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QUATERNARY STRATIGRAPHY

By

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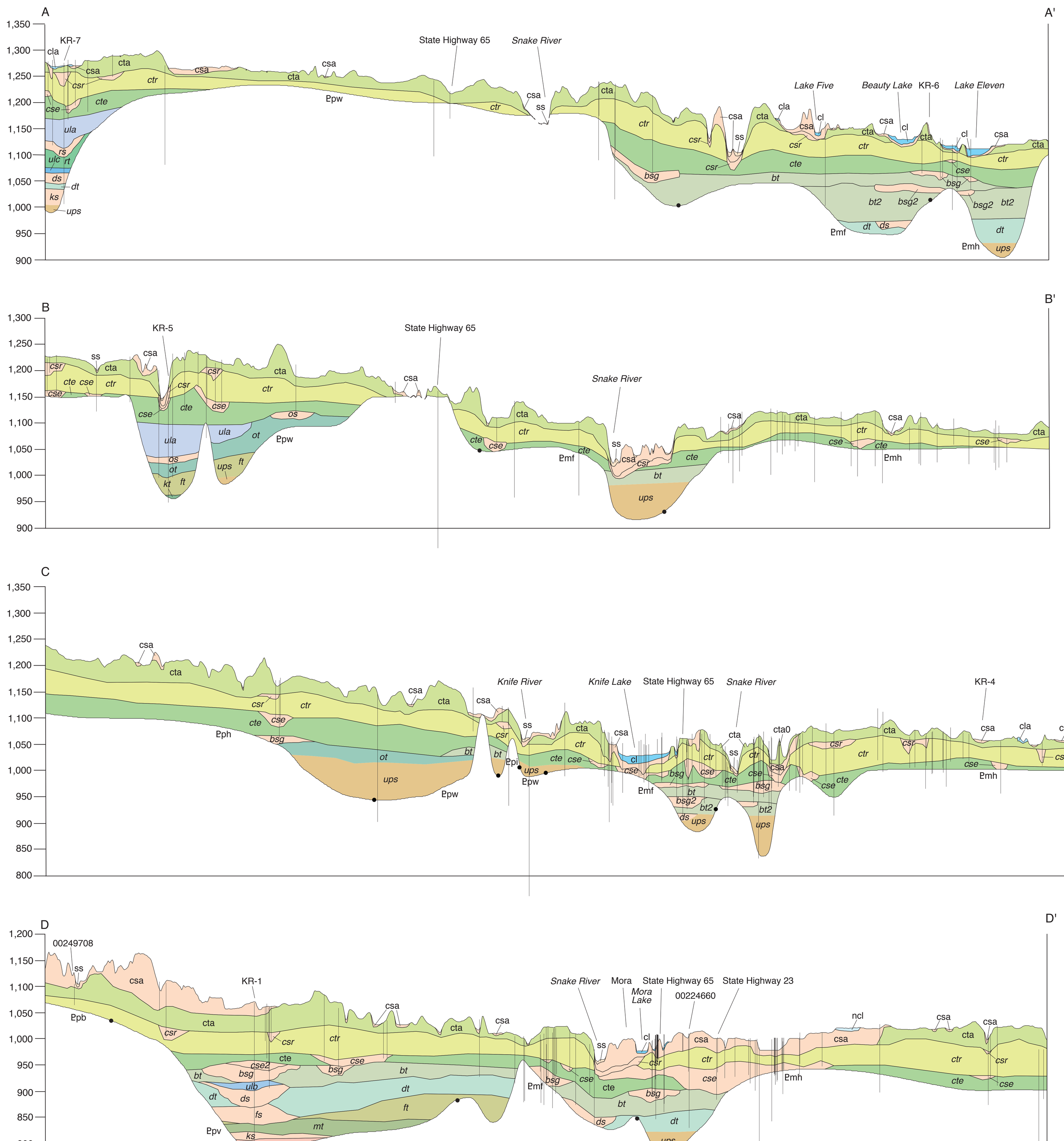
2016



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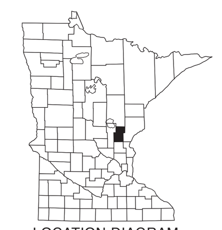

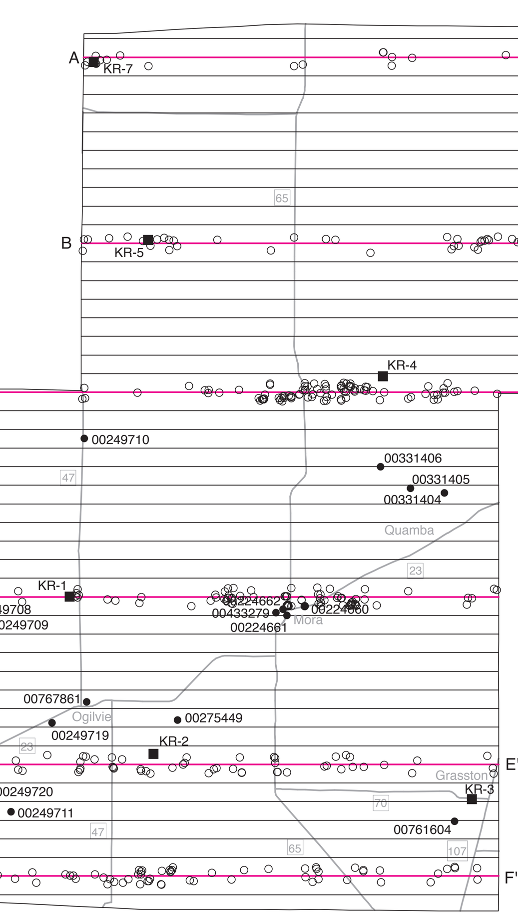

Figure 1. Diagram of Kanabec County showing the locations of cross sections A–A' through F–F' and the locations of the data points used in compiling the stratigraphy for these six cross sections. Open circles represent water-well sites with a stratigraphic log on record in the County Well Index (only shown where within 0.3 mile [0.5 kilometer] of the cross section). Solid circles represent cuttings sets analyzed by the Minnesota Geological Survey. Squares are the Minnesota Geological Survey rotary-sonic core sites.

CROSS SECTION SYMBOLS

Geologic contact—Approximately located. No-line boundaries occur where data were insufficient to reliably extend units.

Drill hole—Includes well records from the County Well Index within 0.3 mile (0.5 kilometer) of the cross section line. Rotary-sonic core holes are labeled by hole number. The top of the drill hole may not coincide with the cross section surface elevation line because the point is located near but not on the cross section line and therefore may have a different surface elevation.

Bedrock contact—Contact point shown at the base of Quaternary deposits. Bedrock labels match those described on Plate 2, *Bedrock Geology*.

Table 1. Correlation of stratigraphic units in Kanabec County with units in adjacent Pine County (Knaeble and others, 2001) to the east. Although units Qsg and Qss were not correlated with the Emerald phase on the Pine County Geologic Atlas, the unit likely includes all three phases of the Cromwell Formation. Omission of the Emerald phase from the Pine County Geologic Atlas was most likely due to lack of data.

Formation	Kanabec County	Pine County
New Ulm Formation		
Glacial Lake Grantsburg	ncl	Qglf, Qglc
Cromwell Formation		
Automba phase	cta, csa	Qsg, Qss
St. Croix phase	*ctr, csr*	Qsg, Qss
Emerald phase	*cte, cse*	Qsg, Qss (likely)

INTRODUCTION

The Quaternary Stratigraphy plate for the Kanabec County Geologic Atlas shows the unconsolidated material expected to be encountered between the land surface and bedrock. Forty-seven west–east oriented cross sections at 0.6 mile (1 kilometer) spacing (Fig. 1) were constructed to create a three-dimensional model of the Quaternary deposits in Kanabec County. All major sand bodies are depicted on Plate 5, *Sand-Distribution Model*. The units shown in the cross sections were defined using various data (Plate 1, *Data-Base Map*), including water well drillers' logs and cuttings sets, and new data in the form of rotary-sonic cores that were collected for this study. Some of the surficial units are modified from those on Plate 3, *Surficial Geology*. However, most of the units that appear on the cross sections are present in the subsurface only, and therefore are unique to this plate. Peat (unit pe), and the silt and fine-grained sand cap (pattern) shown on the *Surficial Geology* map (Plate 3), are too thin to be shown on the cross sections and have been included in the underlying units.

The stratigraphic units in Kanabec County and those depicted in adjacent Pine County (Knaeble and others, 2001) to the east do not precisely match. This mostly reflects differences in the level of subdivision of the Cromwell Formation. On the Quaternary Stratigraphy plate for the Pine County Geologic Atlas, several till units within the Cromwell Formation were combined as one mapped unit, Qsg (Table 1). More data in Kanabec County allowed for subdivision of individual till units. On the Pine County Quaternary Stratigraphy plate (Knaeble and others, 2001), there were only a few units identified by formation or phase and unit Qsg correlated with the St. Croix and Automba phases. Although it was not identified in Pine County, unit Qsg also likely includes till of the Emerald phase. Units Qptg and Qptr from Pine County were not correlated with any named formation and it is likely these units correlate with units in Kanabec County; however, without additional data, this cannot be done with confidence.

The six cross sections (A–A' to F–F'; Fig. 1) that appear on this plate are considered to be representative of the Quaternary stratigraphic relationships of Kanabec County. All 47 cross sections can be viewed in the digital files. The rotary-sonic drill holes (Fig. 1 and Plate 1, *Data-Base Map*) are the key stratigraphic control points in the county. The core associated with each of these drill holes was collected, logged, and interpreted by the Minnesota Geological Survey. Core logs for all seven of these holes are shown on this plate (Figs. 2 through 8). The rotary-sonic holes, cuttings sets, and water wells that occur within 0.3 mile (0.5 kilometer; Fig. 1) of each representative cross section are shown as black vertical lines; the rotary-sonic holes and wells with cuttings sets are labeled. Because not all of the wells fall directly on the cross-section line, they may project above or below the land-surface elevation. This is a result of the change in elevation within 0.3 mile (0.5 kilometer) of the cross section line and was corrected for when creating the cross sections. In some instances (lines C–C', E–E', F–F'), rotary-sonic holes and cutting sets did not occur within 0.3 mile (0.5 kilometer) of the printed cross sections. Because they were still used to map the subsurface, the general area of the hole was labeled on the nearest printed cross section within 1 mile (1.6 kilometers). The vertical exaggeration for all cross sections is 50x.

On this plate, the terms till and diamicton are both used. Till refers to a diamicton that was deposited directly by glacial ice. The term diamicton is used to describe unsorted sediment where the depositional environment is unknown. Figure 9 shows the relationships between age, provenance (Plate 3, Fig. 2), stratigraphic position, and location of the till units present in Kanabec County. The texture and rock-type analysis of the sediment of each till unit (Table 2) indicates the majority of sediment in the county is of Superior provenance. However, there are a few older units of Rainy (units *ot*, *kt*) and Winnipeg (unit *sct*) provenances. By convention, the name designations of depicted sand and gravel bodies are associated with their underlying till. However, sand and till units are likely an admixture of material from immediately above or below the actual named unit. For example, unit *ds* is primarily composed of outwash sediment laid down as the glacier depositing unit *dt* retreated; however, it may also include proglacial meltwater deposits from the advance of ice that deposited the overlying unit *bt*.

Thick sequences of fine-grained sand, silt, and clay in the subsurface (units *ula*, *ulb*), interpreted to be lacustrine sediment, are present in the western part of the county and were not recognized prior to this study. Because these units are typically finer-grained than the surrounding sediments, they disrupt the flow of groundwater through the subsurface. To the north, these units are mostly confined to a prominent buried bedrock valley system (Plate 5, *Bedrock Topography* and *Depth to Bedrock*); however, in the southwestern part of the county, they are present across a more extensive area and are not confined to the valley. Additionally, in situ dateable organic material commonly found in these lake sediments, can be used to constrain the age of the unit. Organic material collected for radiocarbon dating from unit *ula* in cores KR-5 and KR-7 returned ages beyond the reliable limit of radiocarbon dating (Table 3), generally accepted to be about 50,000 ^{14}C yr BP (Walker, 2005; Reimer, 2012). Therefore, the minimum age for this unit can only be constrained to greater than 50,000 ^{14}C yr BP. Samples collected for paleomagnetic analysis from units *ula* and *ulb* yielded normal polarities (supplemental information in digital files), thereby indicating a maximum age of about 780,000 yr BP, which was the last reversal (Lisiecki and Raymo, 2005; Jennings and others, 2006). The numerous units that occur below these lacustrine deposits, which have been correlated to formations between 130,000 and 780,000 yr BP (Johnson and others, 2016), indicate that units *ula* and *ulb* are likely much younger than 780,000 yr BP and were probably deposited no earlier than the last interglacial period, about 130,000 to 116,000 yr BP.

Across the county, the apparent localized complexity of subsurface units mostly reflects variability in data density. In regions of denser data, complex stratigraphic relationships can be deciphered and shown on the cross sections, such as those near Knife Lake (C–C') and Mora (D–D'). This complex stratigraphy is probably representative of much of the county. In contrast, sparse data in other areas are inadequate to delineate these complexities, and the units appear relatively continuous and uniform. Units are extended across areas with fewer data where it seemed reasonable that the units are continuous. It is important to consider the interpretive nature of the cross sections, especially for the deeper units where there are fewer data. Commonly, in areas with little or no data at depth, units are continued from adjacent cross sections. This method was more conservatively applied to the extension of sand bodies than till units. Although sand bodies may not be shown in places, they are more likely to occur along the boundaries of till units and may be encountered in future drill holes at the approximate depths of till contacts shown.

DESCRIPTION OF CROSS SECTION UNITS

All units named here are correlated with formally named units presented in *Quaternary Lithostratigraphic Units of Minnesota* (Johnson and others, 2016), using color, rock-type percentages, texture, and stratigraphic position. Correlations were made using information from Johnson and others (2016), previous County Geologic Atlases, as well as information in the Quaternary Data-Base Index, an internal working data base of the Minnesota Geological Survey. Color, rock-type percentages of the coarse-grained sand fraction and texture (Table 2), and stratigraphic position were the primary methods of correlating units to named formations. It is important to keep in mind that some of the correlated units presented here differ in some respects from the type sections presented in Johnson and others (2016). These differences are acceptable, because laterally extensive till sheets are variable in composition and texture across their extent. Stratigraphic data from rotary-sonic cores (Figs. 2 through 8) indicated that several till units occur as multiple layers separated by sand and gravel (Fig. 10). The texture and composition of each layer is identical; therefore, the layers are interpreted to represent a single till unit containing isolated sand bodies. The unnumbered version of the unit code (such as cta or *ctr*) is the primary unit. A number following the unit code, for example cta0 or *ctr2*, represents local areas where sand bodies occur within the unit, requiring the creation of a second till layer for the purposes of the *Sand-Distribution Model* (Plate 5). As stated before, the actual texture and composition of the till layers (such as units cta0 and cta, or units *ctr* and *ctr2*) are identical. This is also true for the associated sand bodies; the sand bodies that occur within the till units (such as units *csr2* or *rs2*) have the same composition as the sand that overlies the till (such as units *csr* or *rs*). Some units occur only on the core logs (Figs. 2 through 8). These unit distinctions are on a very small scale (2 to 3 feet [0.6 to 0.9 meter]), and therefore were eliminated from the cross sections because neither the printed cross sections nor the sand models can express such fine detail.

ss — **Sandy surficial sediment** *(modified surficial unit)*—Includes surficial units al, ts, and pe from Plate 3.

cl — **Undifferentiated lacustrine sediment** *(modified surficial unit)*—Includes surficial units cl and pe from Plate 3.

New Ulm Formation

ncl — **Undifferentiated lacustrine sediment** *(modified surficial unit)*—Includes surficial units ncl and pe from Plate 3.

Cromwell Formation—Red-brown to brown-gray (7.5YR 4/4 to 10YR 4/2), sandy loam tills, bedded sediments and local lacustrine sediment of Superior provenance. Multiple units of the Cromwell Formation have been identified in all seven rotary-sonic holes (Figs. 2 through 8), which were deposited by different advances of Superior-lobe ice. The tills have slightly different characteristics (Table 2) that were used to differentiate the units.

Automba phase—Separate till layers are units cta0 and cta as encountered from the land surface (top to bottom). Unit cta0 occurs in only one or two locations where a small readvance of Automba-phase ice over sand and gravel occurred.

cla — **Ice-walled lake plain** *(modified surficial unit)*—Includes surficial units cla and pe from Plate 3.

csa — **Sand and gravel** *(modified surficial unit)*—Includes surficial units csa, coe, and pe from Plate 3.

cta — **Sandy loam till** *(modified surficial unit)*—Includes surficial units cta, csg, and pe from Plate 3.

St. Croix phase—Separate till layers are units *ctr* and *ctr2* as encountered from the land surface (top to bottom). St. Croix phase Superior-lobe ice retreated about 18,250 to 19,000 cal yr BP[1] (16,000 to 15,500 ^{14}C yr BP; Clayton and Moran, 1982; Mooers and Lehr, 1997).

csr — **Sand and gravel.**

ctr — **Sandy loam till**—Unit includes common, matrix-supported, fine- to coarse-grained gravel and cobbles.

Emerald phase—Separate till layers are units *cte* and *cte2* as encountered from the land surface (top to bottom). Superior-lobe ice advanced south to Kanabec County after about 32,500 cal yr BP[1] (28,580 ± 220 ^{14}C yr BP; Meyer, 2010), and retreated around 24,000 to 29,000 cal yr BP[1] (20,000 to 25,000 ^{14}C yr BP; Johnson and Mooers, 1998).

cse — **Sand and gravel.**

cte — **Sandy loam till**—Unit includes common, matrix-supported, fine- to coarse-grained gravel and cobbles.

Unnamed deposits

ula — **Undifferentiated lacustrine sediment**—Unit is brown (10YR 4/1 to 10YR 4/4) and gray (5Y 5/1 to 2.5Y 4/2) and is comprised of layers of fine- and medium-grained sand, silt with very fine-grained sand, and laminae of silt and clay. In places, this unit contains shell fragments and woody pieces, some of which were dated (Table 3) to greater than 50,000 ^{14}C yr BP. Unit was identified in rotary-sonic cores KR-5 (Fig. 6) and KR-7 (Fig. 8).

Henderson Formation—Brown to gray (10YR 4/3 to 10YR 4/1), sandy loam till and bedded sediments of Superior provenance. Although this unit has been correlated to the Henderson Formation, there is possible mixing of this unit with Rainy lobe sourced sediments. Separate till layers are units *rt*, *rt2*, and *rt3* as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic core KR-7 (Fig. 8).

rs — **Sand and gravel.**

rt — **Sandy loam till**—Unit includes matrix-supported, fine- to coarse-grained gravel and cobbles. Carbonate percentages for this unit (based on samples from rotary-sonic core KR-7; Fig. 8) are lower (Table 2) than would be expected for Henderson Formation till, indicating the unit has been partially leached.

Unnamed deposits—Brown (7.5YR 3/2 to 7.5YR 4/2), sandy loam till and bedded sediments of Superior provenance. Separate till layers are units *bt* and *bt2*, as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic cores KR-1, KR-2, KR-3, and KR-6 (Figs. 2, 3, 4, and 7 respectively).

bsg — **Sand and gravel.**

bt — **Sandy loam till**—Unit includes common, matrix-supported, fine- to coarse-grained gravel.

Unnamed deposits

ulb — **Undifferentiated lacustrine sediment**—Unit varies from brown-gray to gray (10YR 4/1 to 10YR 4/2 and 2.5Y 5/1). Unit contains thick sequences of massive, very fine-grained sand and silt. Laminations of clayey-silt occur locally throughout. This unit may be correlated with the Saum Formation. No material has been dated from this unit. Unit was identified in rotary-sonic cores KR-1 (Fig. 2) and KR-2 (Fig. 3).

Saum Formation—Brown-gray to gray (2.5Y 3/1 to 2.5Y 4/3 to 5Y 4/1), loamy till and bedded sediments of Rainy provenance. Separate till layers are units *ot*, *ot2*, and *ot3* as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic core KR-5 (Fig. 6).

os — **Sand and gravel.**

ot — **Loamy till**—Unit has common, matrix-supported, fine-grained gravel. Unit also includes diamicton composed of a gray-brown (2.5Y 5/2), loose, fine- to coarse-grained sand and silt matrix, with matrix-supported, fine- to coarse-grained gravel and cobbles.

Unnamed deposits

ulc — **Undifferentiated lacustrine sediment**—Brown (10YR 4/3) fine-grained sand with layers of silty clay. Unit was identified only in rotary-sonic core KR-7 (Fig. 8).

Unnamed till—Brown (10YR 4/3 to 7.5YR 4/2), sandy loam till and bedded sediments of Superior provenance. Separate till layers are units *dt* and *dt2*, as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic cores KR-1, KR-3, KR-6, and KR-7 (Figs. 2, 4, 7, and 8 respectively).

ds — **Sand and gravel.**

dt — **Sandy loam till**—Unit includes common, matrix-supported, fine- to coarse-grained gravel and cobbles. Unit also includes sections of brown to brown-gray (7.5YR 4/2 to 10YR 4/2), loose, poorly sorted diamicton comprised of gravel and cobbles in a loamy sand matrix.

dg — **Sand and gravel**—Brown (7.5YR 4/4), fine- to medium-grained sand and local very fine- to fine-grained gravel.

Lake Henry Formation, Sauk Centre Member—Gray (2.5Y 5/1 to 2.5Y 4/1), loamy till, bedded sediments, and lacustrine sediments of Winnipeg provenance. Separate till layers are units *sct* and *sct2* as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic core KR-2 (Fig. 3).

scs — **Sand and gravel**—Unit is carbonate-rich; woody fragments are incorporated into this unit.

sct — **Loamy till**—Unit includes matrix-supported, very coarse-grained sand and fine- to medium-grained gravel; carbonate-rich.

scl — **Undifferentiated lacustrine sediments**—Uniform silt and very fine-grained sand. Unit is massive with no apparent laminations.

St. Francis Formation—Brown to brown-gray (10YR 4/2 to 10YR 4/3), sandy loam till and bedded sediments of Superior provenance. Separate till layers are units *ft*, *ft2*, *ft3*, and *ft4* as encountered from the land surface (top to bottom). Unit was identified in rotary-sonic cores KR-1, KR-2, and KR-5 (Figs. 2, 3, and 6 respectively). Although this unit is correlated to the St. Francis Formation, it may also correlate to other Superior lobe sourced formations not yet recognized in Kanabec County.

fs — **Sand and gravel**—Medium- to coarse-grained sand and abundant fine- to coarse-grained gravel and cobbles. Unit contains local inclusions of silt.

ft — **Sandy loam till**—Unit includes matrix-supported, fine- to coarse-grained gravel. Unit also includes poorly sorted sandy loam diamicton that contains abundant fine- to coarse-grained gravel and cobbles. Diamicton ranges from brown-gray to dark reddish-gray (10YR 4/2 to 7.5YR 4/2 to 5YR 4/2).

Unnamed deposits—Mixed sediment associated with both Superior and Rainy lobes. This unit cannot be definitively correlated to any named formations. Unit was identified in rotary-sonic core KR-1 (Fig. 2).

mt — **Mixed diamicton**—Brown-gray (10YR 4/2), loose, very poorly-sorted diamicton. Unit contains abundant fine- to coarse-grained gravel and cobbles mixed into a loose sandy loam matrix.

Shooks Formation—Brown to gray (2.5Y 5/1 and 2.5Y 5/3), sandy loam till, diamicton, and bedded sediments of Rainy provenance. Here the unit is correlated with the Shooks Formation, but it may correlate with other older Rainy-provenance formations. Unit was identified in rotary-sonic cores KR-1, KR-2, KR-5, and KR-7 (Figs. 2, 3, 6, and 8 respectively).

ks — **Sand and gravel.**

kt — **Sandy loam till**—Unit contains matrix-supported, fine- to medium-grained gravel. In places, unit includes a loose, sandy loam diamicton containing local fine-grained gravel.

ke — **Sand**—Fine- and medium-grained sand with rare very fine-grained gravel. Unit is brown to gray (2.5Y 3/3 to 10Y 4/1).

Undifferentiated deposits

ups — **Undifferentiated Pleistocene sediment**—Includes till, diamicton, lacustrine sand/silt/clay, and sand and gravel of unknown provenance. Shown in areas where data are scarce to absent and no interpretations of the material could be made.

ACKNOWLEDGEMENTS

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[1]Ages are in calendar years before present (cal yr BP), recalibrated from published radiocarbon dates using CALIB radiocarbon calibration program, Calib7.0.2 (Stuiver and others, 2014) with 2 sigma error.

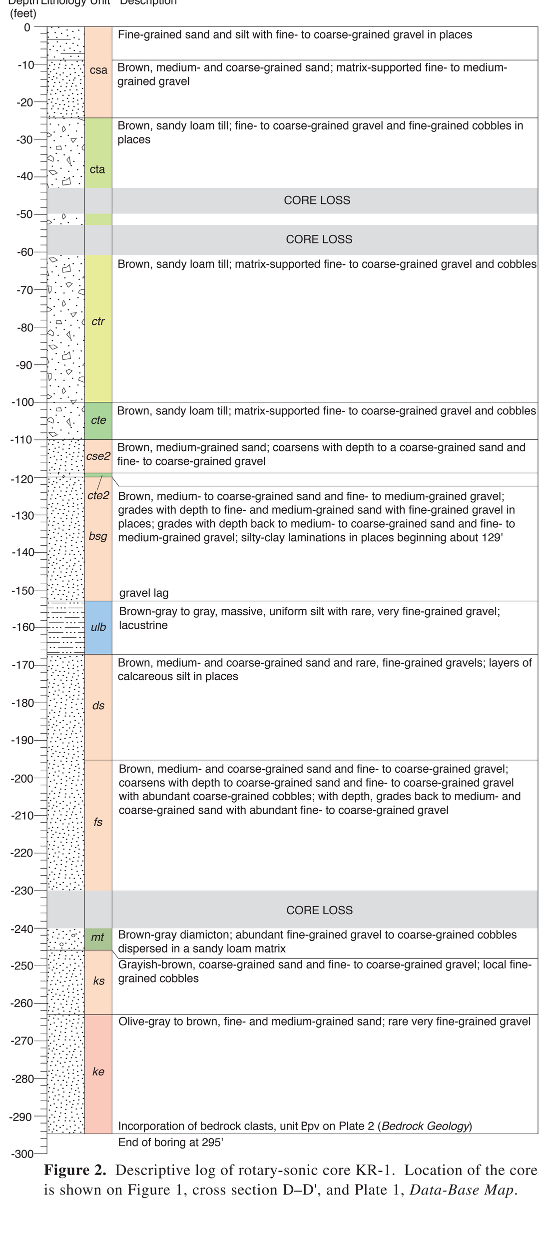

Figure 2. Descriptive log of rotary-sonic core KR-1. Location of the core is shown on Figure 1, cross section D–D', and Plate 1, *Data-Base Map*.

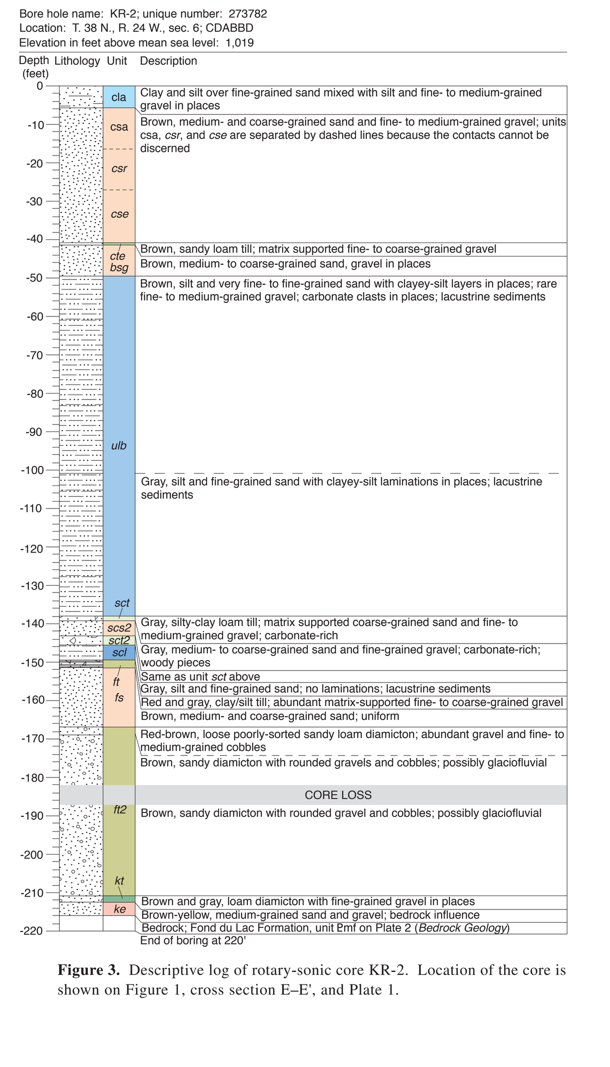

Figure 3. Descriptive log of rotary-sonic core KR-2. Location of the core is shown on Figure 1, cross section E–E', and Plate 1.

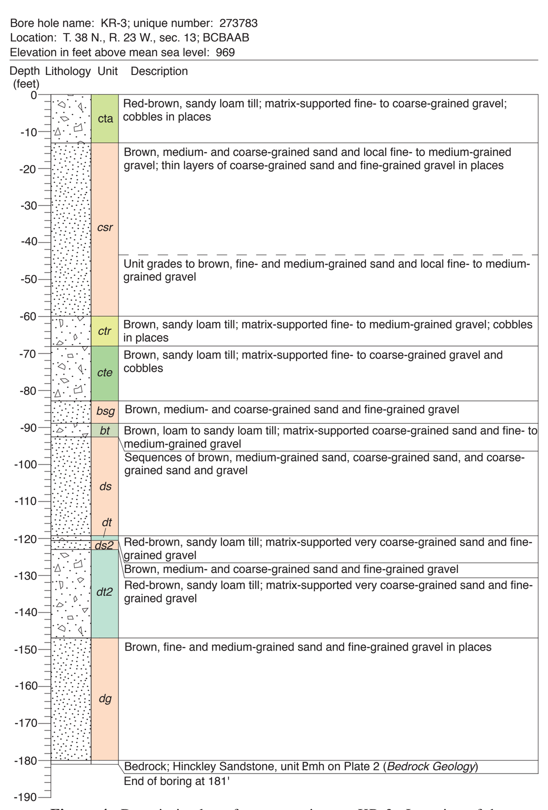

Figure 4. Descriptive log of rotary-sonic core KR-3. Location of the core is shown on Figure 1, cross section E–E', and Plate 1.

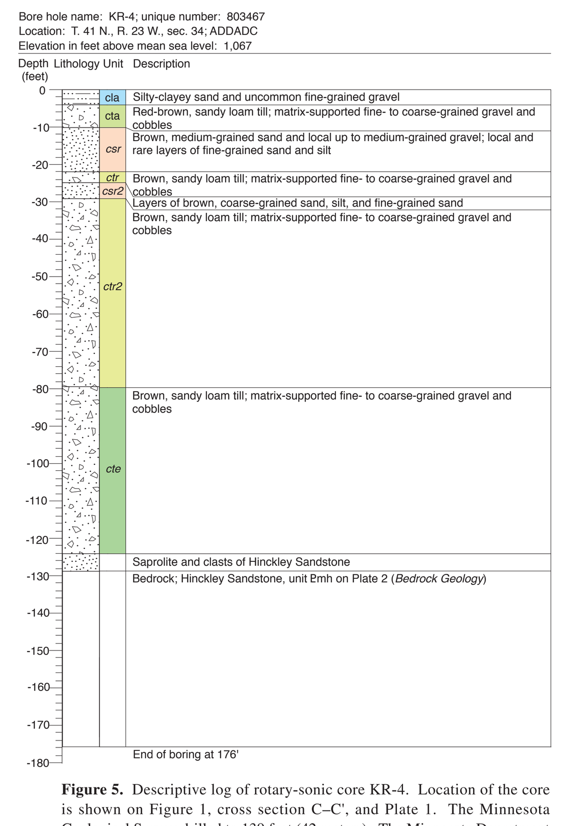

Figure 5. Descriptive log of rotary-sonic core KR-4. Location of the core is shown on Figure 1, cross section C–C', and Plate 1. The Minnesota Geological Survey drilled to 139 feet (42 meters). The Minnesota Department of Natural Resources drilled this hole deeper to 176 feet (54 meters) and set an observation well.

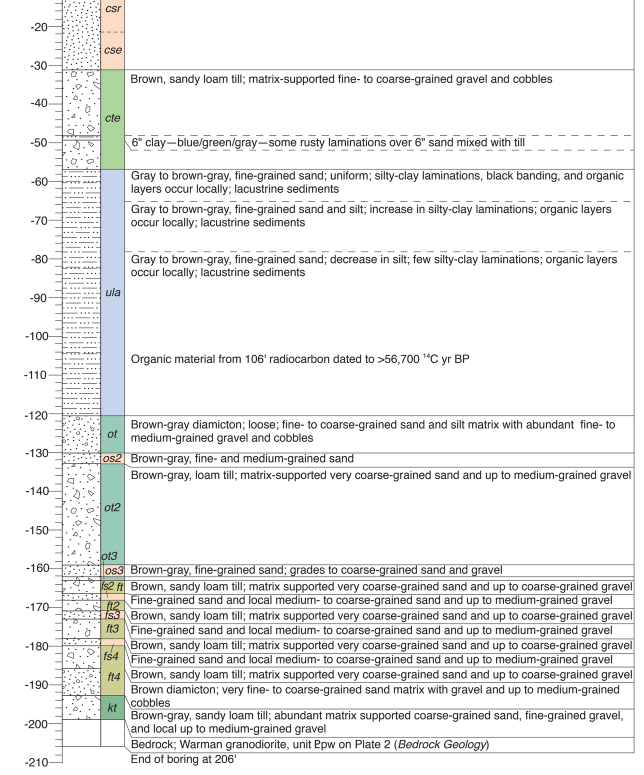

Figure 6. Descriptive log of rotary-sonic core KR-5. Location of the core is shown on Figure 1, cross section B–B', and Plate 1.

Figure 7. Descriptive log of rotary-sonic core KR-6. Location of the core is shown on Figure 1, cross section A–A', and Plate 1.

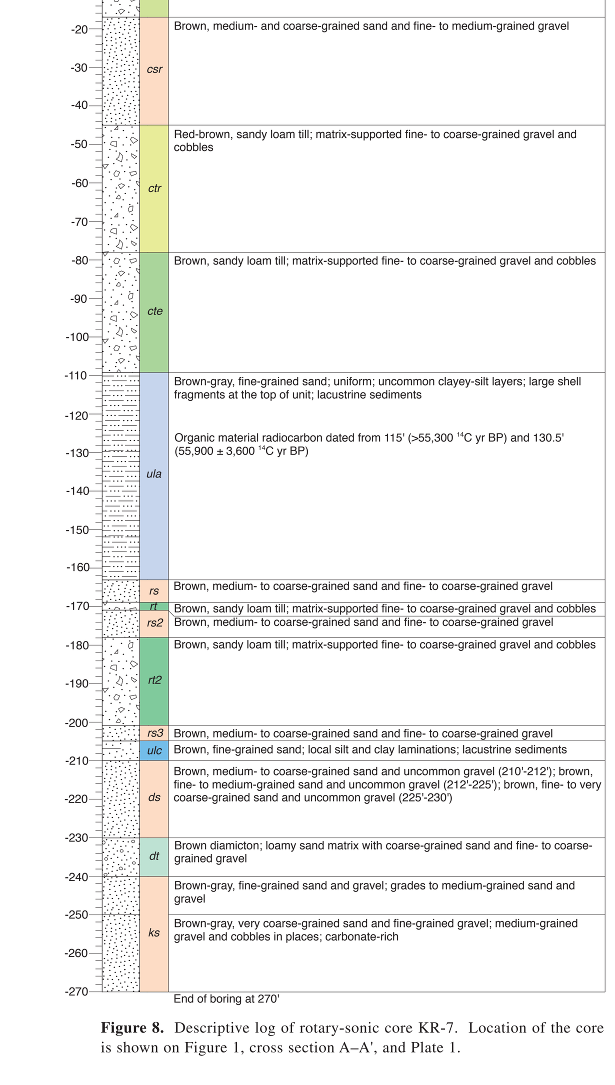

Figure 8. Descriptive log of rotary-sonic core KR-7. Location of the core is shown on Figure 1, cross section A–A', and Plate 1.

Table 2. Average values for the composition and texture of till units identified in Kanabec County. The matrix texture (based on the less than 2 mm grain size fraction) is expressed as the relative proportion of sand, silt, and clay. In an effort to identify the texture of the matrix, samples were selected to avoid large gravel clasts, resulting in low gravel percentages. Therefore, gravel percentages are not listed here. The lithologic composition of the units is based on the very coarse-grained sand fraction (1-2 mm). It is divided into relative proportions of Precambrian crystalline rock, Paleozoic rocks (mostly carbonate) and Cretaceous rocks (mostly shale and shale fragments). The Precambrian fraction is subdivided by rock type—light (granite, gneiss [clear quartz is a percentage of the light category]), dark (mafic-rich igneous and metamorphic rocks), and red (rhyolite, agate, and sandstone).

		MATRIX TEXTURE			CLAST TYPE						
		percentage of the less than 2 millimeter sand fraction			percentage of total grains counted of the 1-2 millimeter fraction			percentage of total crystalline grains counted			percentage of total crystalline light grains counted
Deposit description and geologic units	Total number of samples	Sand	Silt	Clay	Precambrian	Paleozoic	Cretaceous	Light	Red	Dark	Clear quartz
Cromwell Formation till—Automba phase (cta)	92	61	30	9	100	0	0	51	19	30	9
Cromwell Formation till—St. Croix phase (*ctr*)	38	58	31	11	99	1	0	48	17	35	8
Cromwell Formation till—Emerald phase (*cte*)	40	67	23	10	99	1	0	57	16	28	14
Henderson Formation till (*rt*)	11	72	22	6	97	3	0	60	14	26	19
Unnamed till (*bt*)	19	58	32	11	99	1	0	47	16	37	7
Saum Formation till (*ot*)	11	45	32	22	89	10	0	70	6	24	19
Unnamed Superior-provenance till (*dt*)	9	76	17	7	98	2	0	63	15	22	20
Lake Henry Formation, Sauk Center Member till (*sct*)	5	27	49	24	54	45	1	84	1	14	14
St. Francis Formation till (*ft*)	8	64	26	11	91	9	0	77	5	18	25
Shooks Formation till (*kt*)	3	59	29	12	84	16	0	80	5	15	29

Table 3. Organic material found in the Minnesota Geological Survey rotary-sonic cores was sampled for radiocarbon dating. Three samples were prepared by LacCore of the University of Minnesota and processed by Lawrence Livermore National Laboratory, Livermore, California. Sample KR-5-106 was sampled from silty-clay laminations of unit *ula* from core KR-5 at a depth of 106 feet. KR-7-115 was sampled from fine-grained sand and silt of unit *ula* in core KR-7 at a depth of 115 feet. KR-7-130.5 was sampled from fine-grained sand and silt of unit *ula* in core KR-7 at a depth of 130.5 feet. None of these samples could be calibrated to years BP because they are beyond the standard range of calibration curves and beyond the reliable limit of radiocarbon dating (Walker, 2005; Reimer, 2012).

CAMS #	Sample name	MGS ID	Depth (feet)	δ^{13}C	Fraction modern	±	D^{14}C	±	^{14}C age	±
168838	KR-5-106	273784	106	-25	0.0000	0.0004	-1000.4	0.4	>56,700	
168839	KR-7-115	273786	115	-25	0.0002	0.0004	-999.8	0.4	>55,300	
168840	KR-7-130.5	273786	130.5	-25	0.0010	0.0004	-999.0	0.4	55,900	3,600

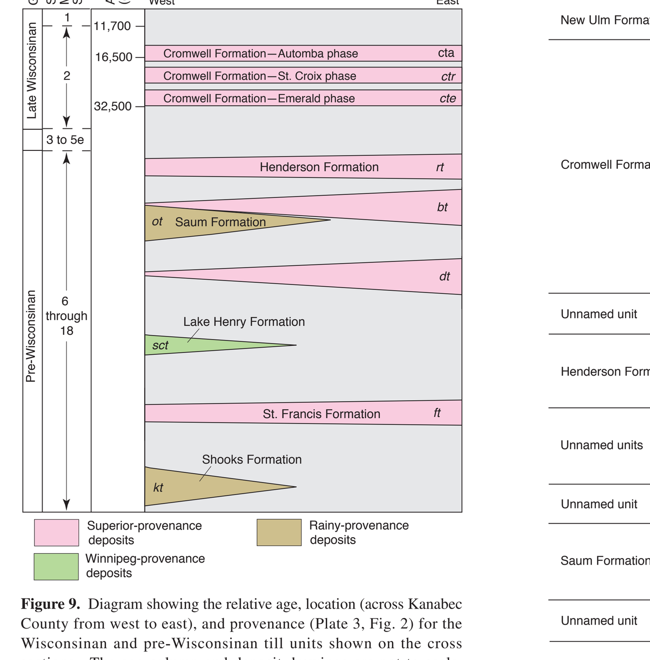

Figure 9. Diagram showing the relative age, location (across Kanabec County from west to east), and provenance (Plate 3, Fig. 2) for the Wisconsinan and pre-Wisconsinan till units shown on the cross sections. The age column and deposit drawings are not to scale. Marine Isotope Stage (MIS) correlations were estimated using figures in Jennings and others (2006). The date of 11,700 cal yr BP (Walker and others, 2008) is considered the start of the Holocene Epoch. The approximate age for the advance of the Automba-phase ice is about 16,500 cal yr BP[1] (14,000 ^{14}C yr BP; Clayton and Moran, 1982). A radiocarbon date from Chisago County to the southeast places a maximum age of about 32,500 cal yr BP[1] (28,580 ± 220 ^{14}C yr BP) on the advance of the Emerald phase (Meyer, 2010). Marl deposits stratigraphically above the Lake Henry and Saum Formations in central Minnesota had a uranium series minimum age of 200,000 yr BP (Knaeble and Meyer, 2007).

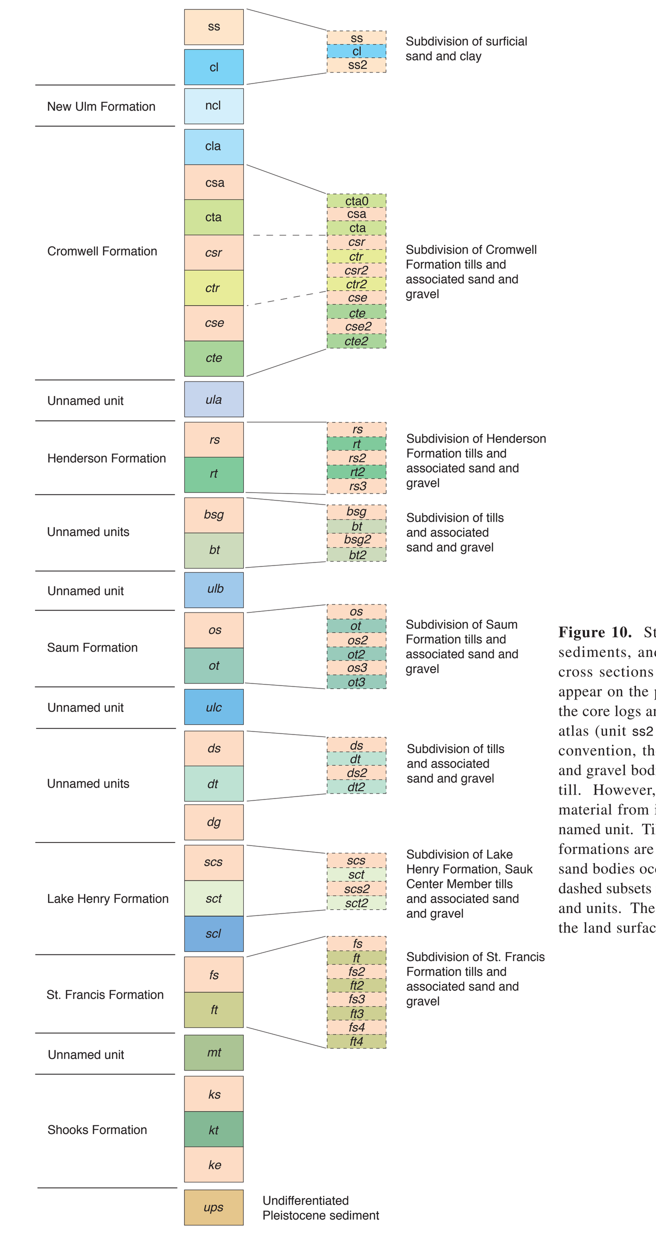

Figure 10. Stratigraphic position of till, lacustrine sediments, and sand and gravel bodies depicted in cross sections and stratigraphic logs. Not all units appear on the printed cross sections, but do occur on the core logs and in the digital files accompanying this atlas (unit ss2 only appears in the digital files). By convention, the name designations of depicted sand and gravel bodies are associated with their underlying till. However, sand units are likely an admixture of material from immediately above or below the actual named unit. Tills and associated sand bodies of several formations are subdivided into multiple layers (where sand bodies occur within the till unit), depicted by the dashed subsets next to each of the associated formations and units. These layers are identified by number from the land surface down.

Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

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