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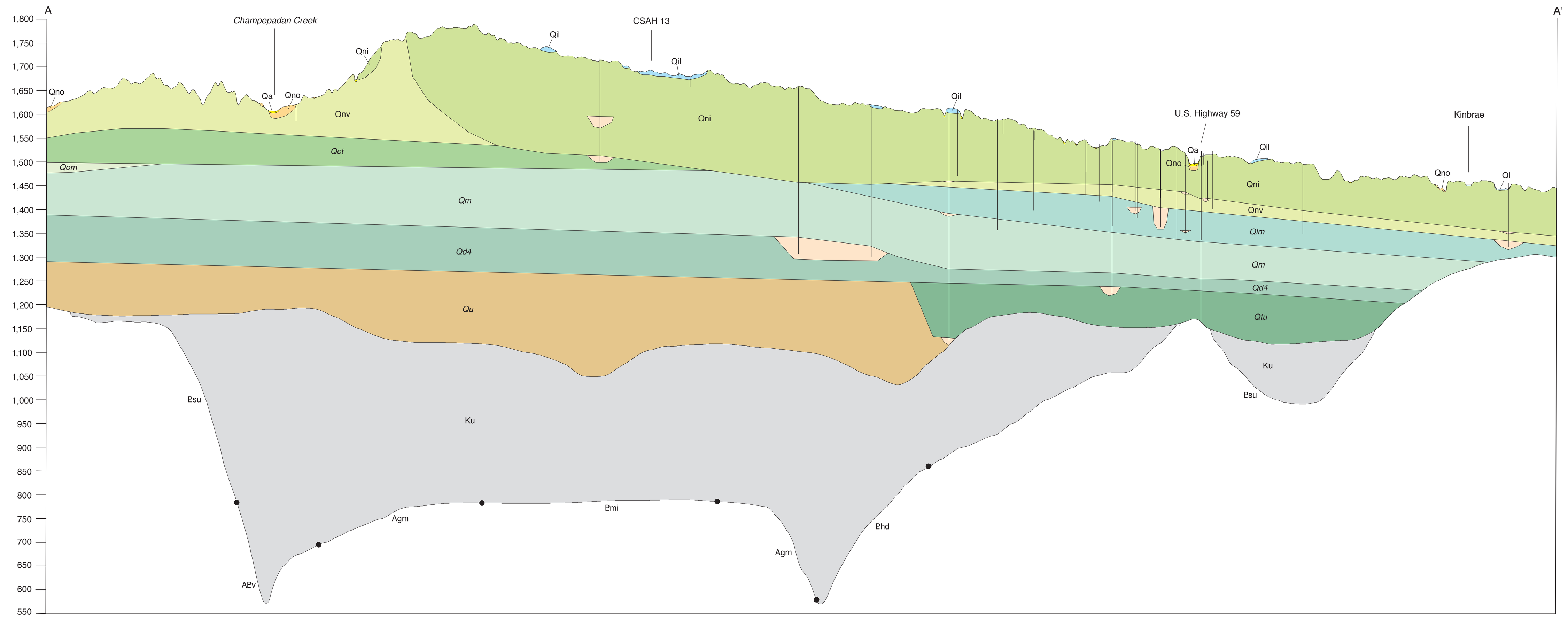

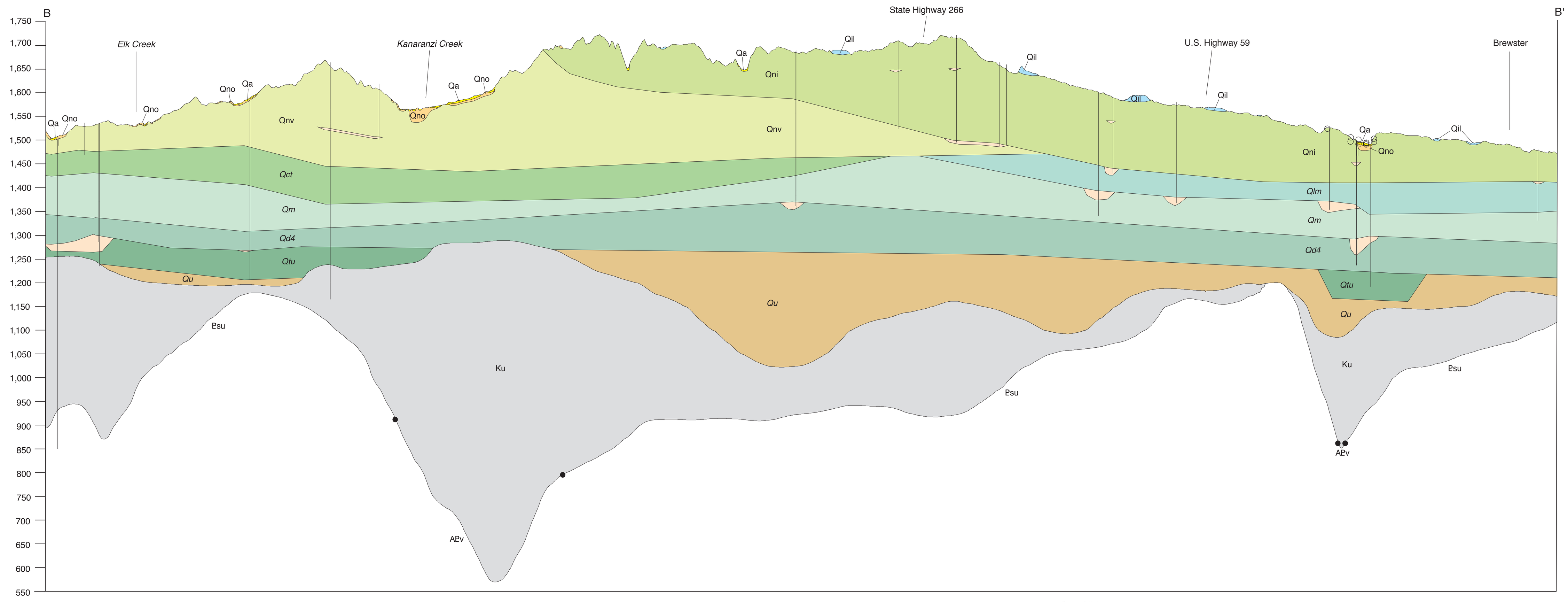

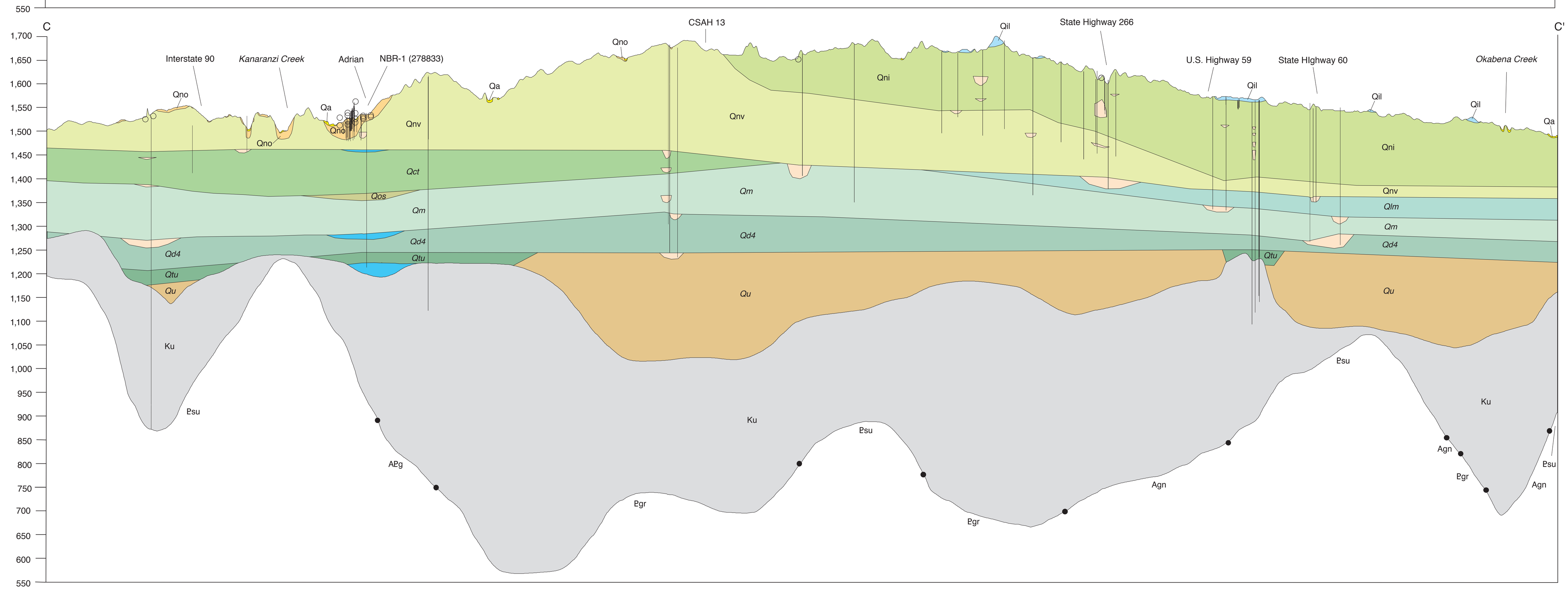

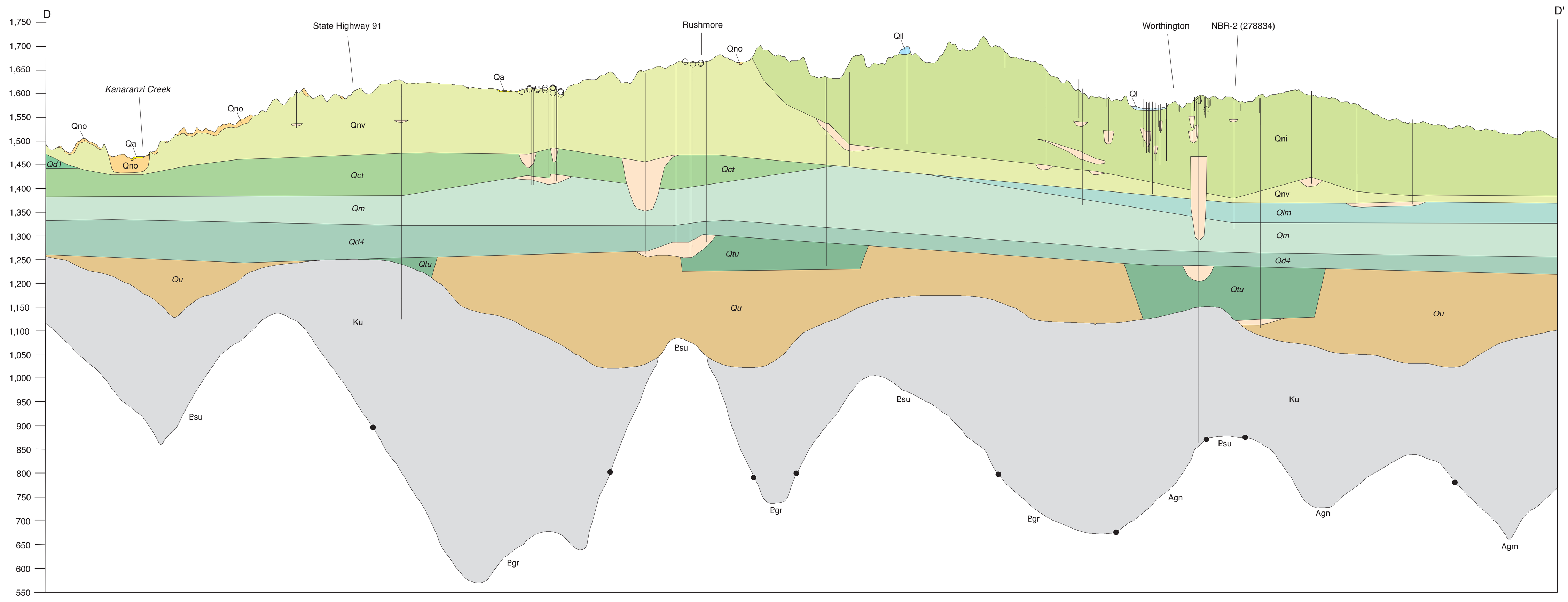

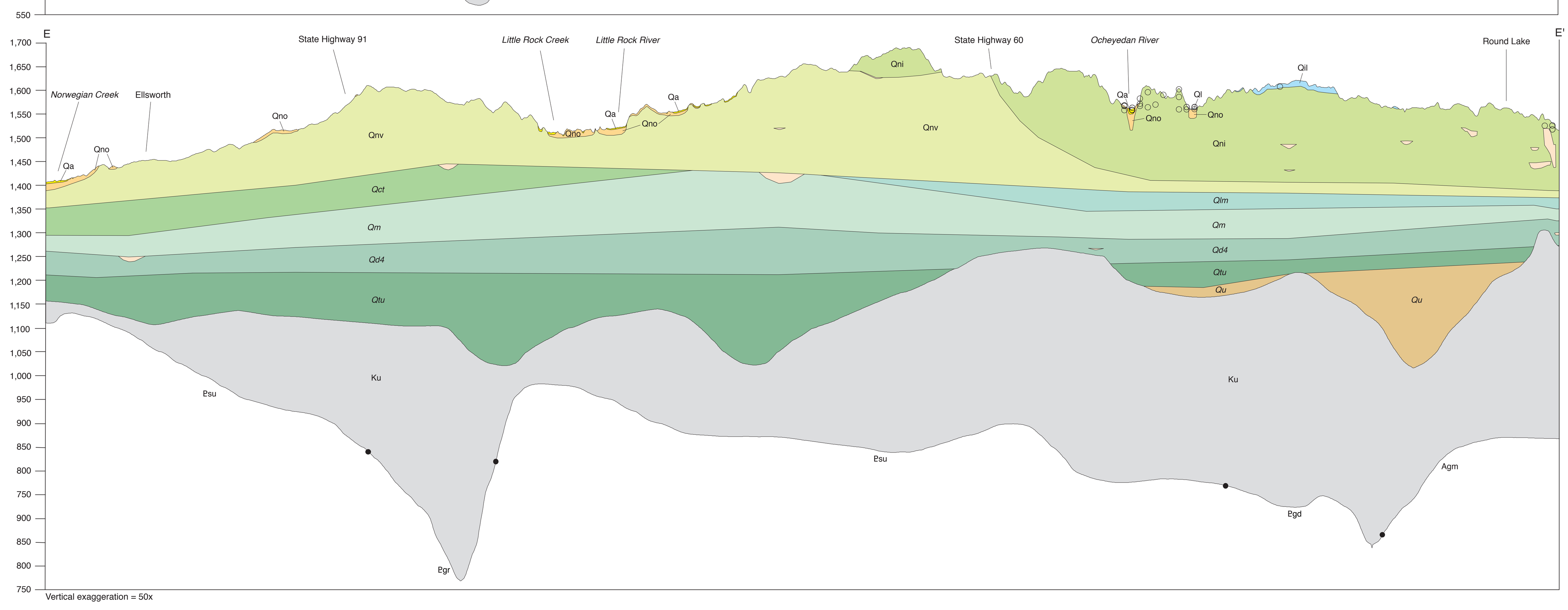

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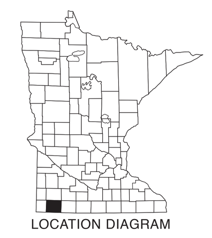

QUATERNARY STRATIGRAPHY

By

Angela S. Gowan

2020

INTRODUCTION

The *Quaternary Stratigraphy* plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Nobles County (Fig. 1). Cross sections A–A' through E–E' are representative of 39 cross sections (Plate 5, *Sand-Distribution Model*, Fig. 1) at 0.6-mile (1-kilometer) spacing that were constructed to create a three-dimensional model of the Quaternary deposits of Nobles County. The Quaternary geologic till units shown on the cross sections were defined from interpretation of new data collected for this study (Table 1 and descriptions below) and from existing data from previous investigations (see Plate 3, *Surficial Geology*, Index to Previous Mapping for adjacent mapping projects). These include rotary-sonic core from two drill holes completed by the Minnesota Geological Survey for this project (NBR-1 and NBR-2; illustrated on Plate 5, *Supplemental Quaternary Stratigraphy*, as Figs. 1 and 2, respectively), and information collected from rotary-sonic core from two drill holes completed by the Minnesota Geological Survey for the Rock County Geologic atlas (Gowan, 2020), water-well drillers' logs, cuttings set descriptions, bridge boring logs (Minnesota Department of Transportation, 2016), exposures, and auger samples (Plate 1, *Database Map*).

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 (in parentheses). Interpreted logs of the two rotary-sonic cores are shown on Plate 5, *Supplemental Quaternary Stratigraphy*, Figures 1 and 2, and their locations are shown on Plate 5, *Sand-Distribution Model*, Figure 1. Water-well drillers' logs and previous rotary-sonic cores collected by the Minnesota Geological Survey in adjacent counties were used for interpretation and provided significant detailed stratigraphic control. Drill hole vertical lines may start above or below the 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 could differ. Vertical exaggeration is 50x for all cross sections.

The availability of data is partially responsible for the spatial extent and complexity of the subsurface units shown on the cross sections. Where the data are scarce, units are generally portrayed (modeled) as continuous, with relatively uniform thicknesses and minimal elevation change. Where there are more data, units appear more discontinuous and variable in thickness and elevation over relatively short distances, which more accurately reflects 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 and associated sand layers. 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, *Sand-Distribution Model*, for explanation). In Nobles County, most of these circles correspond with mapped surficial outwash units due to the scarcity of deeper aquifers, and therefore, water wells.

TILL GEOCHEMICAL ANAYLSES

Till geochemical analyses conducted during this project support the unit separations based on core descriptions, intervening lacustrine and sand bodies, and textural and lithologic changes. Geochemical analysis was conducted on both rotary-sonic cores (NBR-1 and NBR-2) as part of a broader program of analyses (Thorleifson and others, 2019). In a manner consistent with methods used by Thorleifson and others (2007), the less than 63-micron fraction of till samples was analyzed by ICP-mass spectrometry following a four-acid, near-total dissolution. Analysis of the data indicated that several elements appear to correlate with provenances that are characterized by shale, carbonate, crystalline, and Lake Superior-derived sediments (Table 2). Elements appearing to correlate with shale (such as Riding Mountain-provenance units Qni, Qnv, and *Qm*) include arsenic, vanadium (Plate 5, Fig. 1C), thalium, antimony, molybdenum, cadmium, bismuth, zinc, and cesium. Elements appearing to correlate with carbonate (such as Winnipeg-provenance units Qnv and *Qlm*) include calcium and magnesium (Plate 5, Figs. 1B, 2B[calcium only]). Elements appearing to correlate with crystalline-derived debris (such as Rainy-provenance units *Qct* and *Qd4*) include aluminum (Plate 5, Fig. 1B), chromium, cobalt, nickel, potassium, sodium, strontium (Plate 5, Fig. 2C), and titanium. Elements appearing to correlate with Lake Superior-derived sediment (such as Superior-provenance unit *Qos*) include aluminum, potassium (both Rainy-provenance indicators as well), iron, copper, hafnium, yttrium, and zirconium. Other elements may correlate with provenances or hydrologic controls, but the qualitative analysis is weaker and therefore not included in this atlas. Future analysis on these units, and units elsewhere in Minnesota, will allow for comparisons over larger spatial distances.

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. Thanks are extended to all landowners who allowed drilling on their property.

DESCRIPTON 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 three 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; 2. New unit—units that appear only on the cross section and have a unique label and color; and 3. Modified unit—multiple units from Plate 3 that are combined into one unit on the cross sections (for example units Qnv and Qwv are combined into unit Qnv). Contact lines that intersect the land surface on the 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 is not shown on the cross sections because it cannot be reliably identified in well logs.

HOLOCENE

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

Ql — **Silt, clay, and loamy sand** (*Surficial Geology* unit)—*Lacustrine sediment.*

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).

Qil — ***Clay, silt, and sand*** (*Surficial Geology* unit)—*Ice-walled lake plain.*

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

Ivanhoe Member

Qni — **Loam to clay-loam diamicton** (modified unit)—Map units Qhi, Qwi, and Qmi from Plate 3. Color ranges from olive-gray (5Y 5/2) where oxidized to very dark gray (2.5Y 3/1) where unoxidized. Average matrix texture and composition of the very coarse-grained sand fraction is shown in Table 1, with individual data points plotted in Figure 2. Encountered at the surface, as shown on Plate 3, and present to 180 feet (55 meters) deep in rotary-sonic core NBR-2 (cross section D–D'; Plate 5, Fig. 2). Commonly contains layers of sand and/or gravel outwash, with two 5-foot (1.5-meter) intervals in core NBR-2 (cross section D–D'; Plate 5, Fig. 2). Geochemically, this unit has the highest concentrations of cadmium and strontium (Table 2; Plate 5, Fig. 2C), more sulfur than the other units in core NBR-2 (Table 2; Plate 5, Fig. 2D), and the lowest concentration of lithium. *Glacial till.*

Verdi Member

Qnv — **Clay-loam to loam diamicton** (modified unit)—Map units Qnv and Qwv from Plate 3. Color ranges from light olive-brown (2.5Y 5/3) where oxidized to very dark gray (2.5Y 3/1) where unoxidized. Average matrix texture and composition of the very coarse-grained sand fraction is shown in Table 1, with individual data points plotted in Figure 2. Encountered at the surface, as shown in Plate 3, and to the depth of approximately 78 feet (24 meters) in rotary-sonic core NBR-1 (cross section C–C'; Plate 5, Fig. 1), with 26 feet (8 meters) in core NBR-2 (cross section D–D'; Plate 5, Fig. 2). Commonly contains wood fragments and layers of sand and/or gravel outwash, with a 13-foot (4-meter) interval in core NBR-1. Behind the Bemis moraine, erosion by the overriding Ivanhoe Member has typically removed most of the Verdi Member, and locally it has been completely removed. Geochemically, this unit has the highest concentration of manganese, in addition to the Winnipeg-provenance elements, calcium and magnesium (Plate 5, Figs. 1B, 2B), and the lowest concentrations of 16 elements, including three indicative of Superior provenance (hafnium, yttrium, and zirconium) and three indicative of Rainy provenance (Al [Plate 5, Fig. 1B], chromium, and titanium; Table 2). *Glacial till.*

Pre-Wisconsinan

Lake Henry Formation (Johnson and others, 2016)—Sediment deposited by ice of Winnipeg provenance (Plate 3, Fig. 2). The Lake Henry Formation is regionally extensive and continuous into counties to the north and east. It is composed of two Members, the Sauk Centre and Meyer Lake; however, only the Meyer Lake Member was encountered in Nobles County, and only in boring NBR-2 (cross section D–D'; Plate 5, Fig. 2). Both members of the Lake Henry Formation are characterized by zero to very few Cretaceous clasts in the 1-2 millimeter sand fraction. The Sauk Centre Member commonly has more Paleozoic (almost equal to the Precambrian) clasts than the Meyer Lake Member. Both members were present in a rotary-sonic boring completed in southwest Cottonwood County during a previous investigation (boring SWRA-1; Patterson, 1997). Because there is no concrete age for the Lake Henry Formation, its stratigraphic position within the pre-Wisconsinan units is unknown, other than it is younger than unit *Qm*.

Meyer Lake Member

Qlm — **Clay-loam diamicton** (new unit)—Unsorted, with some carbonate clasts. Color ranges from dark gray to olive-brown (2.5Y 4/1 to 4/3) where oxidized to very dark gray (2.5Y 3/1) where unoxidized. Average matrix texture and composition of the very coarse-grained sand fraction is shown in Table 1, with individual data points plotted in Figure 5. Encountered in rotary-sonic core NBR-2 (cross section D–D'; Plate 5, Fig. 2). Geochemically, this unit has the highest concentrations of barium (Plate 5, Fig. 2E) and sodium, while having the lowest concentrations of many Riding Mountain- (arsenic, cadmium, molybdenum, nickel, antimony, vanadium, and zinc) and Superior-provenance elements (copper and iron; Table 2). *Glacial till.*

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

Qd1 — ***Clay-loam to silt-loam diamicton of Winnipeg provenance*** (new unit)—Not encountered in the rotary-sonic borings, but mapped at the surface in Rock County to the west. Projected into the subsurface of Nobles County (see cross section D–D'). Unsorted, slightly pebbly; contains lenses of silt, sand, and gravel in places. Generally oxidized light olive-brown (2.5Y 5/4). This unit is similar texturally to the (perhaps) much younger Verdi Member till (unit Qnv), but unit *Qd1* averages more Paleozoic and less Cretaceous clasts (Gowan, 2020, Fig. 2, Table 1). It is possible that this is a deposit of an earlier advance of the Verdi Member, which would date it as late to middle Wisconsinan in age (Fig. 1, MIS 4 or 6). It may correlate with the older advance of the Sheldon Creek Formation in Iowa, but additional research is required to evaluate this possibility. *Glacial till.*

Cazenovia till

Qct — **Clay-loam diamicton of modified Rainy provenance** (new unit)—Encountered in rotary-sonic boring NBR-1 (cross section C–C'; Plate 5, Fig. 1). Unsorted, with some pebbles; contains pockets of silt, sand, and gravel locally. Oxidized color is a light olive-brown (2.5Y 5/6), and ranges to an unoxidized very dark gray (2.5Y 3/0) color. This unit is less silty locally than the overlying unit *Qd1* and also has significantly more Precambrian and less Paleozoic clasts (Fig. 2; Table 1). Rainy-provenance tills described elsewhere in the state have sandier textures and little to no Cretaceous clasts compared to this unit. Incorporation of underlying finer-grained and Cretaceous-rich sediments may have modified the original Rainy-provenance signature. Geochemically, this unit has the lowest average concentration of strontium and the highest concentrations of 10 elements, including Rainy-provenance indicators aluminum, iron (Plate 5, Fig. 1B), potassium, and titanium (Table 2). This unit was found to have a minimum depositional age of approximately 500,000 years ago (Bierman and others, 1999; Fig. 1, MIS 14). It is probable that this unit correlates with one or more of the till units within the Wolf Creek Formation in Iowa (Hallberg, 1980). Named for the town of Cazenovia in Pipestone County to the northwest (near where 96 feet [29 meters] of this unit [therein designated "till 2"] were described in rotary-sonic boring SWRA-3 [Patterson, 1997]). *Glacial till.*

Qos — ***Clay-loam diamicton of Superior provenance*** (new unit)—Encountered in rotary-sonic boring NBR-1 (cross section C–C'; Plate 5, Fig. 1). Unsorted, with some pebbles, including northeastern Minnesota lithologies; has a sandier texture than the surrounding units (Fig. 2; Table 1), contains a small, silty inclusion. Color is an unoxidized very dark gray to very dark grayish-brown (2.5Y 3/1 to 3/2). Geochemically, this unit has a higher concentration of calcium (perhaps derived from calcium feldspar-rich [anorthosite] deposits along the North Shore of Lake Superior, versus carbonate derived) and lower concentrations of vanadium and lithium than surrounding units *Qct* and *Qm* (Table 2; Plate 5, Figs. 1B, C, D). *Glacial till.*

Qom — ***Clay-loam diamicton of Riding Mountain provenance*** (new unit)—Not encountered in the rotary-sonic borings, but projected into the subsurface of Nobles County (see cross section A–A'). Encountered in rotary-sonic boring RKR-2 in Rock County (Gowan, 2020, Figs. 4, 5, Table 1). *Glacial till.*

Magnolia till

Qm — **Clay-loam to loam diamicton of Riding Mountain provenance** (new unit)—Unsorted, massive, very hard, with some pebbles. The oxidized upper contact in core NBR-1 has an olive-brown color (2.5Y 4/4) and some gley (4/5 GY), with common white gypsum crystals and iron-oxide staining, and becomes an unoxidized black (2.5Y 2.5/1) with depth. This unit averages more clay than the other units, and also has significantly more Cretaceous clasts than the other pre-Wisconsinan units (Fig. 2; Table 1). Geochemically, this unit has the highest average concentrations of 10 elements, including three Riding Mountain-provenance indicators (molybdenum, bismuth, and antimony), two Superior-provenance indicators (copper and yttrium), and one Rainy-provenance indicator (nickel; Table 2). It also has the lowest concentrations of barium (Plate 5, Fig. 2E) and sodium (Table 2). Believed to correlate with the Brandon till of South Dakota (Lineburg, 1993). The Brandon till lies immediately beneath a volcanic ash layer, known as the Lava Creek B, that was deposited about 610,000 years ago (Izett, 1981). This date places unit *Qm* during MIS 16 (Fig. 1). Named for the town of Magnolia in Rock County (near where 105 feet [32 meters] of this unit were described in rotary-sonic boring RKR-2 [Gowan, 2020]. This unit was designated "till 3" in Patterson, 1997, where it was encountered in rotary-sonic boring SWRA-3). *Glacial till.*

Qd4 — ***Clay-loam diamicton of Rainy provenance*** (new unit)—Encountered in rotary-sonic boring NBR-1 (cross section C–C'; Plate 5, Fig. 1). 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 is siltier than overlying unit *Qm* and also has significantly more Precambrian and less Cretaceous clasts (Fig. 2; Table 1). Geochemically, this unit has the lowest concentrations of calcium, magnesium, and manganese (which is the opposite of the Verdi Member), and the highest concentrations of Rainy-provenance indicators chromium and titanium, along with 12 other elements, including lithium (Plate 5, Fig. 1D) and vanadium (Table 2; Plate 5, Fig. 1C). This unit has minimum ages ranging from about 728,000 to 875,000 years (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.*

Qos2 — ***Presumed diamicton of Superior provenance*** (new unit)—Based on a well-log record containing 42 feet (13 meters) of brown/red clay with many pebbles (unique number 236590) beneath unit *Qd4* in Worthington (not seen on the published cross sections, but shown in the digital files). Though the color "red" is a descriptor for Superior-provenance tills, and was not used in any other well log within the county, this could still have a provenance from a different direction given the variability of color descriptions. *Glacial till.*

Qor — ***Silt-loam diamicton of Rainy provenance*** (new unit)—Not encountered in the rotary-sonic borings, but projected to exist in the subsurface in Nobles County (not seen on the published cross sections, but shown in the digital files). Encountered in both rotary-sonic borings RKR-1 and RKR-2 in Rock County (Gowan, 2020).

Qtu — ***Presumed diamicton of unknown provenance*** (new unit)—Based on a material description in well-log records. Till is typically described as clay, sandy clay, silty clay, or pebble clay. Depending on well depths, this can include units that are described above. *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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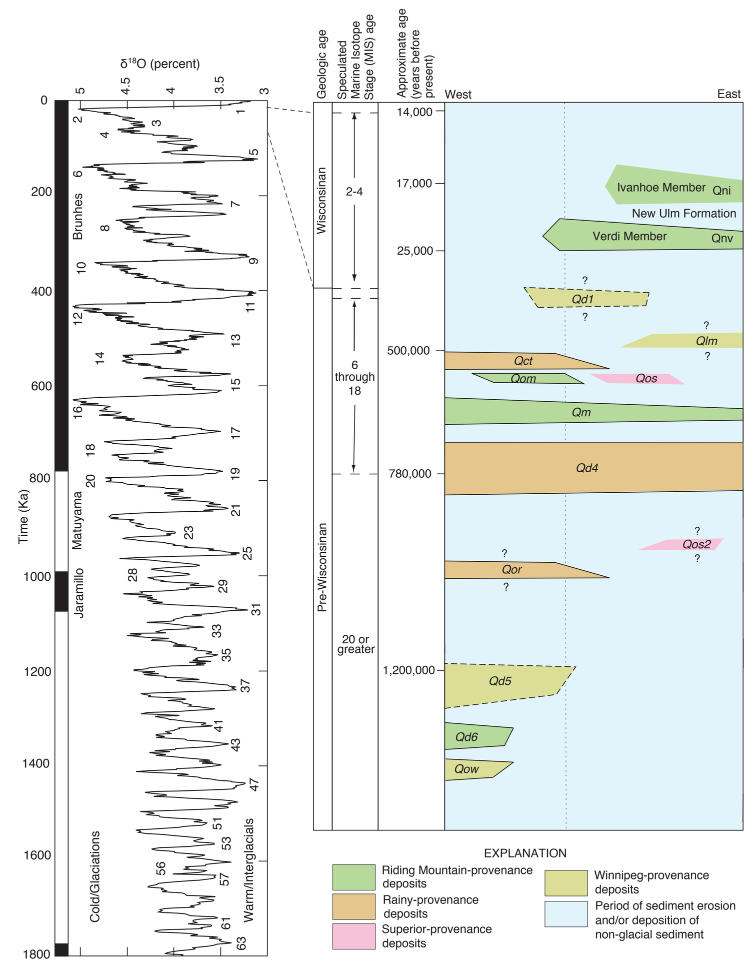

Figure 1. The graph on the left shows $\delta^{18}O$ versus time (modified from Johnson and others, 2016, Fig. 1). High values of $\delta^{18}O$, measured in sediments from deep ocean cores, have been found to correlate with periods of time with large volumes of global glacial ice (Lisiecki and Raymo, 2005). Therefore, peaks to the left in the graph represent periods of active glaciation or glacial maximums, while peaks to the right represent glacial minimums, or interglacials. 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, including Nobles County [boundary shown with dotted vertical line]), 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 Nobles County.

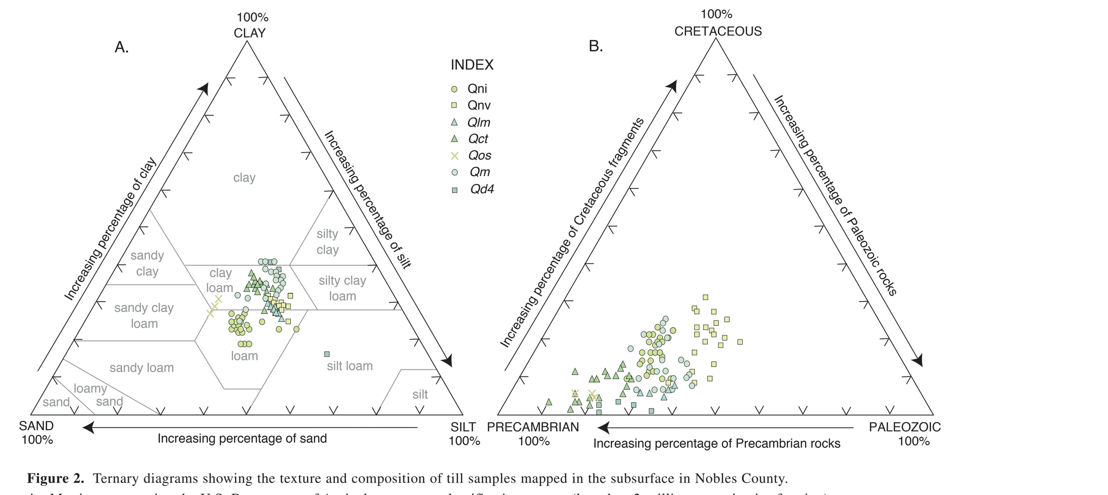

Figure 2. Ternary diagrams showing the texture and composition of till samples mapped in the subsurface in Nobles County.
A. Matrix texture using the U.S. Department of Agriculture texture classification system (less than 2-millimeter grain-size fraction).
B. Composition of the very coarse-grained (1-2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

CROSS-SECTION SYMBOLS

Geologic contact—Approximate.

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 (within 0.3 mile [0.5 kilometer]) but not on the cross-section line, and therefore may have a slightly different surface elevation. Minnesota Geological Survey unique numbers are given for rotary-sonic drill holes with stratigraphic logs provided in Plate 5, *Supplemental Quaternary Stratigraphy*, Figures 1 and 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.

Lacustrine deposit—Undifferentiated.

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

Table 1. Average values for the texture and composition of till units recognized in rotary-sonic core and auger holes in Nobles 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)	3	0	11	59	30	Silty clay loam								
New Ulm Formation														
Ice-walled lake plain sediment (unit Qil on Plate 3 and cross sections)														
Upper fine-grained zone (2 to 9.5 feet)	11	0	7	59	34	Silty clay loam								
Lower coarser-grained zone (4 to 15 feet)	23	2	37	41	22	Loam								
Surficial outwash (unit Qno on Plate 3 and cross sections)	13	12	60	25	15	Sandy loam	4	55	32	13 (10)	86	14	1	16
Ivanhoe Member till (units Qhi, Qmi, and Qwi on Plate 3, unit Qni on cross sections)	71	5	38	37	25	Loam	71	59	28	13 (10)	88	12	0	16
Verdi Member till (units Qnv and Qwv on Plate 3, unit Qnv on cross sections)	77	4	30	41	29	Clay loam	77	42	37	21 (16)	88	12	0	14
Pre-Wisconsinan deposits														
Lake Henry Formation														
Meyer Lake Member till (unit *Qlm* on cross sections)	5	4	30	42	28	Clay loam	5	61	34	5 (1)	86	13	1	11
Cazenovia till (unit *Qct* on cross sections)	28	2	31	36	33	Clay loam	28	74	20	7 (1)	83	16	1	18
Superior-provenance till (MIS-14; unit *Qos* on cross sections)	3	2	43	28	29	Clay loam	3	77	18	5 (1)	80	14	6	19
Magnolia till (unit *Qm* on cross sections)	23	4	27	37	35	Clay loam	23	55	31	13 (5)	84	16	0	17
Rainy-provenance till (MIS 18-20; unit *Qd4* on cross sections)	5	3	24	43	33	Clay loam	5	71	27	2 (1)	87	13	0	24

Table 2. Average concentrations of elements from the till samples. Provenance sources for the till and elements that are diagnostic for the provenance are highlighted. Bold text and italic text show highest and lowest average values for each element, respectively. If there is no apparent difference in the concentrations, no distinctions are made.

Element Unit / Till unit	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm
Qni	0.12	5.26	10.70	483.67	1.17	0.22	7.40	**0.64**	72.46	8.71	63.17	4.14	20.05	2.65	12.37	0.10	3.16	0.05	1.49	34.81	31.04	2.12	653.57	3.29
Qnv	0.12	*4.70*	9.44	464.00	1.29	0.23	**8.82**	0.50	*58.25*	9.41	*44.40*	*3.42*	21.51	2.33	11.75	0.13	*2.92*	0.04	*1.44*	*29.19*	34.68	**3.12**	**722.13**	4.12
Qlm	0.11	5.20	*5.54*	**498.00**	*1.02*	*0.20*	7.42	*0.34*	76.42	*6.92*	50.40	3.64	*17.14*	*2.29*	*11.59*	0.10	3.16	0.04	1.51	37.02	*22.46*	2.19	607.80	*1.96*
Qct	0.11	**6.90**	**15.72**	428.70	**2.02**	0.31	3.87	0.46	89.62	**12.84**	69.04	**5.42**	24.37	**3.71**	17.05	0.15	3.75	0.07	**1.71**	43.28	55.59	1.03	454.17	4.95
Qos	0.11	5.85	7.13	473.33	1.62	0.25	5.37	0.46	79.50	10.43	58.33	3.72	24.27	2.88	14.08	0.14	**4.00**	0.05	1.64	38.33	37.67	1.28	656.67	3.07
Qm	0.13	6.38	13.64	*394.21*	1.80	**0.32**	5.30	0.45	87.13	11.46	64.47	5.19	**27.39**	3.39	15.93	0.14	3.76	0.07	1.62	42.26	52.32	1.33	584.58	**5.45**
Qd4	0.11	6.69	9.00	424.00	1.78	0.25	*3.77*	0.47	**96.70**	10.34	**70.80**	5.37	22.90	2.86	**17.62**	0.15	**4.00**	0.06	1.64	**45.02**	**56.60**	*0.95*	*451.20*	2.20

Element Unit / Till unit	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm	Sc ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
Qni	0.65	12.85	29.46	705.67	15.72	69.13	0.01	0.65	1.10	7.77	1.93	1.52	**227.17**	0.82	0.07	9.10	0.30	0.65	3.66	121.07	0.99	18.34	75.00	118.07
Qnv	0.59	*10.22*	30.53	606.00	19.35	*65.47*	0.04	0.44	0.87	7.47	1.58	*1.35*	175.50	*0.67*	0.06	*8.66*	*0.26*	0.66	4.25	96.47	*0.89*	*16.67*	69.47	*105.65*
Qlm	0.75	11.20	*23.08*	*594.00*	*15.06*	67.56	<0.002	*0.06*	*0.73*	*6.66*	*1.00*	1.44	183.10	0.72	0.07	9.67	0.30	*0.63*	*3.04*	*87.00*	0.92	17.40	*60.00*	119.80
Qct	0.53	17.99	38.11	763.91	**23.55**	**95.57**	0.02	0.57	1.01	11.29	1.90	2.13	*172.04*	1.06	0.08	11.69	**0.40**	**0.92**	4.47	128.22	1.33	23.56	84.43	144.30
Qos	0.67	14.20	32.13	703.33	16.70	80.20	0.01	0.37	0.89	9.50	*1.00*	1.67	206.00	0.87	0.06	10.07	0.37	0.73	3.73	108.67	1.13	22.97	70.67	**151.17**
Qm	0.41	18.47	**39.84**	**773.16**	19.60	89.77	**0.05**	**0.71**	**1.13**	10.78	**2.58**	2.06	191.37	1.08	0.08	11.70	0.38	0.88	**5.17**	132.11	1.32	**24.04**	**90.79**	144.58
Qd4	0.58	**18.66**	31.62	772.00	20.70	90.32	0.02	0.41	1.07	**11.74**	2.40	**2.14**	198.60	**1.16**	0.07	**12.70**	**0.40**	0.73	3.94	**136.80**	**1.38**	23.80	74.40	148.90

PROVENANCE
Riding Mountain — Rainy — Winnipeg — Superior

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