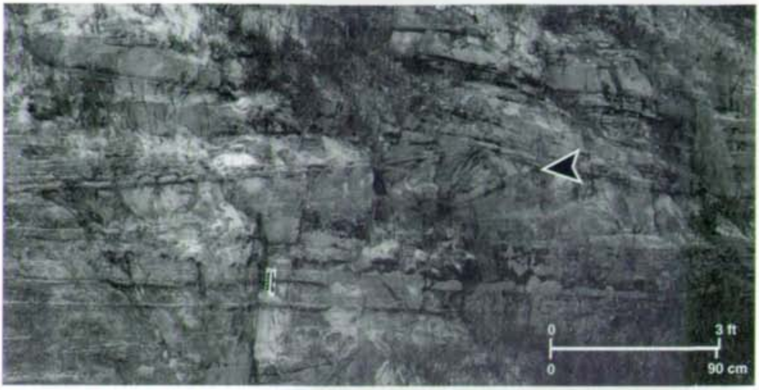


Figure 34. Cross bedding (arrowed) in New Richmond Member sandstone at site 11. The cross bedding here is interpreted to result from deposition by wind as sand dunes.

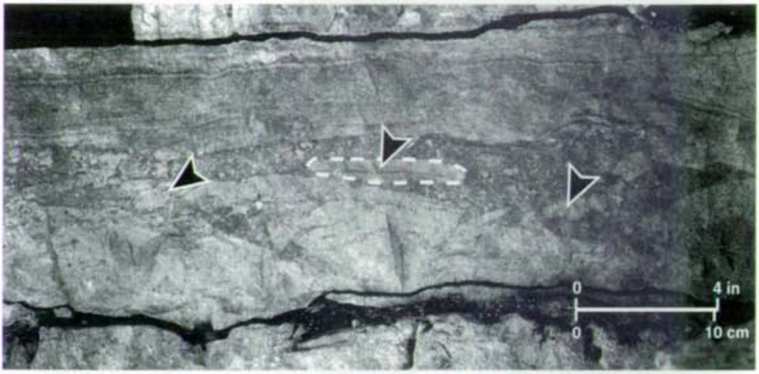


Figure 35. Intraclasts (arrowed; one is highlighted with dashed line) within the sandy dolostone of the Willow River Member at site 11.

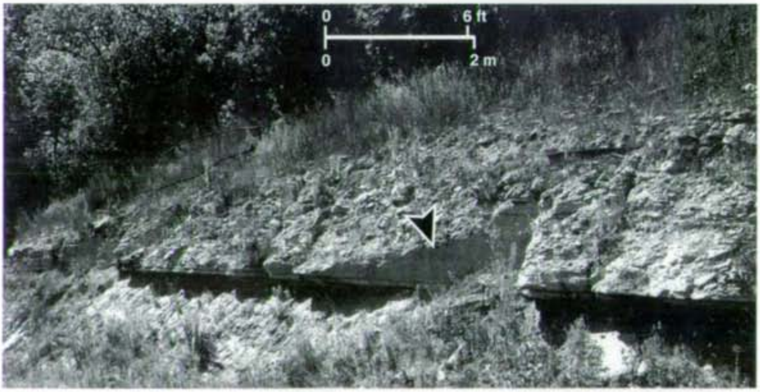


Figure 36. Outcrop of St. Peter Sandstone, Glenwood Formation, and Platteville Formation at site 12. The deep recess in the outcrop is at the contact between the Glenwood Formation and the more resistant, overlying Platteville Formation. Note the large joint surface in the Platteville Limestone (arrowed). Such joints act as conduits for groundwater.

and easily eroded ('friable') nature of the Glenwood Formation and the St. Peter Sandstone is illustrated by the prominent notch beneath the more resistant beds of Platteville Formation (Fig. 36). The Platteville Formation is the most fossiliferous unit exposed in this road cut and contains a variety of invertebrate fossils (Fig. 16). Bryozoans and brachiopods are most abundant here. Some fossils weather out to form loose specimens, but most are embedded in slabs of limestone. The upper part of the road cut, about 4 ft below the top of the exposed Platteville Formation, contains a 3 inch-thick bed of altered volcanic ash that is now yellow- to white-colored clay with a putty-like consistency. The altered volcanic ash is called the Deicke K-bentonite, and it was probably derived from a volcanic eruption from the volcanic chain that extended along the Ordovician margin of the North American continental plate (Fig. 37). Compositionally similar altered volcanic rocks are known from similar age rocks throughout the mid-continental and eastern parts of North America. The bentonite forms a layer that blocks the downward flow of ground water into underlying rocks, so that when there is an adequate water supply, water seeps out of the bentonite—a common feature in southeastern Minnesota. The Decorah Shale used to be exposed above the Platteville Formation in this road cut, but is now overgrown by grass and weeds.

Figure 37. Bentonite bed, named the Deicke K-bentonite, near the top of the Platteville Formation at site 12. Bentonite bed is the clay seam marked by the camera lens cap.

Site 13. At site 13 the trail passes through a railroad cut carved into bedrock of the basal silty dolostone of the New Richmond Member of the Shakopee Formation. You will see that it is noticeably thinner-bedded than it was at site 11. This bedrock is a remnant of the rock spur around which the South Branch of the Root River once flowed (Fig. 38). The South Branch of the Root River used to flow northwest through the valley now occupied by Watson Creek. Just north of the low gentle ridge that you are now on, it swung around to flow southeast. This incised meander loop was abandoned when the river cut through the meander neck south of the private resort. Another abandoned meander with a rock core lies to the south along the south-branching trail to Preston near the private Bed & Breakfast (Fig. 38).

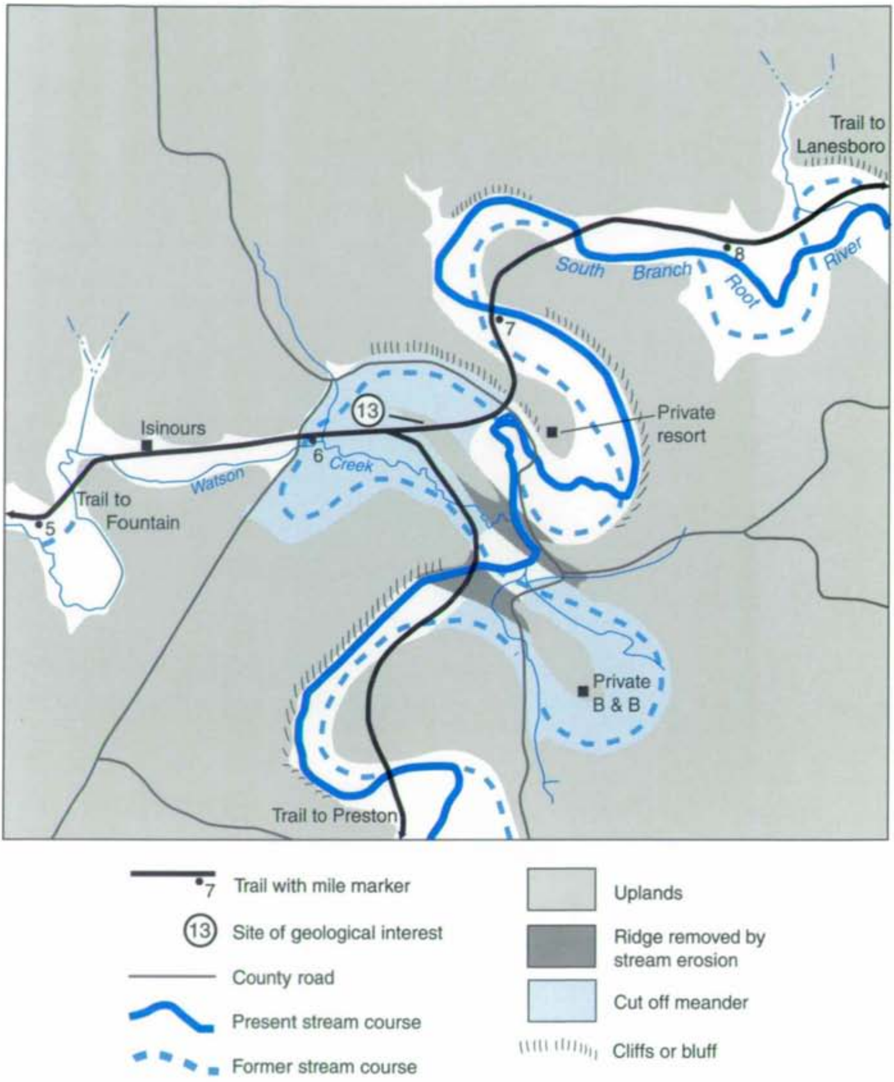


Figure 38. Map of area near junction of Watson Creek and the South Branch of the Root River, showing the formation of meander cutoffs. Streams cut into and erode the outside and downstream sides of meander loops. This results in the stream eventually cutting through the spur and abandoning the meander. The abandoned meander typically becomes occupied by a tributary such as Watson Creek. The remnant meander spur becomes an abandoned meander core, such as the outcrop at site 13, or the abandoned core near the private Bed and Breakfast. A–A' refers to the cross section on side 1 of the trail map (back pocket).

Site 14. At this site to the northeast of the county road, a railroad cut exposes the lower part of the New Richmond Member of the Shakopee Formation on both sides of the trail (Fig. 39). Sandy beds that range from 2 to 3 ft thick underlie a more thinly-bedded siltstone and sandstone (beds range from less than 1 inch to as thick as 1 ft). The thicker-bedded unit includes a 1-ft-thick siltstone unit that contains pebble and cobbles of sandstone (intraclasts). The intraclast-bearing unit is best seen about 4 ft above the ground, underneath an overhang (Fig. 40). It has been sheared, making it difficult to distinguish the intraclasts. The intraclast-bearing unit has weathered recessively, which has resulted in development of the overhang. The sandstone beds below the overhang are separated from each other by undulating contacts; these surfaces represent places where currents scoured rolling surfaces on the seafloor sands. Cross-bedded sandstone similar to that at site 11 is exposed in outcrops on the east side of the county road where the road continues uphill to the private resort.

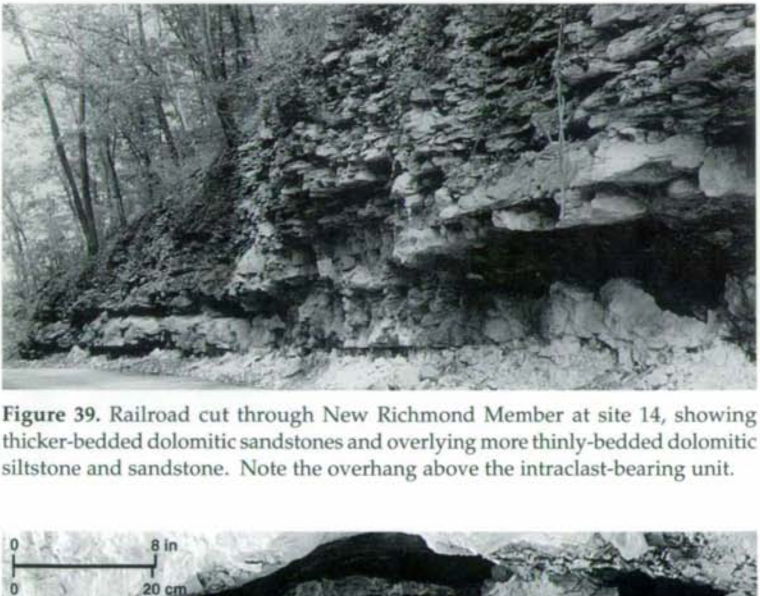


Figure 39. Railroad cut through New Richmond Member at site 14, showing thicker-bedded dolomitic sandstones and overlying more thinly-bedded dolomitic siltstone and sandstone. Note the overhang above the intraclast-bearing unit.

Figure 40. Sheared siltstone containing sandstone intraclasts (arrowed) in New Richmond Member at site 14.

Site 15. The trail now follows the valley of the south branch of the Root River, until it joins the main branch of the Root River east of Lanesboro. As you look to the east and north here, you will have views of cliffs formed in Shakopee Formation.

Site 16. Between site 15 and here the trail has cut down, and Oneota Dolomite now crops out on the north and east side of the trail (Fig. 41). The contact with the overlying New Richmond Member of the Shakopee Formation is about 20 ft upslope from the trail. The Oneota Dolomite is more thickly bedded (the beds range from less than 1 to 3 or more feet thick) than the overlying beds of the New Richmond Member; this is characteristic of the upper part of the Oneota Dolomite. Most of the upper part of the Oneota Dolomite was deposited in shallow marine water below low tide level.

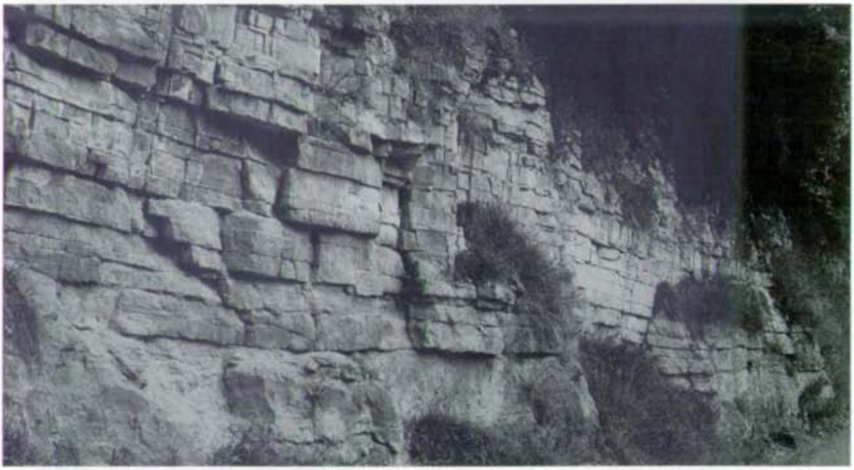


Figure 41. Outcrop of Oneota Dolomite on State Highway 16 between Lanesboro and Rushford.

Site 17. The flat area just west of Lanesboro is the bed of a former lake, Lost Lake, which formed behind a dam that was constructed at Lanesboro in the mid-1800's. The lake was quickly filled with silt derived from erosion of farm fields on the plateaus. The silt was carried away by water that ultimately drained to the Root River. Several feet of silt were deposited in the lake.

Site 18. As the trail enters Lanesboro from the west, the railroad cut exposes Oneota Dolomite at the base of the bluff. At about eye level, the dolostone is made up of angular fragments, and is called a breccia. The breccia formed by partial dissolution and collapse of Oneota Dolomite carbonate sediments when they were exposed at or near the surface prior to deposition of the New Richmond Member eolian sand dunes (site 11) by winds. In western

Wisconsin, the Oneota Dolomite contains ancient sinkholes that formed during the Ordovician Period, prior to deposition of the overlying New Richmond Member. These ancient sinkholes in western Wisconsin are infilled with New Richmond Member sandstone. The township road immediately west and north of the trail here marks the location of a former oxcart trail that was cut into Oneota Dolomite in the side of the bluff; the oxcart trail was one of the first roads into Lanesboro.

Site 19. Lanesboro was founded as a railroad town. The first dam across the Root River at Lanesboro was built in 1868 to provide power for the evolving flour-milling center; this dam was washed out in a matter of months. It was replaced by another dam. Both dams were built from local Oneota Dolomite quarried from nearby bluffs. The former mill pond associated with the Lanesboro dam can be seen near the trail. It is the long pond that contained the water used to drive the mill wheels. None of the three mills have survived. They were all wooden structures that were destroyed by fire. They also suffered economic losses caused by the shift from wheat farming to other crops. The dam is now used to generate hydroelectric power.

Site 20. The Root River used to meander through the area that now forms the City of Lanesboro. The course of the river was modified by early settlers in Lanesboro (Fig. 42). The pond in Sylvan Park marks part of the former course of the Root River. The pond is now fed by a spring.

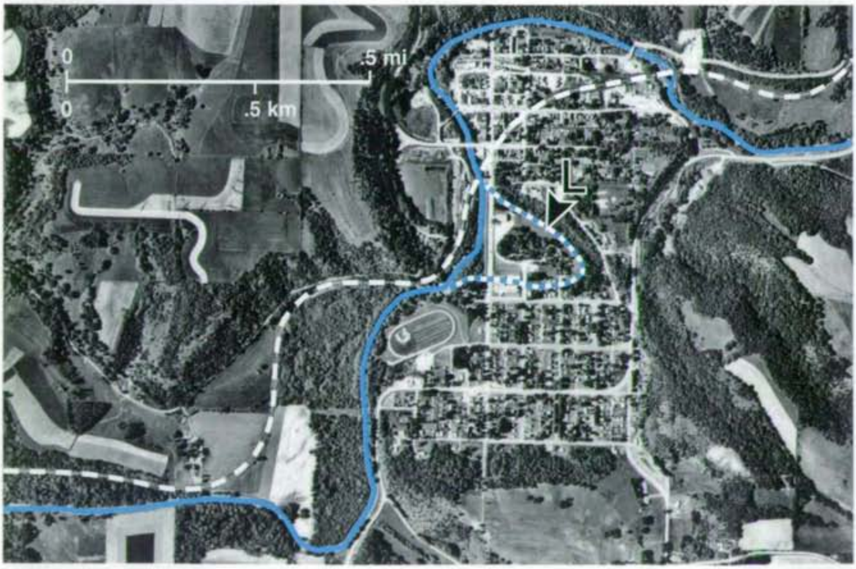


Figure 42. Aerial photograph of Lanesboro shows present course of river (blue line), former course of river (blue and white dashes), lake in Sylvan Park (L), and bike trail (dashed white line).

Site 21. The high bluffs and the road cut on County Road 8 expose the upper part of the Oneota Dolomite and the lower part of the Shakopee Formation, including a thick sequence of New Richmond Member sandstone. These are the same units that form the bluffs along the trail from about a mile west of Isinours through to Lanesboro. You have now descended well below the upper surface of the lower plateau. You may have noticed as you traveled down the south branch of the Root River, that the river gorge became clearly evident for the first time as you approached Lanesboro. That is because this is where the river has entrenched its channel into the softer, more easily eroded rocks of the Jordan Sandstone and underlying units, which lie beneath the more resistant Oneota Dolomite. The increased river gradient here was an important factor in the siting of the dam at Lanesboro.

Site 22. The quarry just to the north of the trail is a privately owned abandoned Oneota Dolomite quarry. Oneota Dolomite was quarried at many other places in and near Lanesboro and many early buildings were constructed from this stone, including the Lanesboro Hotel, the Thompson and Williams flour mill, the former Presbyterian Church (now a Lutheran Church), the Catholic Church, the old public school (now abandoned) and a number of stores. The stone was one of the most desirable building stones in southeastern Minnesota because of its durability. Oneota Dolomite is still quarried for building stone in southern Minnesota at Winona and near Mankato. Oneota Dolomite was also burnt in kilns to make lime, which was used in mortar and plaster (although Oneota Dolomite was not as good for this purpose as limestone from the Galena Group farther to the west). Some stone was quarried from the hill on which the Catholic Church and Public School now stand. That hill is the rock core of another abandoned meander similar to those near Isinours. Highway 16 follows the trace of this abandoned meander from the south part of town northeast to the north edge of town.

Site 23. The cliffs that you can see to the southeast of the trail when you leave Lanesboro are formed in Oneota Dolomite. One and a half miles northeast of Lanesboro, Oneota Dolomite crops out on the west side of highway 250, close to the trail. It is also present in numerous road cuts on State Highway 16 between Lanesboro and Petersen (Fig. 41).

Site 24. The North and South branches of the Root River join 2 miles northeast of Lanesboro. They merge to form a single stream that flows northeast, opposite to the direction that the underlying bedrock units are tipping. Therefore, as you travel downstream, the height of the bluffs and the level of the Prairie du Chien plateau increases in elevation relative to points further west (see the cross sections and Fig. 43). Most tributary streams flow from the northwest towards the southeast. Their position is probably controlled by the dominant joint or fracture direction in the bedrock. It was probably easiest for the tributaries to erode bedrock along these fractures.

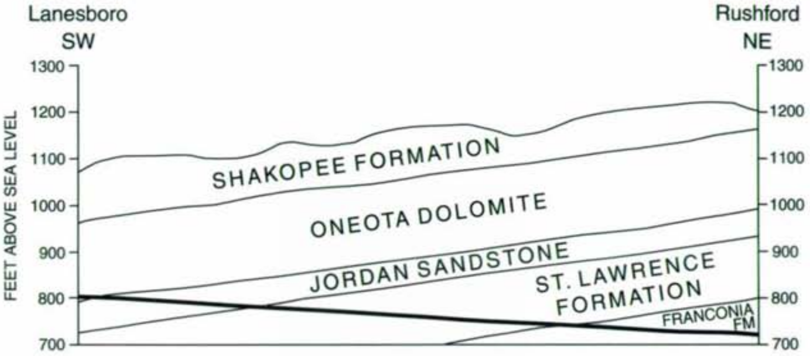


Figure 43. Simple cross section SW to NE from Lanesboro to Rushford, showing drop in river level (thick black line) from 800 ft to 720 ft, and southwest dip of the sedimentary bedrock units, which combine to produce the increased height of the bluffs above the river as one moves to the northeast towards Rushford.

Site 25. A sand and gravel pit to the east of the trail is used seasonally. The sand and gravel was probably deposited during Late Wisconsinan deglaciation. There is also a good view of nearby cliffs formed in Oneota Dolomite. As you travel east on the trail from this site, notice the large (5 ft diameter) colluvial boulders in the gullies on the north side of the trail.

Site 26. The church and cemetery north of the trail at Whalan are built on a terrace (a bench-like landform) formed by gravel that was deposited during and after the Late Wisconsinan glaciation. This gravel was deposited by streams loaded with debris derived from melting ice lobes to the west and north. At the end of the Wisconsinan, sand and gravel extended across the entire valley, to the level of this terrace or even higher. Post-glacial meltwater drainage from Glacial Lakes Agassiz and Duluth (Fig. 22) eroded and deepened the channel of the Mississippi River; this caused local rivers such as the Root River to erode through the sand and gravel filling their valleys as they adjusted to the lower base level. Only scattered terrace remnants, such as this one, remain.

Site 27. The valley of Gribben Creek south of the trail was the site of two water-powered flour mills. The mills were built from local Oneota Dolomite. The old stone building near the mouth of Gribben Creek is the remains of one of the mills. The other mill is beside Gribben Creek about 1.5 miles south of the trail on County Highway 23. The isolated hill to the west of State Highway 16 is the remains of a bedrock core to an incised meander of the Root River.

Site 28. The flat areas within the valley that are used for crops are underlain by Late Wisconsinan gravels and mantled by Holocene sediment. The present-day stream has cut down into the Holocene sediment and Wisconsinan gravels, to leave a terrace. At this locality you have a view (Fig. 44) across the river that shows the present-day flat terrace surface where Holocene sediment mantles the Late Wisconsinan alluvial fill.

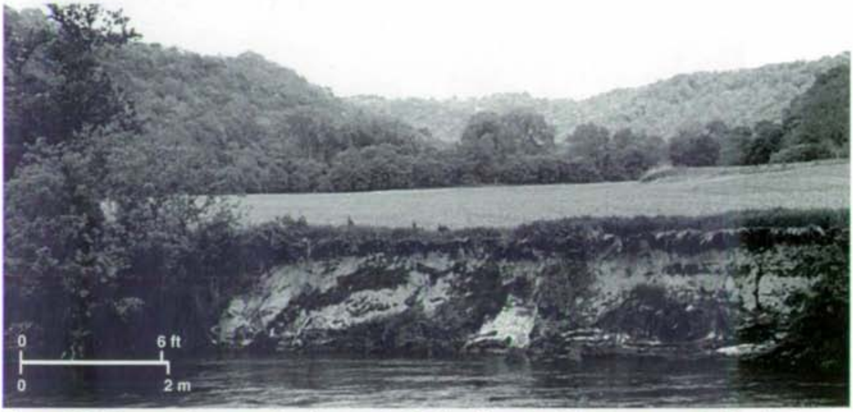


Figure 44. View south across the river at site 28 showing alluvial terrace mantled by Holocene sediment, and steep bank that formed when the present stream cut down after deposition of Holocene sediments.

Site 29. The high cliffs along this part of the trail are formed in Oneota Dolomite, which is underlain by Jordan Sandstone. The Jordan Sandstone is underlain by the St. Lawrence Formation; the contact between these two units is at approximately road level. Rocky colluvium is abundant and is exposed in some of the ravines near milepost 18. This colluvium formed during the last (Late Wisconsinan) glaciation when water in cracks and joints in the rock froze and expanded, ultimately shattering the rock into large angular boulders which slid downslope and built up big piles of rubble at the base of the cliffs.

Site 30. St. Lawrence Formation crops out next to the gravel township road immediately to the west of the trail at milepost 20, just east of where the trail crosses Raaen Creek. The St. Lawrence Formation is a silty shallow-marine deposit. Massive 1–2-ft thick beds of fine- to medium-grained dolomitic sandstone are interbedded with 2–3-ft thick intervals of wavy laminated siltstone and fine sandstone (Figs. 45 and 46). The St. Lawrence Formation is not fossiliferous at this site, but is fossiliferous elsewhere in Minnesota, where it includes trilobites. The valley of the Root River starts to broaden out here. It is now entrenched well below the base of the Oneota Dolomite. As the river meandered from one side of the valley to the other it undercut the cliffs of Oneota Dolomite by eroding underlying less-resistant beds of Jordan Sandstone and St. Lawrence Formation siltstone.

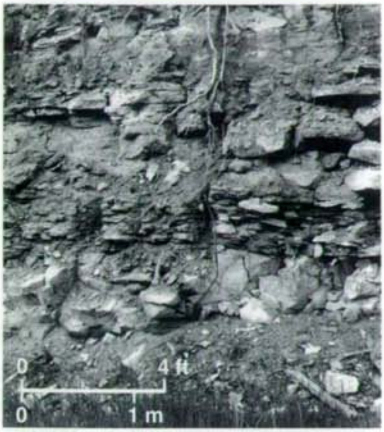


Figure 45. Outcrop of thin- and thick-bedded St. Lawrence Formation at site 30.

Figure 46. Detail of lamination and lenticular bedding in St. Lawrence Formation thin-bedded siltstones and fine sandstones. Pencil for scale.

Site 31. The hillside north of the trail and county road is covered by rocky colluvium that contains angular blocks of Oneota Dolomite. The colluvium conceals the underlying bedrock. The colluvium is well exposed in a small gully on the uphill side of the gravel township road just north of the trail (Fig. 47).

Site 32. Jordan Sandstone can be examined in a rare road cut on the gravel township road. The road has climbed since the last bedrock outcrop, at site 30, so you have effectively moved up the stratigraphic column into the upper part of the Jordan Sandstone. You will notice (Fig. 48) massive sandstones that are locally cross-bedded, as well as some more thinly bedded sandstones. The upper part of the Jordan Sandstone ranges from fine-grained sandstone with trough-shaped cross-beds to medium- to coarse-grained sandstone with large cross-beds as much as several feet thick. Intraclasts of siltstone or sandstone may mark bedding in the large cross-beds. The upper Jordan Sandstone was deposited in a shoreface environment. The lower part of the Jordan Sandstone is composed of very fine sandstone that is either burrowed by marine organisms or has low, hummocky cross-bedding caused by storm waves in an offshore-shelf environment. Jordan Sandstone is not typically exposed, and its presence is usually inferred from the vegetation and soils. South- and southwest-facing slopes underlain by the Jordan Sandstone have dry sandy soils and are covered by cedar shrubs or steep grassy 'goat prairies.' Along the bluffs the Jordan Sandstone has a very limited sandy to rocky soil cover, and the only plants that grow are very drought tolerant.

Figure 47. Colluvium conceals underlying bedrock at site 31.

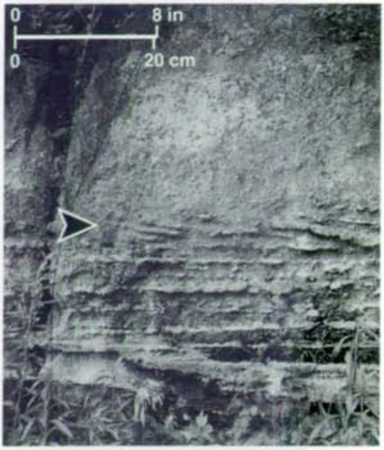


Figure 48. Cross bedding (arrowed) in Jordan Sandstone at site 32.

Site 33. Big Springs Creek is fed in part by a large spring which flows from the upper part of the Franconia Formation, which underlies the St. Lawrence Formation. The springhouse, the pond that the spring flows into, and the marshy land near the spring are on private land, but they can be seen from the gravel township road just northwest of the trail (Fig. 49).

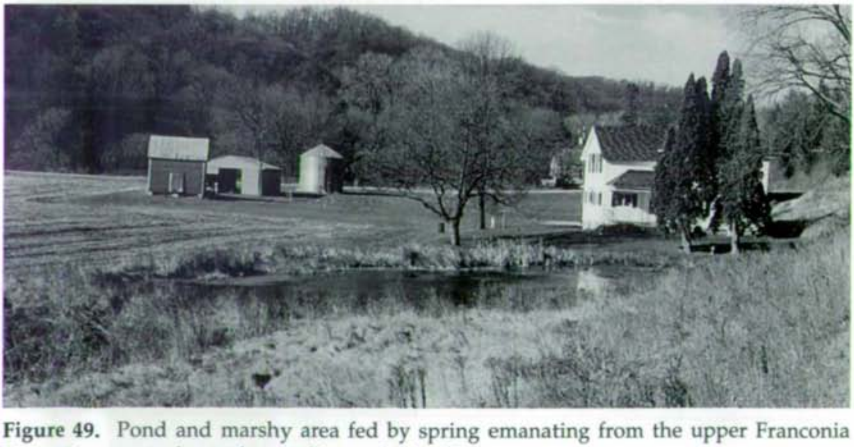


Figure 49. Pond and marshy area fed by spring emanating from the upper Franconia Formation, west of gravel township road (site 33).

Site 34. South of the Root River here there are several sand and gravel pits within the remnants of a Late Wisconsinan gravel terrace. In 1962 a mineral exploration test hole was drilled into bedrock beneath the gravel by a private mining company, to assess whether an aeromagnetic anomaly indicated the presence of economic mineral deposits. Magnetic anomalies are local variations in the earth's magnetic field produced by local variations in rock magnetization caused by concentration of magnetic minerals such as magnetite, which is an ore of iron. The drill hole reached Precambrian igneous rock (gabbro) 724 feet below the land surface. This gabbroic rock is similar to rocks that crop out near Duluth. The gabbro was overlain by 599 feet of Cambrian sandstone and siltstone and 125 feet of river sediment.

Site 35. Between the previous site and Peterson you may notice the remnants of numerous Late Wisconsinan sand and gravel terraces close to the trail. They typically form well-vegetated angled slopes on the uphill side of the trail, that are usually cut by narrow gullies. They also form the flat, cropped areas that the Root River has incised into. The sediments that form the upper terraces were probably deposited during and after Late Wisconsinan glaciation, similar to the terrace sediments at Whalan (site 24). Sediments that form the Late Wisconsinan terraces are the principal sand and gravel resource in Fillmore County and adjoining areas; at this site there is an active sand and gravel pit just north of the trail. However, the limited extent of these terrace deposits, and the lack of sufficient gravel sized material in their deposits (they have less than 35% gravel sized particles; they are dominated by sand and silt), means that rock units such as the Oneota Dolomite are used to create crushed rock (aggregate) for use as 'gravel' in the region.

Site 36. About 20 feet above the top of the Wisconsinan gravel terraces, near the base of the bluff northeast of the gravel township road that parallels the trail, a calcite-cemented gravel from the Illinoian glacial stage is preserved (Fig. 50). This Illinoian gravel was once a thick deposit that filled the valley from wall to wall. But, as happened with the Late Wisconsinan gravels, the Illinoian gravels were stripped from the valley in most places when the Mississippi River eroded the unconsolidated sediment filling its valley, and tributaries such as the Root River responded by eroding sediments that filled their valleys. This lowering of base level either resulted from lowering of sea level (due to storage of water in glacial ice) or from drainage of large volumes of water down the Mississippi River. Regardless of the cause, the Root River flowed on a bedrock surface that was about 100 feet lower than the present valley surface in the vicinity of Peterson, prior to the last Wisconsinan glaciation, and as much as 160 feet lower at Rushford (see cross section B–B' on the map). Only very rarely are the Illinoian terrace sediments preserved.

Figure 50. Calcite-cemented Illinoian gravel terrace at site 36. Fence post for scale.

Site 37. The State Fish Hatchery to the southeast of Peterson is located on a tributary to the Root River next to large springs that flow out of the Franconia Formation sandstone. Large volumes of consistently cold water are needed for trout hatcheries.

Site 38. Just over 2 miles west of Rushford the valley widens, and is filled by Late Wisconsinan gravel terraces (Fig. 51). Prior to deposition of the Late Wisconsinan gravels, the valley was broadened when two meander loops of the Root River eroded and entrenched into the soft Galesville Sandstone. The Galesville Sandstone is now 100 to 125 feet below the alluvial valley fill. Bedrock of the Oneota Dolomite, Jordan Sandstone, and St. Lawrence and Franconia Formations (which overlie the Galesville Sandstone), forms the hills on either side of the Root River valley.

Figure 51. Late Wisconsinan gravel terraces (arrowed) in valley west of Rushford at site 38.

Site 39. Magelsson Park in Rushford is located on a flat-topped hill on the north side of the Root River Valley. The flat hill top is part of the lower plateau, which is separated from the upper plateau by an escarpment (Fig. 18). During pre-Wisconsinan time, erosion and downcutting of the Root River entrenched the lower plateau. The meandering river cut deeply into the bedrock hills, leaving the bedrock spurs that we see on the valley sides today, including the one at Magelsson Park. More recently the valley filled with alluvium, and the present course of the Root River was established. The abandoned quarry just to the east of the park road, at the base of the hill, is mostly overgrown, but it exposes Franconia Formation. If you ride up the road into Magelssen Park you will see thin-bedded dolomitic siltstone of the St. Lawrence Formation exposed just downhill from the side road to the private residence. Jordan Sandstone is intermittently exposed on the uphill side of the park road after it bends to the east. The top of the hill is capped by Oneota Dolomite. Vantage points at the top of the hill give good views of the wide meandering entrenched valley, the Root River, and the flat and level uplands which border the river (Fig. 52). The summits of the upland areas are all at the same level (concordant). This reflects their origin as a plateau or series of plateaus.

Figure 52. View eastward from Magelssen Park showing the level surface of the dissected plateau that now forms the uplands. The rock spurs and steep valley sides formed when the meandering Root River incised sedimentary rocks of the Prairie du Chien Group during the Pleistocene. The flat valley floor is formed in Late Wisconsinan gravel terraces that locally include a capping of Holocene sediment.

FURTHER INFORMATION

Glossary

alluvium General term for unconsolidated clay, silt, sand, and gravel deposited by a stream or other body of running water.

bar A lensoid accumulation of sand, gravel or other alluvial material in a stream bed. Typically deposited where a stream looses velocity.

base level The theoretical lowest level toward which erosion progresses. Base level for streams is ultimately sea level.

bedrock A general term for the solid rock that underlies soil or other unconsolidated surficial material.

braided stream, braided delta A stream or delta that divides into or follows an interlacing or tangled network of branching and reuniting channels, often separated from each other by bars.

biostratigraphy The study and description or division of sedimentary layers or sequences based on aspects of the fossils that they contain.

calcite A common rock-forming carbonate mineral of composition $CaCO_3$ that is typically white, and fizzes in dilute hydrochloric acid.

cementation The process by which sedimentary grains are bound together to make a hard rock by the precipitation of minerals in the spaces between the sedimentary grains.

chert A hard, slightly glassy rock that is made up almost entirely of silica (SiO_2), and ranges in color from white, gray, green, red or black.

clast An individual grain or fragment within a sediment; can range from sand to boulder in size.

colluvium General term for unconsolidated, loose rock fragments deposited at the base of a slope. May range from boulder to silt in size.

denuded the result of processes that have uncovered, worn away or progressively lowered the surface of the earth by erosion.

dolomite A common rock-forming carbonate mineral that has the formula $CaMg\,(CO_3)_2$. It is typically whitish, and fizzes slightly when dilute hydrochloric acid is applied to a scratched surface.

dolostone A carbonate sedimentary rock consisting chiefly of the mineral dolomite. The term limestone is often used loosely to include dolostone.

entrench(ed) The process whereby a stream erodes downward through sediment or bedrock to form a typically steep-walled valley. Similar to incision.

escarpment A more or less continuous cliff or steep slope facing in one general direction, that separates two level or gently sloping surfaces. Produced by erosion or faulting.

exhumation The uncovering or the gradual exposure of a preexisting rock unit or landscape that had been buried by sediments.

geomorphic The shape or form of a feature on the earth's surface.

geophysics The study of the subsurface of the earth that uses rock properties such as magnetization, specific gravity, electrical conductivity, heat flow and the seismic velocity of rock units.

glacier A large mass of ice that survives from year to year, that formed by the compaction and recrystallization of snow. The glaciers that extended across the Upper Midwest were continental glaciers, as much as 2 km thick.

groundwater Water that is present in the subsurface

Glossary (continued)

ice lobe A tongue-like body of ice that extends beyond the main body of ice or glacier.

impermeable A rock, sediment or soil through which water is not able to be transmitted.

incision The process whereby a stream cuts a narrow, steep-walled valley in the sediment or bedrock as the result of the relative movement (uplift) of the earth's crust, or the lowering of base level.

invertebrate An animal that does not have a backbone (such as sponges, corals, snails).

isotope A species of a chemical element that has the same number of protons as other species of the element, but which differs from other species of the element because it has a different number of neutrons (and consequently a different atomic weight). Isotopes of an element typically have essentially similar chemical properties due to similarities in electron configuration.

joints A fracture or break in a rock that forms a plane across which there is no displacement. Groups of joints often form; they may be regularly spaced, parallel, or intersecting. Joints commonly serve as the principal passageways for the movement of groundwater in carbonate rocks.

karst The name given to landforms or topography characterized by closed depressions (sinkholes), caves, and underground drainage systems that develop in areas of limestone or dolostone.

limestone A sedimentary rock consisting chiefly of calcium carbonate in the form of the mineral calcite. It may contain fossils. This term is sometimes used loosely to include dolostone.

lithified, lithification The processes whereby newly deposited, unconsolidated sediment is converted into a coherent solid rock. This process includes cementation and compaction.

loess A homogeneous, unstratified, unconsolidated (but often coherent) sediment, ranging from clay to fine sand, that is transported and deposited by winds.

mineral A naturally-formed chemical element or compound (such as quartz or silica) that has a definite chemical composition, and usually has a characteristic crystal form. The term ore is used for rock that contains economically useful minerals.

outcrop Bedrock that is naturally exposed and visible at the earth's surface.

outwash Sediment 'washed out' from a glacier by meltwater streams, and deposited to form outwash plains, outwash fans and outwash aprons.

paleontologist A person who studies the fossilized remains of animals or plants (i.e. paleontology).

periglacial The term used to cover the processes, conditions and climate at the immediate margins of former and existing glaciers and ice sheets.

permeable A rock, sediment or soil that allows water to pass through it.

relief The slope and elevation of the earth's surface.

sinkhole A closed depression in a karst area that is formed either by solution of the limestone or dolostone, or by the collapse of underlying caves. They are basin- or funnel-shaped.

solifluction The slow downslope movement or flow of waterlogged soil and other unsorted and water-saturated surficial material.

solution cavity A shallow surface depression produced by the solution of surface material.

stratigraphy The branch of geology that deals with the definition and description of rock units, their distinguishing features, and the interpretation of their origins.

surficial A process that took place, or a rock type or sediment that formed at the surface of the earth. Surficial deposits are typically unconsolidated Quaternary sediments that overlie bedrock (or other unconsolidated sediments) at the earth's surface.

Glossary (continued)

tectonic The forces, structures or features that relate to or result from movements within the earth's crust.

terrace The geomorphic term for the level or very gently inclined surface that typically defines the upper surface of an alluvial stream deposit; it may be bounded on one margin by a steep slope formed by erosion during later stream incision.

till Unsorted, unstratified and unconsolidated sediment deposited directly by and underneath a glacier. Consists of a heterogeneous mixture of clay, sand, gravel and boulders.

unconformity A break or gap in the geologic record, where an older rock unit is overlain by a younger rock unit. The break or gap may represent a period of erosion, tilting, or non-deposition.

unconsolidated (sediment) A sediment that is loosely arranged, and not lithified, and in which the particles are not cemented together.

water table The changeable boundary that separates the zone saturated with water from that which is aerated and only intermittently contains water. This definition of water table does not always apply in localized karst areas.

valley train A long, narrow body of outwash deposited by meltwater streams beyond the terminal moraine or margin of an active glacier, but which is confined within the walls of the valley.

Further Reading

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