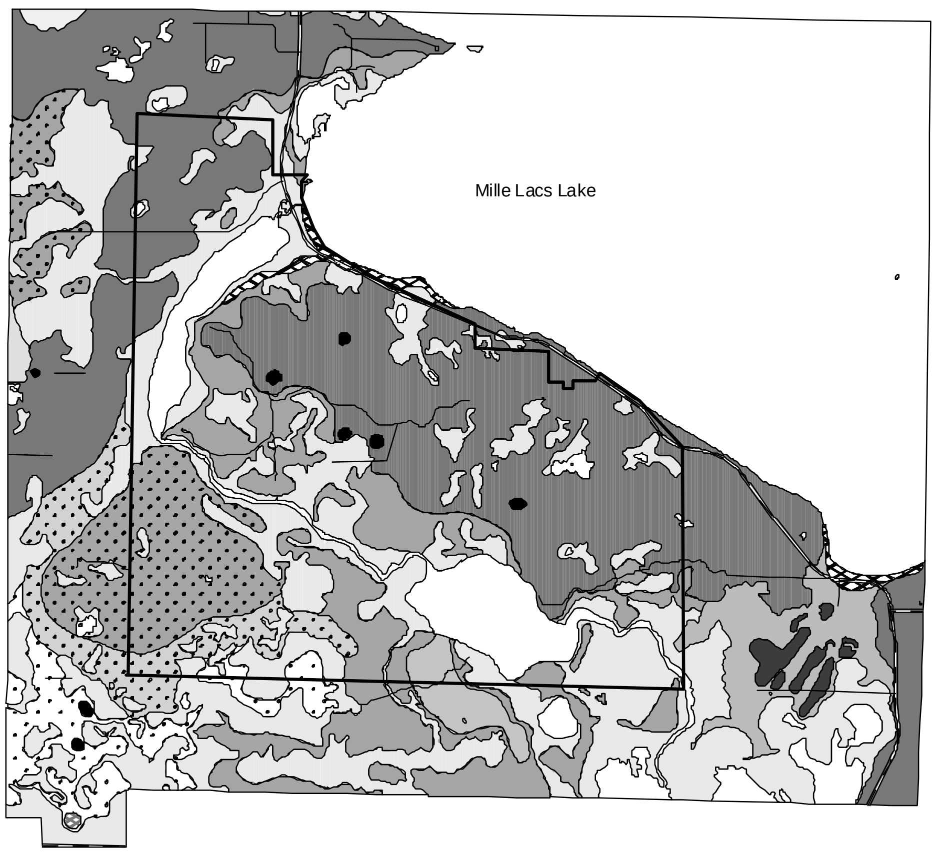
A Summary of the Surficial Geology of Mille Lacs Kathio State Park

Heather Anderson

1998



Department of Natural Resources

Division of Minerals

William C. Brice, Director

Project 336

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A Summary of the Surficial Geology of Mille Lacs Kathio State Park

The landforms of Kathio State Park were sculpted during the last glacial event of the Pleistocene Epoch. Glacial ice and meltwater primarily deposited the surficial sediments that make up the park's landscape. To better understand the geologic history of Kathio State Park, a study of the surficial geology was completed. The term surficial implies sediments found directly below the soil horizon. The surficial map of Kathio State Park was based on 1:24,000 -scale USGS topographic quadrangles with additional information from 1:90,000 -scale black and white aerial photographs (spring of 1969), shaded relief maps, Digital Ortho Quadrangles, USGS well log data, published maps and reports, and field work (from August to September, 1998).

The Pleistocene

The **Pleistocene** is a period of geologic time that started 1.65 million years before present (BP) and lasted to the start of the **Holocene** 8,000 years before present. Due to a global drop in climate, the Pleistocene marks a time when large continental glaciers advanced over 30% of the world's land mass (Sugden and John, 1976). Ice domes in Canada fed tongue-like streams of ice into Minnesota (Figure 1). These ice streams are called glacial **lobes** and they advanced and retreated multiple times.

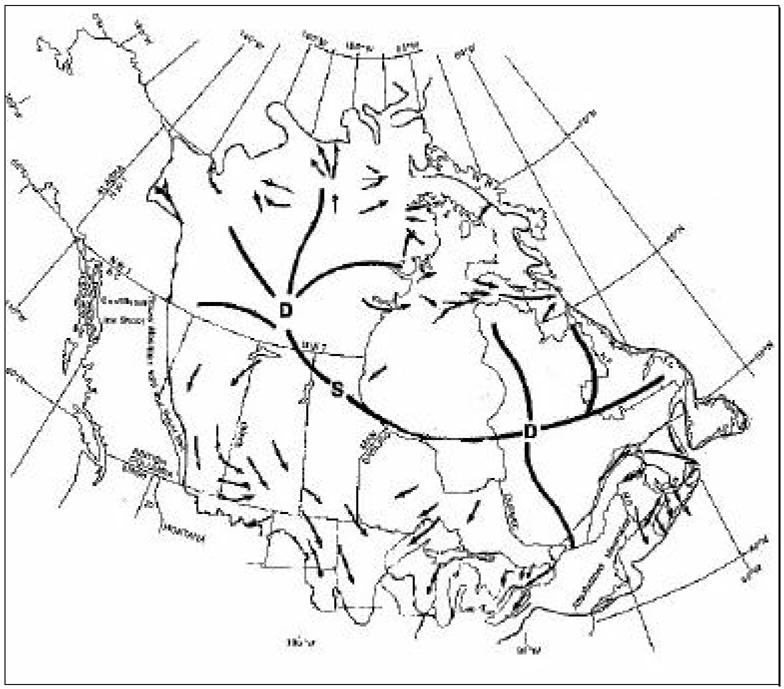

Figure 1. Ice domes in Canada fed lobate streams of ice causing glaciers to advance over the northern United States: D = Ice Dome, S = Saddle. Compilation of ice streams modified from Patterson, 1998.

Minnesota's landscape dramatically changed as glaciers advanced and retreated for more than 1.5 million years. Older glacial phases are difficult to reconstruct because remnants of these glaciations are either buried or eroded. The landforms seen in Kathio State Park were deposited during the last glacial phases of the Pleistocene approximately between 22,000 years BP and 8,000 years BP.

The Surficial Geologic History of Kathio State Park

Phases of ice lobes are differentiated by long standing, or stable, ice margins. A stable ice margin results when the accumulation of ice at the top of a glacier equals the loss (melting) of ice down glacier. Therefore, the glacier is being fed ice at the same rate it is losing ice. The ice continues to flow, but the position of the ice margin does not move. The effect of a stable ice margin is the transportation of sediments on a virtual ice "conveyor belt." Sediments are eroded, transported down ice and finally dumped along the margin. Over time, the sediments build a landform along the front edge of a glacier called an **end moraine**.

Kathio State Park is located on an end moraine. A traditional interpretation of the region is that a glacial lobe advancing from the Superior Lake basin (called the Superior lobe) formed a stable ice margin and deposited the Mille Lacs end moraine. When the climate became warmer, the Superior lobe melted back (retreated). Meltwater was "ponded" between the moraine and the glacier to form Lake Mille Lacs. However, recent research and evidence within the park suggests a more complex story.

Different types of sediments are categorized into different mapping units in the Kathio State Park surficial geology map. The mapping units are like pieces of a jigsaw puzzle, where each unit reveals a piece of the bigger geologic picture. By explaining the mapping units chronologically from oldest to youngest, the events that make up the surficial geology will unfold to tell an interesting story. The different types of sediments found in Kathio State Park are listed as follows: Rainy Outwash, Superior Tills, Pitted Outwash, Ice Walled Lake Plains, Kames, Channel Bars, Channel Lag, Beach Sands, and Peat. Other associated landforms are the headwaters of the Rum River, an abandoned outlet channel, and a buried valley. Mapping units and landforms will be briefly described and interpreted (detailed descriptions of the mapping units can be found in the legend of the surficial geology map, Plate 1)

Rainy Lobe Outwash during the St. Croix Phase

Sometime between 22,000 and 18,000 years BP, two glaciers advanced from the northeast and deposited the St. Croix moraine (Goldstein 1985, Wright 1972). The Superior lobe advanced out of the basin of Lake Superior flowing over bedrock of red sandstones, basalt, and agates. Simultaneously, the Rainy lobe advanced along the north side of the Superior lobe crossing highlands of **granite** and **gneiss**. (Different rock types are important to note because it helps determine the flow path of the glacier). As the climate warmed, the two glaciers retreated and glacial meltwater deposited sand and gravel called **outwash**.

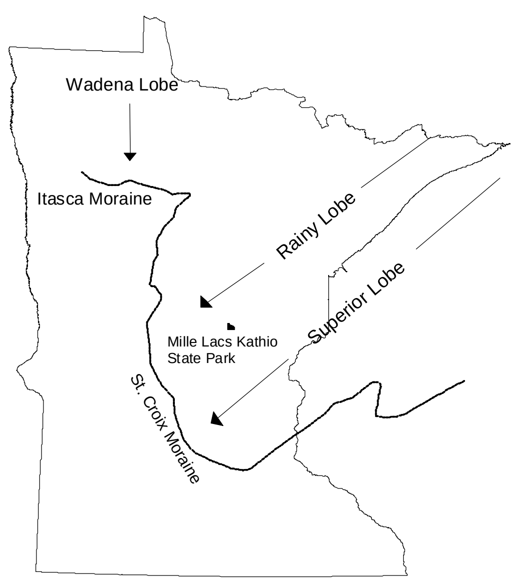

Figure 2. Positions of the Rainy and Superior lobes during the Late Wisconsin. (Modified from Minnesota's Geology; Ojakangas and Match, 1982)

In the study area, exposures of a thick deposit of outwash are found in local gravel pits. The outwash is thinly capped by younger sediments, except for a ridge along the western edge of the map. Gravel pit exposures also show that the unit is highly faulted and deformed with some evidence of collapse. Collapse occurs when ice blocks are incorporated into the outwash as it is being deposited. Over time the ice blocks melt and the sediments "collapse" into the void.

The dominant rock types of the outwash are crystalline rocks with minor influences of red sandstone, basalt and agates. Since one characteristic of Rainy lobe deposits is a high percentage of crystalline rock, the source of the outwash appears to be from the Rainy lobe. However, thePage 2 presence of agates indicates the Rainy lobe either incorporated some Superior lobe deposits or the Superior lobe was in close proximity.

A Buried Valley

The outwash deposited by the Rainy lobe buried a pre-existing valley. Wide, segmented valleys have been extensively mapped in central Minnesota (Mooers, 1989 and Patterson, 1994). They represent landforms where meltwater eroded channels into the land **subglacially** (at the bed, or base, of a glacier); these channels are called **tunnel valleys**. They formed a large drainage system that transported water from the interior of a glacier to the margin.

Ogechie Lake now occupies a small tunnel valley eroded during the advance of the Rainy and Superior lobes during the St. Croix Phase (approximately 22,000 to 18,000 years BP). The shape of the lake is long and narrow which is indicative of lakes found in tunnel valleys. Shaded relief maps and aerial photographs show the valley extends to the southwest. The valley extension is expressed as two **escarpments** located between Ogechie Lake and another well-defined tunnel valley (figure 4). The escarpments are interpreted as a buried section of the Ogechie tunnel valley formed during the St. Croix phase. The trends of the two escarpments, Ogechie Lake and the walls of the well-defined tunnel valley all align in the same direction (N30E). The alignment of valley walls suggests that the tunnel valleys were formed in the same glacial meltwater system. When the Rainy lobe retreated, outwash sediments subsequently buried the Ogechie tunnel valley with outwash sediments. The valley was further modified during a later glacial event- the advance of the Superior lobe during the Automba Phase.

Superior Lobe Till of the Automba Phase

The deposition of Rainy lobe outwash signaled a climatic change. A brief warming period, lasting for a couple thousand years, melted the glaciers back and marked the end of the St. Croix phase. Sometime between 19,000 and 17,000 years BP (dates are approximate), the climate cooled and the next phase of glaciation began: the Automba Phase.

During the Automba Phase, the Superior lobe advanced to the Mille Lacs moraine. The Superior lobe covered the Rainy outwash with **till** (sediments directly deposited by ice). The various forms of till found in the park were mapped as the following: till, meltout till, flowtill, and till with modified surfaces. Overall, the four till types were similar. However, notable variations of texture and landforms were distinguished. These variations represent different depositional environments.

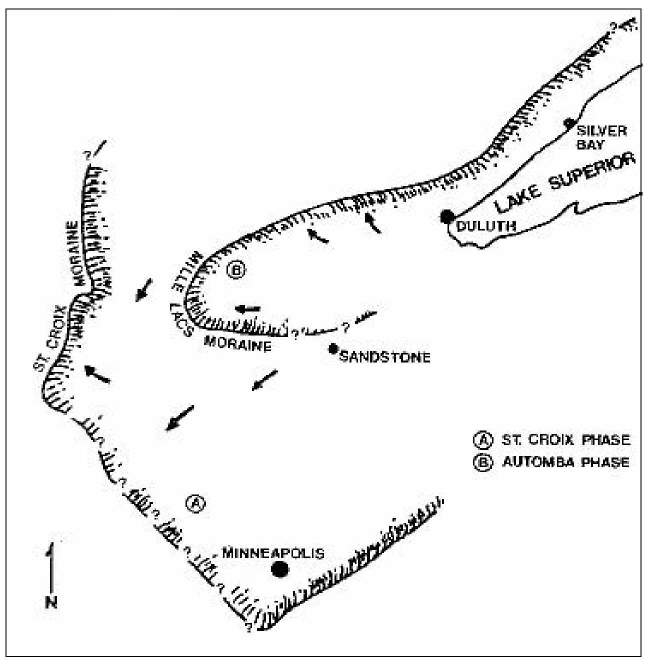

Figure 3. Ice positions during the St. Croix and Autumba phase. Modified from Wright, 1972.

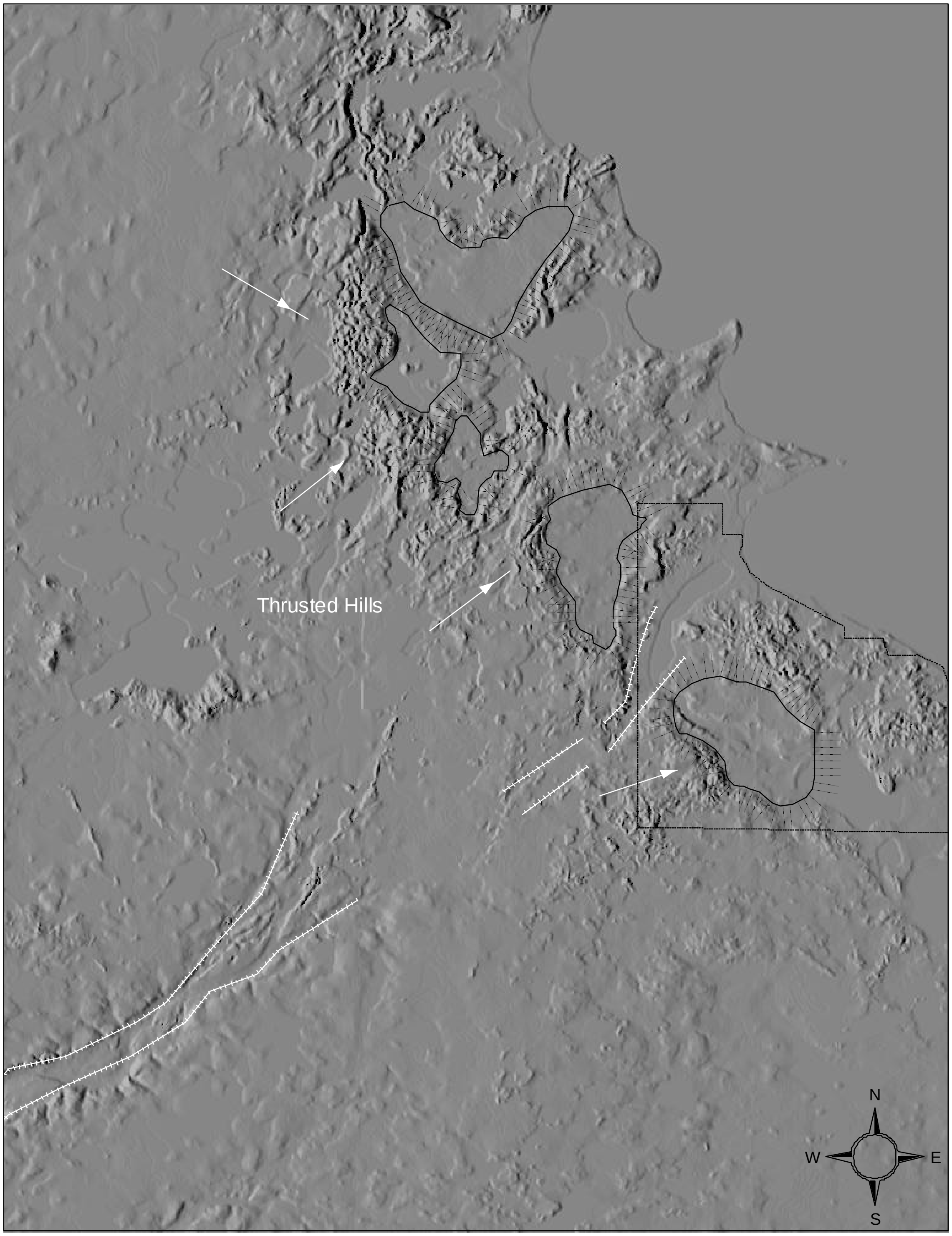

Figure 4. Tunnel valleys and ice thrusted hills. Black hatched lines = ice thrusted depressions, white hatched lines = tunnel valley escarpments, white arrows point to thrusted hills, and gray dotted outline = Kathio State Park boundary.

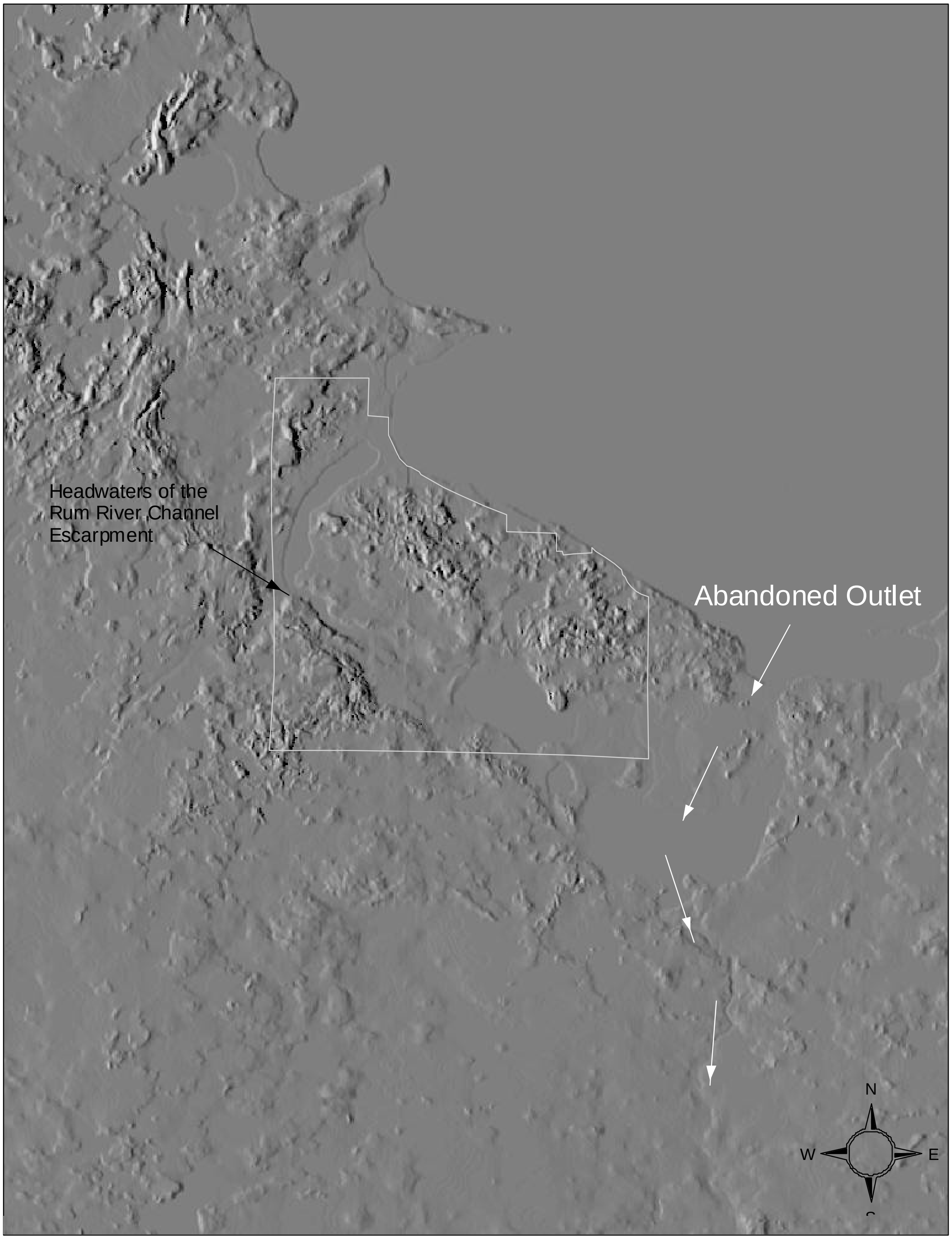

Figure 5. The headwaters of the Rum River and an abandoned outlet of Lake Mille Lacs. White arrows = direction of flow for the first outlet of Lake Mille Lacs. Black arrow = point of breech that formed the second outlet of Lake Mille Lacs. Gray outline is Kathio State Park.

TILL: Represents the general till type of the Superior lobe. Typically silty to sandy loam that is very compacted and retains some moisture. The color is distinctively red-brown. The thickness is between 10-20 feet with occasional thickness of 30 to 50 feet.
MELTOUT TILL: Found in the southwest half of the park, the texture of this till is notably sandier, less compact and retains less moisture. Historically, these sediments have been mapped as till from a different lobe.
FLOWTILL: A distinguishing characteristic of flowtill is the flow landform it creates. Elongate landforms that slope away from the margins of the glacier seem to be indicative of flow. The shape of the landform indicates deposition controlled by gravity. The contact between meltout till and flowtill is gradational.
MODIFIED TILL: This till does not vary much from the general till type; however, it has been modified by running water. Found along the Rum River, this till has been partially eroded during higher water levels of Lake Mille Lacs. Mantling the till is an intermittent lag deposit of silt, sand, gravel, or organic soils.

The four tills represent a till complex: tills that have slight but distinguishable characteristics which can be explained by different depositional processes. Meltout till is **englacial** (within glacial ice) and **supraglacial** (on top of glacial ice) sediment, deposited out as the glacier melts. Meltout till tends to be less compacted than subglacial till and sandier due to the removal of fines by water (Dreimanis, 1990). Flowtill is till that basically slumped or moved due to the forces of gravity. Finally, modified till is altered till due to partial erosion by running water.

Ice Thrusted Hills

When the Superior lobe advanced to the Mille Lacs moraine, it did more than just cap the Rainy lobe outwash. The advancing ice pushed and thrusted outwash into crenulated hills leaving behind divot-like depressions. Both aerial photographs and shaded relief maps show a pattern of corresponding hills with divots across the moraine (figure 4). One well-defined couplet is located in the northern part of the mapping area. They are mapped as an ice thrusted margin and an ice thrusted depression. This glacial process may have caused the Ogechie tunnel valley to be further obscured by sediments.

In North Dakota and Wisconsin similar landforms along glacial margins were mapped by geologists (Aber *et al*, 1993). These landforms are called ice thrusted hills. With widespread thrusting, the Mille Lacs moraine may be better described as a pushed end moraine.

Meltwater Deposits of the Superior Lobe

As the climate warmed, the rate of ice flowing to the glacier's margin stopped and the glacier stagnated. In stagnant ice, meltwater passages remained open and grew. In Kathio State Park there are several features deposited during stagnant ice conditions; **kames**, an **ice walled lake plain** and **esker**-like ridges.

Kames are scattered throughout the park. They were formed as holes in the ice which transported water and sediments from the top of the glacier to the base of the glacier. When the ice melted, the resulting landforms are conical hills made of a mixture of silt, sand and gravel.

A small ice walled lake plain is located in the very southwest corner of the mapping area. This feature is formed when depression in the ice pools water. The sediment collects in the lake which leaves behind a landform that is a flat-topped circular hill.

Esker-like ridges flow from the margin of the glacier. An esker is stream bounded by ice that leaves a steep, sinuous ridge. The streams can either be flowing under the ice or between ice blocks. The streams eventually flow into a larger meltwater stream.

All three of these landforms represent a unique aspect of glacial topography. Negative topography on glacial ice are features such as holes, lakes and streams. They carve into the ice. These negative topographic feature produce positive features when the ice melts, like hills and ridges.

Meltwater deposits also include outwash. There are some varying outwash deposits associated with the Superior lobe retreat. The outwash to the southwest is coarser and not as pitted. The two remaining outwash units are finer and pitted. However, the southern pitted outwash is capped with a patchy layer of till. All three outwash units represent a period of ice stagnation and glacial retreat.

The Abandoned Outlet

The Superior lobe eventually retreated. As the glacier was retreating, meltwater was trapped between glacial ice and the moraine. This formed the moraine blocked lake that is now known as Mille Lacs Lake, a "lake of a thousand lakes." After the glacier retreated, the regional slope of the land was to the south. Therefore, Mille Lacs drained to the south. At the highest lake level (15 to 20 feet higher than present), water was draining from two large outlets: Ogechie Lake and a channel eroded from Lake Mille Lacs to Lake Onamia. The region was inundated with water. The channel between Lake Mille Lacs and Lake Onamia is now abandoned, but it deposited distinct landforms indicative of flowing water.

Located in the channel between Mille Lacs Lake and Onamia Lake are streamlined landforms made of well-sorted, red-brown sand. These represent channel bars. As the lake drained, the channel deposited silt, sand and gravel which were mapped as channel lag. Capping both channel lag and channel bar sediments is a patchy layer of Superior lobe till. The till indicates a brief pulse of glacial ice to the area; however, the till is too patchy to map as a separate unit.

Old Beaches

The abandoned spillway drained Lake Mille Lacs to the elevation of approximately 1260 feet above sea level. At this water elevation, water stopped flowing out of Ogechie Lake or a small creek flowed from the lake. However, water levels stabilized long enough to form well developed beach lines. Two historic beaches are located at the lip of the abandoned channel and on the south side of Ogechie Lake (United State Soil Conservation -unpublished). Beaches form as lake currents flow into a bay and deposit its sediment load. Bays tend to be shallower than open water which slows down the current. Since currents are the means of sediment transportation, sediments are deposited as currents slow down. Beaches form when the lake level is relatively stable and beach sediments can accumulate. The beaches found approximately at the 1260 elevation contour represent a time when Mille Lacs Lake water level was approximately ten feet higher than today and lasted for a long period of the lake's history.

The Head Waters of the Rum River

The beach line means that Ogechie Lake was also approximately 10 feet higher. At a higher lake level, Ogechie Lake would have been perched above the Shakopee Lake basin. The headwaters of the Rum River was carved by a breech of the southern side of Ogechie Lake. There are a couple hypotheses about what caused the breech. One, the wall gave out due to an influx of glacial meltwater. Two, a buried ice block collapsed to cause the wall to fall. A sudden breech of water is indicated by well-defined channel escarpments connecting Ogechie Lake to Shakopee Lake (figure 5).

The Aging Lake

The demise of the ice age sowed the seeds of vegetation. Soon the cycle of plant life and death started the formation of various soils, including peat. Peat is the partially decomposed plant material located around the margins of lakes and isolated depressions of the moraine. The majority of the peat in Kathio State Park formed as a process of lakefill. As plant communities grow around the edges of water-filled basins, they slowly migrate inward. The lakes will eventually fill with sediment and plant material. In thousands of years most of Minnesota's lakes will meet the same fate.

Discussion

An interesting question arises when the pieces of this geologic puzzle are put together: to which lobe should the Mille Lacs push end moraine be attributed? On one hand, exposures in gravel pits show the Superior lobe as a 10-20 foot cap over Rainy lobe outwash. The topographic relief of the pushed end moraine is greater than the cap of till. This indicates the moraine is a function of the underlying Rainy lobe topography. On the other hand, the Superior lobe played a role by thrusting the Rainy lobe sediments into these large hills; indicating the moraine is a thrusted feature of the Superior lobe.

One purpose of this question is to partially discuss the glacial origin of the Mille Lacs moraine. My interpretation takes the middle road. The Rainy lobe stopped and stagnated in the region. Large volumes of water deposited outwash and large blocks of ice. Then the Superior lobe advanced over and thrusted the outwash into hills and ridges.

Another purpose of the discussion is to address the missing pieces of the puzzle. The number of pieces is as infinite as the amount of data one can collect. The more data the better the understanding of the geologic processes. The irony is that one drill hole, one observation, one piece of data could shed a different light on any geologic subject.

The geologic history is more complex than traditional geologic interpretations. From evidence found within the park, the Mille Lacs moraine is not a simple end moraine. Rainy lobe sediments form the hills and dales of the Mille Lacs end moraine. Therefore, the Mille Lacs moraine is a pushed end moraine.

*A list of various geologic interest points within the park includes:

-Ogechie Lake tunnel valley
-Kames
-Headwaters of Rum River
-Peat and the lake fill process
-Old water levels and beach lines
-Formation of the Mille Lacs moraine
-Exposures of till and its formation
-Outwash ridges
-Hummocky landscape of a moraine
-Agate hunts

AGE (relative)	**EVENT**	**DEPOSIT**	**LANDFORM or EXPOSURE (found within the study area)**
Holocene (recent) 8,000 years to present	Lake process End of ice age-climate warmed to support plant communities.	Fine, well-sorted beach sands. Peat	Modern beaches are found below the 1260 elevation contour. Lowlands in moraine and surrounding lakes and streams.
Pleistocene (Ice Age) **Late Wisconsin** **Post Automba**			
Sometime between 9,000-6,000 years BP	Breech of Ogechie Lake		Carved a channel linking Ogechie Lake to Shakopee Lake.
Sometime between 10,000-7,000 years BP	Long standing lake level of 1260 feet above sea level	Fine, well sorted sands	Beach found on the south side of Ogechie Lake and in Cove Bay.
Sometime between 15,000-10,000 years BP	Glacial pulse	Patchy till cap	Found capping outwash deposits, sediments of channel lag, and sediments of bar deposits. Too patchy to map as single unit.
Automba Phase			
Sometime between 18,000-15,000 years BP	Superior lobe retreat	Sands and gravels	Located to the south southwest, and northwest within the study area.
Sometime between 18,000-16,000 years BP	Superior lobe stagnation	Silts, sand and gravel	Kames, ice walled lake plains, esker-like ridges, and outwash.
Sometime between 19,000-17,000 years BP	Superior lobe advance	Tills	Push moraine and hummocky topography. Pushed sediments buried Ogechie tunnel valley.
St. Croix Phase			
Sometime between 19,000-17,000 years BP	Rainy lobe retreat	Sands and gravels with occasional boulders	Large aerially extensive outwash plain.
Sometime between 22,000-18,000 years BP	Rainy lobe and Superior Lobe advance		Tunnel valleys were carved subglacially during the advance of the Superior lobe and Rainy lobe to the St. Croix moraine.

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Glossary

alluvium Stream deposits of recent time.

Automba phase A stage of glaciation in Minnesota where the Superior lobe's maximum position is marked by the advance to the Mille Lacs moraine.

drift A general term applied to all rock material (clay, silt, sand, gravel, and boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.

escarpment A cliff or ridge with a marked and distinguishable face or slope**.**

end moraine A ridge-like accumulation of till that is deposited during a standstill position of a present or past glacial front.

esker A long, narrow, sinuous, steep-sided ridge composed of irregularly stratified and gravel; deposited by a stream flowing between ice walls or in an ice tunnel of a stagnant or retreating glacier.

gneiss A metamorphic rock that is banded.

granite A crystalline intrusive igneous rock formed by the slow cooling of magma deep within the earth. Granite primarily consists of light colored minerals, alkali feldspars and quartz with secondary darker minerals of biotite, hornblend and pyroxene.

glaciotectonic Structural impacts and features on sediments or rocks from forces applied by the movement of ice.

Holocene The second epoch of the Quaternary period; 10,000 years before present to the present.
englacial Embedded, contained, or transported within the body of a glacier or sheet of ice; said of till, meltwater streams, drift, etc.

ice walled lake plain The collection of stratified sediments in a pond of water within ice.

kame A low mound, knob, hummock or short irregular ridge, composed of irregularly stratified sand and gravel deposited by meltwater either at the glaciers margin or within a low place or hole on the surface of stagnant ice.

lobe A large tongue-like protrusion from the margin of an icesheet.

moraine A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacier ice, in a variety of topographic landforms that are independent of control by the surface on which the drift lies.

outwash Stratified sediments, chiefly sand and gravel, removed or "washed out" from a glacier by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier.

outwash plain A broad gently sloping sheet of outwash deposited by meltwater streams flowing in front of or beyond a glacier, and formed by coalescing outwash fans.

peat An unconsolidated deposit of partially decomposed plant matter in a water-saturated environment such as a bog.

pitted A term applied to landform features that are hommocky due to the deposition and subsequent melting of ice blocks within a sedimentary unit.

Pleistocene The first epoch of the Quaternary period, 1.65 million years before present to 10,000 years before present.

push moraine Arcuate ridges formed at the glaciers margin caused by thrusting and faulting in response to shear pressure.

Quaternary The second period of the Cenozoic era, 1.65 million years before present to the present. The Quaternary is comprised of the Pleistocene and the Holocene epochs

recession A decrease in the length of a glacier due to the rate of melting at the terminus exceeding the rate of snow accumulation.

St. Croix phase A stage of glaciation in Minnesota where the Superior lobe and Rainy lobe advanced to the maximum position marked by the St. Croix Moraine.

sediment Material, organic or mineral, that has been, or is in, transport by air, water or ice.

sorted Said of an unconsolidated sediment or of a cemented detrital rock consisting of particles essentially the same size.

stable ice margin Occurs when the rate of snow accumulation up ice equals the rate of melting down ice

stagnant ice (a) Ice that is not flowing forward and is not receiving material from an accumulation area. (b) Detached blocks if ice left behind by a retreating glacier, usually buried in moraine and melting very slowly without the production of large quantities of water.

subglacial Carried beneath, deposited from or pertaining to the base of a glacier or ice sheet; said of meltwater streams, till, drift, etc.

surficial Unconsolidated material composed of clay, silt, sand and/or gravel found on the surface of the earth.

supraglacial Carried upon, deposited from, or pertaining to the top surfaces of a glacier or ice sheet; said of meltwater streams, till drift, etc.

till A sediment that has been transported and subsequently deposited by or from glacial ice, with little or no sorting by water.

topography The expression of elevations of the land.

tunnel valley A trench cut in unconsolidated sediments or bed rock from the erosion by subglacial meltwater streams not loaded with course sediments.