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THE MINNESOTA LEGACY AMENDMENT'S CLEAN WATER FUND, AND THE GREAT LAKES COALITION**

QUATERNARY STRATIGRAPHY

By

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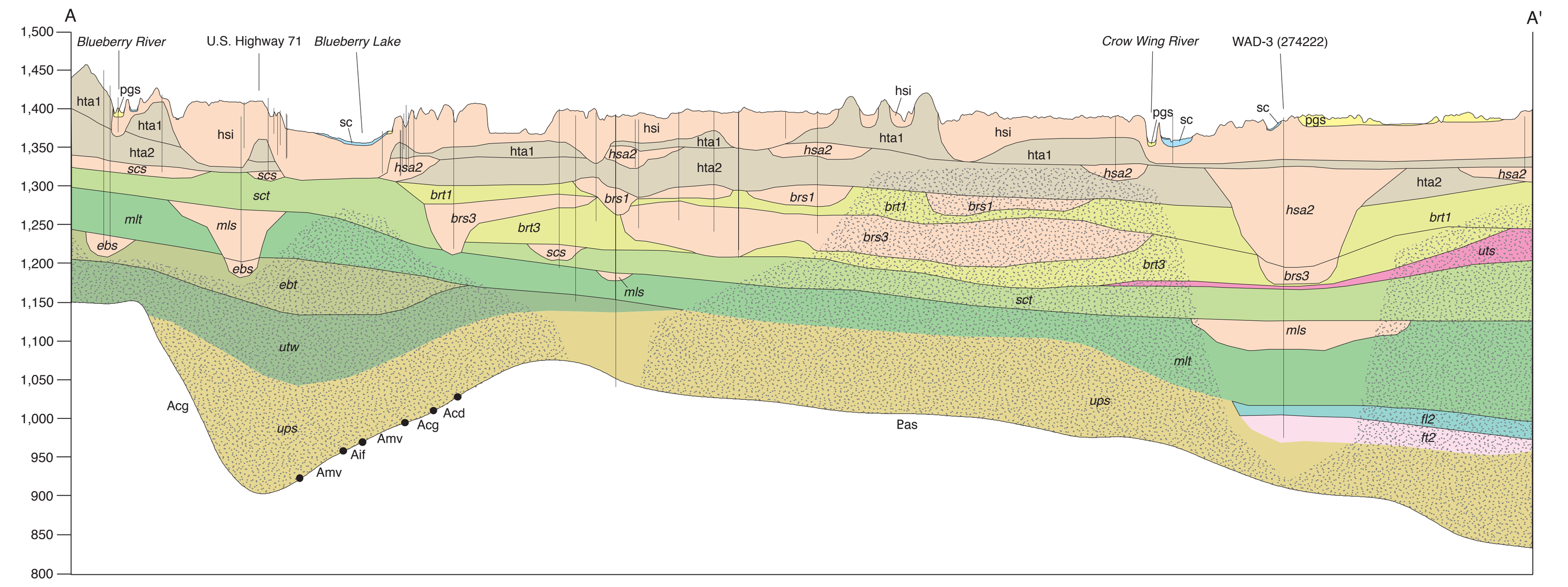
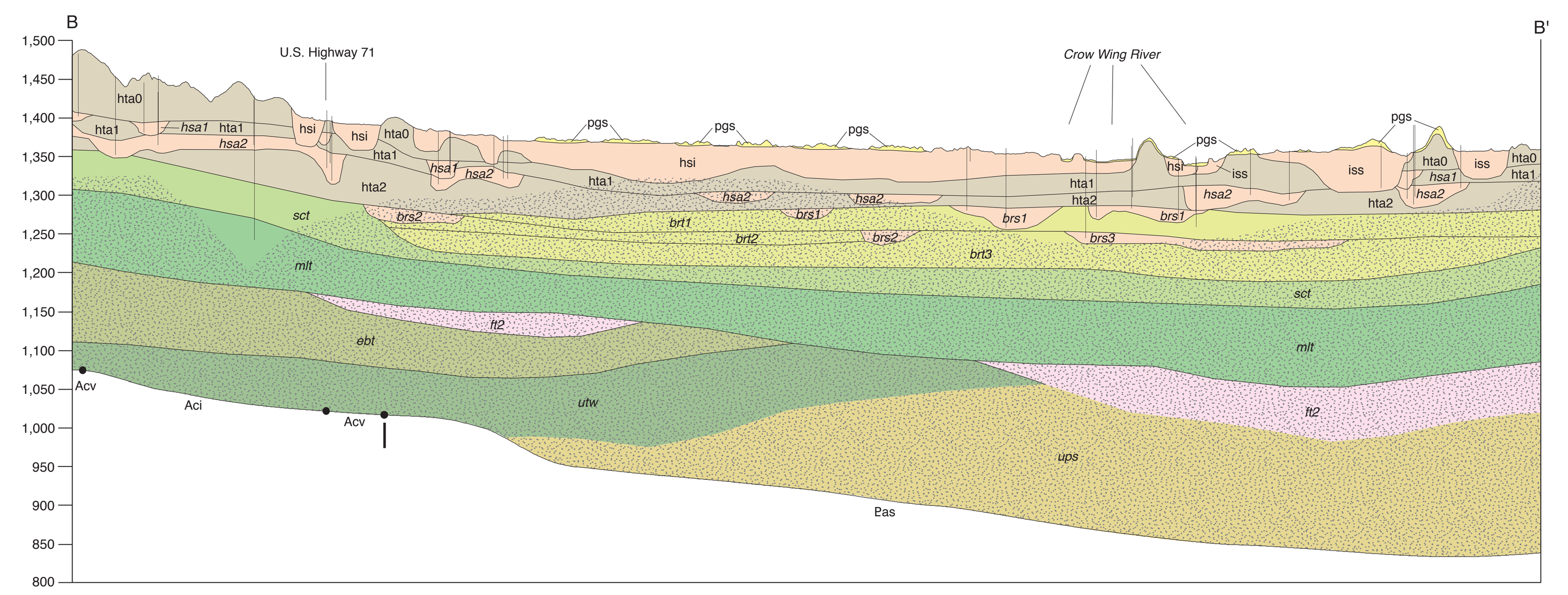
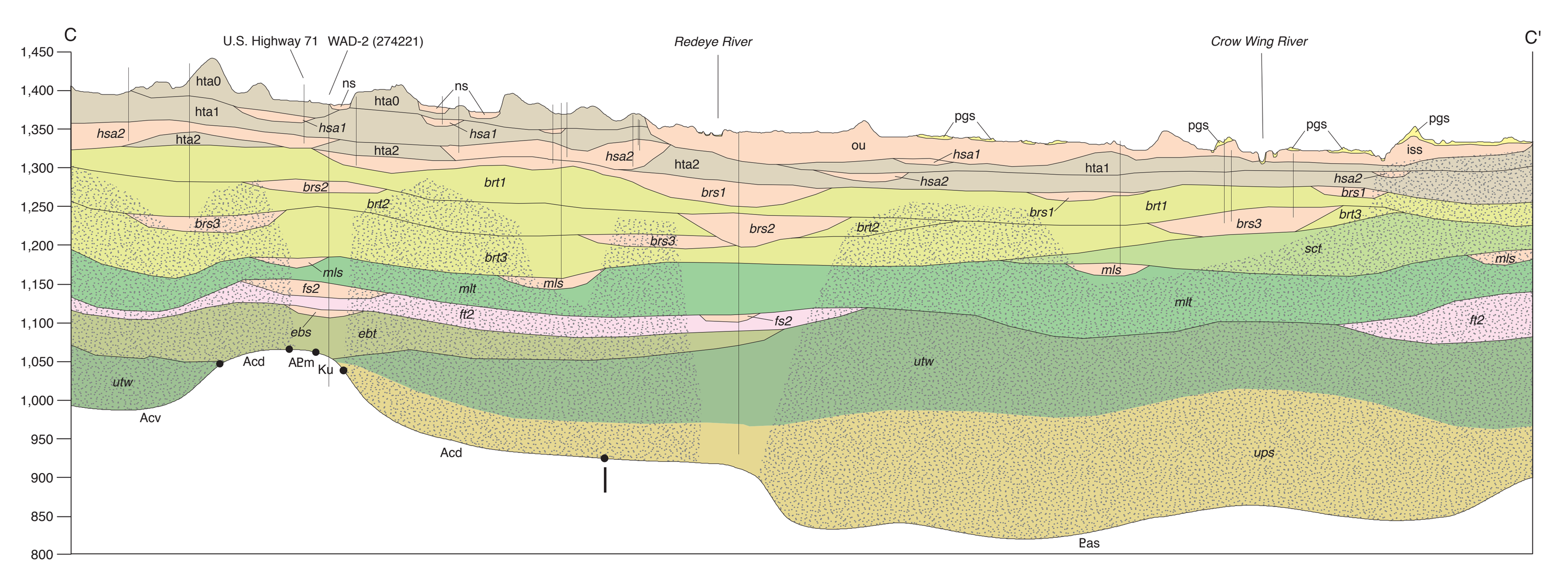
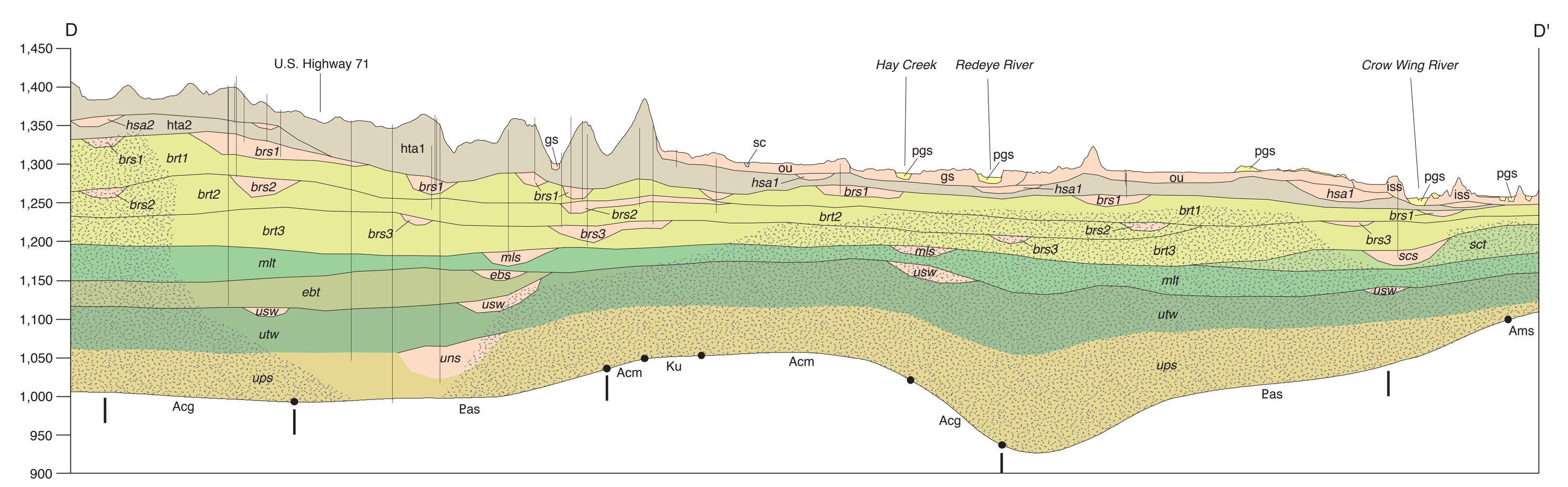
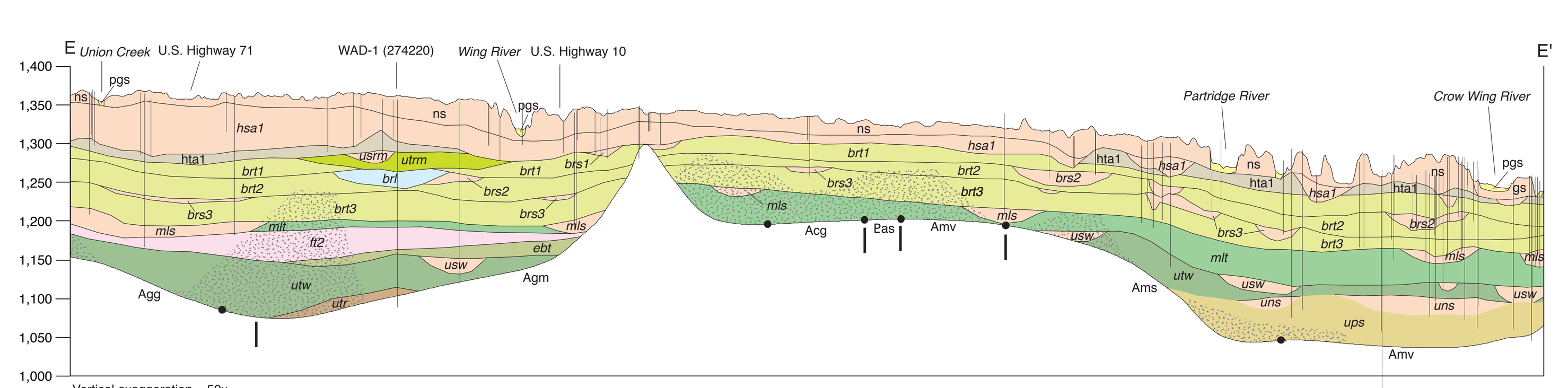
2016











CROSS SECTION SYMBOLS

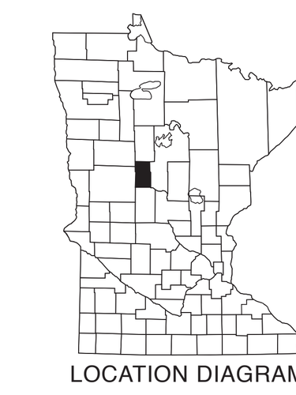
Geologic contact—Approximate. No-line boundaries are shown between unit *ups* and surrounding Quaternary units due to insufficient data.

Bedrock contact—Contact point shown at the base of the Quaternary deposits with the associated bedrock map unit label from Plate 2, *Bedrock Geology*.

Bedrock fault

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. Minnesota Geological Survey unique well numbers are given for rotary-sonic drill holes with stratigraphic logs provided in Figures 5 through 7.

Speculative area—Denotes the area below the depth of water wells and thus where identification of unit boundaries and sand bodies is highly speculative. Areas correspond to those shown on Plate 5, *Sand-Distribution Model*.


LOCATION DIAGRAM

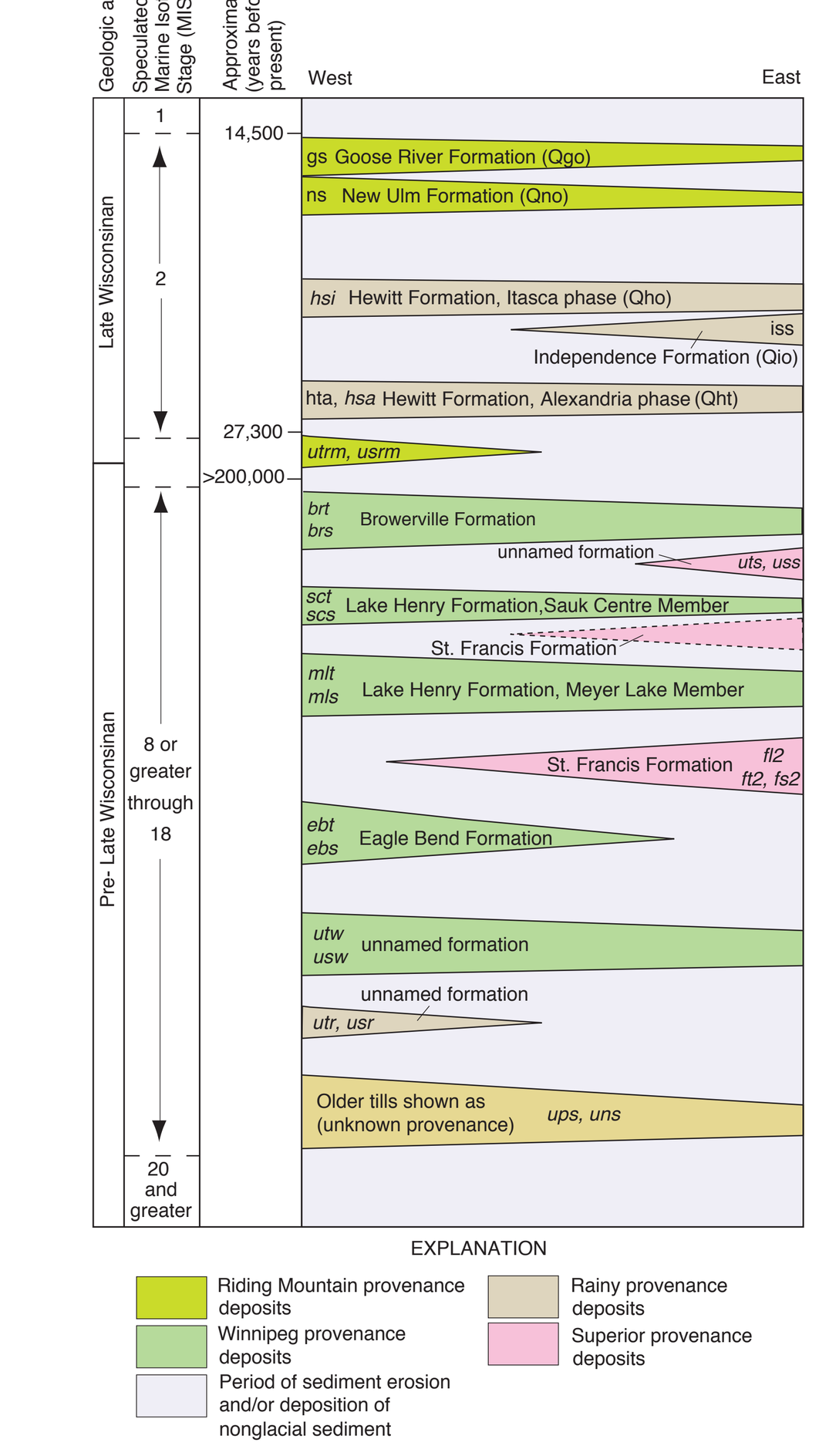


Figure 1. Diagram showing relative age, location (from west to east), provenance (Fig. 2), and related unit labels from the cross sections for Wisconsinan and pre-Wisconsinan glacial deposits. The age column and deposit drawings are schematic and not to scale. Multiple advances of an individual formation are not shown. Dashed lines indicate units found in the regional stratigraphy but not encountered in drill holes in Wadena County. Marine Isotope Stage (MIS) correlations were estimated using figures in Jennings and others (2006). See Figure 2 in Meyer (2015) for a discussion of the radiocarbon dates and sources; modified from Meyer (2015).

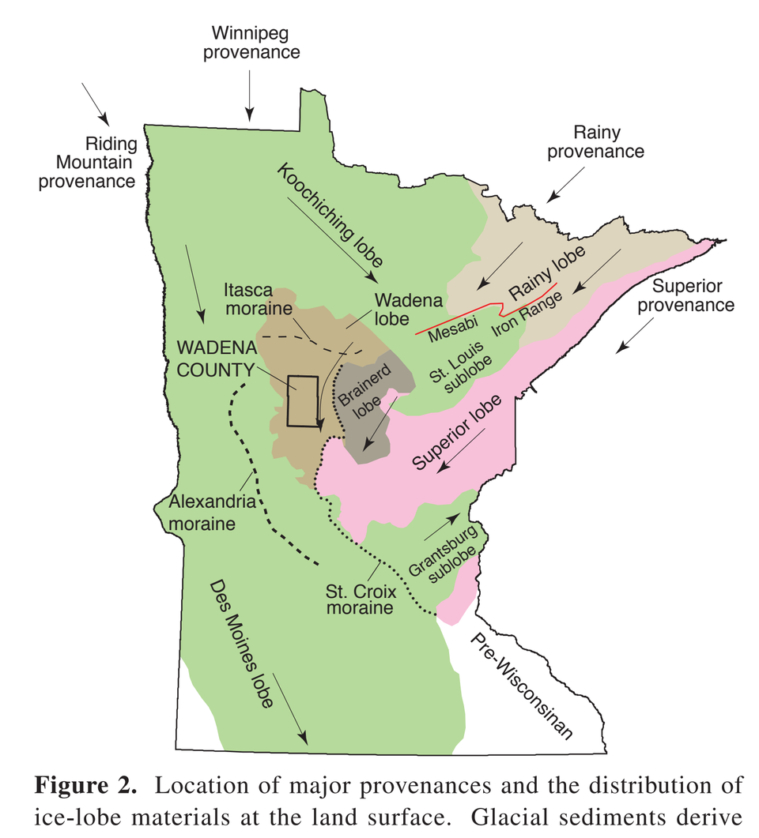


Figure 2. Location of major provenances and the distribution of ice-lobe materials at the land surface. Glacial sediments derive their distinct material content from bedrock and sediment found in the region of these source areas. The extent of Riding Mountain and Winnipeg provenance Des Moines- and Koochiching-lobe and associated sublobe deposits is shown in green. The surface extent of the Rainy provenance Wadena-, Brainerd-, and Rainy-lobe deposits is shown in shades of brown. The extent of Superior-lobe deposits is shown in pink. Moraines are indicated by the dotted or dashed lines. Wadena County is outlined in black.

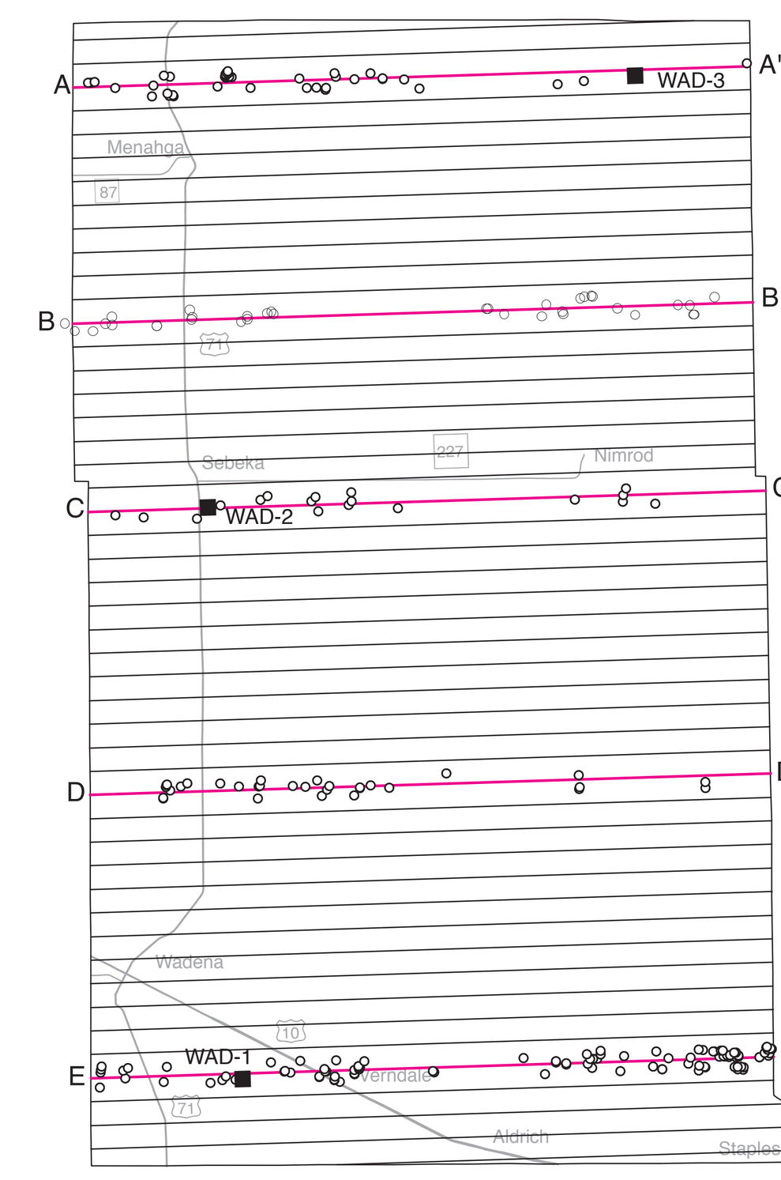


Figure 3. Location of the 49 cross sections, constructed at regular 0.6-mile (1-kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Wadena County. Cross sections A–A' through E–E' appear on this plate. Squares denote the location of rotary-sonic cores drilled for this project. Open circles denote the location of water wells within 0.3 mile (0.5 kilometer) of the published cross sections.

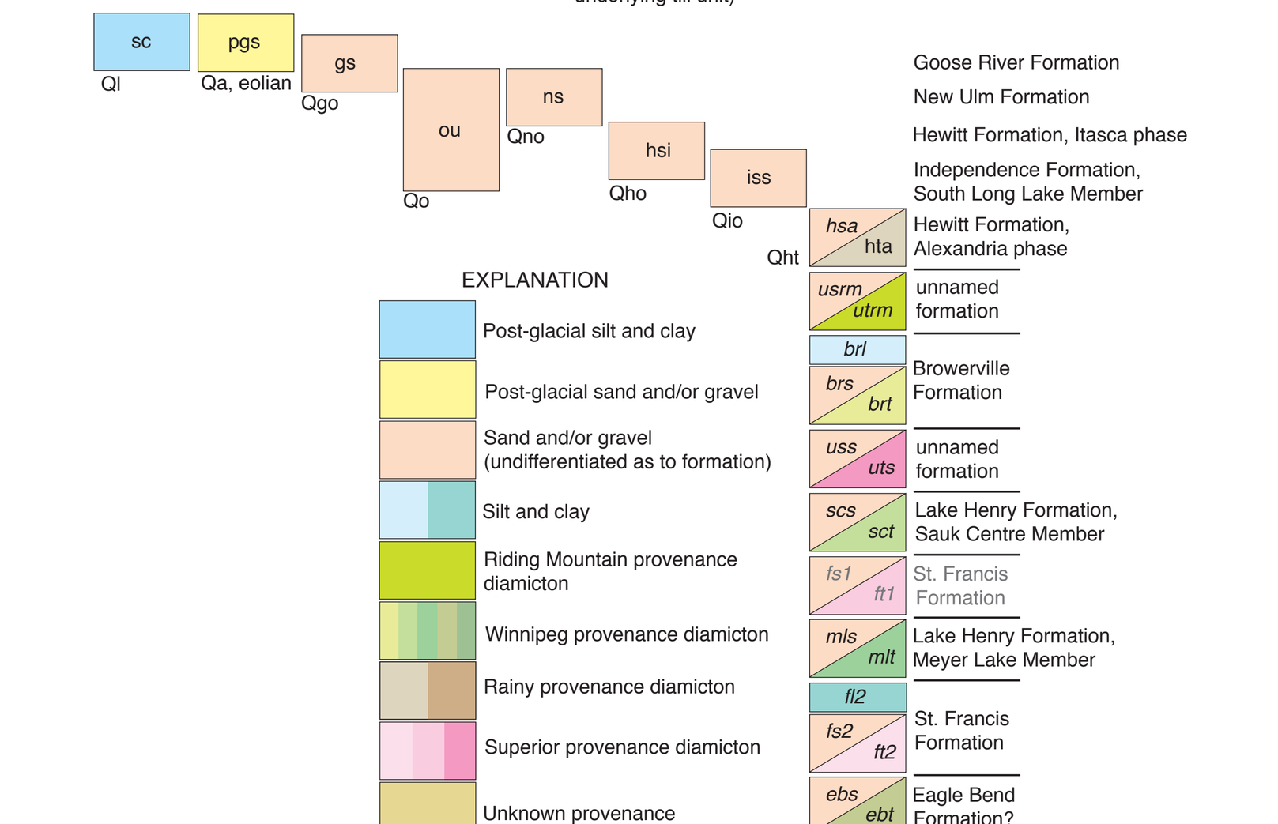


Figure 4. Stratigraphic position of sand and gravel bodies depicted in the cross sections and figures. By convention, the name designations of sand and gravel bodies are associated with their underlying till. On the cross sections, tills and associated sands of the Hewitt and Browerville Formations are subdivided into multiple layers. These layers are identified by ascending numbers from the surface down. Colors represent provenance from which the sediments were derived. Multiple formations from the same provenance are distinguished by shades of the base color. Gray text indicates units found in the regional stratigraphy but not encountered in drill holes in Wadena County. Associated surficial map unit labels are shown, where appropriate, beneath the stratigraphic unit boxes and labels.

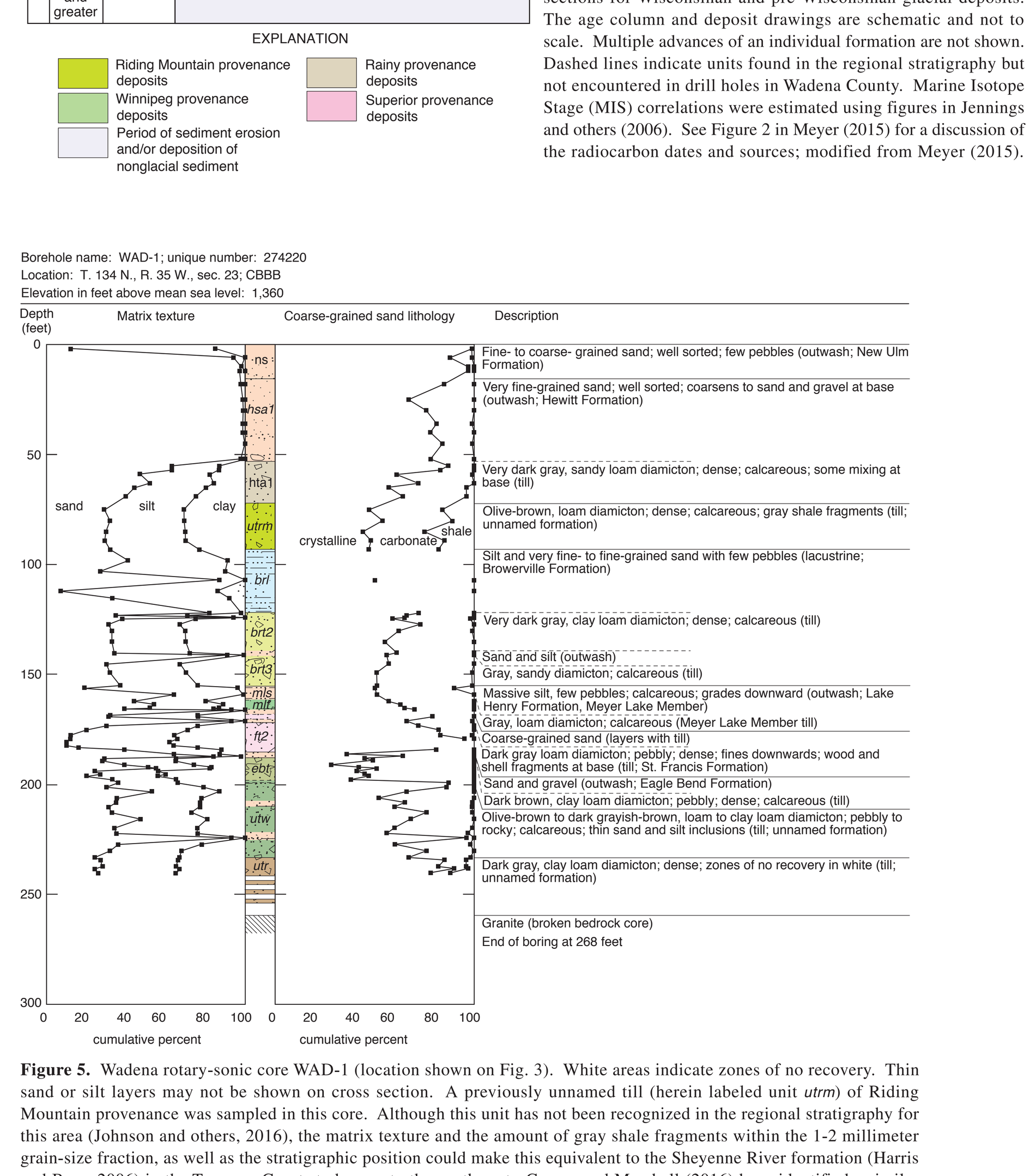


Figure 5. Wadena rotary-sonic core WAD-1 (location shown on Fig. 3). White areas indicate zones of no recovery. Thin sand or silt layers may not be shown on cross section. A previously unnamed till (herein labeled unit *utrm*) of Riding Mountain provenance was sampled in this core. Although this unit has not been recognized in the regional stratigraphy for this area (Johnson and others, 2016), the matrix texture and the amount of gray shale fragments within the 1-2 millimeter grain-size fraction, as well as the stratigraphic position could make this equivalent to the Sheyenne River formation (Harris and Berg, 2006) in the Traverse-Grant study area to the southwest. Gowan and Marshall (2016) have identified a similar unit, informally named the Smoky Hills formation, in Becker County. While the matrix texture and lithology of both units are similar, the Smoky Hills formation is stratigraphically lower than the unnamed Riding Mountain-provenance till encountered in Wadena County, occurring within the Lake Henry Formation, between the Sauk Centre and Meyer Lake Members. More data are needed in order to establish the extent and correlate this unit within the regional stratigraphy.

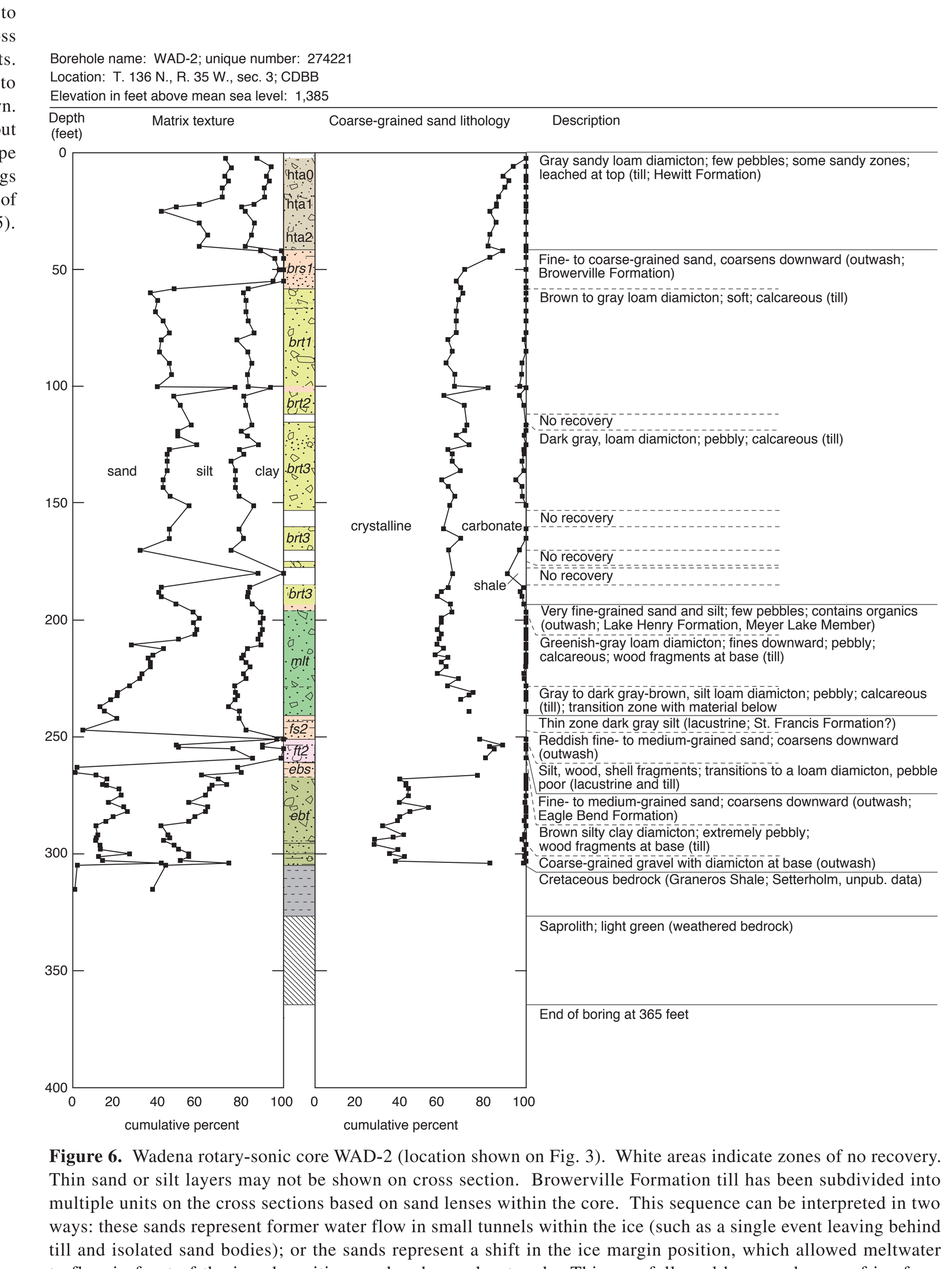


Figure 6. Wadena rotary-sonic core WAD-2 (location shown on Fig. 3). White areas indicate zones of no recovery. Thin sand or silt layers may not be shown on cross section. Browerville Formation till has been subdivided into multiple units on the cross sections based on sand lenses within the core. This sequence can be interpreted in two ways: these sands represent former water flow in small tunnels within the ice (such as a single event leaving behind till and isolated sand bodies); or the sands represent a shift in the ice margin position, which allowed meltwater to flow in front of the ice, depositing sand and gravel outwash. This was followed by a readvance of ice from the same provenance that deposited another layer of similar till on top of the sand and the process repeated as the ice margin shifted (multiple events leaving behind layers of similar tills separated by sand bodies). The sands within the Browerville Formation till were most likely deposited by a combination of both processes described above—small isolated sand bodies (many too small to show on the cross sections) exist within the main till body (single event) and larger, more widespread sand layers laid down in front of the ice margin as the ice shifted position (multiple events).

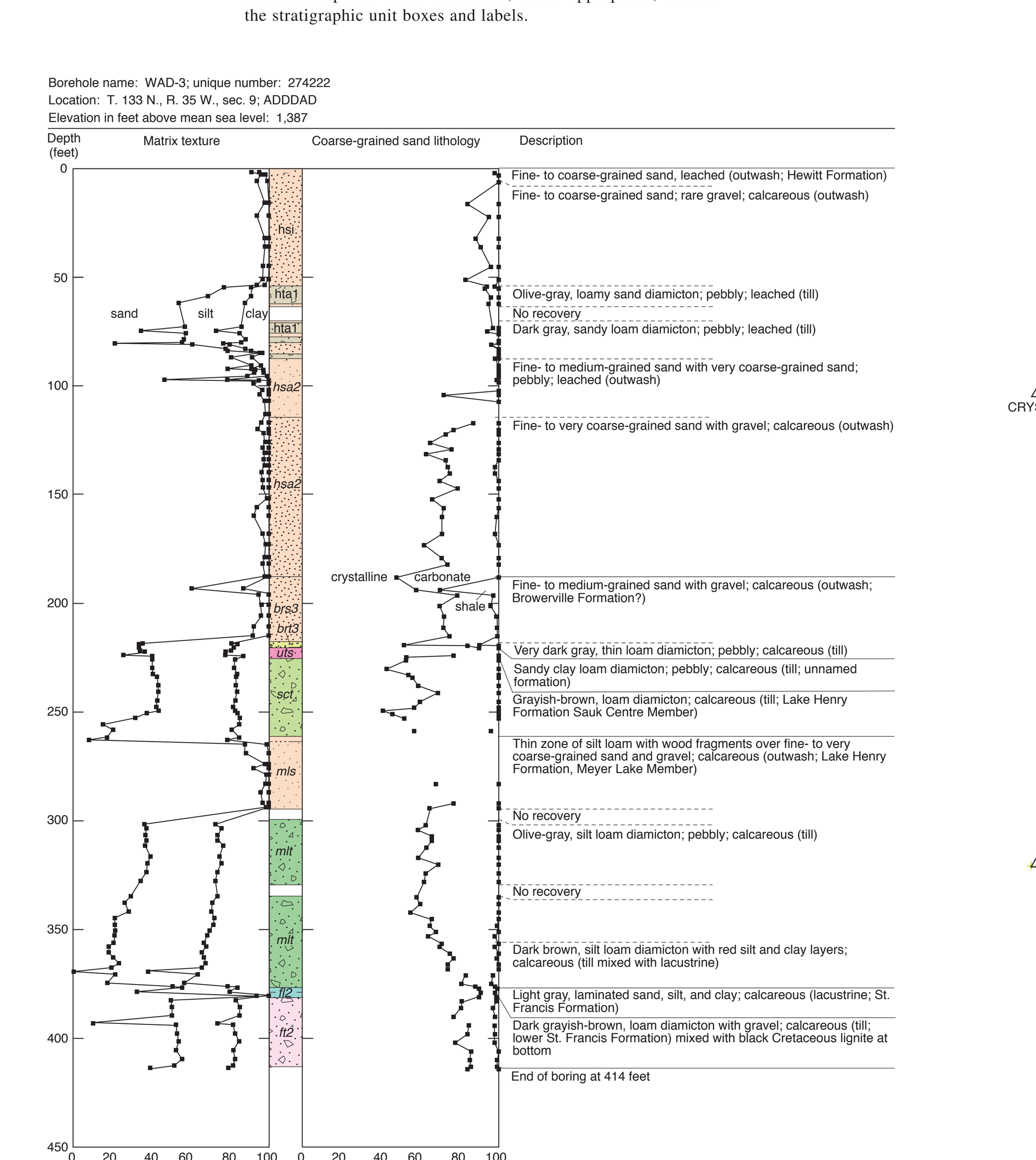


Figure 7. Wadena rotary-sonic core WAD-3 (location shown on Fig. 3). White areas indicate zones of no recovery. Thin sand or silt layers may not be shown on cross section. The Hewitt Formation is thick in this core (over 185 feet [56 meters]), and is mostly outwash composed of sand and gravel. Sand and gravel between 188 to 219 feet (57 to 66 meters) contains minor amounts of gray shale and Cretaceous limestone and is, therefore, attributed to the Browerville Formation. A single sample from a thin (less than 1 foot [0.3 meter] thick) till unit is also interpreted to be part of the Browerville Formation (unit *brt3*). It is possible that this unit could be part of the unnamed Riding Mountain provenance unit (*utrm*) that was identified in core WAD-1. However, this single sample contains only 9 percent shale fragments, whereas the samples from core WAD-1 have an average of 17 percent shale fragments in the 1-2 millimeter very coarse-grained sand fraction (Table 2).

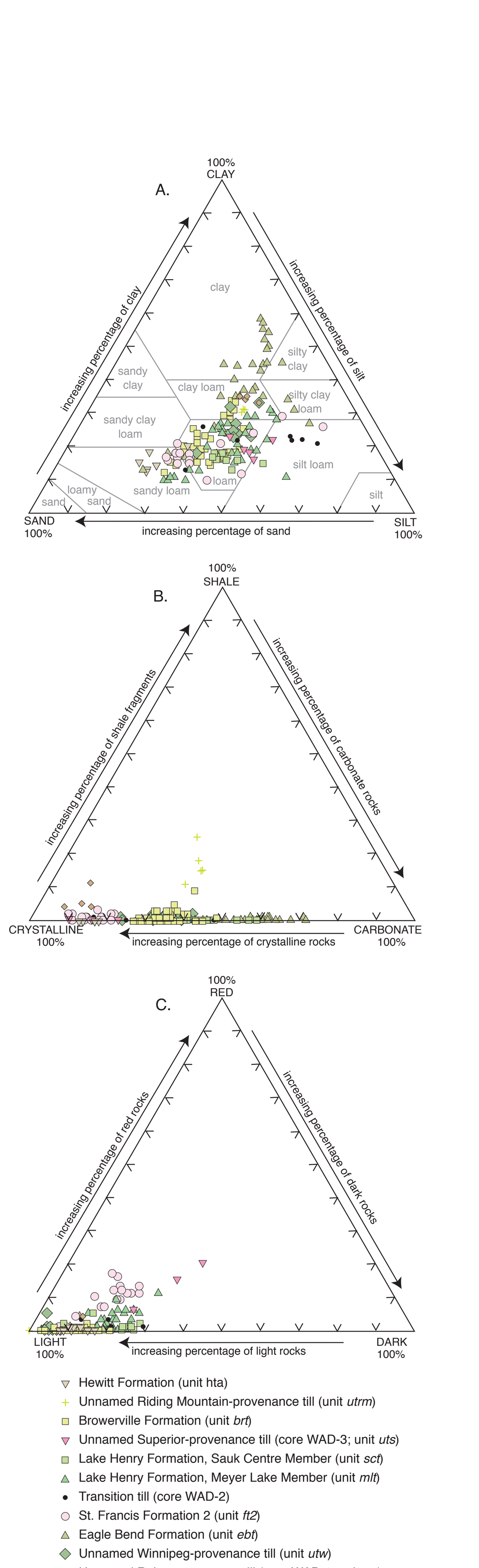


Figure 8. A. Ternary diagram showing matrix texture (less than 2-millimeter size fraction) of till samples from the rotary-sonic cores in Wadena County using the U.S. Department of Agriculture textural classification system.

B. Ternary diagram showing lithologic composition of the very coarse-grained (1-2 millimeters) sand fraction in samples from the rotary-sonic cores in Wadena County.

C. Ternary diagram showing the amount of light, or felsic grains (granite, gneiss, quartzite, and quartz), dark, or mafic grains (basalt, graywacke, and other metamorphic rocks), and red grains (volcanic and sandstone) within the crystalline category shown in Figure 8B.

INTRODUCTION

This Quaternary Stratigraphy plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Wadena County (Figs. 1, 2). Cross sections A–A' through E–E' are representative of 49 cross sections (Fig. 3) that were constructed to create a three-dimensional model of the Quaternary deposits of Wadena County. The major sand and gravel 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 Quaternary geologic units (Fig. 4) 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 drill core from three drill holes completed by the Minnesota Geological Survey for this project, one rotary-sonic drill hole completed as part of the Otter Tail Regional Hydrologic Assessment by the Minnesota Geological Survey (Harris and Knaeble, 1999), a rotary-sonic drill hole described and sampled by the Minnesota Geological Survey but completed for another agency in eastern Becker County (Gowan and Marshall, 2016), water-well drillers' logs, bridge boring logs (Minnesota Department of Transportation, 2015), exposures, and auger samples (Plate 1, *Data-Base 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. Interpreted logs of the three Minnesota Geological Survey rotary-sonic cores completed for this project are shown in Figures 5 through 7; their locations are shown on Figure 3. Water well drillers' logs and cuttings samples collected from sites in adjacent counties near the Wadena County border were used for interpretation and provided significant detailed stratigraphic control. Drill holes 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 from those at the cross-section line. Vertical exaggeration is 50x for all cross sections.

The complexity of subsurface units shown on the cross sections is partly a function of the amount of data available. Where the data are scarce (Fig. 3; Plate 1), the cross-section units are generally portrayed (modeled) as continuous, with relatively uniform thicknesses and minimal elevation change. Where there are more data, units tend to be discontinuous and variable in thickness and elevation over relatively short distances, which reflects more accurately the complexity of glacial deposits, especially those that are older, more deeply buried, and 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 tills are continuous. Although sand bodies are not drawn in all of these areas, sand and gravel commonly occur at till boundaries and may be encountered in future drill holes at the approximate depth of till contacts shown.

The scarcity of deep water-well data, especially in northern Wadena County where the Quaternary sediment is more than 300 feet (91 meters) thicker than in the south (see cross sections and Plate 5, *Depth to Bedrock*), makes it difficult to interpret and delineate the extent of older till units and associated sand layers. Rotary-sonic drill cores provide the only 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 isolated, deeper water-well records. 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.

No-line contacts and the stippled pattern indicate areas where the regional interpretation is especially speculative. This area of greatest uncertainty is shown on the sand-distribution models (Plate 5) as well. Identification of unit boundaries and sand bodies in these areas is highly speculative.

The surficial units that appear in the cross sections are similar, but not identical to those mapped and described on Plate 3, *Surficial Geology.* Peat (unit Qp on Plate 3) is too thin to show on the cross sections and is combined with the surrounding surficial units as noted in the unit descriptions. Sandy units, including alluvium (unit Qa on Plate 3) and eolian sand (indicated by a pattern on Plate 3), are combined into one unit (pgs) for the purpose of modeling. Subsurface units appear only on the cross sections (labeled in italics).

By convention, the name designations of depicted sand and gravel bodies are associated with their underlying till, except for those at the land surface and those that intersect the lowermost unknown units (Fig. 4). However, sand and till units are likely an admixture of material from immediately above or below the named unit. For example, sand unit *brs* is composed chiefly of outwash sediment laid down as the glacier depositing unit *brt* (Browerville Formation) retreated. However, it may also include proglacial meltwater deposits from the advance of ice that deposited the overlying unit hta (Hewitt Formation). Where a particular stratigraphic unit is absent from the section, the units immediately above and below that missing unit likely include eroded remnants that are not shown.

Table 1 shows the correlation of units mapped in Wadena County with those mapped in adjacent Todd (Knaeble and Meyer, 2007) and Becker (Gowan and Marshall, 2016) Counties, where correlations can be made. Not all units were found in all three counties. This variation in stratigraphy between counties likely reflects the position of former ice margins. For example, the Red River lobe, which deposited the Goose River formation in Becker County, did not enter Wadena County. However, meltwater streaming from that ice margin flowed eastward across Wadena County and deposited outwash of the Goose River formation (unit gs; unit Qgo on Plate 3). Alternatively, units may be absent from the regional stratigraphy as a result of erosion. The Browerville Formation occurs in Wadena and Todd Counties, but is absent in Becker County, where it may have been eroded.

DESCRIPTION OF CROSS SECTION UNITS

(Mapped unit labels are from Plate 3, *Surficial Geology*)

HOLOCENE

sc **Fine-grained surface sediment** (includes mapped units Ql, Qp)—Silt and clay of modern (Holocene) lake sediment and slackwater fluvial sediment.

pgs **Sandy surface sediment** (post-glacial sands not part of a named formation listed below; includes eolian sand and mapped unit Qa)—Sand and gravel of modern streams and windblown silt and sand.

PLEISTOCENE

Late Wisconsinan

Goose River formation (Harris, unpub. data)—Sediment deposited by ice of the Riding Mountain sourced Red River lobe.

gs ***Sand to gravelly sand*** (includes mapped units Qgo, Qp)—*Outwash.*

Undifferentiated—Sediment deposited by meltwater issuing from multiple ice lobes of Riding Mountain and Rainy provenances.

ou ***Sand to gravelly sand*** (includes mapped units Qo, Qp)—*Outwash.*

New Ulm Formation (Johnson and others, 2016)—Sediment deposited by ice of the Riding Mountain sourced Des Moines lobe.

ns ***Sand to gravelly sand*** (includes mapped units Qno, Qp)—*Outwash.*

Hewitt Formation (Johnson and others, 2016)—Itasca phase of the Wadena lobe—Sediment deposited by the Rainy sourced Wadena ice lobe during the Itasca phase. In Wadena County, only outwash was deposited during this stage.

hsi ***Sand to gravelly sand*** (includes mapped units Qho, Qp)—*Outwash.*

Independence Formation—South Long Lake Member (Johnson and others, 2016)—Sediment deposited by ice of the Rainy sourced Brainerd lobe.

iss ***Sand to gravelly sand*** (includes mapped units Qio, Qp)—*Outwash.*

Hewitt Formation (Johnson and others, 2016)—Alexandria phase of the Wadena lobe—Sediment deposited by the Rainy sourced Wadena ice lobe as it formed the Alexandria moraine and Wadena drumlin field. Stratigraphic data from water-well records and rotary-sonic cores indicate that there are multiple till layers that may be attributed to the Wadena lobe that deposited the Hewitt Formation. Where sampled, the texture and composition of each layer is nearly identical (Fig. 8; Table 2; see also Table 2 on Plate 3, *Surficial Geology*); therefore, units are separated on the basis of thin sand layers. Separate till layers and their associated sands are numbered 0, 1, 2 as encountered from top to bottom. Unit hta0 is a discontinuous layer that is shown in order to accommodate additional sand and gravel layers within the drumlins on the western side of Wadena County. Unit hta1 is the surface till unit across the rest of the county. Moving southward, the uppermost layers may be eroded or missing, thus exposing older till layers (with a correspondingly higher number) at the surface.

hsa ***Sand to gravelly sand***—*Outwash.*

hta ***Sandy loam diamicton*** (includes mapped units Qht, Qp)—Pebbly, unsorted; generally yellowish-brown (10YR 5/4) where oxidized and olive-brown (2.5Y 3/1) where unoxidized. *Glacial till.*

Pre-Late Wisconsinan (?)

Unnamed formation—Sediment deposited by Riding Mountain-provenance ice. Contains gray shale fragments and abundant Cretaceous limestone grains (Fig. 8; Table 2). Approximately 25 feet (7.6 meters) of this unit were encountered in rotary-sonic core WAD-1 (Fig. 5). Because this stratigraphic layer has not been recognized in other regional studies, units *utrm* and *usrm* are only identified on cross sections within the immediate vicinity of the cores in which they were sampled. This unit may correlate to the Sheyenne River formation of Harris and Berg (2006).

usrm ***Sand to gravelly sand***—*Outwash.*

utrm ***Clay loam diamicton***—Pebbly, unsorted; calcareous; very dark grayish-brown (5Y 3/2). *Glacial till.*

Pre-Late Wisconsinan

Browerville Formation (Johnson and others, 2016)—Sediment deposited by Winnipeg sourced ice. Dark gray Cretaceous limestone is a key indicator of this unit (Fig. 8; Table 2). Stratigraphic data from water-well records and rotary-sonic cores indicate that there are multiple till layers that may be attributed to Winnipeg-provenance ice that deposited the Browerville Formation. Where sampled, the texture and composition of each layer is nearly identical; therefore, units are separated on the basis of thin sand layers that indicate a change in depositional environment. Separate till layers and their associated sands are numbered 1, 2, 3 as encountered from top to bottom.

brl ***Silt loam***—*Lake sediment.*

brs ***Sand to gravelly sand***—*Outwash.*

brt ***Loam diamicton***—Pebbly, unsorted; very dark gray (5Y 3/1) to dark gray (2.5Y 3/1) where unoxidized. *Glacial till.*

Unnamed formation—Sediment deposited by Superior sourced ice. Only 5 feet (1.5 meters) of this unit were encountered in a single rotary-sonic core (WAD-3; Fig. 7), which included finer-grained lacustrine sediment at the top. Because this stratigraphic layer has not been recognized in other regional studies, units *uss* and *uts* are only identified on cross sections within the immediate vicinity of the core in which they were sampled. This unit is similar in texture to the till of the older St. Francis Formation, but contains a higher percentage of red rock fragments (Fig. 8; Table 2). It contains a higher percentage of carbonate grains than does till of the Cromwell Formation, a younger advance of the Superior lobe (Lusardi, 2014).

uss ***Sand to gravelly sand***—*Outwash.*

uts ***Loam diamicton***—Pebbly, unsorted; calcareous; light olive-brown (2.5Y 5/3) to dark grayish-brown (2.5Y 4/2). *Glacial till.*

Lake Henry Formation (Johnson and others, 2016)—Sediment deposited by Winnipeg sourced ice. The Sauk Centre and Meyer Lake members of the Lake Henry Formation are similar in texture; however, the Sauk Centre Member contains more carbonate and fewer crystalline rock fragments than does the Meyer Lake Member (Fig. 8; Table 2). In Morrison County to the southeast, the two members of the Lake Henry Formation are typically separated by the uppermost red till of the St. Francis Formation (Lusardi, 2014); however, this upper red till was not identified in cores or in water-well records in Wadena County.

Sauk Centre Member

scs ***Sand to gravelly sand***—*Outwash.*

sct ***Loam diamicton***—Pebbly, unsorted; light olive-brown (2.5Y 5/3) where oxidized and very dark gray (2.5Y 3/1) to dark gray (5Y 4/1) where unoxidized. This unit was identified in rotary-sonic drill cores WAD-3 (Fig. 7) and OTT-1 in eastern Becker County (originally the Gervais Formation of Harris and Knaeble, 1999). *Glacial till.*

Meyer Lake Member

mls ***Sand to gravelly sand***—*Outwash.*

mlt ***Sandy loam to clay loam diamicton***—Pebbly, unsorted; dark grayish-brown (2.5Y 4/2) to gray (5Y 5/1). This unit is generally loamy in rotary-sonic drill cores WAD-1 (Fig. 5) and WAD-2 (Fig. 6) and is finer-grained in core WAD-3, where the lower 20 feet (6 meters) of till are mixed with red silt and clay, interpreted to be lake sediment (Fig. 7). *Glacial till.*

St. Francis Formation (Johnson and others, 2016)—Sediment deposited by Superior sourced ice. Regionally, the St. Francis Formation consists of two distinct till layers and associated fluvial and lacustrine deposits that separate members of the Lake Henry Formation. Only the lower till unit (*ft2*) was identified and sampled in Wadena County.

fl2 ***Silt, sand, and clay loam***—Laminated, calcareous, dark gray (2.5Y 4/1) clay-rich layers and light gray (2.5Y 7/2) silt-rich layers. This unit was encountered only in rotary-sonic core WAD-3 (Fig. 7). *Glacial lake sediment.*

fs2 ***Sand to gravelly sand***—*Outwash.*

ft2 ***Sandy loam diamicton***—Pebbly, unsorted; dark grayish-brown (2.5Y 4/2) to dark brown (10YR 3/3). This unit was encountered in rotary-sonic cores WAD-1 (Fig. 5) and WAD-3 (Fig. 7). This unit is similar in texture to the till of a younger, unnamed red till (unit *uts*), but contains fewer red rock fragments (Fig. 8; Table 2). It contains a higher percentage of carbonate grains than does till of the Cromwell Formation, a younger advance of the Superior lobe (Lusardi, 2014). *Glacial till.*

Eagle Bend Formation (Johnson and others, 2016)—Sediment deposited by Winnipeg sourced ice. This unit has more carbonate rock fragments in the 1-2 millimeter very coarse-grained sand fraction than does till of the underlying Elmdale Formation (Fig. 8; Table 2).

ebs ***Sand to gravelly sand***—*Outwash.*

ebt ***Clay to clay loam diamicton***—Pebbly, unsorted; olive-brown (2.5Y 4/4) where oxidized or black (2.5Y 2.5/1) where unoxidized, and dark greenish-gray (5GY 4/1) where reduced. *Glacial till.*

Unnamed till—Sediment deposited by Winnipeg sourced ice. Units *utw* and *usw* were sampled only in rotary-sonic core WAD-1, but are widely portrayed in cross section below the Eagle Bend Formation. Stratigraphically, the next unit below the Eagle Bend Formation is typically the Elmdale Formation; however, the amount of carbonate present in the 1-2 millimeter very coarse-grained sand fraction (Table 2) is higher than is found in the Elmdale Formation as defined in Johnson and others (2016). This unit may be related to the unnamed till (unit *vt*) in Morrison County, which lies below the Elmdale Formation in rotary-sonic core Mo-02 (Lusardi, 2014). In cross sections and sand models, unit *utw* likely includes sediment of multiple formations that are as yet undifferentiated.

usw ***Sand to gravelly sand***—*Outwash.*

utw ***Loam to clay loam diamicton***—Dark olive-brown (2.5Y 3/3). This unit was only encountered in rotary-sonic core WAD-1 (Fig. 5). *Glacial till.*

Unnamed till—Sediment deposited by Rainy sourced ice. Units *utr* and *usr* are only depicted within the immediate vicinity of rotary-sonic core WAD-1, where unit *utr* was encountered with poor recovery (Fig. 5). These units likely occur elsewhere but without additional samples to support identification as such, they have been labelled as the unknown units below. There are several potential units identified in cores from north-central Minnesota (Meyer, 1997) to which this might correlate. With its fine-grained texture and low carbonate content (Fig. 8; Table 2), however, it is not a clear match for any of the defined formations.

usr ***Sand to gravelly sand***—*Outwash.*

utr ***Clay loam diamicton***—Pebbly; dark gray (2.5Y 2.5/1). *Glacial till.*

uns **Undifferentiated Quaternary sand to gravelly sand**—Identified in water-well logs; overlies unit *ups*.

ups **Undifferentiated Pleistocene sediment**—This unit includes all sediment (till, sand and gravel, and lake silt and clay) below the lowermost identified till units. Although some water wells extend below this boundary, the data are too sparse to make meaningful correlations.

ACKNOWLEDGEMENTS

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Table 1. Correlation of stratigraphic units in Wadena County with units identified in adjacent Becker (Gowan and Marshall, 2016) and Todd (Knaeble and Meyer, 2007) Counties. Provenance colors match those in Figure 1, with the addition of blue lake sediment.

FORMATION	BECKER sand and gravel	BECKER lake	BECKER till	WADENA sand and gravel	WADENA lake	WADENA till	TODD sand and gravel	TODD lake	TODD till
Goose River	gss	gsl	gst	gs					
New Ulm	nhs	nhl	nht	ns			nou		ntu
Otter Tail River	ons		ont						
Independence				iss					
Cromwell							cou, ci	cl	ctt, ctu
Hewitt, Itasca phase				hsi					
Hewitt, Alexandria phase	hs	hl	ht	hsa (0-2)		hta (0-2)	hou, hii		htu
Unnamed Riding Mountain				usrm		utrm			
Browerville				brs (1-3)	brl	brt (1-3)			bt
Unnamed Superior				uss		uts			
Lake Henry, Sauk Centre Member	scs	scl	sct	scs		sct	usg	ul	xls
St. Francis (upper)							usg	ul	xsu
Lake Henry, Meyer Lake Member	mls	mll	mlt	mls		mlt	usg	ul	xlm
Smoky Hills	shs		sht						
Unnamed Rainy	urs	url	urt						
Unnamed Winnipeg/Rainy	uwrs	uwrl	uwrt						
St. Francis (lower)	sfs	sfl	sft	fs2	fl2	ft2	usg	ul	xsl
Eagle Bend	ebs	ebl	ebt	ebs		ebt	usg	ul	xet
Unnamed Superior	rs		rt						
Elmdale	es		et	usw		utw	usg	ul	et
Unnamed Rainy				usr		utr	usg	ul	
Older deposits	qsu		qtu, qu	uns		ups	usg	ul	ups

Table 2. Average values for the texture and composition of till units (listed in stratigraphic order) recognized in Wadena County based on samples from rotary-sonic cores. Matrix texture (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 crystalline rock, carbonate rock, and shale fragments. The crystalline fraction is further subdivided by rock type—light (granite and gneiss), dark (mafic-rich igneous and metamorphic rocks), red (rhyolite, agate, and sandstone), and clear quartz. The lithologic composition can also be divided into relative proportions of grains based on age—Precambrian, Paleozoic, and Cretaceous (see Hobbs, 1998 for rock types included in these categories). The percentage of gray shale and limestone is the amount of these grains identified in the Cretaceous fraction.

Deposit description and geologic units shown on cross sections	Total number of samples	MATRIX TEXTURE: percentage of the less than 2 millimeter sand fraction: Sand	Silt	Clay	Gravel (percentage of total sample weight)	CLAST TYPE: percentage of total grains counted of the 1-2 millimeter fraction: Crystalline	Carbonate	Shale	Gray shale (percentage of Cretaceous grains counted)	Precambrian	Paleozoic	Cretaceous	Limestone (percentage of Cretaceous grains counted)	percentage of total crystalline grains counted: Light	Dark	Red	Clear quartz
Hewitt Formation																	
Leached till	14	63	24	13	6	96	4	0	0	96	4	0	14	89	10	1	32
Till (unit hta)	9	59	26	15	8	85	15	0	0	85	15	0	33	88	12	0	26
Unnamed formation (Riding Mountain provenance)																	
Till (unit *utrm*)	5	30	41	29	4	48	35	17	56	48	22	30	34	91	9	0	40
Browerville Formation																	
Till (unit *brt*)	40	43	37	20	6	65	34	1	12	64	30	6	64	88	12	0	36
Unnamed formation (Superior provenance)																	
Till (unit *uts*)	5	33	47	20	4	84	16	0	0	83	17	0	0	56	30	14	12
Lake Henry Formation, Sauk Centre Member																	
Till (unit *sct*)	12	41	43	16	5	54	46	0	0	53	47	0	25	79	20	1	10
Lake Henry Formation, Meyer Lake Member																	
Till (unit *mlt*)	36	38	41	21	4	62	38	0	10	62	38	0	20	77	20	3	16
St. Francis Formation																	
Till 2 (unit *ft2*)	15	43	38	19	3	81	18	1	38	75	19	6	15	74	16	10	15
Eagle Bend Formation																	
Till (unit *ebt*)	29	24	37	39	8	41	59	0	0	40	56	4	52	91	9	0	31
Unnamed formation (Winnipeg provenance)																	
Till (unit *utw*)	9	34	41	25	5	66	33	1	0	65	25	10	63	94	5	1	44
Unnamed formation (Rainy provenance)																	
Till (unit *utr*)	4	26	40	34	9	83	11	6	1	83	7	10	39	90	9	1	30