

# SURFICIAL GEOLOGY OF MINNEOPA STATE PARK



Minnesota Department of Natural Resources  
Division of Lands and Minerals  
William C. Brice, Director

Project 336-2

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PROJECT 336-2  
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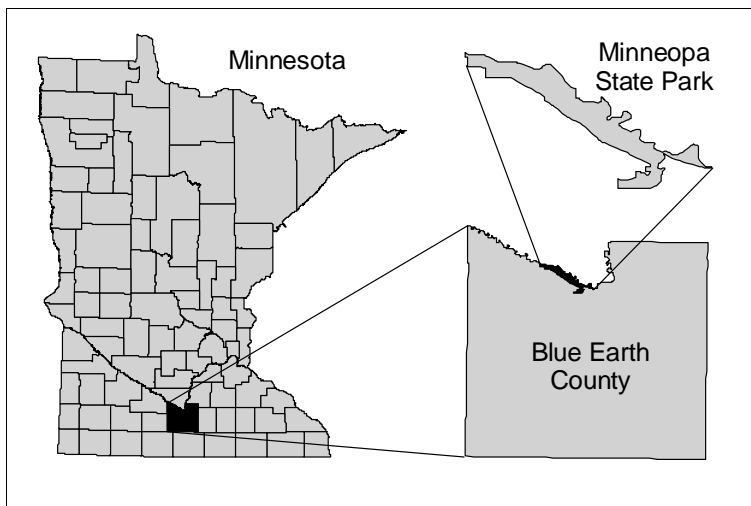
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The purpose of this project is to describe the surficial geology of Minneopa State Park. Surficial geology includes the geologic materials and characteristics within 10 feet of the land surface, directly below the soil profile. Detailed descriptions and sampling at this level enable us to interpret the geologic history of the area and the environment in which the rocks and sediments (geologic units) formed.

## INTRODUCTION

*Minneopa* is a Dakota Indian word meaning “water falling twice” or “two water falls.” The park was given this name for the double water fall on Minneopa Creek. Minneopa State Park contains 2,894 acres along the south side of the Minnesota River Valley, three miles west of the “bend” area near Mankato, Minnesota (Figure 1). At the bend, the Minnesota River changes course approximately 84° to flow north into the Mississippi River at St. Paul, Minnesota. The geologic history of the park spans more than 500 million years (Figure 2, on next page). The oldest geologic

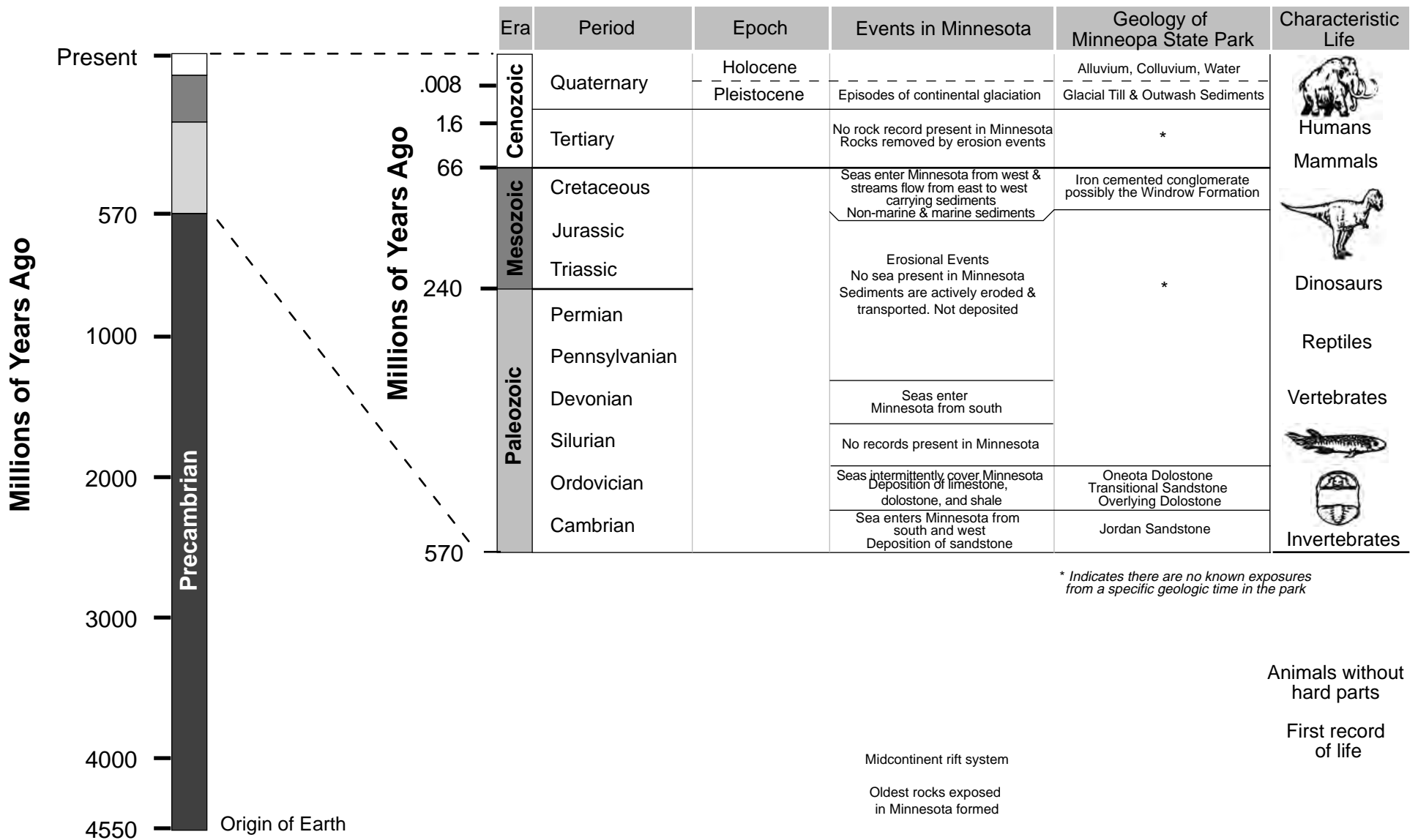


**Figure 1.** Location of Minneopa State Park statutory boundary, Blue Earth County, Minnesota.

units consist of sedimentary bedrock exposed in the Minneopa Creek gorge, at the waterfall, and along several erosional terraces in the park. These rocks began forming before the first known vertebrate animals began to evolve. The next geologic unit exposed in Minneopa State Park is a younger sedimentary rock. It is iron-cemented, pebble conglomerate which formed during the time of dinosaurs. As mammals emerged over the following 80 million years, the climate began to grow colder. About 1.6 million years before present, glaciers repeatedly

advanced and retreated across Minnesota. When glaciers of the most recent Ice Age began to retreat about 12,000 years ago, they left a landscape covered with glacial till, which is unsorted clay, silt, sand and boulders; braided outwash streams; and glacial lakes. This type of landscape is much younger than the bedrock, and dominates much of Minnesota today.

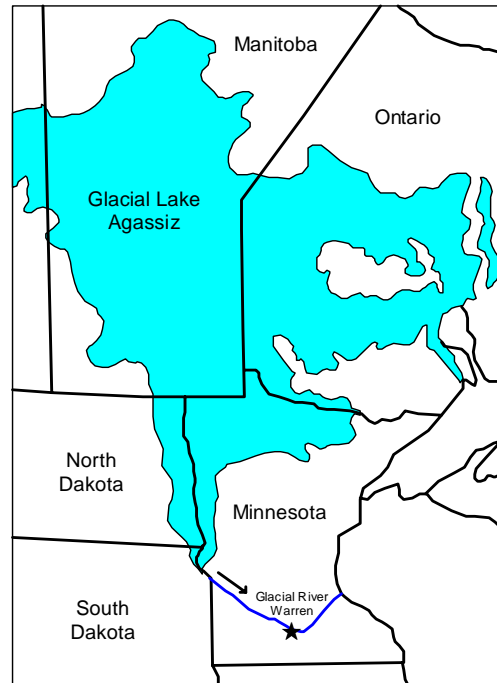
As the continental ice sheet retreated, it melted to a point north of the continental drainage divide in western Minnesota. The divide is located between modern-day Lake Traverse (drains to the north) and Big Stone Lake (drains to the south) near Browns Valley, Minnesota. Water from the melting ice sheet was unable to flow northward to Hudson Bay because its outlet to the north was blocked by ice. Meltwater was impounded between the ice sheet and the divide. This accumulation of water, called Glacial Lake Agassiz, was the largest glacial lake ever known with approximate dimensions of 700 miles long by 200 miles wide (Figure 3). As the ice continued to melt, the lake level rose and then fell when the lake overtopped its boulder-dammed outlet on the drainage divide, and drained to the southeast through Glacial River Warren. Repeated catastrophic



**Figure 2.** Generalized History and Geologic Time Scale for Minnesota emphasizing the geologic record in Minneopa State Park. (Modified from Figure 9 in *Geology of Minnesota, A Guide for Teachers*, 1995.)

outpourings of water flowed down Glacial River Warren Valley, carving the wide, deep valley we recognize today as the Minnesota River Valley. The north portion of Minneopa State Park occupies a small portion of the Minnesota River Valley as shown on Plate 1. The Minnesota River is now an underfit stream that flows in a fraction of the former Glacial River Warren Valley.

Even though the park is located in a region where rocks represent the geology of hundreds of millions of years, the erosive power of Glacial River Warren is responsible for reworking those rocks and sediments into many of the present-day landforms. Some examples are the expansive river valley, the bedrock terraces strewn with boulders; sandstone cliffs; and silt, sand, and gravel alluvial terraces. Several terrace levels in the modern river valley represent the elevation of different channel floors and river levels that previously existed. As Glacial River Warren shrank in size and power, alluvial fans from tributaries were deposited onto old channel floors and sand and gravel terraces emerged and can be seen in the north part of the park. Within the last 10,000 years, Minneopa Creek has been a tributary to the Minnesota River and quickly eroded through the glacial sediments to the sandstone bedrock that forms the gorge. Water in the creek is still eroding the sandstone at the double waterfall. Most likely, that waterfall was originally located at the confluence of the Minneopa Creek and the Minnesota River. Headward erosion has caused the falls to move upstream. Given enough time, the falls could continue to erode upstream, all the way to Lake Crystal, the headwaters of Minneopa Creek.



**Figure 3.** Extent of Glacial Lake Agassiz showing the Glacial River Warren outlet to the south. Star represents approximate location of Minneopa State Park. (Modified from Ojakangas & Matsch, 1982)

## PROMINENT LANDFORMS IN MINNEOPA STATE PARK

*Landform* is a term used to describe a specific feature we see on the landscape, such as a hill or a valley. A *landscape* includes a group of landforms that have a related history, such as a “glacial landscape.” This means that hills or valleys formed because of specific events related to the existence and disappearance of an ice sheet. Geologists recognize that the rocks and sediments (geology) control how certain landforms come to exist. In order to unravel the history of Minneopa State Park, a description of landforms will be helpful to illustrate how they relate to the geology and vice versa.

### **Minneopa Creek Waterfall**

At some point during the last 8,000 to 10,000 years, Minneopa Creek began flowing as a tributary to the Minnesota River and cutting down through the overlying sediments. Water flowing down the creek encounters resistant ledges of sandstone which have resulted in a forty foot high staircase-like, double waterfall, for which the park was named (Figure 4, a-c). The general direction of flow is from the southwest to the northeast, where it enters the south side of the Minnesota River (Plate 1). There are about fifteen feet of moderately resistant sandstone at the top of the falls which water has eroded down to encounter a ledge of very durable, well-cemented sandstone. This three to ten feet of rock forms the “step” on the staircase. The sandstone above the protruding, well-cemented ledge is much softer. The twenty feet of sandstone below the ledge has less silica cement to hold the grains of sand together. It is very “friable,” meaning it will fall apart in your hand. On either side of the falls, the sandstone is curved inward and stands nearly vertical (Figure 4, d-e). This amphitheater-like area is constantly eroding away because of weathering due to water spray and the freeze-thaw cycle removing individual grains and occasionally, large slabs of sandstone. Large blocks of sandstone lie at the bottom of the falls and the sides of the gorge as sandstone talus (broken rock). Many vertical and horizontal joint sets are noticeable in the sandstone cliffs of the amphitheater. On the south wall of the amphitheater, there are diagonal joints. These “cracks” in the sandstone may have been caused by a variety of stresses.

### **Minnesota River Valley**

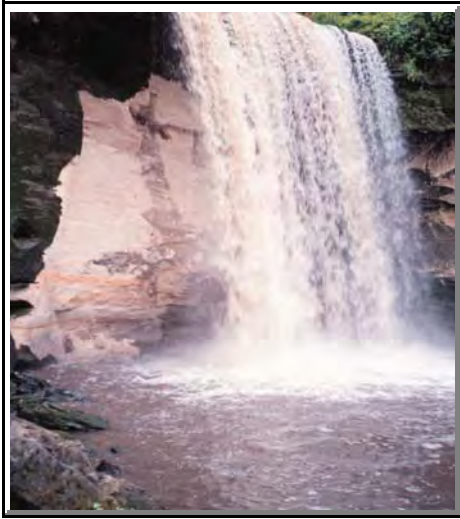
The Minnesota River Valley is a channel that formed about 11,700 years ago and once carried water from Glacial Lake Agassiz via Glacial River Warren. It probably formed when braided streams carried meltwater outwash (sand and gravel) from the receding glacier. The streams were able to erode the till and deposit water-sorted sediments at the same time. The channel was much shallower then, than its present depth. The view across the remnant channel is about one and one-half miles and almost two hundred feet deep. Only a tiny portion of the channel is occupied by the modern Minnesota River. Within Minneopa State Park, the river changes in character from relatively straight to highly sinuous (see Plate 1). This may reflect a change in underlying bedrock character. The current river channel has a broad flood plain below scarps or cliffs of bedrock that indicate former channel levels when water flows were much greater. Found within the flood plain are sediments consisting of clay, silt, and sand that are deposited annually when the river level is much higher, usually during spring and summer floods. Wetlands occupy low areas and former channels of the river.

### **Oxbows and Wetlands**

Several wetlands within the river floodplain formed as a result of low areas from former channels and channel migration. Occasionally, meanders in the river are short-circuited or “cut off” leaving a curved reach of channel that no longer carries the current (Figure 5). During times of high water, the stream will change its regular course and cross the neck of a meander. Water takes the shortest route or course that requires the least amount of energy. A new main channel section is created, leaving these oxbow cutoffs to fill with sediments and become short-lived oxbow lakes and wetlands. Wetlands also developed in low spots on the bedrock terraces, such as those near the campground on sandstone, and a few in the far northwest part of the park on the dolomite bench.



**a**

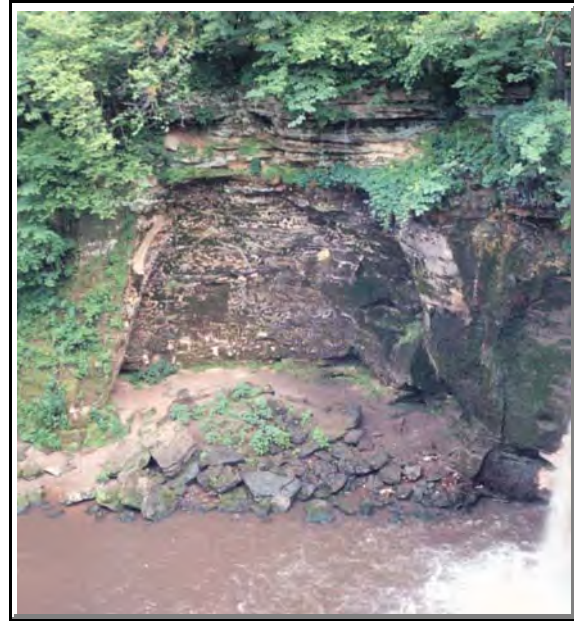


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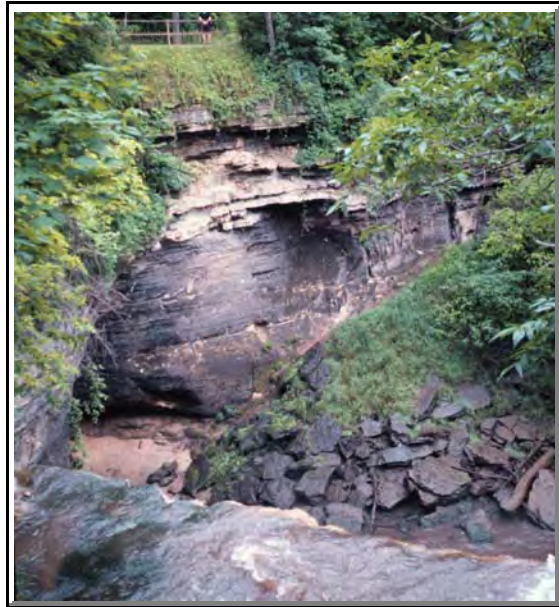


**c**

**Figure 4.** (a) Upper portion of Minneopa Falls. (b) Lower portion of Minneopa Falls. Lighter colored rock behind falls is a fresh exposure after a recent rock fall. (c) View of Minneopa Creek and lower falls looking northwest. (d) Amphitheater-like cliff on south side of creek. Lower falls are visible to the right. (e) Amphitheater-like cliff of sandstone on north side of creek. Top of lower falls is in foreground.

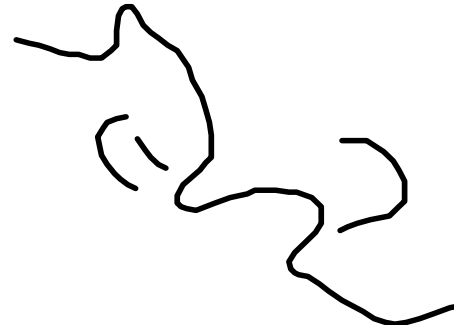
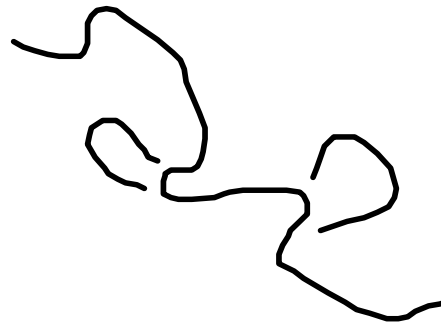
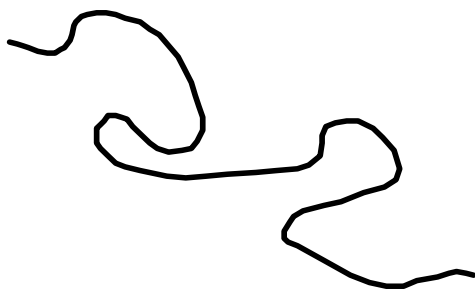
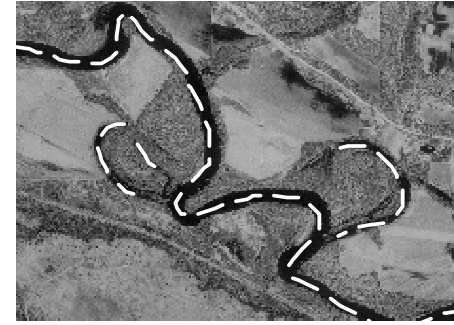


**d**



**e**





1949

1964

1991

Figure 5. Aerial photographs of a section of the Minnesota River over a 42 year time span show how meander cut-offs, oxbow lakes, and wetlands are formed. White, dashed lines on the photos depict the water-filled channel and the meander cut-offs. Water crosses the neck of a meander and abandons the curved reach. The black lines below the photos, show how the channel changes shape on the valley floor over time, leaving the old meanders as "scars" on the floodplain.

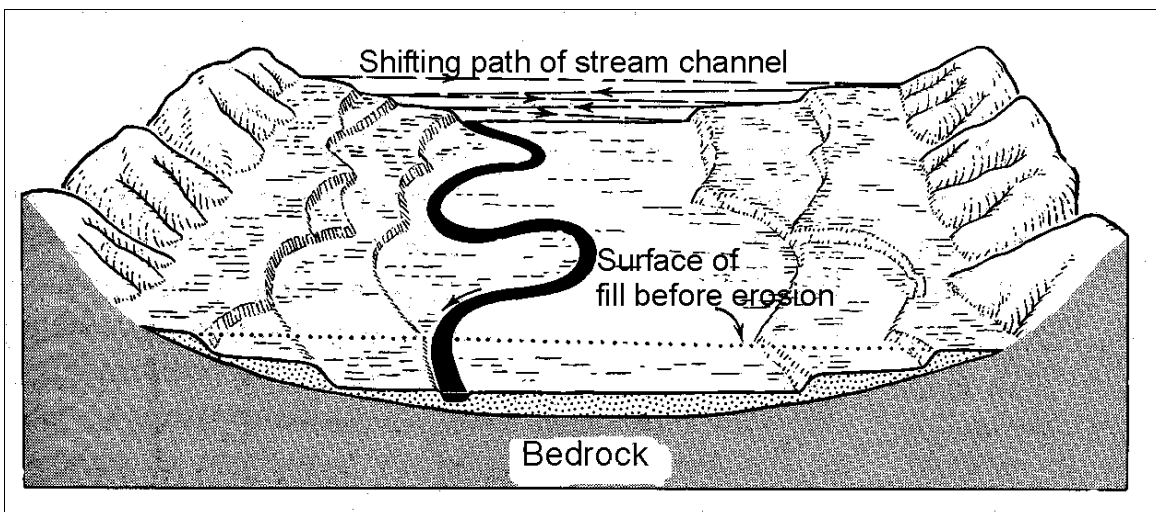
## Terraces

As the ice advanced and retreated over the area, a thick blanket of till covered the preglacial landscape. A series of terraces, or bench-like features, were developed in the glacial sediments and bedrock along the edges of the Minnesota River Valley (Figure 6). Stream terraces are characterized by a relatively flat surface bounded by a steep slope above the horizontal bench on one side and a



**Figure 6.** View overlooking Minnesota River Valley to the northwest from a point near Seppmann Mill. The vegetated slope in the foreground represents an alluvial (sand and gravel overlying till) terrace above the broad, flat, grassy sandstone bedrock terrace.

steep slope below on the other side (Figure 7). Each of these terrace levels resulted from periodic discharges of Glacial Lake Agassiz down the Glacial River Warren Valley. Glacial Lake Agassiz, at its largest extent, was larger than all present-day Great Lakes combined and dammed an enormous amount of water. Because of the continuously changing level of Lake Agassiz, the drainage from the lake down Glacial River Warren varied greatly but could reach flows that



**Figure 7.** Diagram illustrates how a river erodes through sediments to form terraces. First, the valley was filled with glacial till and alluvium. Glacial River Warren excavated a broad valley, carrying away most of the sediments and depositing some as alluvium on the terraces. Eventually, the river carved through the underlying bedrock and formed erosional bedrock terraces. Presently, the Minnesota River is an underfit stream below the bedrock benches. (Modified from Longwell, Flint, & Sanders, 1969)

exceeded discharge rates of millions of cubic feet of water per second past a specific point. Then, discharge would lessen until the next catastrophic burst of water. When there was a decrease in water, the stream would drop part of its load, leaving a variety of sediments behind, including boulders or gravel, sand and silt alluvium. The flood events occurred over and over for a several thousand years. These flows had tremendous erosive power which carved the Minnesota River Valley through glacial sediments and underlying bedrock. In comparison, one of the highest present-day (1997) discharge rates for the Minnesota River at Mankato was more than one thousand times *less* in volume than its predecessor river.

The terraces of the Minnesota River Valley, in Minneopa State Park, are erosional and depositional remnants of the Ice Age flows. The higher elevation terraces are called alluvial terraces and resulted from the first or oldest outwash flows carrying away the till and leaving behind a deposit of silt and fine sand overlying till. Lower terraces have coarser sand and gravel overlying till. The lowest terraces were eroded through bedrock (bedrock terraces) and have deposits of boulders that range in diameter from two to seventeen feet. The power of the glacial river could only move the boulders a short distance and they remained relatively close to where they were originally deposited by the ice. The sides of the sandstone terrace in the north part of the park create cliffs that range from ten to thirty feet high overlooking the Minnesota River and up to fifty feet high along the Minneopa Creek gorge. These terraces trend from northwest to southeast, representing ancient flow directions that echo the current flow of the river. Seppmann Mill and the granary were built on an alluvial terrace of sand and gravel.

The terraces in the Minneopa Creek gorge are mostly erosional (Figure 8). Water from the creek carved down through glacial till and then bedrock to form steep-sided till hills upstream from the falls and sandstone cliffs downstream of the falls.



**Figure 8.** Two levels of erosional terraces in sandstone located in the falls region of the park. Minneopa Creek eroded the more resistant bedrock until it carved down to the softer sandstone below. The creek is now confined to the narrow gorge downstream of the falls.

## Glacial Erratics

The large boulders (erratics) scattered throughout the north part of the park exhibit every shape and size (Figure 9). They are typically granite boulders transported from Canada and other parts of Minnesota. Others consist of Sioux Quartzite or gneiss, a banded, metamorphic rock (Figure 10). Quartzite, granite, and gneiss are located further upstream in the Minnesota River Valley. Granite is a very durable rock and therefore, can be transported for greater distances and withstand more intense erosion than less durable rocks. That is one reason it may appear there are so many granite boulders. Some of the boulders are greater than ten feet across and six feet high, indicating that there was an enormous amount of energy in the ice and water that transported them to their resting place in the park.



**Figure 9.** This erratic is large enough to be seen above the tall grass. It is about five feet wide and four feet tall. Many other boulders are hidden in the grass.



**Figure 10.** Glacial erratics remain on the landscape. These were probably first transported by ice and then left behind as water from Glacial River Warren carried away sand, silt, and clay particles, in which they were buried. The boulder in the background (left) is granite. The boulder in the foreground (right) is quartzite.

north part of the park, east of Seppmann Mill (Plate 1).

## Highlands

The highlands within Minneopa State Park are the remnants of a former landscape. Erosion from water, wind and slumping have lowered the landscape around an area leaving a hill or ridge. Hills and ridges in the falls part of the park are primarily glacial till and stand at the highest elevation on the south side of the creek. They are the remnants of the greater till plain (sediments

## Alluvial Fans

Alluvial fans are subtle landscape features that are associated with the entrance of tributary streams to the Minnesota River Valley. As these tributary streams enter the larger Minnesota River Valley, the stream slope and velocity decrease, in turn causing a decrease in the stream's capacity to carry sediment. Consequently, sediment is deposited at the intersection of the tributary and the main valley in a fan shape with the coarser material nearer the valley wall and the finer material toward the edges of the fan. Intermittent drainage has created a small fan on top of an older, larger fan in the



**Figure 11.** View looking south towards the “hill” on which Seppmann Mill is built. The mill is actually built on an alluvial terrace of sand and gravel overlying till.

deposited directly by glacial ice) that were eroded away by water within the gorge. The north part of the park is relatively flat-lying, although there are small changes in relief created by outcrops of bedrock that were not worn flat on the main sandstone terrace. In the campground area, one hill is capped by iron-cemented conglomerate rock overlying the sandstone bedrock. An exposure of the conglomerate can be seen in campsite A-4. The hill on which Seppmann Mill is built that overlooks the Minnesota River Valley is a sand and gravel terrace underlain by glacial sediments (Figure 11).

## SURFICIAL GEOLOGY WITHIN MINNEOPA STATE PARK

Detailed physical descriptions of all geologic units within the park are found on Plate 1.



**Figure 12.** Cross-bedding exposed in the Jordan sandstone. These dunes were shaped by water and wind in a nearshore environment. The pen is for scale.

### Jordan Sandstone

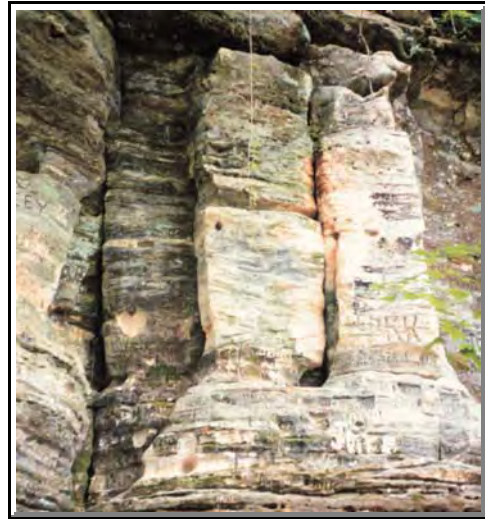
The Jordan Sandstone is white, buff, tan, pink or yellow, medium to coarse grained quartzose sandstone that is exposed in the waterfalls, the terrace cliffs overlooking the Minnesota River Valley, and the Minneopa Creek gorge. The Jordan Sandstone is the oldest formation exposed in the park. This sedimentary rock often exhibits cross-bedding and iron-stained burrows in the lower exposures and is also massive and burrowed in other exposures (Figure 12). The best outcrops of the sandstone in the park can be seen at the waterfall in the south part of the park and the cliffs overlooking Minneopa Creek gorge (Figure 13) and the Minnesota River in the north part of the park.

500 to 570 million years ago, a relatively warm, shallow ocean covered most of North America. It retreated out of the area we know as southern Minnesota. Sand was abundant and formed on- and off-shore dunes, sandbars and beaches in a coastal environment. The climate was probably subtropical. Time, pressure from overlying sediments, and groundwater movement turned the sand deposits to stone. Different amounts of silica precipitated from the ground water to cement individual grains together and the result is that some parts of the sandstone are very soft and some parts are very hard. The best example that shows the different hardness of sandstone is the double waterfall (Plate 1).

### Transitional Dolostone Overlying Sandstone

Less visible than the Jordan Sandstone, the transitional dolostone overlies the Jordan Sandstone, and underlies the Oneota Dolostone. This sandy dolostone comprises a distinct bedrock terrace with few actual exposures because a soil profile has developed on it (Figure 14), which is farmed extensively outside of the recreational part of the park. Limited exposures of this bedrock are found in small outcrops of buff, tan, gray and pink, fine grained dolostone overlying and intermixed with fine to medium buff, white, gray and pink sandstone. It often has small calcite-lined cavities and veins of calcite included in the outcrop. Dolostone is often referred to as limestone and is very similar chemically to limestone, but has more magnesium than limestone. It is difficult to tell them apart unless a simple chemical test is conducted.

This unit represents a zone of transition from one environment to another. It is very mixed and is sandier in some spots and more dolomitic in others. At the time the rock was forming, sand was becoming less abundant and the minerals that make up the dolostone were increasing and precipitating out of the seawater. Eventually, the change would be significant enough that the sandstone would disappear and only dolostone would be prevalent in the area of the park. This rock probably formed around 500 million years ago.



**Figure 13.** Jordan sandstone cliffs. Note the columnar jointing. This is characteristic weathering for this sandstone.



**Figure 14.** Scoured bedrock exposure. Soil overlying the bedrock terrace is only one to six inches thick. The surface of the underlying bedrock is irregular and soil profiles can be as deep as two feet. On the Minnesota River Floodplain, sediments over the bedrock will increase to ten feet deep.

### Oneota Dolostone

The highest bedrock terrace is found in the northwest part of the park and forms a prominent ridge visible from Highway 68 (Plate 1). This ridge is covered by prairie grasses and the actual rock is exposed in a small road cut. The Oneota Dolostone was formed 500 to 440 million years ago.

The dolostone formed in a warm, shallow sea from a mix of carbonate and

magnesium minerals that were dissolved in water. The minerals would form as grains, like salt grains form as water evaporates from saltwater. The Oneota Dolostone is classified as a chemical sedimentary rock. Water cut down in the valley and removed most of the dolostone within the park, except for this one terrace, and another small outcrop in the far east end of the park.

### **Conglomerate**

One of the unique geologic features, is a conglomerate deposit that originated on an exposed bedrock surface during a time when the climate was much warmer and wetter, approximately 100 million years ago. The deposit is characterized by sand, pebbles, and cobbles bound with an iron-rich cement (Figure 15). Based on the description of the rock and where it is exposed, this unit most likely belongs to the Late Cretaceous Windrow Formation. During the climate change, cavities were formed in the limestones that dominated the landscape. Braided streams transported sand, pebbles, and cobbles to the sea that covered south-central Minnesota. Sometimes, the sediments fell into cavities and were protected from continued erosion. Iron and other minerals that were dissolved in the water helped to cement the sediments together. Most of the land surface was eroded during the glacial advance, but some of the exposures remain. There are patches exposed throughout the park. One of the best places to see an exposure is on the south side of Highway 68, just east of the bridge crossing Minneopa Creek. Campsite A-4, within the campground, is another place to see this rock that looks similar to concrete. The pebbles found in the rock are pieces of limestone, sandstone, and quartzite and form rusty, red soils. Because the limestone and sandstone had to be formed before erosion could transport pieces of them, we can tell that the conglomerate is much younger than the other sedimentary rocks.



**Figure 15.** Lichen covered conglomerate boulder. Pits on surface are from large pebbles of sandstone and limestone that weathered-out of the iron-rich matrix.

## Glacial Sediments

Pleistocene (Figure 2) glaciers eroded sediments and rock from the preglacial landscape, transported them, and ultimately deposited them as till, river deposits, and other landforms to depths of several hundred feet. As ice left the Pleistocene landscape, meltwaters simultaneously deposited and eroded sediments. Debris from the glacier consisting of cobbles, gravel, sand, silt, and clay (outwash) was sorted and deposited by several streams that divide and reunite, called braided streams. When bars of sediment built-up, the stream had to change course and flow around them. This would cause the water to erode through an adjacent bar and transport the material downstream, where it would again be deposited. As Glacial Lake Agassiz drained to the south, the volume of water increased, and a main channel became established as the greatest agent of erosion. The most significant example being Glacial River Warren, which removed the till cover and scoured the bedrock in the valley which is now Minneopa State Park. There were phases of deposition from Glacial River Warren, too, as stream volume changed and sorted sand, silt, gravel deposits were left on the terraces. Till blankets the upland landscape and is exposed as till slump in the valley wall of Minneopa Creek. The uppermost terraces in the park are composed of till which is exposed only in road cuts and drainage ditches, because a thick soil profile has developed on it. In the falls part of the park, a collapsed till channel exists (Plate 1). A former outwash channel was carved through the glacial sediments, where buried pockets of ice within the till weakened the channel walls as the ice melted. After the water level declined, the channel walls collapsed and filled in the waterway. This landform is typical of postglacial landscapes.

## Modern Sediments

Superimposed on the bedrock and glacial landscape are modern sediments, those materials deposited within the last 8,000 years. They include flood plain deposits, modern alluvial fans, till slumps, and sandstone talus (Figure 16). The creek and river are continually eroding their channel bottoms, transporting material away and depositing sand, silt, and clay on the floodplain. As water undercuts a bank, till or sandstone collapse. The



**Figure 16.** Sandstone talus. Water seeps from the sandstone cliff face and weakens the rock. Eventually, slabs fall and are deposited at the foot of the cliff. Till slumps occur in a similar manner.

landscape is continually being shaped by water, wind and gravity. Recent changes may not be as spectacular as those in the past, but they are occurring. Enhanced erosion and deposition can be seen after a particularly large flood on the river or at the waterfall. Even human beings have an impact on increased bank erosion by creating walking trails or carving in the sandstone.



## HUMAN INTERACTIONS WITH THE LANDSCAPE

Once people encountered the geology of the area, they found uses for the land and the rocks. American Indians were able to build burial mounds on the higher terraces. The waterfall was a main attraction and picnic area. The terraces were used for grazing and continue to be used for farming because every year the river delivers overbank deposits on which rich soil can form. Some of the sand and gravel terraces were mined for local use and the hard, durable Jordan sandstone was cut into blocks and used for building materials in the Seppmann Mill and granary in the north part of the park (Figure 17), and for the stairs that lead down to the glen below the falls in the south part of the park. You can still see the results of those activities today.

### GEOLOGY AND LANDFORMS TO SEE IN THE PARK INCLUDE:

Confluence of Minnesota River and Minneopa Creek

Minneopa Creek Gorge

Sandstone cliff overlooks from various points in the park

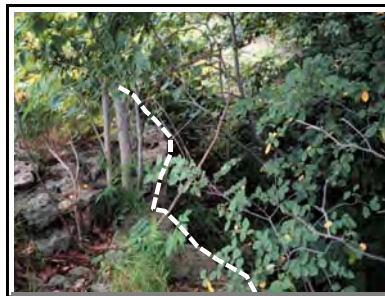
Waterfall and sandstone amphitheater

Minnesota River Floodplain

Overlook of the Minnesota River Valley from Seppmann Mill

Walking trail over the alluvial fan (very subtle) northeast of Seppmann Mill

Former stream beds cut into the sandstone terrace in north part of park



**Figure 17.** Left and top right: Seppmann Mill and the granary. Both are built from Jordan sandstone. Lower right: Former stream channel. Dotted line marks the former channel width and drop-off of a small waterfall which is now obscured by vegetation. The water flowed from left to right and polished the surface of the sandstone terrace.

**Table 1.** Relationship between Geologic Age and Landforms in Minneopa State Park

<b>Relative Age</b>	<b>Feature or Landform found within park boundary</b>	<b>Sediment or deposit</b>	<b>Process of Formation</b>
<b>Holocene Epoch of the Quaternary Period 8,000 years to present</b>	Water, wetland, oxbow Flood plain Fan	Silt, clay, sand, gravel	Stream currents, flooding events
<b>Pleistocene Epoch of the Quaternary Period (Ice Age)  11,700 to 9,500 years before present</b>	Alluvial terraces	Silt, sand and gravel overlying till	Episodes of erosion by glacial meltwater through till blanket followed by Glacial River Warren deposits of sand and gravel created a series of terraces.
<b>15,000 to 12,000 years before present</b>	Collapse channel  Till Plain	Poorly sorted clay, silt, sand, gravel, cobbles, boulders with lenses of well sorted sand and gravel  Poorly sorted clay, silt, sand, gravel, cobbles, & boulders	Meltwater outlet channel carved through and removed glacial sediments after which the channel walls became unstable and collapsed.  Deposited directly by ice at the base of the glacier, from within the glacier or from on top of the glacier.
<b>Late Cretaceous Period 130 to 70 million years before present</b>	Discontinuous bedrock unit that caps a few knolls	Conglomerate: Sand, gravel, pebbles, cobbles cemented with iron and other minerals	Braided stream transport and slump into cavernous carbonate bedrock. Ground and surface water carried cementing minerals which bound clasts together.
<b>Early Ordovician Period 500 to 440 million years before present</b>	Bedrock terraces	Dolostone and Transitional Dolostone overlying Sandstone	Intermittent seas precipitated carbonate and mixed with sand in a nearshore environment.
<b>Late Cambrian Period 570 to 500 million years before present</b>	Bedrock terraces	Sandstone: consolidated and friable quartzose sand	Warm, shallow sea deposited sand in a nearshore environment and was shaped by wave and wind action.

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## **BIBLIOGRAPHY**

- Bates, R.L. and Jackson, J.A., eds., 1990, Glossary of Geology, third edition, American Geological Institute, Alexandria, Virginia.
- Ellingson, J.B., 1999, Surficial Geology Blue Earth County, Minnesota, Minnesota Department of Natural Resources Report 335, scale 1:100,000.
- Hobbs, H.C., and Goebel, J.E., 1972, Geologic Map of Minnesota, Quaternary Geology: Minnesota Geologic Survey Site Map Series S-1, scale 1:500,000.
- Humphrey, W.R., 1958, A Study of the Lithologic Relations of the Early Paleozoic and Cretaceous Rocks in the Mankato, Minnesota area, Master's Thesis, University of Minnesota, p. 44-60.
- Longwell, C.R., Flint, R.F., and Sanders, J.E., 1969, Physical Geology, John Wiley and Sons, Inc., New York, New York, p. 223.
- Matsch, C.L., 1983, River Warren, the southern outlet of Glacial Lake Agassiz, *in* Teller, J.T., and Clayton, L., eds., Glacial Lake Agassiz, Geological Association of Canada, Special Paper 26., p. 231-243.
- Minnesota Department of Natural Resources, Minneopa State Park Mangement Plan, 1998, p. 25-70.
- Mitton, G.B., Guttormson, K.G., Larson, W.W., Stratton, G.W., and Wakeman, E.S., 1997, Water Resources Data Minnesota, Water Year 1997: U.S. Geological Survey Water Data Report MN-97-1, p. 461.
- Morey, G.B. and Dahlberg, H., 1995, Geology of Minnesota, A Guide for Teachers. State of Minnesota, Department of Natural Resources publication, p. 9-21.
- Ojakangas, R.W., and Matsch, L.C., 1982, Minnesota's Geology; University of Minnesota Press, Minneapolis, Minnesota, p. 109.
- Runkel, A.C., 1994, Revised Stratigraphic Nomenclature for the Upper Cambrian (St. Croixan) Jordan Sandstone, Southeastern Minnesota, *in* Southwick, D.L., ed., Short Contributions to the Geology of Minnesota, 1994, Minnesota Geological Survey Report of Investigations 43, p. 60-68.
- Sloan, R.E., 1964, The Cretaceous System in Minnesota, Minnesota Geological Survey Report of Investigations 5, p. 32-52.

United States Department of Agriculture, Soil Conservation Service, 1978, Soil Survey of Blue Earth County, p. 212.

Wright, H.E., Jr., 1990, Geologic History of Minnesota Rivers, Minnesota Geological Survey Educational Series 7, p. 11-14.

Wright, H.E., Jr., 1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 515-547.