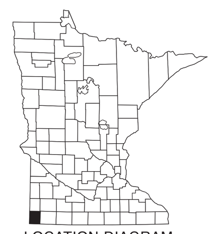
UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director

Prepared and Published with the Support of
THE ROCK COUNTY BOARD OF COMMISSIONERS,
THE MINNESOTA DEPARTMENT OF NATURAL RESOURCES, AND
THE MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND
AS RECOMMENDED BY THE LEGISLATIVE-CITIZEN COMMISSION ON MINNESOTA RESOURCES

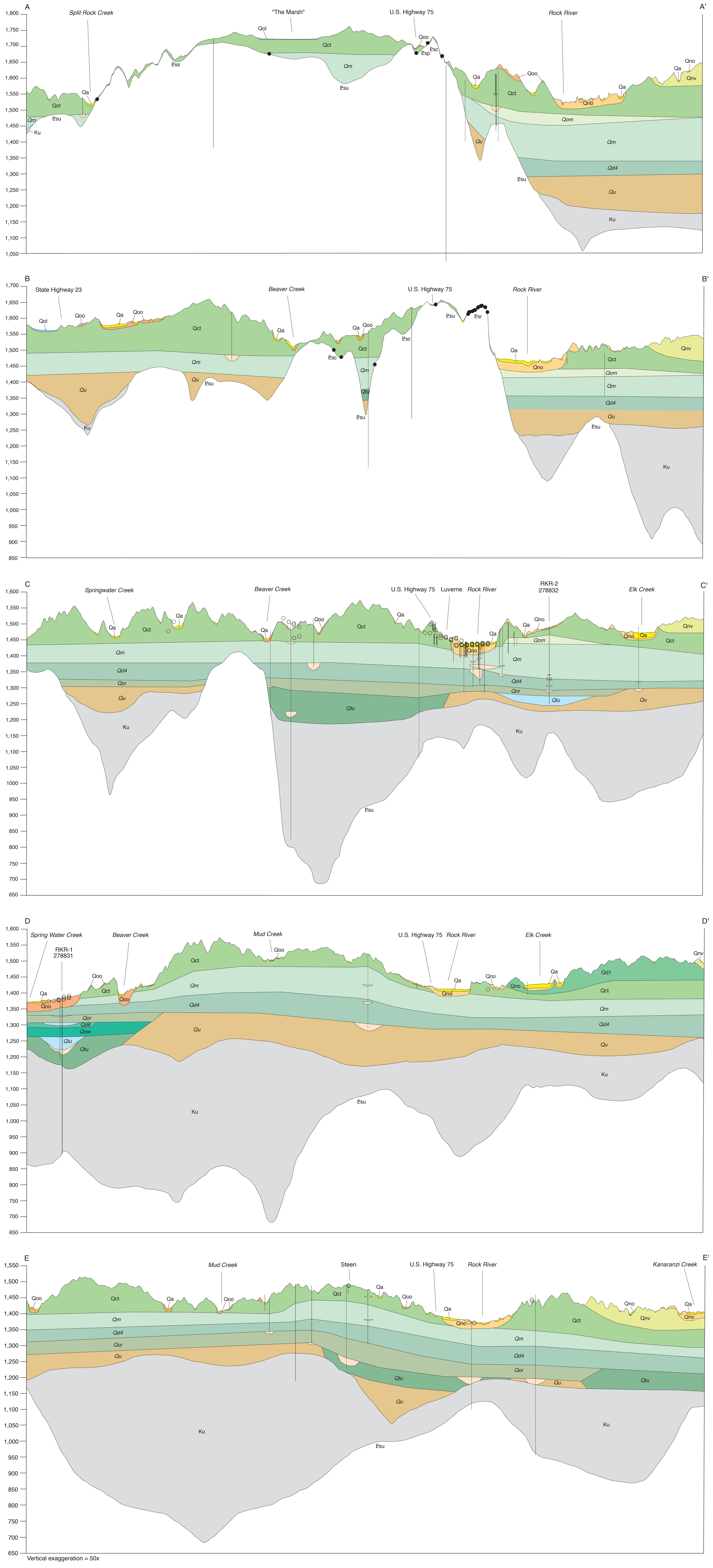

LOCATION DIAGRAM

QUATERNARY STRATIGRAPHY

By

Angela S. Gowan

2020



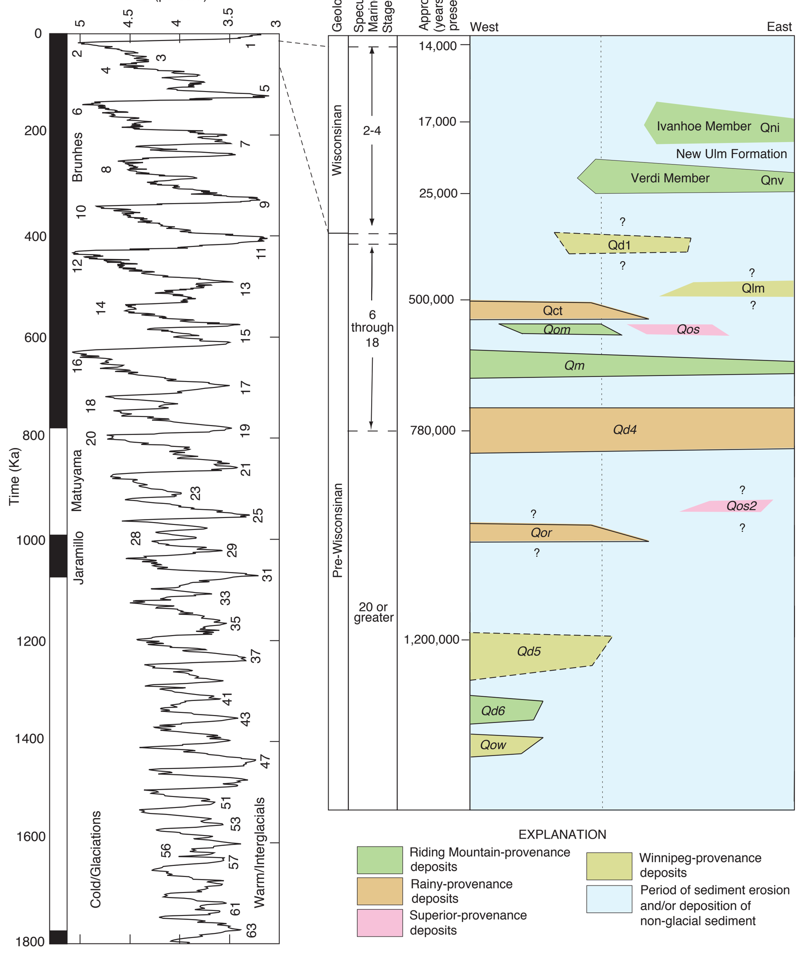


Figure 1. The graph on the left shows δ[18]O versus time (modified from Johnson and others, 2016). High values of δ[18]O, measured in sediments from deep ocean cores, have been found to correlate with periods of time with large volumes of global glacial ice (Lisiecki and Raymo, 2005). Therefore, peaks to the left in the graph represent periods of active glaciation or glacial maximums, and peaks to the right represent glacial minimums. The numbers next to the peaks start at 1 (representing our current glacial minimum) and precede sequentially back in time; they represent the Marine Isotope Stage (MIS), with odd numbers representing minimums and even numbers for maximums. The black and white bar on the far left represents recorded time periods of normal (black; compass points north) and reversed (white; compass points south) polarity of the Earth's magnetic field. The graph on the right shows a time-distance diagram depicting relative age, location (from west to east), provenance (see Plate 3, Fig. 2), and related unit labels from the cross sections for Wisconsinan and pre-Wisconsinan glacial deposits. The age column and deposit drawings are schematic and not to scale. Dashed lines indicate units in the regional stratigraphy but not encountered in drill holes in Rock County; no-line boundaries surround units only encountered in Nobles County (Gowan, 2020). The dotted vertical line indicates the Rock/Nobles County border.

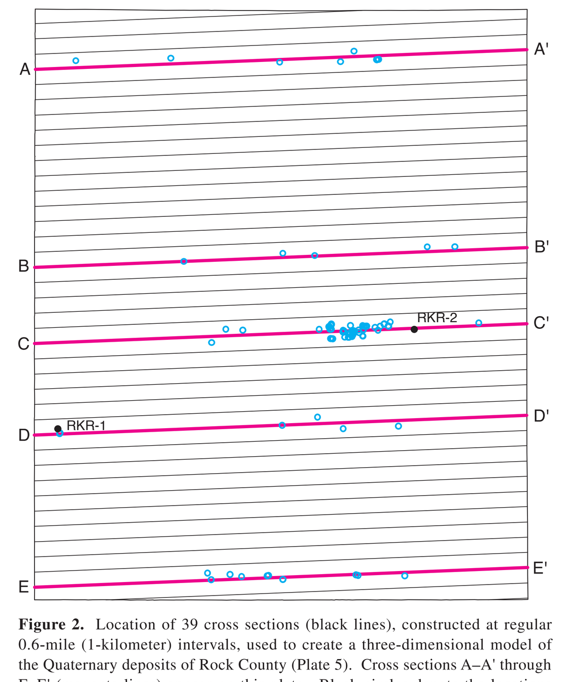


Figure 2. Location of 39 cross sections (black lines), constructed at regular 0.6-mile (1-kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Rock County (Plate 5). Cross sections A–A' through E–E' (magenta lines) appear on this plate. Black circles denote the locations where rotary-sonic cores were collected. Blue circles denote the location of water wells within 0.3-mile (0.5-kilometer) of the published cross section.

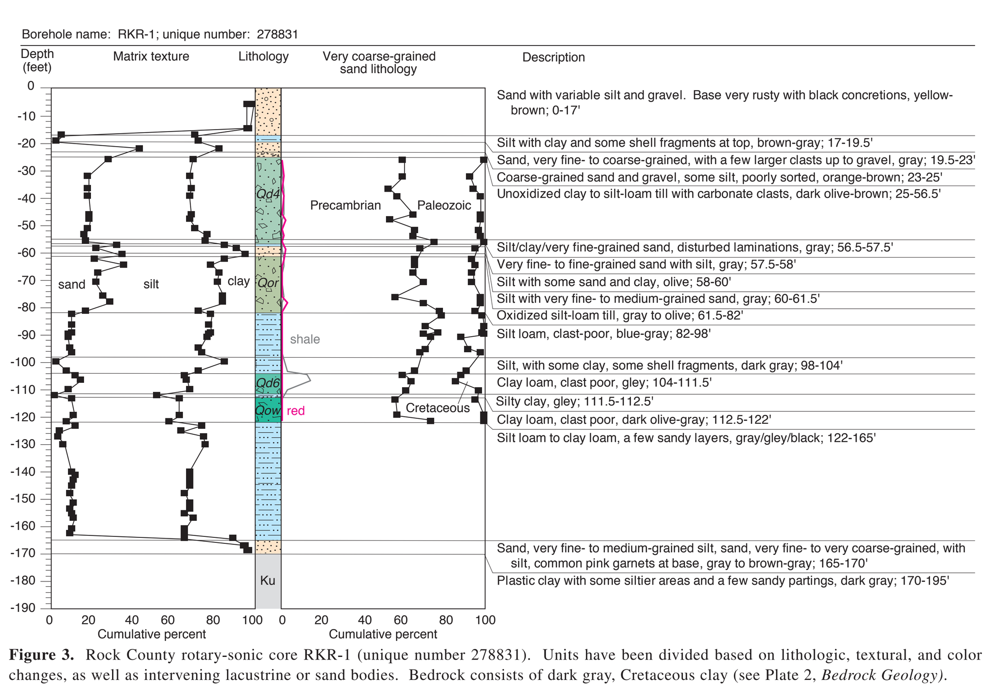


Figure 3. Rock County rotary-sonic core RKR-1 (unique number 278831). Units have been divided based on lithologic, textural, and color changes, as well as intervening lacustrine or sand bodies. Bedrock consists of dark gray, Cretaceous clay (see Plate 2, *Bedrock Geology*).

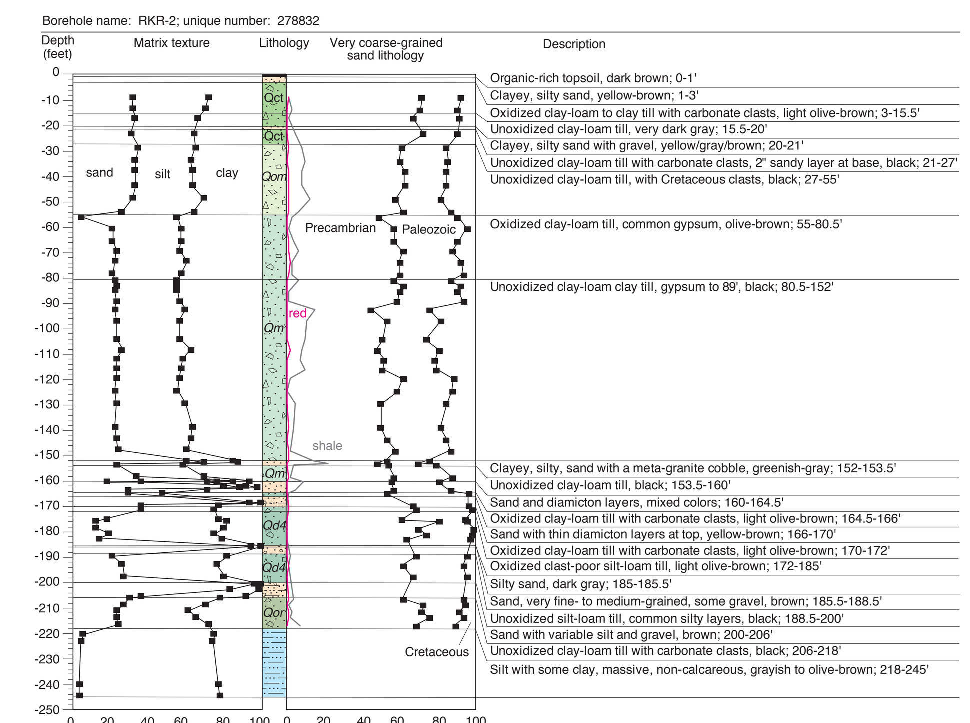


Figure 4. Rock County rotary-sonic core RKR-2 (unique number 278832). Units have been divided based on lithologic, textural, and color changes, as well as intervening lacustrine or sand bodies. Bedrock was not encountered in this boring.

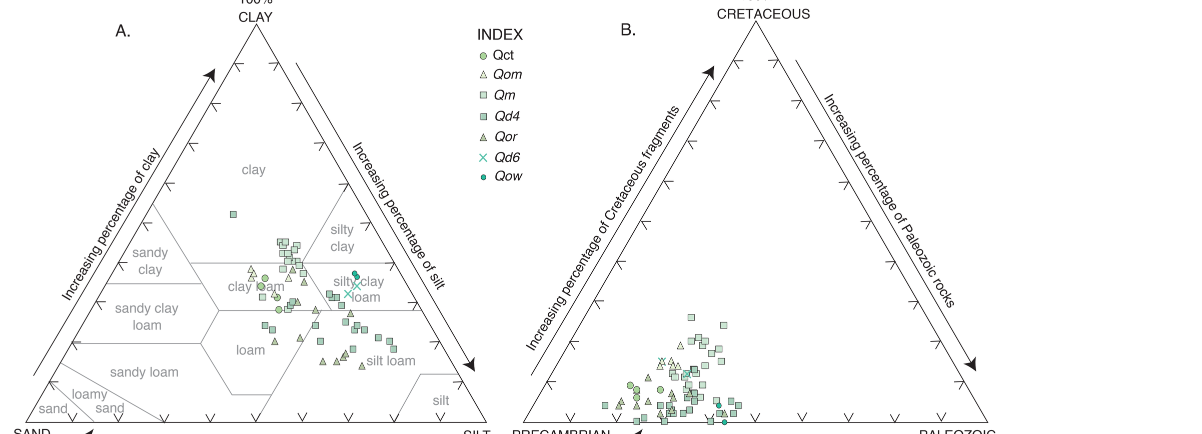


Figure 5. Ternary diagrams showing the texture and composition of till samples mapped in the subsurface in Rock County.
A. Matrix texture using the U.S. Department of Agriculture texture classification system (less than 2-millimeter fraction).
B. Composition of the very coarse-grained (1-2 millimeters) sand fraction (after Hobbs, 1998).

INTRODUCTION

The *Quaternary Stratigraphy* plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Rock County (Fig. 1). Cross sections A–A' through E–E' are representative of 39 cross sections (Fig. 2) at 0.6-mile (1-kilometer) spacing that were constructed to create a three-dimensional model of the Quaternary deposits of Rock County. The Quaternary geologic till units shown on the cross sections were defined from interpretation of new data collected for this study and from existing data from previous investigations (see Index to Previous Mapping on Plate 3, *Surficial Geology*, for references to adjacent mapping projects). These include rotary-sonic core from two drill holes completed by the Minnesota Geological Survey for this project (RKR-1 and RKR-2; Figs. 3, 4, respectively), and information collected from rotary-sonic core from two drill holes completed by the Minnesota Geological Survey in Nobles County to the west (Gowan, 2020), water-well drillers' logs, cuttings-set descriptions, bridge boring logs (Minnesota Department of Transportation, 2016), exposures, and auger samples (see Plate 1, *Database Map*, for distribution).

On the cross sections, drill holes are represented by vertical lines. Rotary-sonic drill holes are labelled with their borehole name and associated unique number. Interpreted logs of the two rotary-sonic cores are shown in Figures 3 and 4 and their locations are shown in Figure 2. Water-well drillers' logs and other rotary-sonic cores collected by the Minnesota Geological Survey in adjacent counties were used for interpretation and provided significant detailed stratigraphic control. Drill-hole lines may start above or below the cross-section land surface because the data are projected onto the cross section from a distance of up to 0.3 mile (0.5 kilometer), where surface elevations may differ. Vertical exaggeration is 50x for all cross sections. The white areas beneath the cross sections consist of Sioux Quartzite bedrock (see Plate 2 for more information).

The availability of data is partially responsible for the spatial extent and complexity of the subsurface units shown on the cross sections. Units are generally portrayed (modeled) as continuous, with relatively uniform thicknesses and minimal elevation change, where the data are scarce. Where there are more data, units appear more discontinuous and variable in thickness and elevation over relatively short distances, which reflects more accurately the complexity of glacial deposits. Fewer data exist for the older, deeper units, but they are more likely to be portrayed as discontinuous and variable because they are more eroded and dissected. These factors should be kept in mind when viewing the cross sections. Diamicton units, interpreted to be glacial till, are extended across areas where there are little to no data but where it seems reasonable that the till units are continuous.

The scarcity of deep water-well data makes it difficult to interpret and delineate the extent of older till units. Rotary-sonic drill cores provide data for identifying these units; however, the extent of those units is highly uncertain only a short distance beyond the immediate vicinity of the core location. Based on the established stratigraphy for the region (Fig. 1), interpretations have been made using limited information provided by the records of isolated, deeper, water wells. Where there are no data available at depth, the general regional stratigraphy has been extended in a schematic fashion in order to illustrate the potential presence of previously recognized glacial units. The surficial units that appear in the cross sections are equivalent to those mapped and described on the Surficial Geology map (Plate 3).

Subsurface sands are shown on the published cross sections, but are not described as separate units below. Instead, they are referred to within the till unit descriptions. The potential presence of sand is shown in the cross sections by open black circles, which were produced by an interpolated sand model (see Plate 5 for explanation). As with the drill holes, the open black circles may appear above or below the land surface because they are projected onto the cross-section lines. In Rock County, most of these circles correspond with mapped surficial outwash units due to the scarcity of groundwater, and therefore, water wells.

ACKNOWLEDGEMENTS

Rotary-sonic drilling was conducted by Traut Drilling. Minnesota Geological Survey staff members Anik Regan, Sonia Ellison, Amie Staley, and Marguerite Pettus provided essential support during rotary-sonic drilling. Sincere thanks are extended to all landowners who allowed drilling on their property.

DESCRIPTION OF CROSS-SECTION UNITS

Each unit on the cross sections is designated by a letter code, which is described below and placed in one of two categories that designates the origin of the code, as indicated in parentheses after the description: 1. *Surficial Geology* unit—units having an identical description, label, and color as on Plate 3, *Surficial Geology*; see Plate 3 for the detailed descriptions; or 2. New unit—units that appear only on the cross section and have a unique label and color. Contact lines that intersect the land surface on cross sections do not match all contact lines shown on the surficial map because some units shown on Plate 3 are too small or thin to be shown on the cross sections. It should also be noted that all of the till units described below may include pods, lenses, and thin layers of outwash sand and gravel, and sand, as well as lacustrine sand, silt, and clay. Loess of the late Wisconsinan Peoria Formation (Plate 3) is not shown on the cross sections because it cannot be reliably identified in well logs.

QUATERNARY

HOLOCENE

Qa — **Sand, gravel, and sandy loam to silt loam** (*Surficial Geology* unit)—*Alluvium.*

PLEISTOCENE

Late Wisconsinan

New Ulm Formation (Johnson and others, 2016)—Sediment deposited by ice of the Riding Mountain provenance Des Moines lobe (Fig. 1; Plate 3, Fig. 2).

Qno — ***Silty sand, sand, sandy silt, gravelly sand, and sandy gravel*** (*Surficial Geology* unit)—*Glacial stream sediment, outwash.*

Verdi Member

Qnv — **Clay-loam to loam diamicton** (*Surficial Geology* unit)—Not encountered in the rotary-sonic borings. A complete section was encountered in rotary-sonic boring NBR-1 located in Nobles County to the west (see Gowan, 2020 for more information). *Glacial till.*

Pre-Wisconsinan

Unnamed units—Glacial sediments without formalized names. Units Qd1, *Qd4*, and *Qd6* were originally designated in Patterson (1997) as tills 1, 4, and 6.

Qd1 — ***Clay-loam to silt-loam diamicton of Winnipeg provenance*** (*Surficial Geology* unit)—Not encountered in the rotary-sonic borings. *Glacial till.*

Qoo — ***Silt to sand to sand with some gravel*** (*Surficial Geology* unit)—*Glacial stream sediment, outwash.*

Qol — ***Silt, clay, and loamy sand with some gravel*** (*Surficial Geology* unit)—*Lake sediment.*

Cazenovia till

Qct — **Clay-loam diamicton of modified Rainy provenance** (*Surficial Geology* unit)—Encountered in rotary-sonic boring RKR-2, where a thickness of 27 feet (8.2 meters) was recovered (Fig. 4; cross section C–C'). This is a truncated section, located beneath an alluvial stream channel, given that 86 feet (26.2 meters) of this unit were encountered in rotary-sonic boring NBR-1 in Nobles County near the town of Adrian (Gowan, 2020). In core RKR-2, the unit is mostly massive, but it has a 1-foot (0.3-meter) interval of dirty sand and gravel at 20 feet (6.1 meters). The unit is oxidized to a depth of 17 feet (5.2 meters) with a light olive-brown color (2.5Y 5/6, 5/4); the unoxidized colors range from very dark grayish-brown to very dark gray to black (2.5Y 3/2, 3/1, 2.5/1). The average texture and composition are shown in Table 1, and the textures and compositions of the samples from core RKR-2 are plotted in the ternary diagrams in Figure 5. Named for the town of Cazenovia in Pipestone County to the north (near where 96 feet [29.3 meters] of this unit [therein designated "till 2"] were described in rotary-sonic boring SWRA-3 [Patterson, 1997]). *Glacial till.*

Qom — ***Clay-loam diamicton of Riding Mountain provenance*** (new unit)—Encountered in rotary-sonic boring RKR-2 (Fig. 4; cross section C–C'). Unsorted, with some pebbles; has slightly more total Cretaceous grains than the other units (Table 1). Color is an unoxidized black (5Y 2.5/1). May correlate with Drift Complex 5 of Lineburg (1993). *Glacial till.*

Magnolia till

Qm — **Clay to clay-loam diamicton of Riding Mountain provenance** (new unit)—Unsorted, massive, very hard, with some pebbles. The oxidized upper 10 feet (3 meters) in core RKR-2 have an olive color (5Y 4/4) with common white gypsum crystals and iron-oxide staining. Directly beneath this oxidized interval are about 15 feet (4.6 meters) of a mixture of colors (olive, olive-brown, dark olive-gray, olive-gray, and gray) with the gypsum and iron oxide, which becomes an unoxidized black color (5Y 2.5/1). There is a thin layer of clayey, silty sand near the base of the unit (Fig. 4). This unit averages more clay and less Paleozoic clasts than the other units (Fig. 5; Table 1). It is believed to correlate with the Brandon till of South Dakota (Lineburg, 1993). The Brandon till lies immediately beneath a volcanic ash layer, known as Lava Creek B, that was deposited about 610,000 years ago (Izett, 1981). This date gives a minimum age for unit *Qm* during MIS 16 (Fig. 1). Named for the town of Magnolia (near where 105 feet [32 meters] of this unit were described in rotary-sonic boring RKR-2 [Fig. 4; cross-section C–C']. This unit was designated "till 3" in Patterson, 1997, where it was encountered in rotary-sonic boring SWRA-3). *Glacial till.*

Qd4 — ***Silty clay-loam diamicton of Rainy provenance*** (new unit)—Encountered in both rotary-sonic borings RKR-1 (Fig. 3; cross section D–D') and RKR-2 (Fig. 4; cross section C–C'). Unsorted, massive, with some pebbles; contains layers of silt and sand mixed with till toward the base. Color is an unoxidized black (2.5Y 2.5/1) with a very thin gley (4/5 GY) layer at the top. This unit averages more silt than the overlying unit *Qm*, and also has significantly more Precambrian and less Cretaceous clasts (Fig. 5; Table 1). This unit was found to have a minimum age ranging from about 728,000 to 875,000 years old (Balco and others, 2005; Fig. 1; early MIS 18 to MIS 20). It is probable that this unit correlates with one or more of the till units within the Wolf Creek Formation in Iowa (Hallberg, 1980). *Glacial till.*

Qor — ***Silt-loam diamicton of Rainy provenance*** (new unit)—Encountered in both rotary-sonic borings RKR-1 (Fig. 3; cross section D–D') and RKR-2 (Fig. 4; cross section C–C'). Unsorted, massive, silty, with some pebbles, a few cobbles were present in core RKR-2, rusty seams and partings were present in core RKR-1. Color is an unoxidized, very dark gray to black (5Y 3/1 to 2.5/1) in core RKR-2, but is more oxidized in core RKR-1, ranging from 5Y 5/1 (gray) to 5Y 4/3 (olive), with very thin, dark greenish-gray (4/10 Y), reduced layers at the top and base. This unit is sandier and less clayey than the adjacent units, and also has more Precambrian clasts (Fig. 5; Table 1). It is possible that this unit correlates with one of the till units within the Wolf Creek Formation in Iowa (Hallberg, 1980). *Glacial till.*

Qd6 — ***Silty clay-loam diamicton of Riding Mountain provenance*** (new unit)—Encountered in rotary-sonic boring RKR-1 (Fig. 3; cross section D–D'). Unsorted, massive, with a few pebbles, including Paleozoic carbonates. Contains local silt and very fine-grained sand layers, partings, and inclusions. The upper contact has reduced blue and green colors (4/5Y, 4/10Y), which become a grayish-teal color with some yellowish and blackish patches with depth (4/5GY, 5Y 3/1-2). This unit averages more silt and less sand than the other units, and the Cretaceous clasts are almost exclusively shale (Fig. 5; Table 1). *Glacial till.*

Qow — ***Silty clay-loam diamicton of Winnipeg provenance*** (new unit)—Encountered in rotary-sonic boring RKR-1 (Fig. 3; cross section D–D'). Unsorted, sand-poor, with some pebbles, commonly carbonate and Sioux Quartzite; has more Paleozoic and less clear quartz grains than the overlying units (Table 1). Color varies from olive (5Y 4/3) to dark olive-gray (5Y 3/2) with depth. *Glacial till.*

Qlu — ***Silt loam of unknown provenance*** (new unit)—Two thick, gray to black, calcareous horizons were encountered in core RKR-1 (Fig. 3; cross section D–D'). The lacustrine unit encountered at the base of core RKR-2 (Fig. 4; cross section C–C') was massive, brown, with some green seams and webbing lines, and non-calcareous. This unit is only shown in these two borings and cross-section lines because of the difficulty in identifying lacustrine sediments from water-well records. *Lacustrine sediments.*

Qtu — ***Presumed diamicton of unknown provenance*** (new unit)—Based on a material description in water-well records. Till is typically described in well logs as clay, sandy clay, silty clay, or pebble clay. The presence of this unit beneath core RKR-1 in cross-section D–D' is from the log of a boring that is closer to the cross-section line (see Fig. 2), where the depth to bedrock is greater by about 45 feet (13.7 meters). *Glacial till.*

Qu — ***Undifferentiated Quaternary sediment*** (new unit)—Areas where there are no sediment descriptions. Depending on well depths, this can include units that are described above.

CRETACEOUS

Ku — **Sandstone, mudstone, shale, and marl** (new unit)—Undifferentiated (see Plate 2, *Bedrock Geology*, for details). *Bedrock.*

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Table 1. Average values for the texture and composition of tills recognized in rotary-sonic core and auger holes in Rock County. Matrix texture (the less than 2-millimeter grain-size fraction) 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 rocks, and Cretaceous rocks, with the total shale percentage in Cretaceous rocks in parentheses. The Precambrian fraction is further subdivided by crystalline rock type—light (granite and gneiss), dark (mafic-rich igneous [such as basalt] and metamorphic rocks), red (rhyolite, agate, and sandstone), and clear quartz. These lithologic distinctions are some of the tools used to distinguish between glacial sediments and identify provenance (Hobbs, 1998).

	MATRIX TEXTURE						CLAST TYPE							
			Percentage of the less than 2-millimeter fraction				Percentage of total grains counted of the 1-2 millimeter fraction				Percentage of total crystalline grains counted			
Geologic units	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay	Average USDA texture	Total number of samples	Precambrian	Paleozoic	Cretaceous (total shale)	Light	Dark	Red	Clear quartz
Late Wisconsinan deposits														
Peoria Formation (shown on Plate 3)	52	0	8	70	22	Silt loam								
New Ulm Formation														
Verdi Member till (unit Qnv)	31	3	26	46	28	Clay loam	31	44	39	17 (14)	88	12	0	15
Pre-Wisconsinan deposits														
Winnipeg-provenance till (pre-MIS 14; unit Qd1)	24	4	22	50	28	Clay loam	24	47	44	9 (6)	88	11	1	14
Cazenovia till (unit Qct)	124	2	30	39	31	Clay loam	124	72	21	7 (2)	85	14	1	23
Riding Mountain-provenance till (MIS 14-16; unit *Qom* on cross sections)	6	3	31	33	36	Clay loam	6	61	24	15 (9)	88	11	1	18
Magnolia till (unit *Qm* on cross sections)	25	4	23	36	41	Clay	24	56	31	13 (5)	83	17	0	21
Rainy-provenance till (MIS 18-20; unit *Qd4* on cross sections)	21	3	20	53	27	Silty clay loam	21	64	33	3 (1)	84	16	0	22
Rainy-provenance till (MIS 20+; unit *Qor* on cross sections)	12	2	24	53	23	Silt loam	12	69	26	5 (2)	89	10	1	26
Riding Mountain-provenance till (MIS 30+; unit *Qd6* on cross sections)	2	1	12	55	33	Silty clay loam	2	62	25	13 (13)	87	13	0	28
Winnipeg-provenance till (MIS 30+; unit *Qow* on cross sections)	2	2	9	54	37	Silty clay loam	2	56	42	2 (0)	92	8	0	17

CROSS-SECTION SYMBOLS

Geologic contact—Approximate. No-line boundaries occur where data are insufficient to reliably extend units.

Drill hole—The top of the drill hole may not coincide with the cross-section surface-elevation line because the drill hole may be located near (commonly within 0.3 mile [0.5 kilometer]), but not on the cross-section line, and therefore may have a slightly different surface elevation. Boring names are given for rotary-sonic drill holes, with stratigraphic logs provided in Figures 3 (RKR-1) and 4 (RKR-2).

Sand—Area where sand and/or gravel is predicted to occur (see Plate 5 for explanation of model interpolation methods). As with the drill holes, the open black circles may appear above or below the land surface because they are projected onto the cross-section lines.

Outwash—Undifferentiated.

Bedrock contact—Contact shown at the base of the Quaternary deposits and above the bedrock units; see Plate 2, *Bedrock Geology*, for descriptions.

ENVIRONMENT AND NATURAL RESOURCES TRUST FUND

GIS compilation by J.D. Hamilton
Edited by Lori Robinson