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MINNESOTA GEOLOGICAL SURVEY
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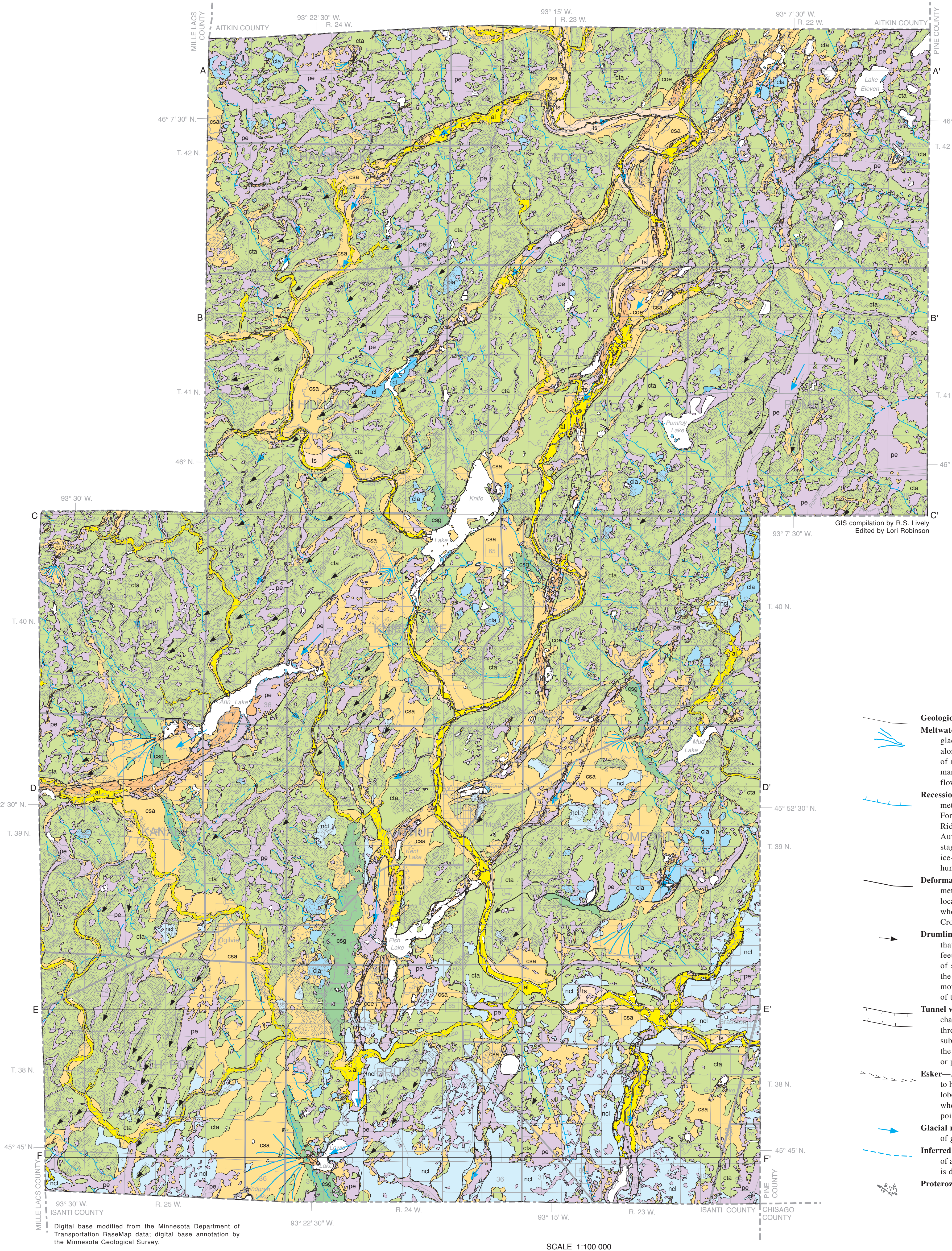
COUNTY ATLAS SERIES
ATLAS C-38, PART A
Kanabec County
Plate 3—Surficial Geology

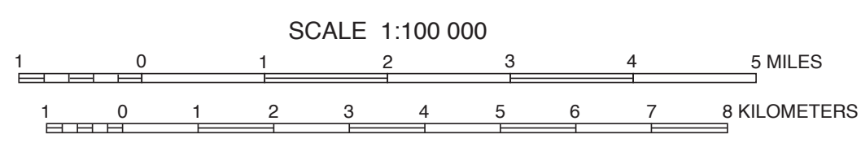


GIS compilation by R.S. Lively
Edited by Lori Robinson

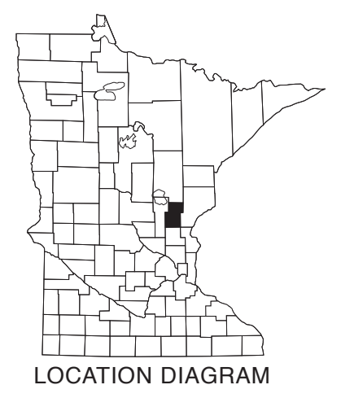
Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by the Minnesota Geological Survey.

Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.

Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum



CONTOUR INTERVAL 15 METERS



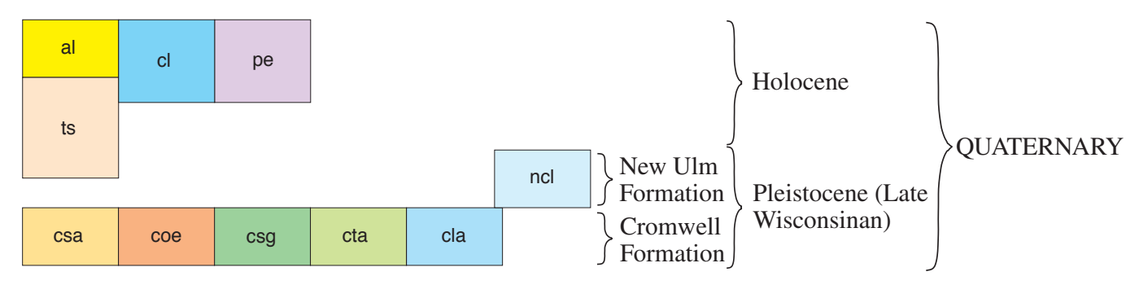
SURFICIAL GEOLOGY

By

Elizabeth L. Dengler

2016

CORRELATION OF MAP UNITS



MAP SYMBOLS

Geologic contact—Approximately located.

Meltwater fan—Sand and gravel deposits interpreted to be alluvial fans associated with glacial outwash. These fans occur adjacent to the outlet of eskers and commonly along the margins of recessional moraines, indicating these features are the result of meltwater drainage systems of the retreating ice. In places abutting the ice margin, these fans are thinly draped by till (unit cta) locally, likely due to mud flows off the ice as it retreated.

Recessional moraine—Hummocky ridges that range from about 10 to 30 feet (3 to 9 meters) in height, composed of till and pockets of sand and gravel of the Cromwell Formation (mapped as unit csg where sand and gravel are significant components). Ridges are interpreted to be recessional moraines related to the retreat of the Automba phase of Superior-lobe ice. These ridges formed when ice-retreat stagnated or during seasonal readvances of short duration, resulting in frozen or ice-cored ridges. The irregular melting of the sediment-covered ice resulted in the hummocky topography associated with these features. Ticks on the up-ice side.

Deformation complex—A discontinuous, sinuous ridge, about 20 to 50 feet (6 to 15 meters) high, composed of till (unit cta) and pockets of sand and gravel (unit csg) locally, of the Cromwell Formation. This feature is interpreted to have been formed when Automba-phase ice overrode and deformed features formed during the St. Croix phase (sections of which likely remained ice-cored).

Drumlin—Subglacially molded streamlined or elongate hills composed of glacial till that parallel ice-flow direction. Drumlins in Kanabec County are as tall as 50 feet (15 meters). Typically, these have a dense core of till covered by a mantle of supraglacial till that is less compacted. These features form at the base of the ice under extreme pressure conditions. The arrow indicates direction of ice movement and the length of the arrow is approximately equivalent to the length of the drumlin.

Tunnel valley—These broad valleys are interpreted to be subglacial meltwater drainage channels that were subsequently partially filled with sediment. Some likely persisted throughout the Wisconsinan glaciation (possibly earlier), reactivating with each subsequent ice advance. The sediments filling the valleys are variable; however, the surficial deposits are related to Automba-phase ice, glacial Lake Grantsburg, or post-glacial deposition. Hachures point down-slope.

Esker—A narrow, sinuous ridge of predominantly sand, gravel, and cobbles interpreted to have been deposited in an ice-walled subglacial or englacial channel in Superior-lobe ice. This map symbol is congruent with unit coe, but also occurs on the ridges where unit coe is draped by more than 8 feet (2 meters) of diamicton. Arrowheads point in the direction of flow.

Glacial meltwater flow direction—Arrow points downstream in the general direction of glacial meltwater flow.

Inferred northern extent of glacial Lake Grantsburg—Interpreted to be at an elevation of approximately 1,060 feet (323 meters) at the northern margin, although this limit is difficult to discern.

Proterozoic bedrock outcrop—Undifferentiated; see Plate 2, *Bedrock Geology*.

INTRODUCTION

This map emphasizes the origin and distribution of the surficial geologic sediments in Kanabec County, Minnesota. High-resolution lidar imagery (Fig. 1) was used to interpret glacial features and delineate boundaries of surficial geologic units. Previous work in and adjacent to the study area aided the mapping and interpretation of sediments and landforms (see Index to Previous Mapping). These data were collected and compiled from the Mora quadrangle (Meyer, 2008), the Pine County geologic atlas (Patterson and Knaeble, 2001), and the Chisago County geologic atlas (Meyer, 2010b). Additional resources, including the soils survey map for Kanabec County (Natural Resources Conservation Service, 2012), the Minnesota Geological Survey County Well Index (CWI; see Plate 1, *Data-Base Map*), the Minnesota Department of Natural Resources Aggregate Resources map (Friedrich, 2012), and the National Wetlands Inventory maps (U.S. Fish and Wildlife Service, 2014), were also utilized. Fieldwork, conducted from 2013 to 2014 to verify and enhance interpretations, consisted of analyzing surficial exposures in gravel pits and road cuts and was supplemented with auger borings across the county, drilled to an average of 10 feet (3 meters) deep (see Plate 1).

GLACIAL HISTORY

The glacial history of Minnesota began about 2.5 million years ago at the start of the Pleistocene Epoch and is marked by the advance and retreat of many glaciers from the region that left behind sediments and glacially sculpted landscapes. Because glaciers entrain sediments from the bedrock and sediment over which they flow, the texture and composition of the deposits left behind after they retreat is critical to understanding the origin and direction of the ice flow. For instance, ice that advanced into Minnesota from the northwest Riding Mountain provenance (Fig. 2) deposited sediments composed primarily of yellow to gray, loamy to clayey sediment rich in shale and limestone clasts. Glacial sediment derived from the northeast Superior provenance (Fig. 2) is primarily a reddish-brown, sandy loam with fine- to coarse-grained gravels and cobbles of Precambrian sandstone and igneous clast types. Sediment derived from both provenance areas occur in Kanabec County.

The most recent glacial episode, the Wisconsinan, began about 110,000 years ago and lasted until the beginning of the Holocene Epoch about 11,700 years ago. Most of the near-surface sediment in Kanabec County was deposited during the Wisconsinan episode by glacial ice in its final stages of retreat. The majority of these sediments were deposited by the Superior lobe (Fig. 2) that advanced from the northeast, extending from the Lake Superior basin across Kanabec County. There have been several phases of Superior-lobe ice advances. The two that most influenced the surficial geology of Kanabec County were the St. Croix phase and the Automba phase (Wright, 1972). Although sediments of the older St. Croix phase are not present at the surface in Kanabec County, some landforms created during this phase are still discernible despite the presence of overlying younger deposits.

St. Croix-phase ice reached its maximum extent (marked by the St. Croix moraine; Fig. 2) about 19,000 cal YBP[1] and began to retreat by about 18,200 cal YBP[1] (Wright, 1972; Wright and others, 1973; Clayton and Moran, 1982; Mooers and Lehr, 1997). Following the retreat of the St. Croix phase, there was a distinct readvance of the Superior lobe, the Automba phase (Fig. 2), at about 16,500 cal YBP[2] (Wright and others, 1969; Clayton and Moran, 1982) that extended as far south as Anoka and Chisago Counties (Meyer, 2010b, 2012). The extent of the Automba-phase ice to the northwest is marked by the Mille Lacs moraine (Fig. 3). Previously, the extent of ice to the west has been associated with the Rum River moraine (Fig. 3; Johnson and Mooers, 1998); however, this feature is small and discontinuous, and therefore cannot be reliably defined as the Automba-phase ice limit. Although the limit is not delineated by a distinct margin, the extent of tunnel valleys and eskers associated with the Automba phase, which extend across Kanabec County and into Mille Lacs County, indicate that Automba-phase ice covered the entire study area. Therefore, the majority of glacial sediment at the surface in Kanabec County is inferred to have been deposited by Automba-phase ice. Sediments deposited by Automba-phase ice are part of the Cromwell Formation (Johnson and others, 2016). In Kanabec County the till (unsorted sediment laid down directly by glacial ice) associated with this phase is mapped as Cromwell Formation till (unit cta), a reddish-brown, sandy loam to loamy sand with an abundance of northeast-sourced gravel and cobbles (Plate 4, Table 1; Johnson and others, 2016).

Landforms left behind by glaciers indicate ice-lobe flow direction. Although many of the landforms in Kanabec County are associated with the Automba phase, some that were formed during the St. Croix phase were likely still partially ice-cored or frozen when Automba-phase ice advanced. This allowed the advancing ice to override these preexisting features with minimal erosion or deformation, possibly even augmenting them. One such example is the here-named Deformation complex in eastern Kanabec County, interpreted to have been southwest-trending features deposited during the St. Croix phase that were overridden by Automba-phase ice and modified into a feature resembling a sinuous and discontinuous ridge oriented primarily east–west.

Automba-phase landforms indicating ice flow direction, such as drumlins, tunnel valleys, and eskers (unit coe), trend southwest throughout Kanabec County. Tunnel valleys (Fig. 3) were the primary outlet channels for basal meltwater flow of Superior-lobe ice. The surficial sediment within these valleys is outwash (unit csa) deposited during the Automba phase. The largest eskers (sinuous, narrow ridges of irregularly stratified sand and gravel) typically occur within tunnel valleys, and smaller eskers occur over till near ice margins. In places, the eskers have a thin drape (about 2 to 8 feet [1 to 2.5 meters]) of till that was likely deposited by the ice as it retreated, rather than during a separate advance.

A number of small recessional moraines (Fig. 4) mark the retreat of Automba-phase ice through the region. These features indicate retreat of the ice front to the northeast punctuated by episodic stagnation and small readvances. Due to the insulation of overlying sediment, it is likely many of these moraines would have remained ice-cored or frozen for an extended period of time. The resulting slow and inconsistent melting of this buried ice produced the hummocky topography associated with these features. Small, ice-walled lake plains (unit cla) occur on and adjacent to these recessional margins. These plains resulted from lakes or ponds forming in depressions in the ice, or ice-cored sediment. The lakes filled with fine-grained sand, silt, and clay, with coarser-grained sediment deposited along the edges. After the ice walls melted, the lake bottoms became small topographic highs, commonly no more than 0.5 mile (800 meters) in diameter, which remained above the surrounding topography by as much as 30 feet (9 meters). The resulting plateaus consist of fine-grained sand, silt, and clay encircled by a rim of coarser-grained sand, gravel, and diamicton. Ice-marginal fans (Fig. 4) occur adjacent to recessional moraines, proximal to eskers, indicating stagnation of ice retreat, during which meltwater continued to drain from beneath the ice, creating large outwash channels and fan deposits composed of sand and gravel (unit csa).

The youngest glacial deposits at the surface in Kanabec County were deposited about 14,600 to 14,000 cal YBP[3] (Wright and Rubin, 1956; Clayton and Moran, 1982), coincident with the advance of the Grantsburg sublobe (Fig. 2). The Grantsburg sublobe, an offshoot from the Des Moines lobe, advanced from the southwest to the northeast through the Twin Cities metropolitan area, extending to Grantsburg, Wisconsin. Although the ice did not reach Kanabec County, it extended far enough east to cut off river drainage from the north, resulting in the formation of glacial Lake Grantsburg (Fig. 5), which covered the southern portion of Kanabec County (Johnson and Hemstad, 1998; Meyer, 2008).

The highest elevation of sediment interpreted to be glacial Lake Grantsburg deposits in Kanabec County is about 1,060 feet (323 meters). This is similar to elevations presented in previous studies that place the northern extent of the lake between 1,050 and 1,120 feet (320 and 341 meters) in the area (Cooper, 1935; Johnson, 2000; Meyer, 2008). The inferred northern extent on the map is therefore placed at an elevation of about 1,060 feet (323 meters). However, because there are no shorelines or deltas in the study area to delineate the northern margin, the inferred extent is based primarily on the topography of Kanabec County and the highest elevation of lake sediment. Based on rhythmic sequences of lake deposits in Pine County to the east, which are interpreted to be varves, the lake is thought to have been relatively short-lived, persisting for about 100 years (Johnson and Hemstad, 1998).

The sediments associated with glacial Lake Grantsburg range from brown, very fine- to medium-grained sand to yellow to gray silt and clay (unit ncl) included within the Falun Member of the New Ulm Formation (Johnson and others, 2016). The distribution of glacial Lake Grantsburg sediments in Kanabec County is patchy, but more continuous in the south. This patchy distribution could be due to the erosion of deposits as the lake level dropped. It could also reflect an originally patchy pattern of deposition due to melting of stagnant ice below the lake, which would have created an uneven lake bottom. Sediments flowing into the lake would have settled within the lows, leaving the higher topography relatively free of lacustrine deposits. In addition, glacial Lake Grantsburg appears to have been fed from several inlets, each with slightly different depositional conditions that contributed to the varied distribution of sediment.

Meltwater from Grantsburg-sublobe ice delivered clay and silt derived from the Twin Cities Member of the New Ulm Formation (Johnson and others, 2016) to the southern margin of the lake. The deposits vary but are typically about 20 feet (6 meters) thick; however, in places well logs imply that the unit may be up to 60 feet (18 meters) thick. The sediments are characterized as calcareous, yellow to gray clay and silt that is laminated locally. Streams flowing over Cromwell Formation till and outwash into the northern end of the lake deposited brown, fine-grained sand that is commonly intermixed with finer-grained lake sediment. These coarser-grained sediments are typically much thinner, only 3 to 5 feet (1 to 1.5 meters) thick, and very patchy. Additional inlets farther west, such as in Benton County (Meyer, 2010a), deposited a variety of sediment to the lake, with finer-grained material likely settling in lows as far as southeastern Kanabec County. Because the sediment distribution is so variable, unit ncl has been classified as undifferentiated for the purposes of this map.

Just prior to and during the advance of the Grantsburg sublobe, the expansion of glacial Lakes Aitkin I and Upham I (which formed in the basin left by the retreating Rainy and Superior lobes; Fig. 2) north of Kanabec County resulted in increased drainage to the south and initiated the incision of the Snake River (Fig. 5), one of several northern inlets to glacial Lake Grantsburg (Wright, 1972; Hobbs 1983; Jennings and Kostka, 2014). As the Grantsburg sublobe retreated from its maximum position, glacial Lake Grantsburg drained to the south. Meltwater from the expanding St. Louis sublobe and the retreating Superior lobe maintained flow and deepened the incision of the Snake River (Hobbs, 1983). During this time sand and gravel (unit ts) aggraded along the Snake River while laterally migrating into adjacent Pleistocene units.

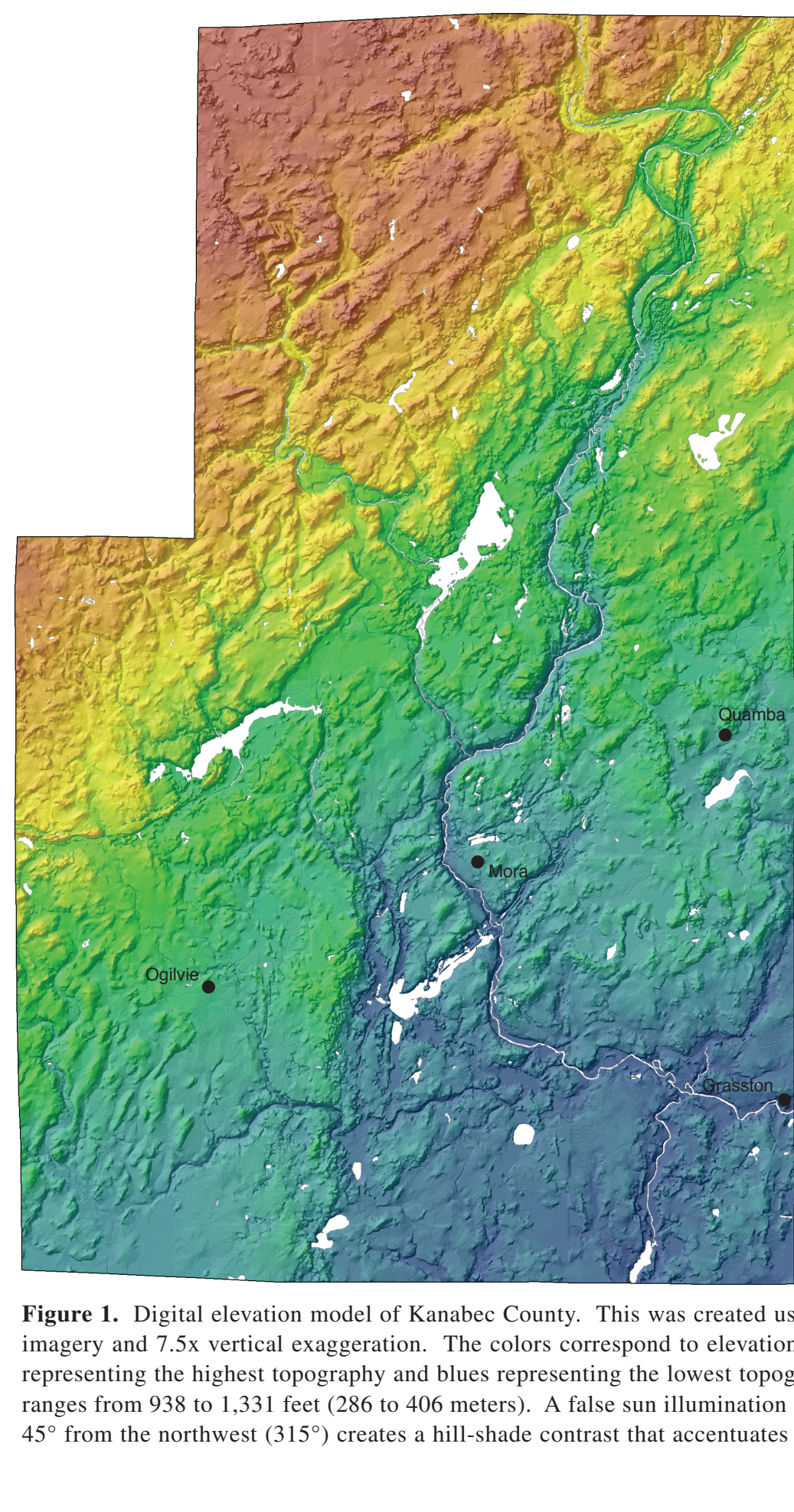


Figure 1. Digital elevation model of Kanabec County. This was created using 1-meter lidar imagery and 7.5x vertical exaggeration. The colors correspond to elevation with red-orange representing the highest topography and blues representing the lowest topography. Elevation ranges from 938 to 1,331 feet (286 to 406 meters). A false sun illumination at an elevation of 45° from the northwest (315°) creates a hill-shade contrast that accentuates features.

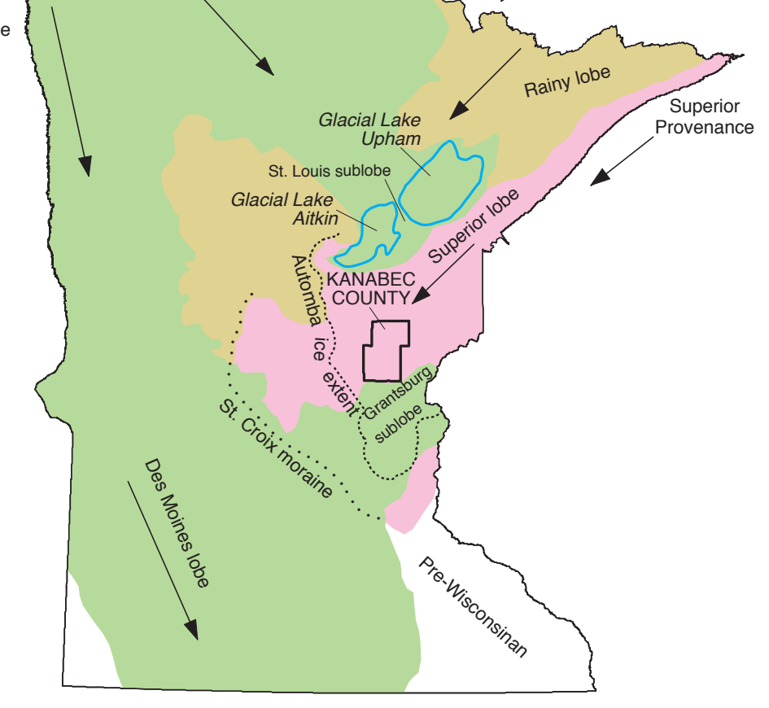


Figure 2. Map showing the location of the mapping area (Kanabec County) relative to the major source regions (provenances) from which glacial deposits in Minnesota were derived. Maximum ice extents of the St. Croix and Automba phases are shown by dotted lines.

HOLOCENE GEOLOGY

The formation of the Snake River continued into the middle Holocene Epoch (Hobbs, 1983) as the headwaters developed in the area of Aitkin County to the north in what is now Solana State Forest. Meanwhile, organic-rich deposits (unit pe) accumulated in basins and low-lying areas across the county. Organic-rich silt and clay (unit cl) were deposited in the modern lakes when they were larger than at present. As the lake levels dropped, the abandoned lake deposits were covered with marshes and/or peat (unit pe). Alluvium (unit al) was deposited within the modern channel and floodplain of the Snake River and other rivers during the mid to late Holocene Epoch.

DESCRIPTION OF MAP UNITS

HOLOCENE

pe	**Organic matter and silt**—Moderately to highly decomposed plant matter deposited in bogs, swamps, and marshes. Along stream beds it is commonly interlayered with alluvial deposits. Unit is modified from Natural Resources Conservation Service (2012) map units. *Peat and organic deposits.*
al	**Fine- to coarse-grained sand and gravel**—Sand and gravel occur within modern river channels, with finer-grained sediments and silt to medium-grained sand on the floodplains. In places, sediments on the floodplain are overlain by or interbedded with organic sediment and/or peat. Unit occurs within modern channels and floodplains. *Floodplain alluvium.*
cl	**Silt, sand, and clay with organic layers**—Undifferentiated sand, silt, and clay that may overlie or be overlain by peat. These deposits commonly extend beyond the modern lake extent, although these sections are typically covered by marshes or peat. *Lake deposits.*

HOLOCENE AND PLEISTOCENE

ts	**Fine- to coarse-grained sand and gravelly sand**—Sediment is composed primarily of fluvial reworked glacial outwash sediments. Some may have originated from the Aitkin Formation (Johnson and others, 2016), which was deposited by the St. Louis sublobe; however, the primary material is from the Cromwell Formation. In places unit may form small, discontinuous terraces. Unit was deposited during the end of the Pleistocene Epoch into the early Holocene Epoch. *Alluvial terrace deposits.*
▨	**Silt and fine-gained sand**—Sediment is eolian in deposition. Light pinkish-tan (7.5YR 6/3) and typically 1 to 3 feet (0.3 to 0.9 meter) thick. The unit occurs locally throughout the county, more commonly in the northern half. Unit is modified from Natural Resources Conservation Service (2012) mapped units. *Loess mantle.*

PLEISTOCENE

New Ulm Formation—Falun Member (Johnson and others, 2016)—Sediments associated with glacial Lake Grantsburg.

ncl	***Undifferentiated clay, silt, and fine- to medium-grained sand***—Undifferentiated sediment deposited in glacial Lake Grantsburg over the Cromwell Formation. In places this unit consists predominately of calcareous, rhythmically laminated gray to yellow clay and silt typically with precipitated secondary carbonate. In other parts of the county, the lake sediment consists of layers of very fine- to medium-grained sand. The clay and silt are not differentiated from sand because there are not enough data to significantly differentiate between the two on a regional scale. Typically, the sediment is interlayered and in places mixed. Unit ncl is typically about 20 feet (6 meters) but may be as much as 60 feet (18 meters) thick near the southern border of Kanabec County. It becomes thinner and discontinuous to the north. *Glacial lake sediment.*

Cromwell Formation (Johnson and others, 2016)—Sediments associated with ice of the northeast-sourced Superior lobe.

cla	***Clay, silt, and very fine-grained sand***—Sediments accumulated in basins bound by ice or ice-cored sediments, most commonly on and adjacent to recessional moraines. After the supporting ice melted, flat-topped topographic highs, about 10 feet (3 meters) above the surrounding topography, remained. These features range from small (less than 0.1 mile [161 meters] wide) to large (about 0.5 mile [805 meters] wide). Some formed adjacent to or on top of other ice-walled lake plains due to the irregular nature of the meltout of the supporting ice. The edges of most of these plains consist of coarser-grained, poorly sorted to unsorted sediment (diamicton); the centers consist of clay, silt, and fine-grained sand. *Ice-walled lake plain sediments.*
coe	***Irregularly stratified sand, gravel, cobbles, and boulders***—Sediments were deposited by englacial or subglacial ice-walled meltwater streams. Clasts are predominately northeast-sourced material similar to that of the Cromwell Formation outwash and are typically rounded. Sediments occur as sinuous, steep sided, narrow ridges and range in size from about 5 feet (1.5 meters) high, to long, continuous ridges up to 100 feet (30 meters) high. Anticlinal bedding is common, and formed when the sides of the ridge collapsed after the supporting ice melted. Typically, this unit occurs within the confines of tunnel valleys. These ridges, in places, are draped by diamicton that was deposited as the ice retreated. Where unit coe is mapped, overlying diamicton is interpreted to be less than 8 feet (2.5 meters) thick if present. *Esker deposits.*
csa	***Fine- to coarse-grained sand and gravel***—Moderately to well-sorted sediments deposited by meltwater from Superior-lobe ice during the Automba phase. Sediment is typically located in former meltwater channels, including tunnel valleys, and adjacent to recessional ice margins. *Glacial outwash.*
cta	***Sandy loam to loamy sand***—Unsorted sandy loam to loamy, fine- to medium-grained sand with subangular to subrounded fine-grained gravel to coarse-grained cobbles throughout. This unit varies in thickness (10 to 70 feet [3 to 21 meters]). The oxidized color is brown to reddish-brown (5YR 4/4 to 7.5YR 4/4); the unoxidized color is typically grayish-brown (5YR 4/2 to 7.5YR 4/2). The average sand, silt, and clay percentages are 58, 32, and 10, respectively. The unit has low carbonate content and is typically leached to as deep as 20 feet (6 meters). The unit contains at least 5 percent gravel, but commonly this percentage is closer to 10. Gravel and cobbles within the unit are sourced from Mesoproterozoic rocks from along the North Shore of Lake Superior, including rhyolite, granophyre, agate, basalt, red basalt, diabase, gabbro, anorthosite, as well as more locally sourced granite and sandstone. *Glacial till.*
csg	***Variable layers of till (unit* cta*), sand, and gravel (unit* csa*)***—This unit occurs locally along recessional moraines where small readvances of ice overrode preexisting deposits. Also occurs where meltout of underlying stagnant ice produced collapse of the sediment. *Sand/till/gravel complex.*

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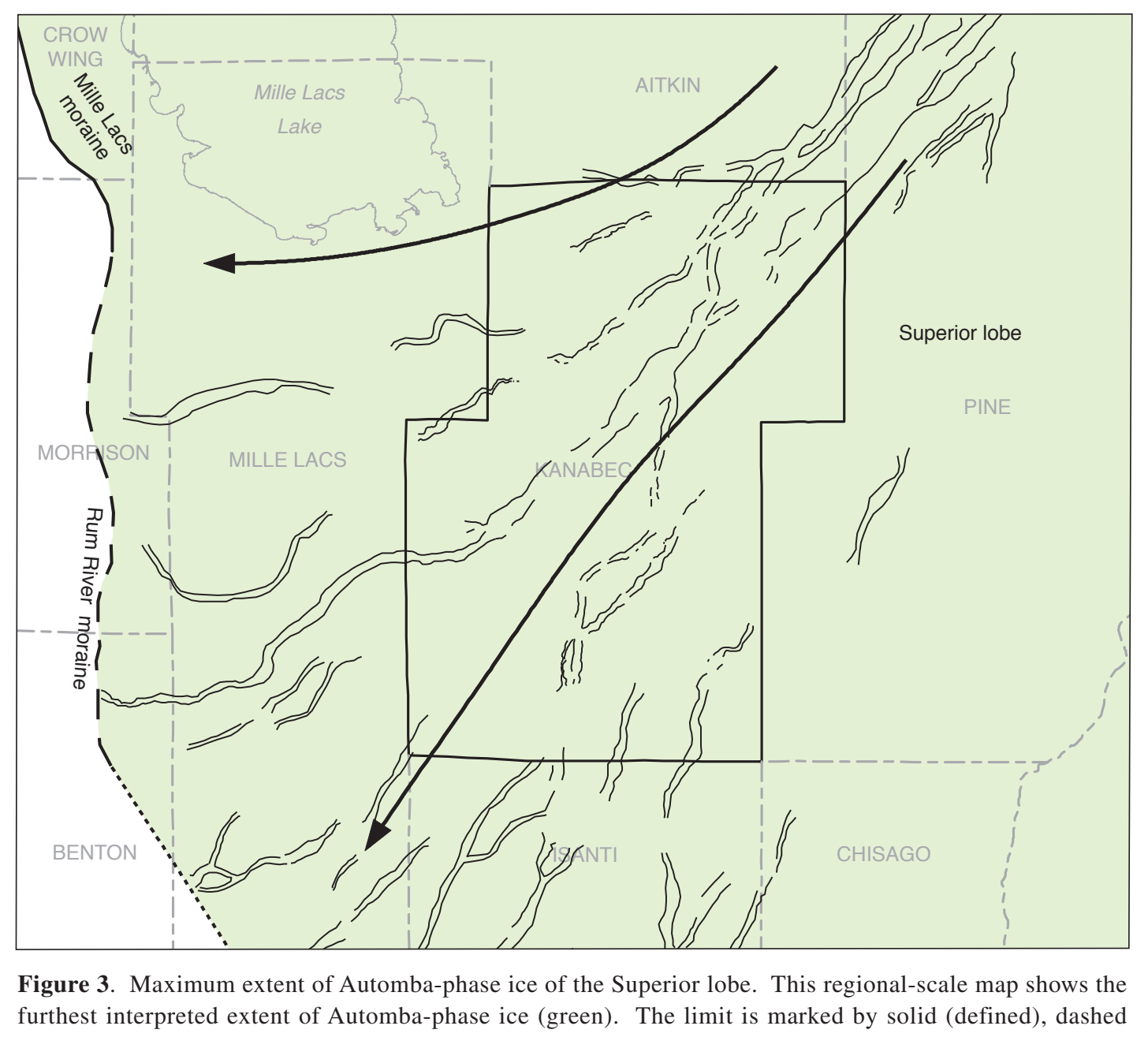


Figure 3. Maximum extent of Automba-phase ice of the Superior lobe. This regional-scale map shows the furthest interpreted extent of Automba-phase ice (green). The limit is marked by solid (defined), dashed (inferred), and dotted (speculated) lines. The Mille Lacs moraine is a well-defined feature on the west side of Mille Lacs Lake. The limit of the Rum River moraine is not as well-defined, but has previously been interpreted to be the maximum extent of Automba-phase ice (Johnson and Mooers, 1998). The black arrows indicate direction of ice flow. A number of tunnel valleys (thin, black, subparallel lines) roughly parallel ice flow and can be traced across both Kanabec and Mille Lacs Counties.

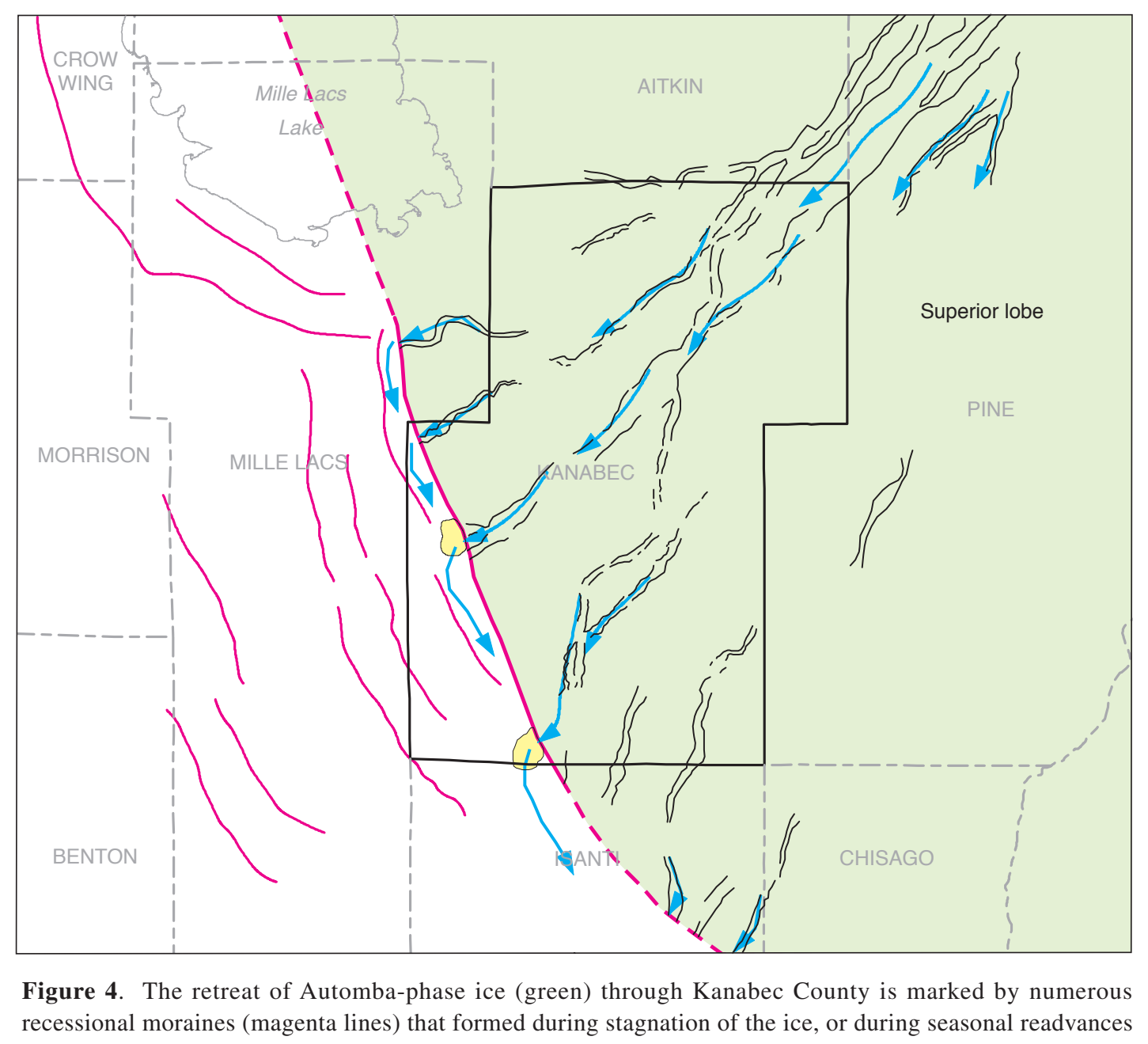


Figure 4. The retreat of Automba-phase ice (green) through Kanabec County is marked by numerous recessional moraines (magenta lines) that formed during stagnation of the ice, or during seasonal readvances of short duration. Tunnel valleys (subparallel black lines) acted as the primary drainage systems for the retreating ice and during stagnation, forming meltwater fans (yellow) along the ice margin. Blue arrows indicate meltwater flow direction.

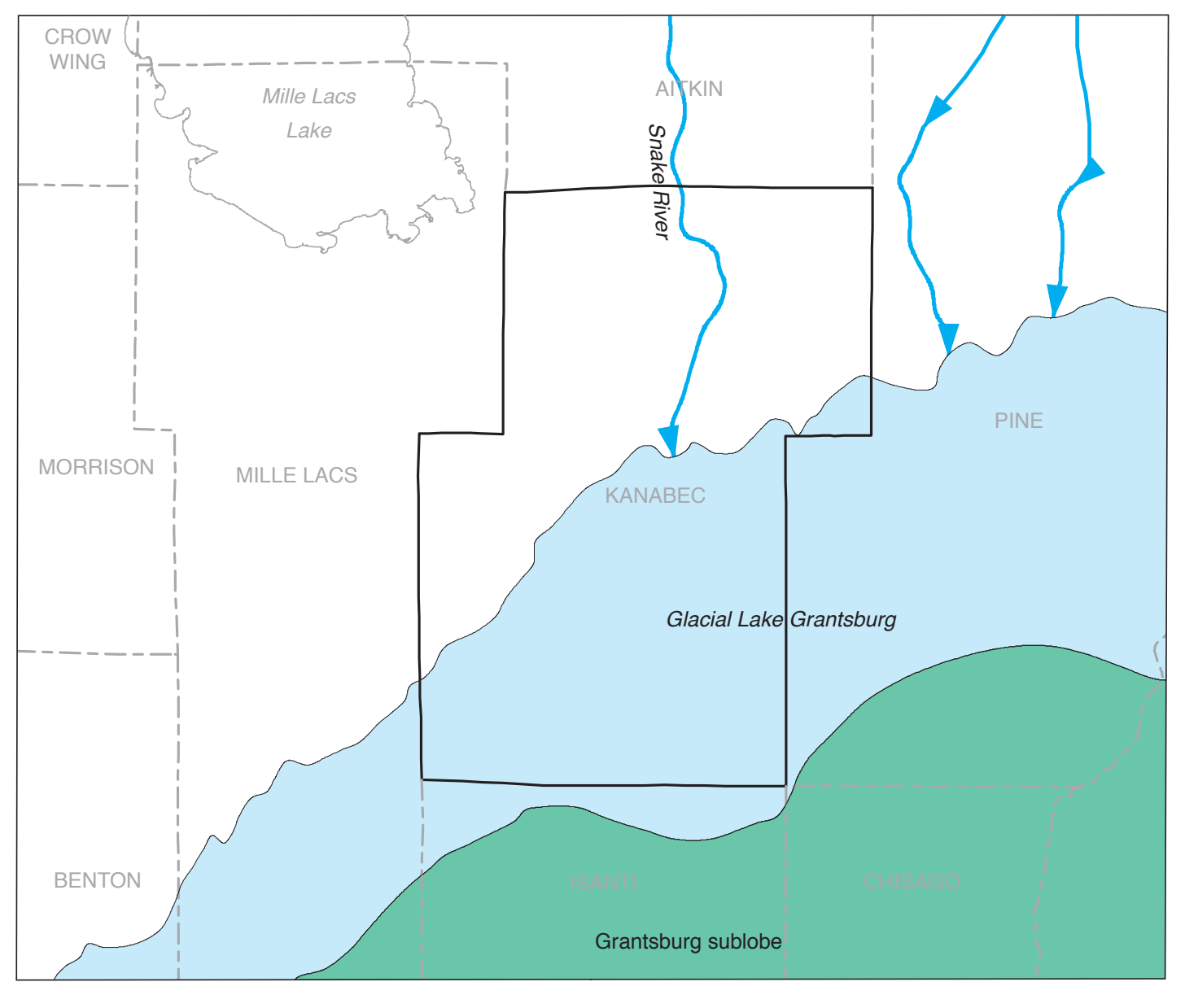
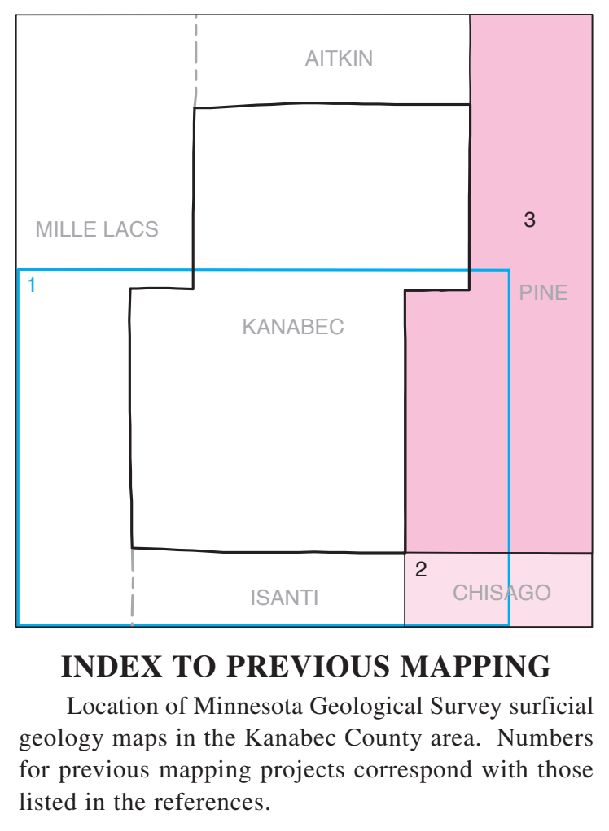


Figure 5. The advance of the Grantsburg sublobe (an offshoot from the Des Moines lobe) dammed water flowing from the north. This created a large ice-marginal lake, glacial Lake Grantsburg, which covered the southern portion of Kanabec County. The maximum northern extent of the lake is difficult to constrain due to thin, discontinuous sediments and a lack of clear geomorphic evidence. During this time, the Snake River began to incise into the glacial sediments in the northern part of the county.



INDEX TO PREVIOUS MAPPING

Location of Minnesota Geological Survey surficial geology maps in the Kanabec County area. Numbers for previous mapping projects correspond with those listed in the references.

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[1] Ages are in calendar years before present (cal YBP) recalibrated (then averaged) from radiocarbon dates 16,000 ^{14}C, 15,500 ^{14}C, and 15,000 ^{14}C (Clayton and Moran, 1982; Mooers and Lehr, 1997) using CALIB radiocarbon calibration program, Calib7.0.2 (Stuiver and others, 2014) with 2 sigma error.

[2] Ages are in calendar years before present (cal YBP) recalibrated (then averaged) from radiocarbon dates 14,000 ^{14}C and 12,300 ^{14}C (Clayton and Moran, 1982) using CALIB radiocarbon calibration program, Calib7.0.2 (Stuiver and others, 2014) with 2 sigma error.

[3] Ages are in calendar years before present (cal YBP) recalibrated (then averaged) from radiocarbon dates 12,300 ^{14}C and 12,030 ^{14}C (Wright and Rubin, 1956; Clayton and Moran, 1982) using CALIB radiocarbon calibration program, Calib7.0.2 (Stuiver and others, 2014) with 2 sigma error.