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QUATERNARY STRATIGRAPHY

By

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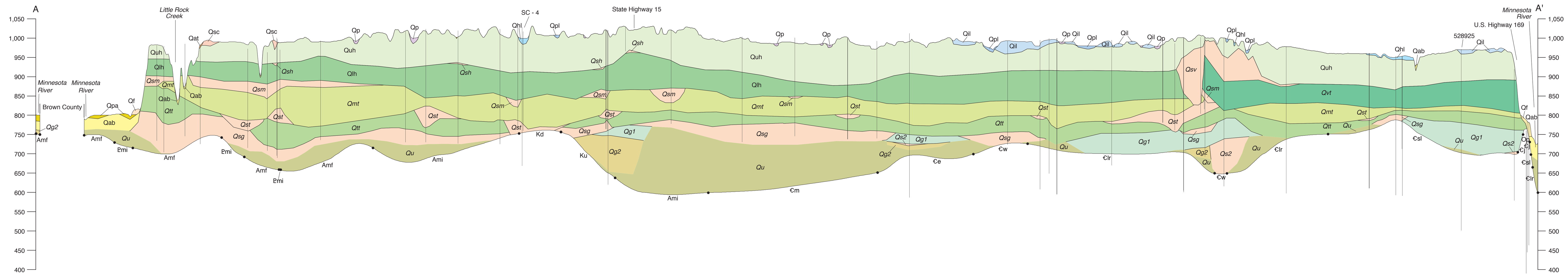
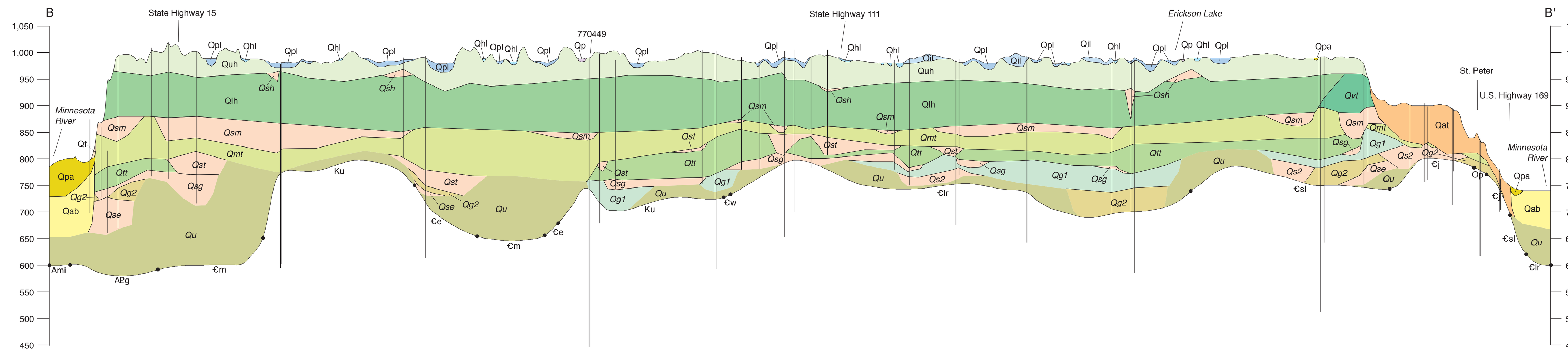
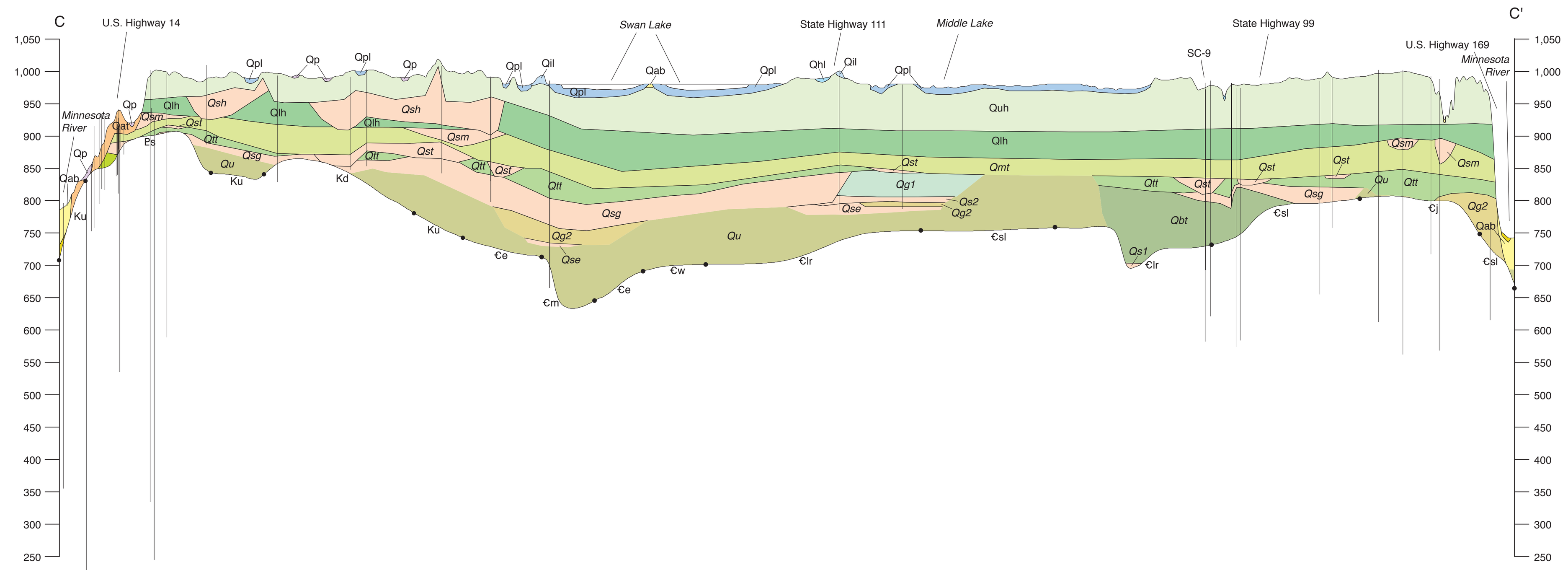
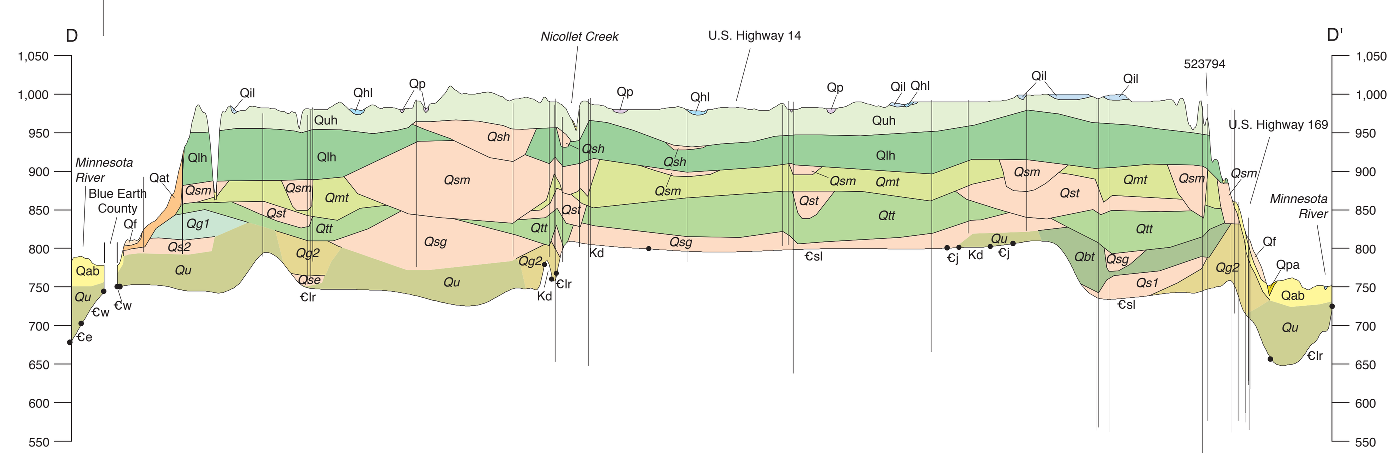
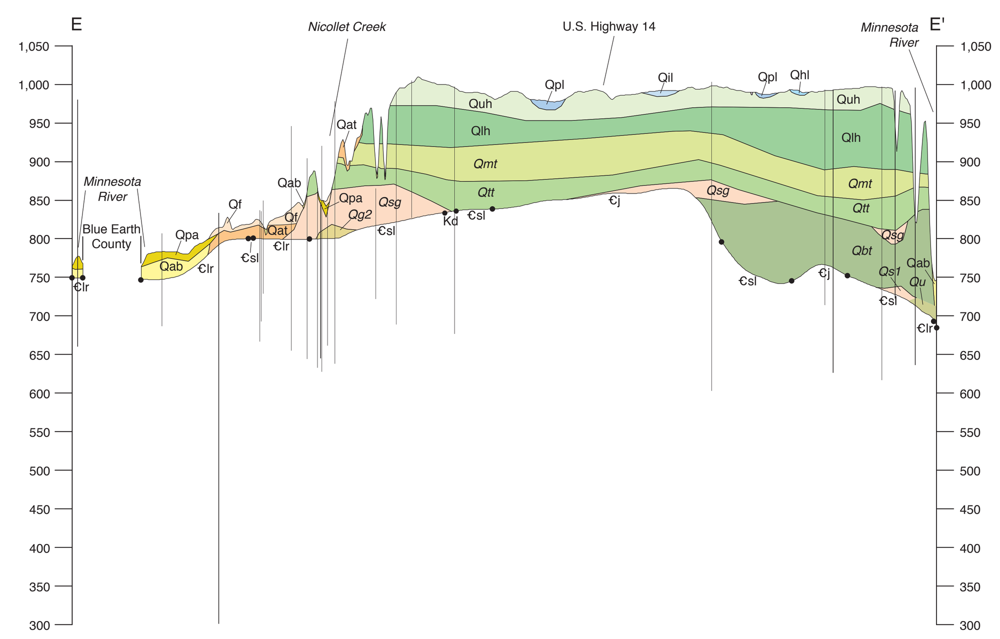
2012

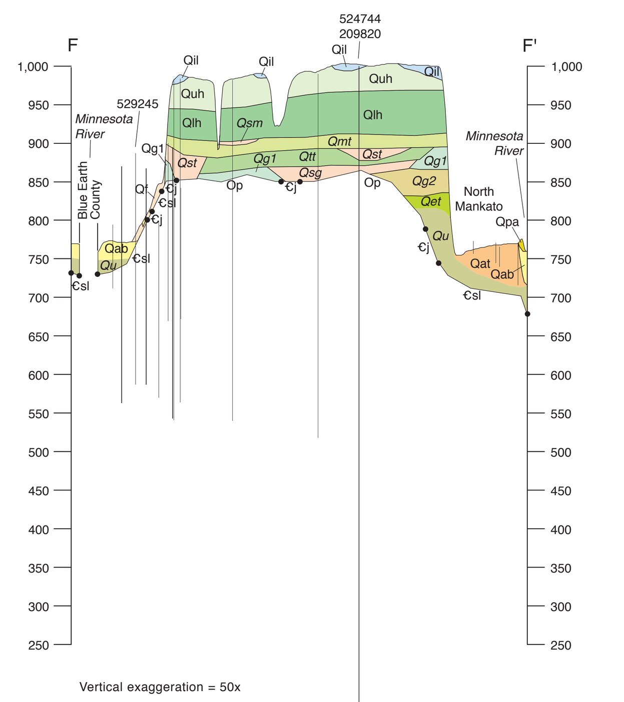












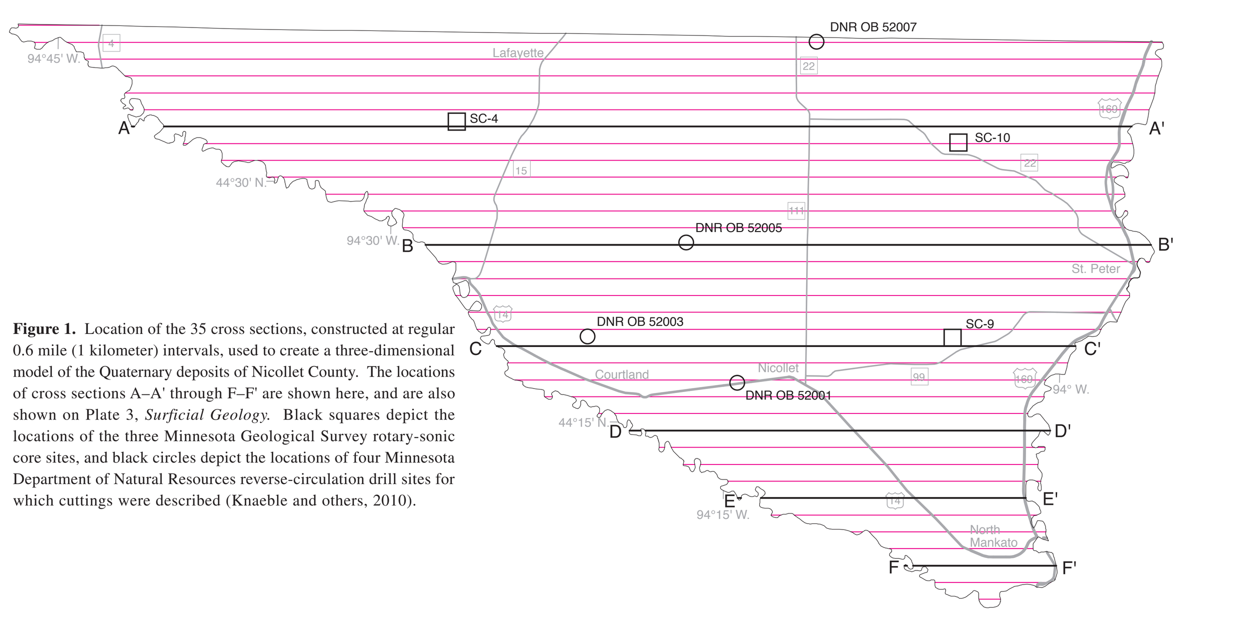


Figure 1. Location of the 35 cross sections, constructed at regular 0.6 mile (1 kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Nicollet County. The locations of cross sections A–A' through F–F' are shown here, and are also shown on Plate 3, *Surficial Geology.* Black squares depict the locations of the three Minnesota Geological Survey rotary-sonic core sites, and black circles depict the locations of four Minnesota Department of Natural Resources reverse-circulation drill sites for which cuttings were described (Knaeble and others, 2010).

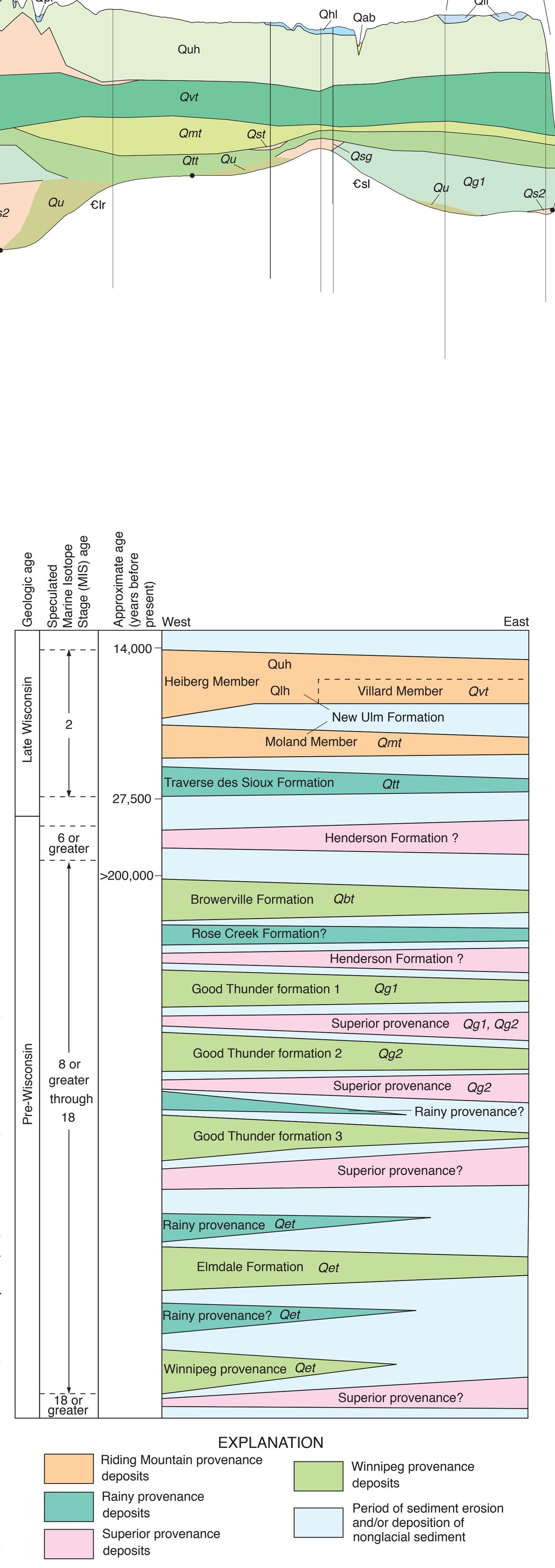


Figure 2. Diagram showing relative age, location (across the county from west to east), provenance (Plate 3, Table 1), and related unit labels from the cross sections for glacial deposits of Nicollet County (Table 1). The age column and deposit drawings are not to scale. The presence of some of the deposits shown is speculated from their occurrence to the south. Ice that deposited these units presumably crossed Nicollet County. Marine Isotope Stage (MIS) correlations were estimated using figures in Jennings and others (2006). The age shown for the end of deposition for till of the Heiberg Member of the New Ulm Formation is the calendar year conversion of a radiocarbon date (12,260 ± 90) from wood at the contact between the till and overlying lake sediment from a site to the south in Blue Earth County (Jennings and others, 2012). At a site in Sibley County to the north, the base of peat above pond sediment above the Heiberg Member yielded a radiocarbon date of 12,400 ± 60 (Ashworth and others, 1981). Similar radiocarbon ages have been determined for wood in similar depositional settings in the Twin Cities area (Meyer, 1998). The approximate age for the onset of deposition of the Traverse Des Sioux Formation is the calendar year conversion of a radiocarbon date (22,960 ± 90) from wood in a core drilled in Blue Earth County (Meyer and others, 2012). Two calcite samples from marl deposits above Browerville Formation till in Todd County in central Minnesota had an uranium series minimum age of 200,000 years before present (Knaeble and Meyer, 2007). All core samples from the area that have undergone detrital remnant magnetization analysis at the Institute for Rock Magnetism at the University of Minnesota have yielded normal polarity, indicating they were likely deposited after the Bruhnes normal–Matuyama reversed polarity boundary, dated at 780,000 years B.P., and thus no older than MIS 18. However, the oldest deposits may have been laid down during the relatively brief Jaramillo normal polarity event dated at over 1 million years ago, which is correlated with MIS stages 28 to 30 (Lisiecki and Raymo, 2005).

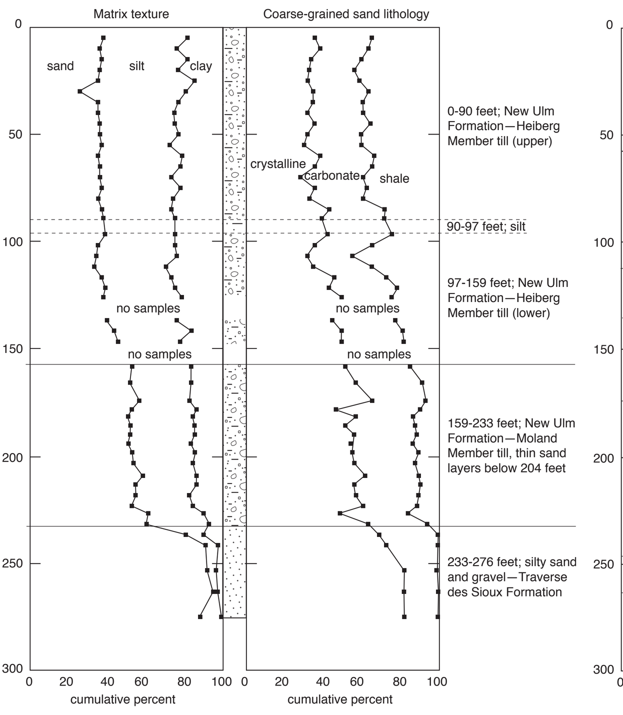


Figure 3. Nicollet County rotary-sonic core SC-4, unique number 270340 (shown on Fig. 1). Collected at T. 111 N., R. 30 W., sec. 20, elevation 1,009 feet. Under coarse-grained sand lithology, with reference to Table 1, crystalline is the same as Precambrian, carbonate includes both Paleozoic and Cretaceous carbonate, and shale is the shale portion of the Cretaceous category.

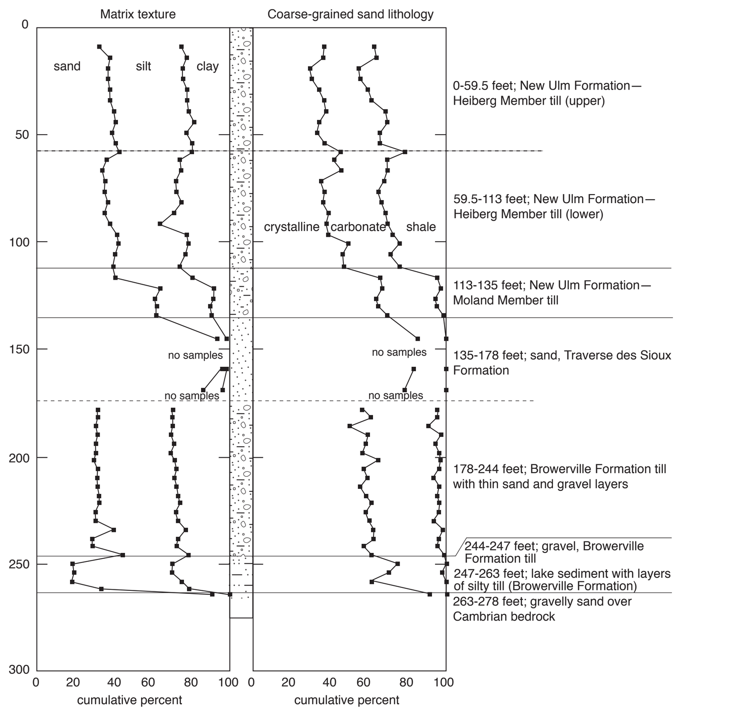
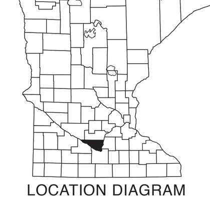


Figure 4. Nicollet County rotary-sonic core SC-9, unique number 270359 (shown on Fig. 1). Collected at T. 110 N., R. 27 W., sec. 28, elevation 977 feet. Under coarse-grained sand lithology, with reference to Table 1, crystalline is the same as Precambrian, carbonate includes both Paleozoic and Cretaceous carbonate, and shale is the shale portion of the Cretaceous category.



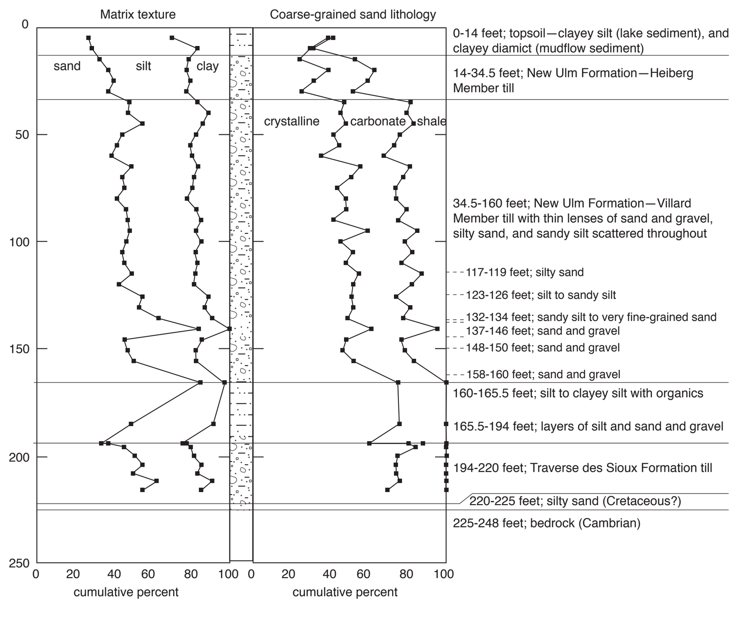


Figure 5. Nicollet County rotary-sonic core SC-10, unique number 270360 (shown on Fig. 1). Collected at T. 111 N., R. 27 W., sec. 21, elevation 985 feet. Under coarse-grained sand lithology, with reference to Table 1, crystalline is the same as Precambrian, carbonate includes both Paleozoic and Cretaceous carbonate, and shale is the shale portion of the Cretaceous category.

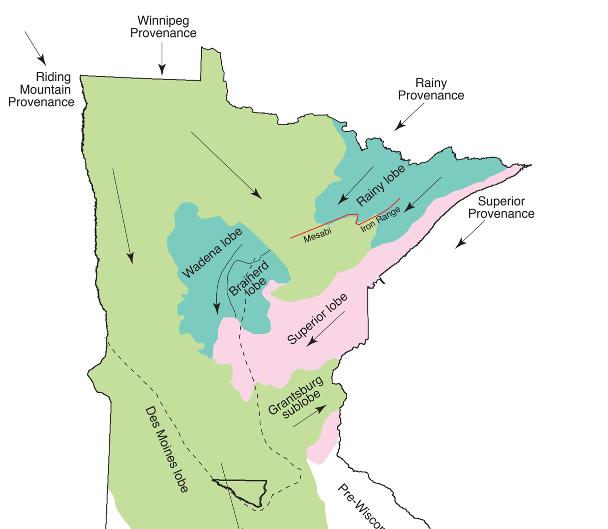


Figure 6. Location of major provenances (source regions). Glacial sediments deposited in the county derive their distinct material content from bedrock and sediment found in the region of these provenances. During the last glaciation, the Late Wisconsin, Nicollet County was initially covered by ice carrying debris of predominantly Rainy provenance—the Wadena lobe. The approximate maximum extent of the Wadena lobe is shown by the dashed line. When the Wadena lobe waned, the county was completely covered by at least three advances of the Des Moines lobe.

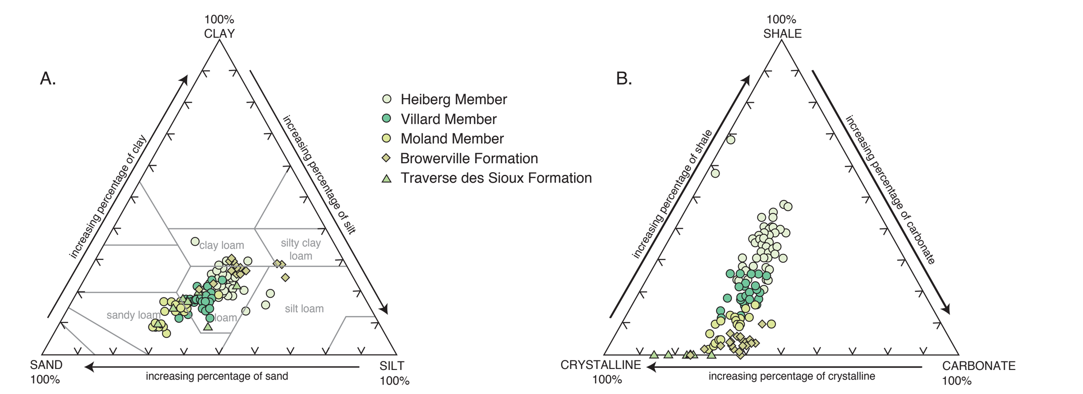


Figure 7. Ternary diagrams showing (A) matrix texture (less than 2 millimeter size fraction) and (B) composition of the very coarse-grained (1 to 2 millimeters) sand fraction in samples from the rotary-sonic cores of Nicollet County (Figs. 3, 4, 5).

	MATRIX TEXTURE					CLAST TYPE								
Deposit description and geologic units	Total number of samples	Gravel (percentage of total sample weight)	Percentage of the less than 2 millimeter fraction: Sand	Silt	Clay	Total number of samples	Percentage of total grains counted of the 1-2 millimeter fraction: Precambrian	Paleozoic	Cretaceous	Percentage of total Precambrian grains counted: Light	Clear quartz	Dark	Red	Gray shale/total Cretaceous (percent)
New Ulm Formation														
Heiberg Member till (units Quh and Qlh)	254	5	37	39	24	254	37	26	37	76	15	9	0	96
Villard Member till (unit *Qvt*)	52	6	44	36	20	52	48	30	22	72	16	11	1	90
Moland Member till (unit *Qmt*)	38	9	56	31	13	38	59	31	10	73	16	10	1	90
Traverse des Sioux Formation till (unit *Qtt*)	48	7	51	33	16	48	75	24	1	62	23	13	2	24
Browerville Formation till (unit *Qbt*)	62	4	35	41	24	62	56	32	12	47	38	14	1	28
Good Thunder formation till 1 (unit *Qg1*)	16	5	33	42	25	16	47	47	6	68	21	11	0	45
Good Thunder formation till 2 (unit *Qg2*)	10	4	40	39	20	10	61	37	2	65	22	11	2	60
Red Superior-source till (mostly unit *Qg2*; leached)	3	2	50	31	19	3	100	0	0	51	33	11	5	
Rainy-source till (mostly unit *Qet*)	5	5	61	25	14	2	85	14	1	51	32	14	2	
leached						3	100	0	0	49	42	7	2	
Elmdale Formation till (unit *Qet*)	12	1	33	44	23	5	80	19	1	62	29	9	0	6
leached						7	100	0	0	50	44	5	1	

Table 1. Average values for the matrix texture and sand composition of tills recognized in Nicollet County. Matrix texture (the less than 2 millimeter grain size fraction of the sample) is expressed as relative proportions of sand, silt, and clay in percent. The lithologic composition of the very coarse-grained sand fraction (1-2 millimeters) is expressed in percent as relative proportions of Precambrian rocks, Paleozoic (mostly carbonate) rocks, and Cretaceous rocks (mostly shale and limestone) using the classification system of Hobbs (1998). The Precambrian 1-2 millimeter fraction is further differentiated by rock type—light (granite and gneiss), monomineralic (clear) quartz, dark (mafic-rich igneous and metamorphic rocks), and red (rhyolite, sandstone). Gray shale as a percent of the total Cretaceous is also given, as this helps to differentiate units of the New Ulm Formation from older deposits.

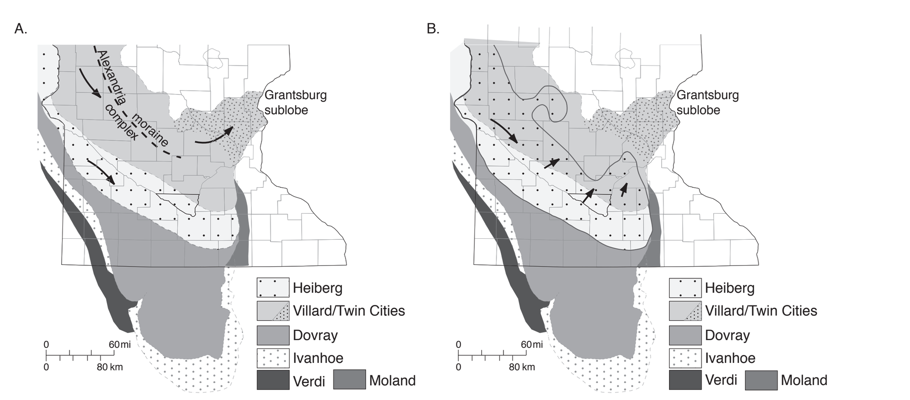


Figure 8. Distribution of members of the New Ulm Formation.

A. Early distribution of the Villard and Heiberg Members (from Lusardi and others, 2011).

B. Subsequent distribution of the Villard and Heiberg Members as the Villard Member ice source diminished and the Heiberg Member ice spread into the area. The area where the Heiberg Member overlaps the Villard Member is both shaded and sparsely stippled (from Lusardi and others, 2011).

CROSS SECTION SYMBOLS

Geologic contact—Approximate. No-line boundaries occur where data are insufficient to reliably extend units. Dots at the base of the Quaternary section denote bedrock contacts (as depicted on Plate 2, *Bedrock Geology*).

Drill hole—Well records from the County Well Index. The top of the drill hole may not coincide with the cross section surface elevation line because the point is located near (within 0.3 mile [0.5 kilometer]) but not on the cross-section line and therefore may have a different surface elevation.

INTRODUCTION

The Quaternary Stratigraphy plate describes the unconsolidated sediment expected to be encountered between the land surface and bedrock in Nicollet County. Cross sections A–A' through F–F' are representative of 35 cross sections (Fig. 1) that were constructed to create a three-dimensional model of the Quaternary deposits of Nicollet County. The major sand bodies from this model are depicted on Plate 5, *Sand Distribution Model*; the full model and all the cross sections used to develop it can be accessed through the digital files of the Minnesota Geological Survey. The geologic units shown on the cross sections were defined using outcrops, drill core, auger samples, drill cuttings, and water-well and bridge-boring logs (Plate 1, *Data-Base Map*). Some units match those on Plate 3, *Surficial Geology*, some new units appear only on the cross sections, and others for simplification purposes are a combination of multiple units from Plate 3. Vertical exaggeration is 50x for all cross sections.

Figure 2 is a schematic illustration showing the relationships between age, provenance, stratigraphic position, and location of the sediments deposited by major glacial episodes (see Plate 3). Analysis of the texture and clast types of the Quaternary sediments was done for selected geologic units, as listed in Table 1. Logs of three rotary-sonic cores drilled for the Minnesota Geological Survey by Miller Drilling Company of Lawrenceburg, Tennessee, are shown in Figures 3 to 5.

ACKNOWLEDGEMENTS

Mark Johnson, formerly of Gustavus Adolphus College and now of the University of Gothenburg, Sweden, made many contributions to our understanding of the stratigraphy of the area, as have several of his former students. Seth Greenwood and his staff at the Nicollet County Public Works Department granted access to county bridge boring records. Thanks are extended to Neil and Peter Anderson and Jeff Franta, landowners who allowed rotary-sonic drilling on their property; Charles Vogel, who granted permission to drill in a township road right-of-way; and to all gravel pit operators and landowners who gave permission to examine exposures on their property.

DESCRIPTION OF CROSS SECTION UNITS

Each unit description on the cross sections is placed in one of three categories, as indicated in parentheses after the description: 1. *Surficial Geology* unit—unit having an identical description, label, and color as on Plate 3, *Surficial Geology*. See Plate 3 for detailed descriptions. 2. Modified unit—multiple units from Plate 3 combined into one unit on the cross sections. 3. New unit—unit that appears only on the cross sections that has a unique label and color. Some surficial geology deposits along the cross-section line are too small or thin to be shown, including all colluvium (unit Qc).

Key stratigraphic control points, such as rotary-sonic drill holes completed by the Minnesota Geological Survey and analyzed cuttings sets collected by water-well drillers and the Minnesota Department of Natural Resources (Knaeble and others, 2010), are differentiated on the cross sections and have an associated unique number on file at the Minnesota Geological Survey. Drill samples and outcrops along the Minnesota River valley have established the presence of a number of subsurface deposits in Nicollet County that predate those of the last glaciation, the Late Wisconsin (Fig. 2, Table 1), but they have been highly eroded and are discontinuous across most of the county. Distinguishing individual stratigraphic units from water-well records, the primary subsurface data base, is difficult, so the pre-Wisconsin units have been combined as described below. Detailed descriptions of those units that have been formally named can be found in Johnson and others (in press).

QUATERNARY

Holocene deposits

Qp — **Organic debris, clay, and silt** (*Surficial Geology* unit)

Qf — **Loamy sand and gravel sand** (*Surficial Geology* unit)—Elevated by artificial fill in cross section E-E.'

Qhl — **Silt to clay** (*Surficial Geology* unit)

Qpl — **Organic sediments over silt to clay** (modified unit)—A combination of map units Qp and Qhl from Plate 3 where too thin or complex to map separately.

Qpa — **Organic sediments and/or sand, silt, and clay** (modified unit)—A combination of map unit Qp and finer-grained portions of unit Qa from Plate 3. Minor sand at depth, but generally loamy-textured. Elevated by artificial fill in section F–F.'

Holocene and Pleistocene deposits

Qab — **Sand, loamy sand, and gravel** (modified unit)—A combination of map units Qhb and coarser-grained portions of unit Qa from Plate 3. Fine-grained layers in places, but generally sandy-textured. Elevated by artificial fill in section C–C.'

Qst — **Sand and gravelly sand with silt and clay** (*Surficial Geology* unit)

Pleistocene deposits of the Late Wisconsin glaciation

New Ulm Formation—Light olive-brown to dark gray, bedded sediment and clay loam to sandy loam-textured diamicton of northwestern (Riding Mountain) provenance, deposited by ice and meltwater of the Des Moines lobe (Fig. 6). This is the dominant Quaternary formation across most of Nicollet County.

Qsc — ***Sand, gravelly sand, and cobbly gravel*** (*Surficial Geology* unit)

Qcl — ***Diamicton with silt, clay, and sand*** (*Surficial Geology* unit)

Quh — ***Upper Heiberg Member till*** (modified unit)—A combination of map units Qts, Qt, Qth, Qtm, and Qtw. Loam to clay loam diamicton; shale clasts generally compose from 35 to 45 percent of the very coarse-grained (1-2 millimeter) sand fraction (Fig. 7, Table 1). Till of the Heiberg Member is split into an upper (Quh) and lower (Qlh) unit; it is separated in places by a generally thin silt or sand (Qsh) layer. The till above and below the "break" is not noticeably different in texture or lithology. This "break" is interpreted to represent a pause or possible retreat in the advance of the ice stream that deposited the Heiberg Member before it covered the now stagnant ice that deposited the Villard Member to the northeast and continued its advance (Fig. 8). A thin layer of black clay or loam noted at the depth of the contact of the upper and lower units in two water-well logs (unique numbers 585564 and 733642) may imply enough time for organics to accumulate in between advances of the ice that deposited the two similar till layers. Sand and gravel beds are present in the upper portion of unit Quh in places, particularly in northern Nicollet County, but are too thin and discontinuous to show. The unit includes fine-grained lake sediment in places.

Qsh — ***Sand and gravel*** (new unit)—Deposited just before or during the final advance of the Des Moines lobe. The thick sand bodies in southwestern Nicollet County (cross sections C–C' and D–D'; Plate 5) may have been deposited in the zone between ice streams that deposited the Heiberg and Garden City Members of northwest Blue Earth County to the south (Meyer and others, 2012).

Qsv — ***Sand and gravel*** (new unit)—The thick sand body in northeastern Nicollet County (cross section A–A'; Plate 5) was deposited in the zone between ice streams that deposited the Heiberg and Villard Members.

Qlh — ***Lower Heiberg Member till*** (new unit)—Deposited by ice advancing at the same time as the ice that deposited the Villard Member (Fig. 8; see Plate 3, Fig. 2). The separate ice streams advanced from different source areas and the resulting glacial deposits are distinguished by their matrix texture and grain composition (Fig. 7, Table 1). The contact between till of the Heiberg Member and the adjacent Villard Member is variable and may include layers of sand and gravel or silt, as well as mixed or alternating layers of the two tills. The unit includes fine-grained lake sediment in places.

Qvt — ***Villard Member till*** (new unit)—Deposited by ice advancing at the same time as the ice that deposited the lower Heiberg Member (Fig. 8; see Plate 3, Fig. 2). Loam to sandy loam diamicton; shale clasts generally compose from 15 to 25 percent of the very coarse-grained (1-2 millimeter) sand fraction (Fig. 7, Table 1). Pollen from lake sediment below Villard Member till in core SC-10 (Fig. 5) could imply existence of an aspen parkland similar to southern Manitoba (Vania Stefanova, 2011, unpub. data). Sites from similar stratigraphic settings in Iowa have yielded types of insect fauna that imply that even as the Des Moines lobe was advancing at this time, the climate was starting to warm (Schwert and Torpen, 1996). The unit includes fine-grained lake sediment in places.

Qsm — ***Sand and gravel*** (new unit)—Deposited by meltwater of the Des Moines lobe.

Qmt — ***Moland Member till*** (new unit)—Deposited by an early phase of the Des Moines lobe. Coarse-grained loam to sandy loam diamicton; dense, gravelly in places. Shale clasts generally compose from 2 to 12 percent of the very coarse-grained (1-2 millimeter) sand fraction (Fig. 7, Table 1). Thin beds of silt to gravel within the unit are common in places. Where unit Qmt is thick it includes fine-grained lake sediment in places. The unit may also include deposits from more than one early phase of the Des Moines lobe. Without laboratory analyses unit Qmt is difficult to distinguish from till of the older Traverse des Sioux Formation (unit Qtt), so the thickness and extent of the two units relative to each other as shown in the cross sections is approximate.

New Ulm and Traverse des Sioux Formations

Qst — ***Sand and gravel*** (new unit)—Deposited by meltwater of the Des Moines and/or Wadena lobes.

Traverse des Sioux Formation—Yellow-brown to gray, dense, bedded sediment and coarse-grained loam to sandy loam diamicton of north/northeastern (Rainy) provenance, deposited by the Wadena lobe and its meltwater (Fig. 6). The formation crops out in a number of locations along the wall of the Minnesota River valley, including in Seven Mile Creek Park in southern Nicollet County. The unit lies stratigraphically below New Ulm Formation till.

Qtt — ***Sandy till*** (new unit)—Dense, gravelly to rocky in places. Shale clasts are rare or absent in the very coarse-grained (1-2 millimeter) sand fraction (Fig. 7, Table 1). Thin beds of silt to gravel within the unit are common in places. In a few places the lower portion (or entire thin areas) consists of reddish sandy till of the Henderson Formation of Superior provenance (Fig. 2). The unit includes fine-grained lake sediment in places.

Qsg — ***Sand and gravel*** (new unit)—Deposited primarily by meltwater of the Wadena lobe, but includes older sediment of both Winnipeg and Superior provenances.

Pleistocene deposits of pre-Wisconsin glaciations

Browerville Formation—Light olive-brown to dark gray, bedded sediment and dense, loam to clay loam-textured diamicton of north/northwestern (Winnipeg) provenance (Fig. 6). Although the Browerville Formation is prominent in central (Knaeble and Meyer, 2007) and southeast (Meyer and Knaeble, 1998; Meyer, 2000) Minnesota, in south-central Minnesota it has largely been eroded. A thick section of the formation was recovered in rotary-sonic core SC-9 (Fig. 4), and is also exposed in a number of outcrops along the western wall of the Minnesota River valley for about a mile north of North Mankato. A record from a water well (unique number 686862) drilled near core hole SC-9 records "red clay" above gray, hard "sticky clay" at the same depth that the Browerville Formation was cored. If the "red clay" is the Superior provenance Henderson Formation, then it is younger than the Browerville Formation, but the relationship has not been confirmed in core or outcrop.

Qbt — ***Loamy to clayey till*** (new unit)—Common Paleozoic carbonate with some Cretaceous shale, limestone, and fossil fragments, as well as abundant monomineralic quartz grains (Fig. 7, Table 1). Although likely more widespread than shown in the cross sections, this unit is only recognized as preserved in a buried valley in southeast Nicollet County. This unit includes some fine-grained lake sediment.

Qs1 — ***Sand and gravel*** (new unit)—Browerville Formation and Superior provenance sediment, and likely older Winnipeg provenance sediment.

Good Thunder formation—Light olive-brown to dark gray, bedded sediment and dense, coarse-grained loam to clay loam-textured diamicton of Winnipeg provenance (Fig. 6). The till generally has high carbonate and small amounts of gray shale (Table 1). There are at least three tills identified as part of the informally named Good Thunder formation in Nicollet County, but only the upper two are shown in the cross sections on this plate. For the purpose of sand modeling, these tills are numbered 1 through 3 from the top down (Fig. 2). Units Qg1 and Qg2 are similar in texture and grain content, but distinctions can be made. Unit Qg1 has a few gray shale fragments, and the others have only trace amounts. Unit Qg2 is generally coarser-grained and averages less carbonate. These units likely correlate at least in part with the Lake Henry and Eagle Bend Formations of central Minnesota (Johnson and others, in press). The Good Thunder formation is well exposed in the lower part of the bluff at North Mankato in the vicinity of U.S. Highway 14, and in a road cut in the southeast corner of T. 109 N., R. 29 W., sec. 24 in Courtland Township.

Qg1 — ***Loamy to clayey till*** (new unit)—Abundant carbonate rock fragments, minor shale. Unit likely includes or consists of till from the Browerville Formation, unit *Qg2*, or fine-grained lake sediment in places. Reddish sandy till of Superior provenance, likely equivalent to the St. Francis Formation (Johnson and others, in press) of central Minnesota, is included in a few places in the lower portion of the unit.

Qs2 — ***Sand and gravel*** (new unit)—Mostly Good Thunder formation sediment, but includes some sediment of Superior provenance.

Qg2 — ***Loamy to coarse-grained loamy till*** (new unit)—In places the upper and/or lower portions (or entire thin areas) consists of reddish sandy till of Superior provenance, likely equivalent to the St. Francis Formation. Also likely includes older and younger Winnipeg provenance till and fine-grained lake sediment.

Qse — ***Sand and gravel*** (new unit)—Includes Good Thunder formation sediment and older Winnipeg, Superior, and Rainy provenance sediment.

Elmdale Formation—Yellow-brown to dark gray, bedded sediment and clay loam to loam-textured diamicton of Winnipeg provenance (Fig. 6), with only low to moderate amounts of carbonate (Table 1). Exposed in a clay pit between New Ulm and Courtland, along with leached sandy till likely of Rainy provenance.

Qet — ***Clayey to sandy till*** (new unit)—Includes both fine-textured till of the Elmdale Formation and possibly other unnamed formations of Winnipeg provenance, as well as coarse-textured till of Rainy provenance that could correlate to till of the Shooks and Mulligan Formations (Johnson and others, in press).

Undifferentiated Quaternary deposits

Qu — **Undifferentiated sediment** (new unit)—Includes till and bedded clay, silt, sand, and gravel. Shown in areas where control data were scarce or absent.

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