UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
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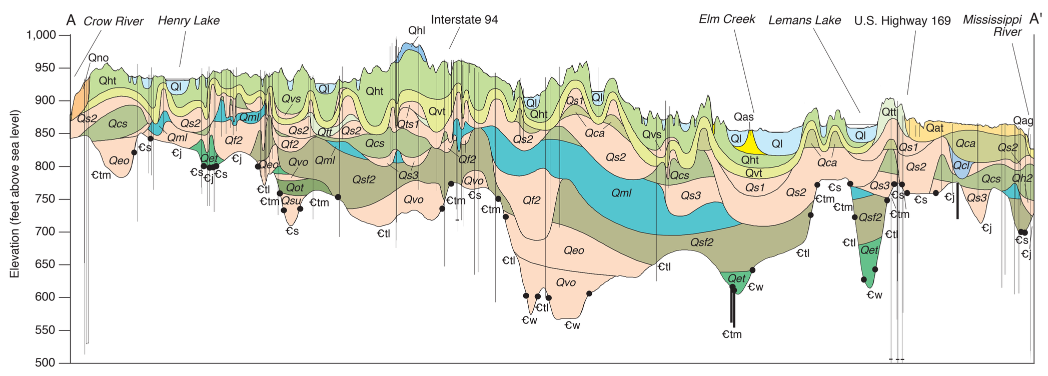
COUNTY ATLAS SERIES
ATLAS C-45, PART A
Hennepin County
Plate 4—Quaternary Stratigraphy

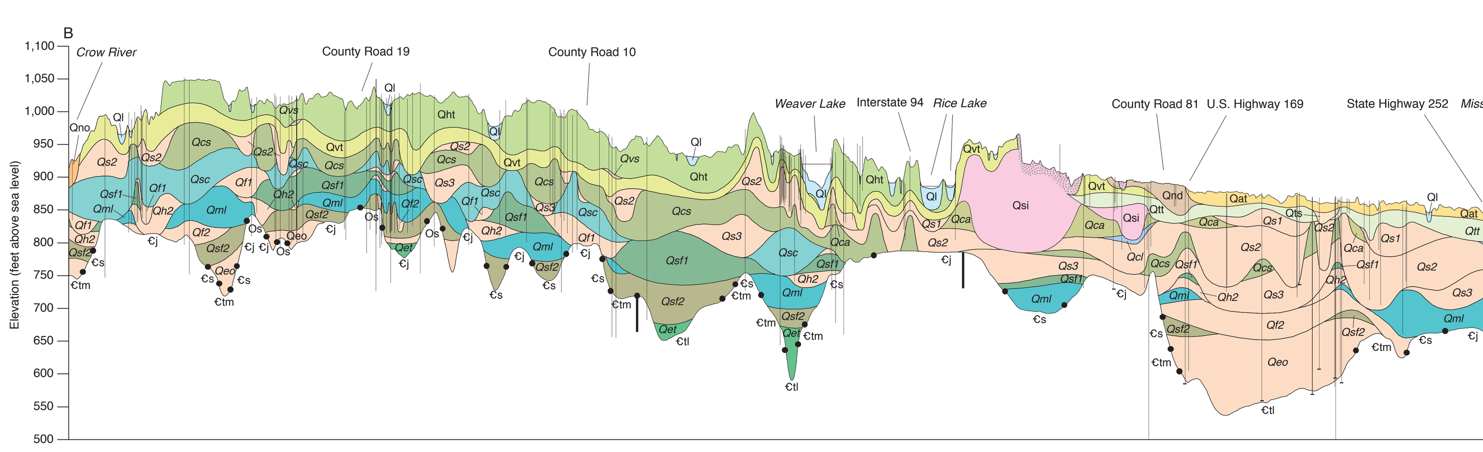
QUATERNARY STRATIGRAPHY

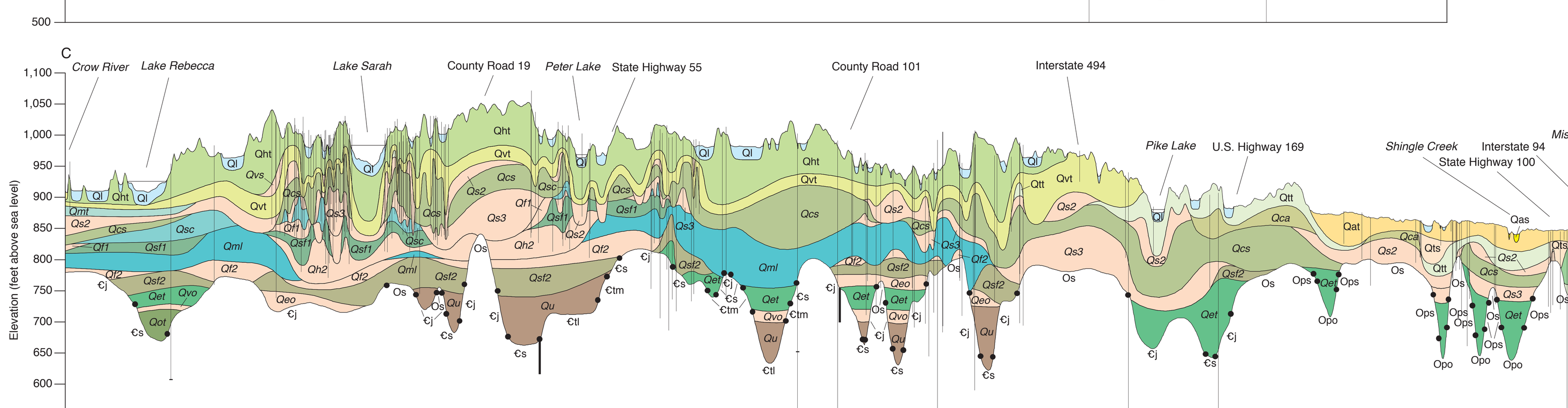
By

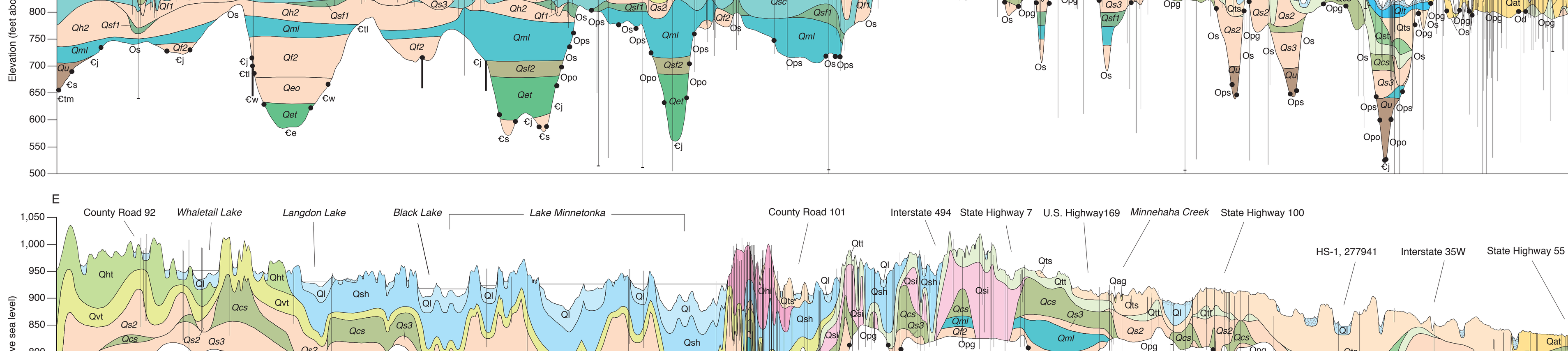
Angela J. Berthold

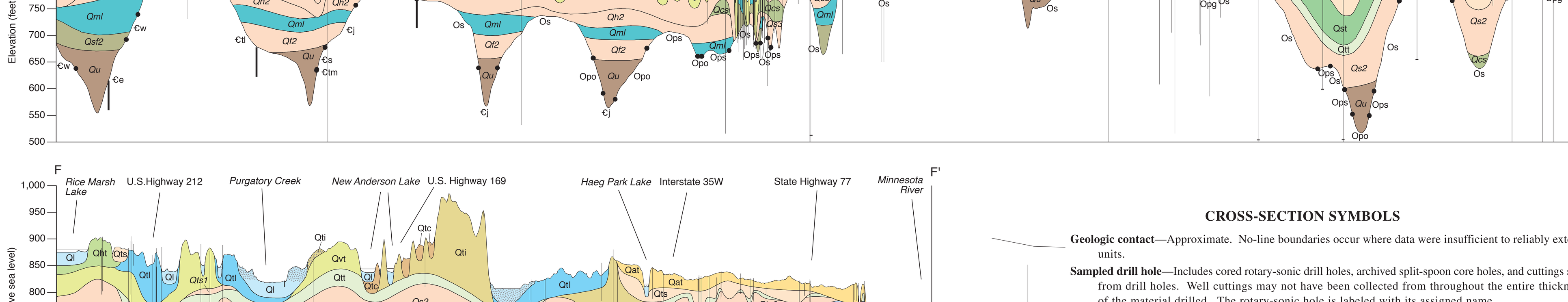
2018

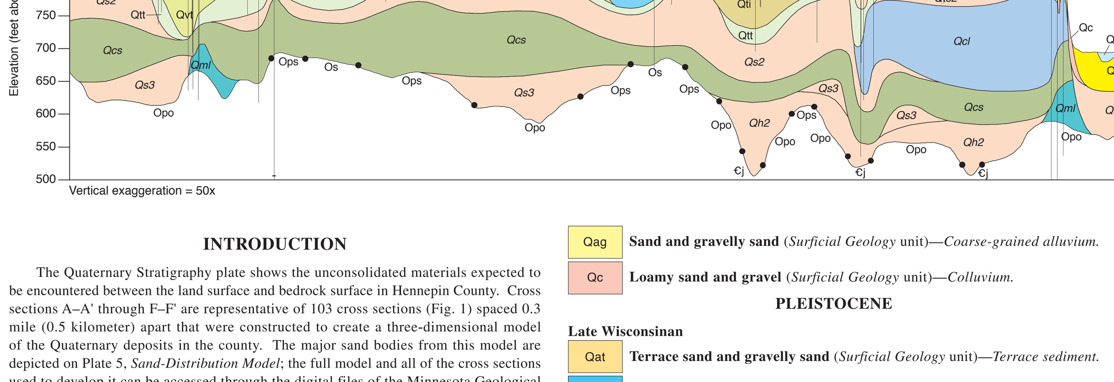












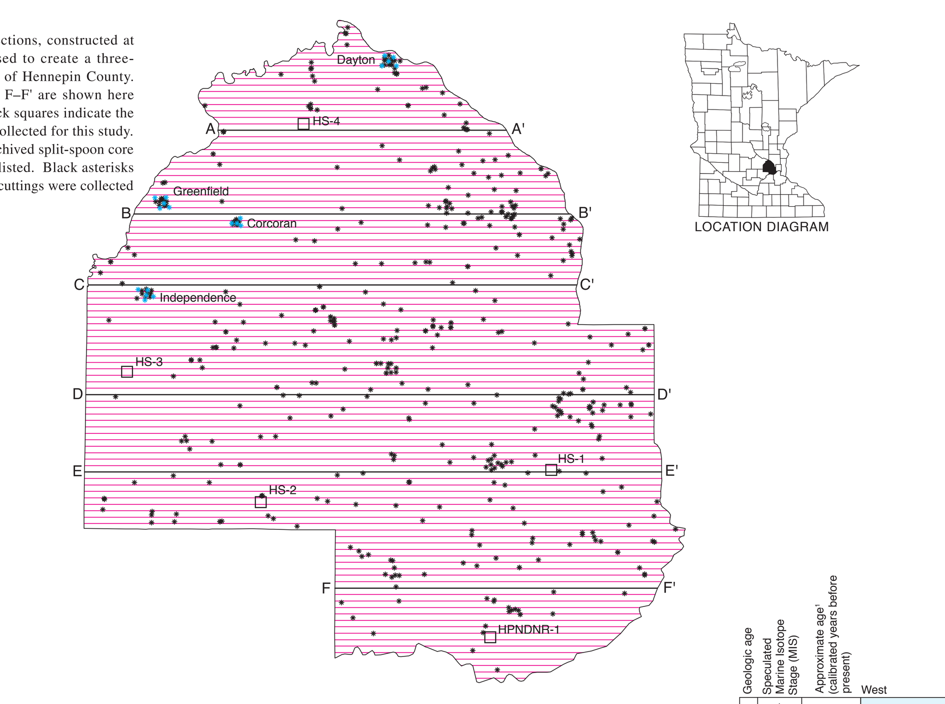


Figure 1. Location of 103 west–east cross sections, constructed at regular 0.3-mile (0.5-kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Hennepin County. The locations of cross sections A–A' through F–F' are shown here and are also on Plate 3, *Surficial Geology*. Black squares indicate the locations of the five rotary-sonic core samples collected for this study. Blue asterisks indicate the locations of the 19 archived split-spoon core holes analyzed for this project. Site names are listed. Black asterisks indicate the locations of 459 borings where drill cuttings were collected and described for this study.

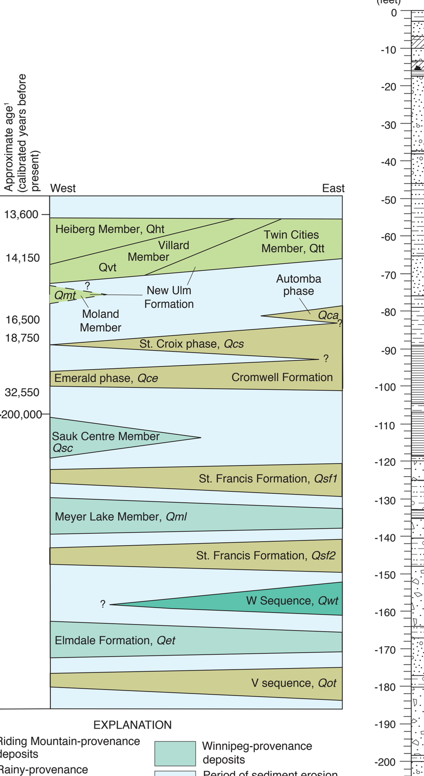


Figure 2. Diagram showing relative age, location (across Hennepin County from west to east), provenance (Plate 3, Fig. 2; Table 1), and related unit labels from the cross sections for late Wisconsinan and pre-late Wisconsinan glacial tills (Table 1). The age column and unit drawings are not to scale. All radiocarbon ages shown are calibrated to calendar years before present (cal YBP; Stuiver and others, 2017). See the text on Plate 3 for a discussion of the late Wisconsinan geologic history. The age of greater than 200,000 YBP for the pre-late Wisconsinan stratigraphy is based on a uranium series minimum age of interglacial marl found atop a till unit stratigraphically above the Sauk Centre Member of the Lake Henry Formation (Knaeble and Meyer, 2007; Johnson and others, 2016). The Elmdale Formation in Hennepin County may correlate with the Pierce Formation mapped in Washington County (Meyer, 2016) and west-central Wisconsin (Baker and others, 1983; Syverson and others, 2011) based on its texture, lithologic composition, and stratigraphic position. The Pierce Formation in Wisconsin has reversed polarity in the stratigraphically lower members and normal polarity in the upper members (Syverson and others, 2011), which suggests that deposition occurred during the Brunhes normal-Matuyama reversed polarity boundary at 780,000 YBP (Lisiecki and Raymo, 2005). The Elmdale Formation in Minnesota does not show this same reversal; in fact, the majority of samples have normal polarity (Meyer, 1986). However, given the variability in polarity found in Wisconsin, it is possible that the Elmdale Formation in Minnesota was deposited later during the same glacial event as the Pierce Formation. The age of the reversal correlates it with the end of MIS 20.

[1]Ages are in calibrated/calendar years before present (cal YBP), and recalibrated from published radiocarbon dates using CALIB radiocarbon calibration program, Calib 7.1 (Stuiver and others, 2017) with 2 sigma error.

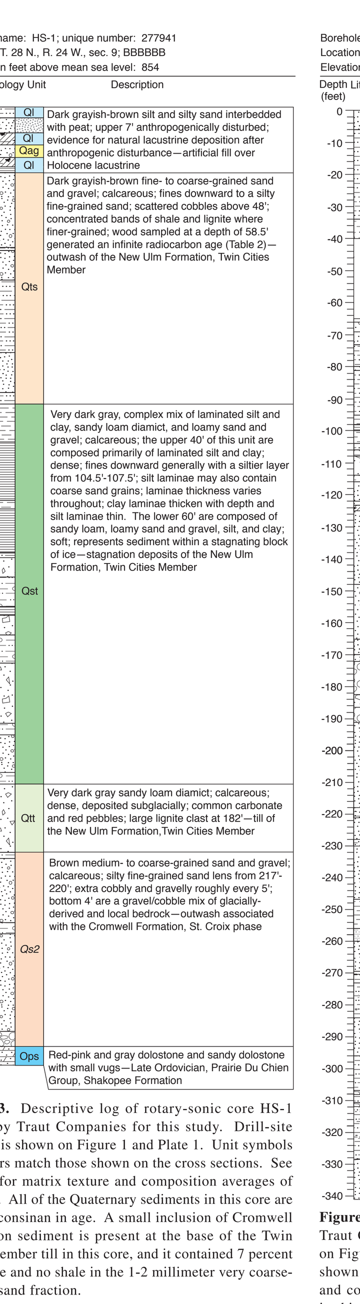


Figure 3. Descriptive log of rotary-sonic core HS-1 drilled by Traut Companies for this study. Drill-site location is shown on Figure 1 and Plate 1. Unit symbols and colors match those shown on the cross sections. See Table 1 for matrix texture and composition averages of till units. All of the Quaternary sediments in this core are late Wisconsinan in age. A small inclusion of Cromwell Formation sediment is present at the base of the Twin Cities Member till in this core, and it contained 7 percent carbonate and no shale in the 1-2 millimeter very coarse-grained sand fraction.

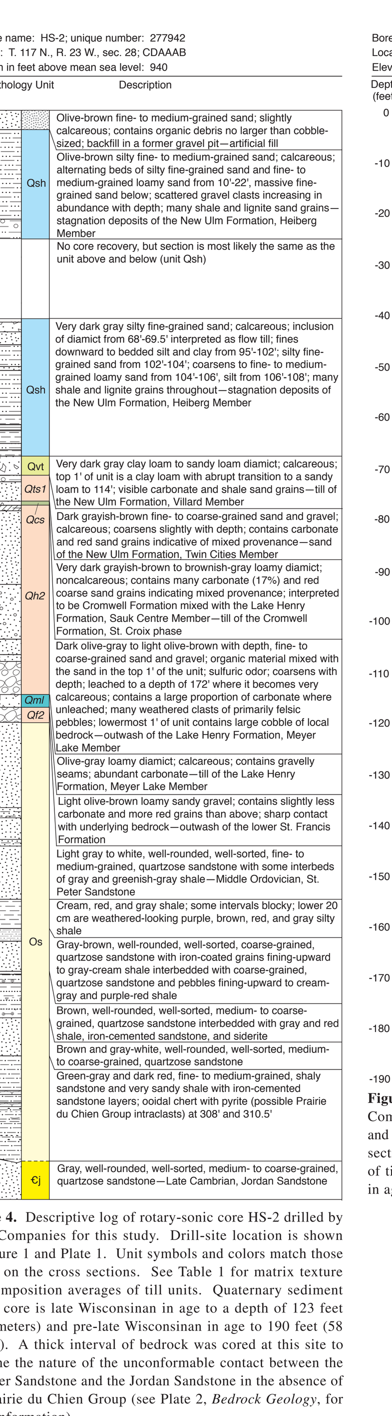


Figure 4. Descriptive log of rotary-sonic core HS-2 drilled by Traut Companies for this study. Drill-site location is shown on Figure 1 and Plate 1. Unit symbols and colors match those shown on the cross sections. See Table 1 for matrix texture and composition averages of till units. Quaternary sediment in this core is late Wisconsinan in age to a depth of 123 feet (37.5 meters) and pre-late Wisconsinan in age to 190 feet (58 meters). A thick interval of bedrock was cored at this site to examine the nature of the unconformable contact between the St. Peter Sandstone and the Jordan Sandstone in the absence of the Prairie du Chien Group (see Plate 2, *Bedrock Geology*, for more information).

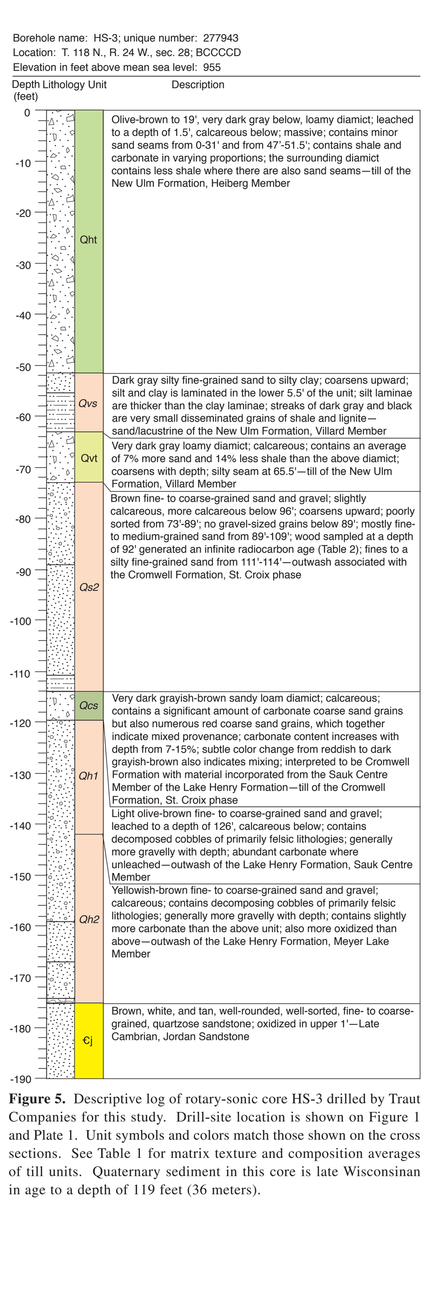


Figure 5. Descriptive log of rotary-sonic core HS-3 drilled by Traut Companies for this study. Drill-site location is shown on Figure 1 and Plate 1. Unit symbols and colors match those shown on the cross sections. See Table 1 for matrix texture and composition averages of till units. Quaternary sediment in this core is late Wisconsinan in age to a depth of 119 feet (36 meters).

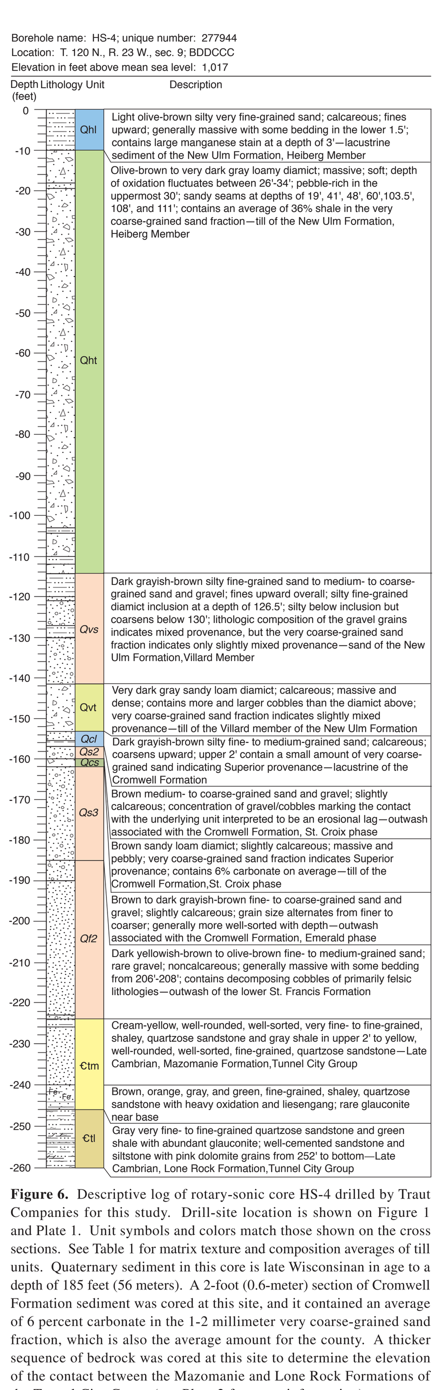


Figure 6. Descriptive log of rotary-sonic core HS-4 drilled by Traut Companies for this study. Drill-site location is shown on Figure 1 and Plate 1. Unit symbols and colors match those shown on the cross sections. See Table 1 for matrix texture and composition averages of till units. Quaternary sediment in this core is late Wisconsinan in age to a depth of 185 feet (56 meters). A 2-foot (0.6-meter) section of Cromwell Formation sediment was cored at this site, and it contained an average of 6 percent carbonate in the 1-2 millimeter very coarse-grained sand fraction, which is also the average amount for the county. A thicker sequence of bedrock was cored at this site to determine the elevation of the contact between the Mazomanie and Lone Rock Formations of the Tunnel City Group (see Plate 2 for more information).

Table 1. Average values for the matrix texture and composition of select tills recognized in Hennepin 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 crystalline rocks, Paleozoic carbonate rocks, and Cretaceous shale using the classification system of Hobbs (1998). The Precambrian crystalline 1-2 millimeter fraction is further differentiated by crystalline rock type: light (felsic rock types including granite, gneiss, and other light-colored metamorphic rock types), dark (mafic rock types including basalt, gabbro, diabase, and also dark-colored metamorphic rock types), and red (iron formation, rhyolite, agate, and sandstone).

		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		
Deposit description	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay	Precambrian crystalline	Paleozoic carbonate	Cretaceous shale	Light	Dark	Red
New Ulm Formation											
Heiberg Member (unit Qht)	591	5	42	38	20	40	26	34	88	11	1
Villard Member (unit Qvt)	268	7	48	35	17	56	25	19	86	12	2
Moland Member (unit *Qmt*)	18	10	62	27	11	69	26	5	83	15	2
Twin Cities Member (unit Qtt)	133	7	55	30	15	72	18	10	73	18	9
Cromwell Formation (unit *Qcs*)	129	11	62	27	11	94	6	0	54	28	18
Lake Henry Formation											
Sauk Centre Member (unit *Qsc*)	44	6	36	42	22	56	44	0	86	12	2
Meyer Lake Member (unit *Qml*)	41	5	39	41	20	67	33	t	82	15	3
St. Francis Formation											
Upper Member (unit *Qsf1*)	12	10	62	26	12	89	11	0	71	17	12
leached	10	4	71	20	9	100	0	0	62	23	15
Lower Member (unit *Qsf2*)	4	3	59	26	15	90	10	0	83	13	4
leached	4	8	65	25	10	100	0	0	76	15	9
Rainy provenance (unit *Qwt*)	1	4	66	24	10	90	10	0	80	16	4
Elmdale Formation (unit *Qet*)	2	4	53	31	16	83	13	4*	82	13	5

Total 1,257

t = trace amount (less than 0.5 percent)
*includes Cretaceous limestone

Table 2. Wood and charcoal were sampled for radiocarbon dating from five rotary-sonic cores and one giddings soil auger boring. Three of the rotary-sonic cores (OB 27075; SF-1 and SF-2 from Carver County to the southwest) were contracted by the Minnesota Department of Natural Resources and collected by the Minnesota Geological Survey. The other two rotary-sonic cores (HS-1, HS-3) were contracted and collected by the Minnesota Geological Survey. The samples were taken at the Minnesota Geological Survey, prepared by LacCore of the University of Minnesota, and processed by the Center for Accelerator Mass Spectrometry of the Lawrence Livermore National Laboratory. All samples were in stratigraphic positions indicating they had the potential to yield finite age dates within the late Wisconsinan glaciation. Most of these results indicate, however, that the ages of the organic materials sampled are older than the reliable limit of radiocarbon dating because they are beyond the standard range of calibration curves used to calibrate radiocarbon ages to calendar years before present (Walker, 2005; Reimer, 2012). The one sample with a finite age (QHPN-1) was generated from charcoal picked from lake sediment just above its contact with till from core collected in Rice Lake in Maple Grove. This age result is younger than other nearby ages for the timing of deglaciation (Meyer, 1998), and only serves to constrain the onset of lacustrine sedimentation at that particular location in the lake.

CAMS number	Sample name	MGS ID	Depth (feet)	$\delta^{13}C$	Fraction modern	±	$D^{14}C$	±	^{14}C age	±	Median probability age
176552	SF-1-101	817606	101	-25	0.0002	0.0004	-999.8	0.4	>55200		N/A
176553	OB 27075-1-149.5	819504	149.5	-25	0.0015	0.0004	-998.5	0.4	52400	2300	N/A
176554	SF-2-215	817603	215	-25	0.0000	0.0004	-1000.0	0.4	>56900		N/A
176555	HS-1-58.5	277941	58.5	-25	0.0010	0.0004	-999.0	0.4	55200	3300	N/A
176556	HS-3-92	277943	92	-25	0.0000	0.0004	-1000.3	0.4	>56900		N/A
176557	MDT-1-14	42945	14	-25	0.0013	0.0004	-998.7	0.4	53600	2700	N/A
179057	QHPN-1	47009	15.5	-25	0.5057	0.0023	-494.3	2.3	5480	40	6284

CROSS-SECTION SYMBOLS

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

Sampled drill hole—Includes cored rotary-sonic drill holes, archived split-spoon core holes, and cuttings sets from drill holes. Well cuttings may not have been collected from throughout the entire thickness of the material drilled. The rotary-sonic hole is labeled with its assigned name.

Drill hole—Includes water-well drillers' sites. The top of the drill-hole symbol may not coincide with the cross-section surface-elevation line because the point is located near (within 0.15 mile [0.25 kilometer]) but not on the cross-section line and therefore may have a slightly different surface elevation.

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

Fault—Bedrock fault, see Plate 2.

INTRODUCTION

The Quaternary Stratigraphy plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Hennepin County. Cross sections A–A' through F–F' are representative of 103 cross sections (Fig. 1) spaced 0.3 mile (0.5 kilometer) apart that were constructed to create a three-dimensional model of the Quaternary deposits in the county. The major sand bodies from this model are depicted on Plate 5, *Sand-Distribution Model*; the full model and all of the cross sections used to develop it can be accessed through the digital files of the Minnesota Geological Survey. The Quaternary geologic units shown on the cross sections were defined from interpretation of new data collected for this study and from existing data and samples from previous investigations (see Plate 3, *Surficial Geology*, Index to Previous Mapping). These data sources include: seven rotary-sonic drill cores, archived split-spoon cores from 19 drill holes at four sites, over 450 well cuttings sets archived in the Minnesota Geological Survey cuttings library, outcrops, soil auger samples, and water-well and soil boring drillers' logs (Plate 1, *Data-Base Map*).

On each of the cross sections shown, rotary-sonic holes, well cuttings sets, and water wells are displayed as black vertical lines; the rotary-sonic hole is labeled; wells with cuttings are shown with a unique line symbol. Well elevation may not match the surface elevation on the cross-section line because data for each line are gathered from a distance of up to 0.15 mile (0.25 kilometer) from both the north and south sides of the line, where the surface elevation may be higher or lower. Bedrock units and faults described on Plate 2, *Bedrock Geology*, are labeled and shown at the base of the Quaternary deposits. Vertical exaggeration is 50x for all cross sections to show the commonly thin, complex units of the Quaternary section.

Because Hennepin County has been highly populated for a long time, it is the most data-dense county in the state. As a result, the cross sections were drawn with more detail and complexity than is possible in less-populated counties. However, where data are comparatively sparse, units are portrayed as continuous with relatively uniform thicknesses and minimal changes in elevation. Glacial till and fine-grained lacustrine sediments are generally considered more continuous than sand and gravel units because of the way glaciers deposited these sediment types. Till was typically laid down as laterally extensive sheets deposited directly by ice. Sand and gravel were deposited by streams and therefore tend to be more discrete and discontinuous. By convention, subsurface sand and gravel units are associated with the till underlying the unit. However, these sand and gravel units likely represent deposition by meltwater from ice that deposited both the underlying and overlying till units. An exception was made to this convention where data were sufficient to make that determination (such as unit *Qts2*). Most of the units from the Late Pleistocene and Holocene Epochs described on Plate 3 match the units mapped on this plate. The exceptions are Holocene peat (unit Qp) and lacustrine deposits (unit Ql), which are combined into unit Ql. Artificial fill related to units Ql, Qti, and Qsi is displayed by a stippled pattern. Additional Late Pleistocene and older units are present only in the subsurface and are thus mapped and described exclusively on this plate. Areas below the depth of available water-well records and above the bedrock surface are mapped as "undifferentiated sediment" (unit Qu). For the most part, this unit is constrained to the deepest parts of the numerous bedrock valleys in the county.

Figure 2 is a time–distance illustration showing the inferred relationships between age, provenance, stratigraphic position, and general geographic location of the sediments deposited by major glacial episodes (supplementary information on Plate 3, Fig. 2; Table 1). Descriptions from the four rotary-sonic drill cores contracted by the Minnesota Geological Survey appear in Figures 3 through 6, and the texture and composition of selected geologic units are summarized in Table 1. Because most samples of pre-late Wisconsinan strata were taken from the 19 archived split-spoon core holes, the interpreted stratigraphy for each of the holes at their four respective sites is shown in Figures 7 through 10. Radiocarbon dates of organic material collected from rotary-sonic cores and during fieldwork appear in Table 2. A diagram correlating the units mapped in Hennepin County with those in adjacent counties is included on Plate 5.

ACKNOWLEDGEMENTS

Thanks to the City of Tonka Bay, the Parks and Recreation Department of Minneapolis, and to landowners for allowing rotary-sonic drilling on their property. Gary Meyer and Andrew Retzler of the Minnesota Geological Survey helped with coordinating drilling sites. Minnesota Geological Survey staff members Matthew Ettsen, Zachary Van Orsdel, Ryan Puzel, and Emily Bauer provided support during rotary-sonic drilling. Numerous water-well companies contributed the subsurface information used in this atlas, and special thanks are given to those who have donated drill cuttings over the years to the Minnesota Geological Survey.

DESCRIPTION OF CROSS-SECTION UNITS

Each unit on the cross sections is placed in one of three categories, as indicated in parentheses after the description: *Surficial Geology* unit—a unit having an identical description, label, and color as on Plate 3, *Surficial Geology* (see Plate 3 for detailed descriptions); subsurface unit—a unit that is depicted only in the subsurface that has a unique label and color; or modified unit—multiple units from Plate 3 that are combined into one unit on the cross sections.

HOLOCENE

Ql — **Organic detritus, clayey silt to sand** (modified unit)—Map units Qp and Ql from Plate 3. Small, thin areas may not be shown on the cross sections. Artificial fill associated with this unit is shown with a stippled pattern.

Qas — **Silty clay loam to loamy fine-grained sand** (*Surficial Geology* unit)—*Fine-grained alluvium.*

Qag — **Sand and gravelly sand** (*Surficial Geology* unit)—*Coarse-grained alluvium.*

Qc — **Loamy sand and gravel** (*Surficial Geology* unit)—*Colluvium.*

PLEISTOCENE

Late Wisconsinan

Qat — **Terrace sand and gravelly sand** (*Surficial Geology* unit)—*Terrace sediment.*

Qlt — **Silty clay loam to silty clay** (subsurface unit)—Fine-grained organic matter (sapropel) that may be massive or laminated; fine-grained sand, silt, and clay deposited in low areas along the upper terraces of the Mississippi River. Brown to black where organic-rich, and gray-green-blue where unoxidized. This sediment was subsequently buried by terrace sand and gravel (unit Qat) because of fluctuating river levels at the end of the Pleistocene Epoch. The thickest and most extensive of these deposits was given the name Lake Bassett and is mapped near Loring Park in Minneapolis (Meyer, 1996). Portions of this unit may have been drained and excavated as part of urban development. *Slackwater lacustrine deposits.*

New Brighton Formation (Johnson and others, 2016)—Sediment associated with glacial Lake Anoka. Only remnant patches of the formation remain at the surface in the county because most of the sediment was washed away when glacial Lake Anoka drained via the Mississippi River through the area in north Minneapolis known as the Camden Breach (Meyer and Hobbs, 1989; Meyer, 1998).

Qnd — ***Sand and gravelly sand*** (*Surficial Geology* unit)—*Sand and gravelly sand facies of glacial Lake Anoka.*

Qnb — ***Very fine- to medium-grained sand*** (*Surficial Geology* unit)—Not portrayed in cross-sections illustrated on this plate, but mapped elsewhere. *Fine-grained sand facies of glacial Lake Anoka.*

New Ulm Formation (Johnson and others, 2016)—Sediment associated with the Des Moines lobe and Grantsburg sublobe of Riding Mountain provenance (Plate 3, Fig. 2). Variations in the amount of shale in the 1-2 millimeter very coarse-grained sand fraction are interpreted to be the result of differential incorporation of underlying Quaternary deposits, which is how the mixed provenance Twin Cities Member (unit Qtt) was formed (see Plate 3 for a more detailed explanation of the glacial history). In addition to the Twin Cities Member, Riding Mountain-provenance tills with low (unit *Qmt*), moderate (unit Qvt), and high shale (unit Qht) content were identified. The low shale unit may have been deposited in a separate, earlier advance of the Des Moines lobe. The other two members and the Twin Cities Member are interpreted to have been deposited as one continuous event (Fig. 2; Plate 5, Fig. 2).

Qno — ***Fine-grained sand to sandy gravel*** (*Surficial Geology* unit)—*New Ulm Formation outwash—undifferentiated.*

Heiberg Member (Johnson and others, 2016)—The till of the Heiberg Member of the New Ulm Formation in Hennepin County has the greatest abundance of shale (34 percent) in the county, although it is less than the defined average of 41 percent (Table 1; Johnson and others, 2016).

Qhl — ***Silty clay loam to silt loam*** (*Surficial Geology* unit)—*Lacustrine deposits.*

Qhi — ***Loamy sand to gravelly sand*** (*Surficial Geology* unit)—*Ice-contact deposits.*

Qsh — ***Silt loam, sandy loam, and loamy sand and gravel*** (*Surficial Geology* unit)—*Stagnation deposits.*

Qht — ***Loam to clay loam diamict*** (*Surficial Geology* unit)—*Till.*

Villard Member (Johnson and others, 2016)—The till of the Villard Member of the New Ulm Formation in Hennepin County contains the defined average of 19 percent shale (Table 1; Johnson and others, 2016). This member is interpreted to be gradational with the Twin Cities Member of the New Ulm Formation, deposited when the Grantsburg sublobe advanced into Hennepin County and flowed northeastward.

Qvs — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater of the Grantsburg sublobe. Discontinuous, and may contain meltwater deposits of the overlying Heiberg Member of the New Ulm Formation. *Sand.*

Qvt — ***Loam to sandy loam diamict*** (*Surficial Geology* unit)—*Till.*

Twin Cities Member (Johnson and others, 2016)—The Twin Cities Member of the New Ulm Formation in Hennepin County contains about equal proportions of shale and red grains in the very coarse-grained sand fraction, indicating mixed Riding Mountain and Superior provenance (Table 1). It was generated by ice carrying sediment of Villard Member lithologic composition.

Qts — ***Fine-grained sand to sandy gravel*** (*Surficial Geology* unit)—*Outwash.*

Qts1 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Twin Cities Member of the New Ulm Formation. Discontinuous, and may contain meltwater deposits associated with the overlying Villard Member of the New Ulm Formation. This unit is the same as unit Qts lithologically. It is differentiated from unit Qts because it only exists in the subsurface. *Sand.*

Qtc — ***Silty clay loam to loamy sand*** (*Surficial Geology* unit)—*Colluvium.*

Qtl — ***Silty clay to silt loam*** (*Surficial Geology* unit)—*Lacustrine deposits.*

Qst — ***Silty clay loam to sandy loam*** (*Surficial Geology* unit)—*Stagnation deposits.*

Qti — ***Silty clay to loamy sand and gravel*** (*Surficial Geology* unit)— Artificial fill associated with this unit is shown with a stippled pattern. *Ice-contact deposits.*

Qtt — ***Loam to sandy loam diamict*** (*Surficial Geology* unit)—*Till.*

Qts2 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Twin Cities Member of the New Ulm Formation. This sand unit is distinct from the other Twin Cities Member sand units because it overlies a thick sequence of Cromwell Formation fine-grained sand and silt. It likely represents proglacial outwash deposited when the Grantsburg sublobe advanced into eastern Hennepin County, which was subsequently buried by Twin Cities Member till. The meltwater also eroded and incorporated the underlying fine-grained sand and silt, giving the unit a slightly finer-grained texture compared to the other Twin Cities Member sand units. *Sand above lacustrine sediment.*

Moland Member (Johnson and others, 2016)—The Moland Member of the New Ulm Formation in Hennepin County is mapped only in the western part of the county. Evidence for the presence of the Moland Member is equivocal. A till with low shale content (1 to 10 percent) in split-spoon cores from Independence (Table 1) is herein considered to be the Moland Member, an interpretation that is extended along the length of the border with adjacent Wright County. In part this interpretation was made in an effort to achieve consistency with the mapped distribution of the Moland Member in adjacent Wright County (Knaeble, 2013). However, no evidence of oxidation, leaching, soil formation, or subaerial exposure is present at the upper contact of this unit in the cores from Independence, which would be expected if it were deposited during an early advance of the Des Moines lobe. It is possible that this low-shale content till was instead generated by ice associated with the Villard Member as it advanced over the sandier units of the underlying Cromwell Formation.

Qms — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater of the Des Moines lobe. Discontinuous, and may contain meltwater deposits of the overlying Villard Member of the New Ulm Formation. *Sand.*

Qmt — ***Sandy loam diamict*** (subsurface unit)—Unsorted, calcareous, very dark gray (2.5Y 3/1), sandy loam till. Contains common pebbles and cobbles; boulders are less common. Average lithologic composition of the very coarse-grained sand fraction is shown in Table 1. *Till.*

Cromwell Formation (Johnson and others, 2016)—Sediment associated with the Superior lobe of Superior provenance (Plate 3, Fig. 2). Includes sediment deposited during the Emerald, St. Croix, and Automba phases of the Superior lobe during the late Wisconsinan glaciation. The till of the Cromwell Formation in Hennepin County is atypical because it contains an average of 6 percent Paleozoic carbonate in the 1-2 millimeter very coarse-grained sand fraction (Table 1). From northeast to southwest, the former flow direction of the Superior lobe, the carbonate content in the Cromwell Formation increases by an average of 10 percent (from 3 to 13 percent, for example). This increase is interpreted to be the result of the Superior lobe eroding and incorporating sediments of the underlying carbonate-rich tills of the Lake Henry Formation. A similar increase in carbonate content of the Cromwell Formation in Stearns County is the result of mixing with the underlying carbonate-bearing Hewitt Formation, and in Washington County from incorporating the underlying Lake Henry Formation and Paleozoic carbonate bedrock (Johnson and others, 2016; Meyer, 2016).

Qsi — ***Loamy sand to sandy gravel*** (*Surficial Geology* unit)— Artificial fill associated with this unit is shown with a stippled pattern. *Ice-contact deposits.*

Qs1 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Automba phase of the Cromwell Formation. Discontinuous, and may contain meltwater deposits of the overlying Villard or Twin Cities Members of the New Ulm Formation. This unit includes proglacial outwash and ice-contact sand and gravel, the latter of which is most abundant within the Elm Creek Park Reserve in Maple Grove. Linear, sinuous ridges previously identified to be eskers within that park (Meyer and Hobbs, 1989) may be eskers associated with this phase of the Superior lobe, which were subsequently buried by at least 30 feet (9 meters) of Grantsburg sublobe till. It is also possible that these ridges are Grantsburg sublobe recessional ice margins, or a combination of both. *Automba-phase outwash and ice-contact deposits.*

Qca — ***Loam to sandy loam diamict*** (subsurface unit)—Unsorted, calcareous, reddish-brown where oxidized (5YR 4/4), dark reddish-brown where unoxidized (5YR 2.5/2), loam to sandy loam till. This unit was identified primarily in well cutting sets and distinguished from the older St. Croix and Emerald phases by its redder color, finer texture, and higher concentration of dark and red grains as opposed to felsic and carbonate grains that are more common in the older units. The Automba-phase till is finer-textured because it incorporated silty fine-grained sand and silt as it advanced over the deposits of an early phase of glacial Lake Lind (Meyer, 1998). *Automba-phase till.*

Qcl — ***Silt loam to silty fine-grained sand*** (subsurface unit)—Reddish-brown (5YR 5/4) to yellowish-brown (10YR 5/4), silty, fine-grained sand to silt loam deposited by meltwater of the Superior lobe between the Automba and St. Croix phases. The thickest deposits of this unit occur along the Minnesota River from Eden Prairie east to Bloomington, just south of the Minneapolis–St. Paul International Airport (cross section F–F'). The presence of thick lake sediment implies that this location was a low spot on the landscape after the Superior lobe retreated. Other low areas on the landscape, including former tunnel valleys, also filled with this fine-grained sediment as the Superior lobe continued to retreat to the northeast (Plate 3, Fig. 3B). Subsequently, this unit was eroded and incorporated into the push moraine ice-contact deposits of the Twin Cities Member of the New Ulm Formation (unit Qti). *Cromwell Formation lacustrine deposits*

Qs2 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the St. Croix phase of the Cromwell Formation. Discontinuous, and may contain meltwater deposits of the Automba phase of the Cromwell Formation. The uppermost portion of this unit was likely reworked by meltwater of the advancing Grantsburg sublobe; this mixed-provenance sand and gravel would then correlate with the Hillside Sand defined in the New Brighton area (Johnson and others, 2016). Meltwater that deposited this unit commonly eroded the underlying till with which it is associated (unit *Qcs*). *St. Croix-phase outwash.*

Qcs — ***Sandy loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, brown (7.5YR 4/4) to dark yellowish-brown (10YR 4/4) where oxidized, very dark grayish-brown where unoxidized (10YR 3/2), sandy loam to loam till deposited during the St. Croix phase of the Superior lobe. Average lithologic composition of the very-coarse grained sand fraction is shown in Table 1. Where the ice eroded and incorporated the underlying carbonate-rich, loamy tills of the Lake Henry Formation, the unit is loamier and more yellow than red. This unit may include sediment from the underlying Lake Henry Formation tills, particularly in the southwestern quarter of the county where underlying strata were thrusted and deformed at the margin of the Superior lobe during this phase. *St. Croix-phase till.*

Qs3 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Emerald phase of the Cromwell Formation. Discontinuous, and likely contains meltwater deposits of the overlying St. Croix phase of the Cromwell Formation. Meltwater that deposited this unit commonly eroded the underlying till with which it is associated (unit *Qce*). *Emerald-phase outwash.*

Qce — ***Sandy loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, brown (7.5YR 4/4) to dark yellowish-brown (10YR 4/4) where oxidized, very dark grayish-brown where unoxidized (10YR 3/2), sandy loam to loam till associated with the Emerald phase of the Superior lobe. This unit is lithologically similar to the St. Croix-phase till of the Superior lobe (unit *Qcs*), and may contain even more locally-derived sediment from underlying Quaternary or Paleozoic bedrock units. In most areas the unit has a patchy distribution, with more continuous and abundant deposits present in the southeastern part of the county near Bloomington and the very southwestern part of the county near St. Bonifacius. Definition of this unit was based primarily on the presence of a sand body between what was described in well logs as two red or rocky clays. *Emerald-phase till.*

Pre-late Wisconsinan

Lake Henry and St. Francis Formations (Johnson and others, 2016)—Sediment of Winnipeg and Superior provenance, respectively (Plate 3, Fig. 2). The vast majority of the pre-late Wisconsinan Quaternary deposits mapped in Hennepin County are composed of four intercalated members of these two formations. The Lake Henry Formation consists of two members: the Sauk Centre and the Meyer Lake. These two members have nearly identical texture but differ lithologically (Table 1). The 1-2 millimeter very coarse-grained sand fraction of the Meyer Lake Member contains less carbonate and more Precambrian crystalline and red grains compared to the Sauk Centre Member. This reflects more mixing with underlying sediment of Superior provenance. These compositional differences are subtle and variable, which can make it difficult to differentiate these members from one another in the subsurface on this basis alone. However, in Hennepin County, as in adjacent Anoka (Meyer, 2013) and Sherburne (Lusardi, 2013) Counties, the two members are discontinuously separated by the upper member of the St. Francis Formation. The Meyer Lake Member is underlain by the lower member of the St. Francis Formation. The upper and lower members of the St. Francis Formation are texturally and lithologically similar; however, the lower member contains more light-colored felsic grains and fewer red and dark grains.

Lake Henry Formation—Sauk Centre Member

Qh1 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Sauk Centre Member of the Lake Henry Formation. Discontinuous, and likely contains meltwater deposits associated with the overlying Cromwell Formation. This unit was mapped sparingly in the western parts of the county where well logs indicated a color or texture change within a sand body. *Outwash.*

Qsc — ***Clay loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, grayish-brown (10YR 5/2) to light brownish-gray (2.5Y 6/2) where oxidized, dark gray (5Y 4/1) where unoxidized, olive (5Y 5/3) where reduced, clay loam to loam till. Present only in the western part of the county. In general, the lower part of the unit locally contains more red Precambrian clasts and silt than the upper part. The differences within the unit are the result of erosion and incorporation of underlying Superior-provenance sediment and interglacial lacustrine deposits (Table 1). This unit may correlate with the uppermost member of the informal Good Thunder formation identified in south-central Minnesota (Johnson and others, 2016). *Till.*

St. Francis Formation—Upper member

Qf1 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the upper member of the St. Francis Formation. Discontinuous, and likely contains meltwater deposits associated with the overlying Sauk Centre Member of the Lake Henry Formation. *Outwash.*

Qsf1 — ***Sandy loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, commonly leached, yellowish-red (5YR 5/6) where oxidized, sandy loam to loam till of Superior provenance. This member contains slightly more abundant red and dark Precambrian very coarse sand grains and more light-colored felsic lithologies than the lower member. In the northern part of the county, where the two members are most commonly in direct contact, it can be difficult to differentiate them using only well logs. *Till.*

Lake Henry Formation—Meyer Lake Member

Qh2 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Meyer Lake Member of the Lake Henry Formation. Discontinuous, and likely contains meltwater deposits associated with the overlying upper member of the St. Francis Formation. *Outwash.*

Qml — ***Clay loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, light brownish-gray (10YR 6/2) to light yellowish-brown (2.5Y 6/4) where oxidized, dark gray (5Y 4/1) where unoxidized, olive (5Y 5/3) where reduced, clay loam to loam till. In general, the lower part of the unit locally contains more red Precambrian clasts and silt than the upper part. The differences within the unit are the result of erosion and incorporation of underlying Superior-provenance sediment and interglacial lacustrine deposits (Table 1). This unit may correlate with the second member of the informal Good Thunder formation identified in south-central Minnesota (Johnson and others, 2016). *Till.*

St. Francis Formation—Lower member

Qf2 — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the lower St. Francis member of the St. Francis Formation. Discontinuous, and likely contains meltwater deposits associated with the overlying Meyer Lake Member of the Lake Henry Formation. *Outwash.*

Qsf2 — ***Sandy loam diamict*** (subsurface unit)—Unsorted, calcareous, commonly leached, yellowish-red (5YR 5/8) to reddish-yellow (7.5YR 6/6) where oxidized, sandy loam to loam till of Superior provenance. The lithologic composition was averaged from four leached and four unleached samples. The lower member contains slightly less red and dark Precambrian very coarse sand grains and more light-colored felsic lithologies than the upper member. This may be the result of mixing with underlying Rainy-provenance sediment. The subtle compositional differences between the two members of the St. Francis Formation make it difficult to differentiate them with well logs alone. *Till.*

Unnamed formation of Rainy provenance

Qwo — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater from an ice lobe of Rainy provenance. Discontinuous, and likely contains meltwater deposits associated with the overlying lower member of the St. Francis Formation. Shown only on Figure 9. *Outwash.*

Qwt — ***Sandy loam to loam diamict*** (subsurface unit)—Unsorted, calcareous, commonly leached, brown (7.5YR 4/4) to olive-brown (2.5Y 4/4) where oxidized, very dark brown (10YR 2/2) where unoxidized, sandy loam to loam till of Rainy provenance. The lithologic composition, based on one sample, differs from that of the lower member of the St. Francis Formation because it contains fewer red grains indicative of Superior provenance (Table 1). This unit was recognized in the subsurface only in a few places within the deepest bedrock valleys in the western part of the county. Shown only on Figure 9. *Till.*

Elmdale Formation (Johnson and others, 2016)—Sediment of Winnipeg provenance (Plate 3, Fig. 2) associated with the "W" sequence units of central and north-central Minnesota (Meyer, 1997). The Elmdale Formation may correlate with the Pierce Formation mapped in Washington (Meyer, 2016) and Scott (Lusardi and Tipping, 2006) Counties (Fig. 2).

Qeo — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with the Elmdale Formation. Discontinuous, and likely contains meltwater deposits associated with the overlying unnamed Rainy-provenance formation. *Outwash.*

Qet — ***Clay loam to sandy loam diamict*** (subsurface unit)—Unsorted, calcareous, clay loam to sandy loam till of Winnipeg provenance. This formation differs from other Winnipeg-provenance formations because it contains less Paleozoic carbonate but more light-colored crystalline lithologies and Cretaceous limestone and shale (Table 1). It also contains red grains, which indicate local incorporation of underlying unnamed Superior-provenance sediment. The texture of this formation, averaged from two samples, is sandier than what has been determined for this formation in other parts of the state. The position of the Elmdale Formation directly on bedrock across much of the county suggests that this sandier texture may be the result of incorporation of Cambrian sandstone. Given that this unit is typically described in well logs as "blue clay," however, it may be finer-grained in many places in the county. *Till.*

Unnamed formation of Superior provenance—Sediment of Superior provenance associated with the "V" sequence units of central, north-central, and east-central Minnesota (Meyer, 1997, 2016).

Qvo — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel deposited by meltwater associated with unnamed Superior-provenance sediment. Discontinuous, and likely contains meltwater deposits associated with the overlying Elmdale Formation. *Outwash.*

Qot — ***Sandy loam diamict*** (subsurface unit)—Unsorted, reddish-brown to brown, sandy loam till of Superior provenance. This unit is mapped locally in the deepest bedrock valleys. Where not overlain by Elmdale Formation till, it likely includes sediment from the lower member of the St. Francis Formation. *Till.*

Undifferentiated Pleistocene deposits

Qsu — ***Fine-grained sand to sandy gravel*** (subsurface unit)—Fine-grained sand to sandy gravel of unknown provenance deposited by meltwater. *Sand.*

Qu — ***Undifferentiated Pleistocene sediment*** (subsurface unit)—Includes till, bedded clay, silt, sand, and gravel of unknown provenance. Shown in places where well-log data were insufficient or absent, particularly in the deepest parts of bedrock valleys. *Sediment.*

INDEX FOR FIGURES 7 THROUGH 10
- New Ulm Formation—Moland, Villard, and Heiberg Members
- New Ulm Formation—Twin Cities Member
- Cromwell Formation—Emerald, St. Croix, and Automba phases
- Lake Henry Formation—Sauk Centre Member
- St. Francis Formation—upper member
- Lake Henry Formation—Meyer Lake Member
- St. Francis Formation—lower member
- Unnamed Rainy-provenance formation
- Elmdale Formation
- Unnamed Superior-provenance formation
- Undifferentiated older sand and lake sediment mix
- Peat/organic material
- Glacial till
- Ice-contact loamy sand and gravel
- Sand and gravel
- Fine-grained sand

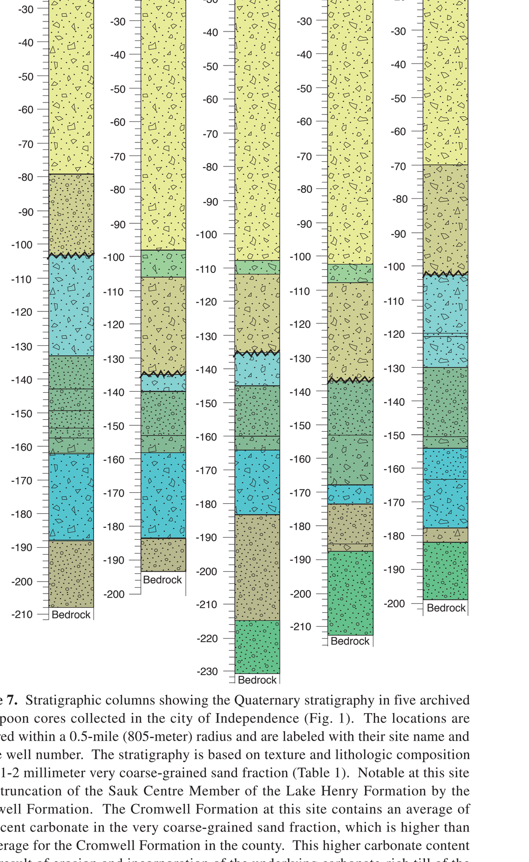


Figure 7. Stratigraphic columns showing the Quaternary stratigraphy in five archived split-spoon cores collected in the city of Independence (Fig. 1). The locations are clustered within a 0.5-mile (805-meter) radius and are labeled with their site name and unique well number. The stratigraphy is based on texture and lithologic composition of the 1-2 millimeter very coarse-grained sand fraction (Table 1). Notable at this site is the truncation of the Sauk Centre Member of the Lake Henry Formation by the Cromwell Formation. The Cromwell Formation at this site contains an average of 10 percent carbonate in the very coarse-grained sand fraction, which is higher than the average for the Cromwell Formation in the county. This higher carbonate content is the result of erosion and incorporation of the underlying carbonate-rich till of the Sauk Centre Member. The surface of this erosion is indicated by a black jagged line.

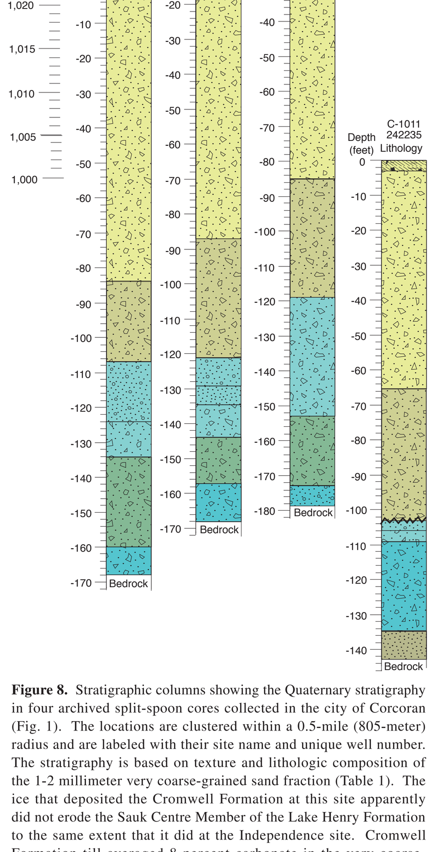


Figure 8. Stratigraphic columns showing the Quaternary stratigraphy in four archived split-spoon cores collected in the city of Corcoran (Fig. 1). The locations are clustered within a 0.5-mile (805-meter) radius and are labeled with their site name and unique well number. The stratigraphy is based on texture and lithologic composition of the 1-2 millimeter very coarse-grained sand fraction (Table 1). The ice that deposited the Cromwell Formation at this site apparently did not erode the Sauk Centre Member of the Lake Henry Formation to the same extent that it did at the Independence site. Cromwell Formation till averaged 8 percent carbonate in the very coarse-grained sand fraction, only slightly above the average for the county (Table 1). Erosion did occur in core C-1011, however, because the carbonate content in the very-coarse grained sand fraction increased from 5 to 11 percent in the lower 6 feet (2 meters) of the Cromwell Formation till section. The surface of this erosion is indicated by a black jagged line.

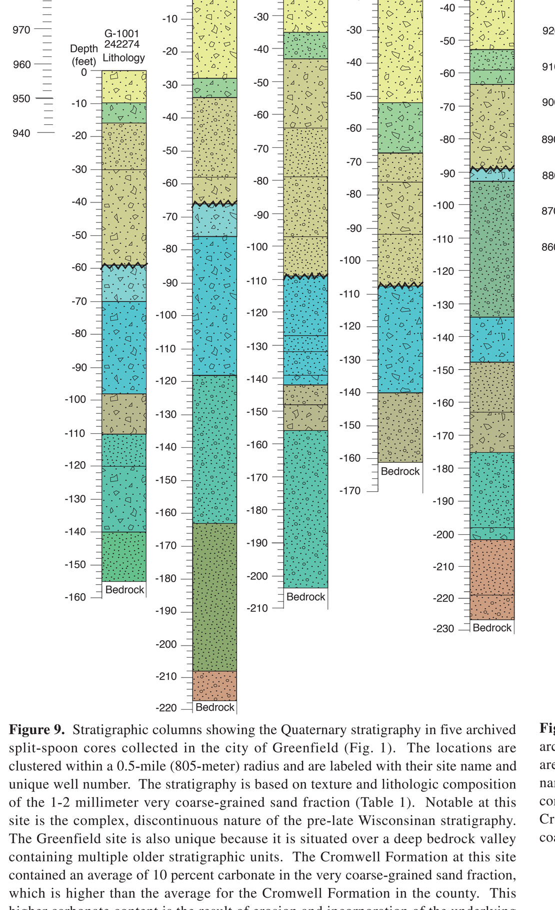


Figure 9. Stratigraphic columns showing the Quaternary stratigraphy in five archived split-spoon cores collected in the city of Greenfield (Fig. 1). The locations are clustered within a 0.5-mile (805-meter) radius and are labeled with their site name and unique well number. The stratigraphy is based on texture and lithologic composition of the 1-2 millimeter very coarse-grained sand fraction (Table 1). Notable at this site is the complex, discontinuous nature of the pre-late Wisconsinan stratigraphy. The Greenfield site is also unique because it is situated over a deep bedrock valley containing multiple older stratigraphic units. The Cromwell Formation at this site contained an average of 10 percent carbonate in the very coarse-grained sand fraction, which is higher than the average for the Cromwell Formation in the county. This higher carbonate content is the result of erosion and incorporation of the underlying carbonate-rich till of the Sauk Centre Member of the Lake Henry Formation, similar to what was found at the Independence site. The surface of this erosion is indicated by a black jagged line.

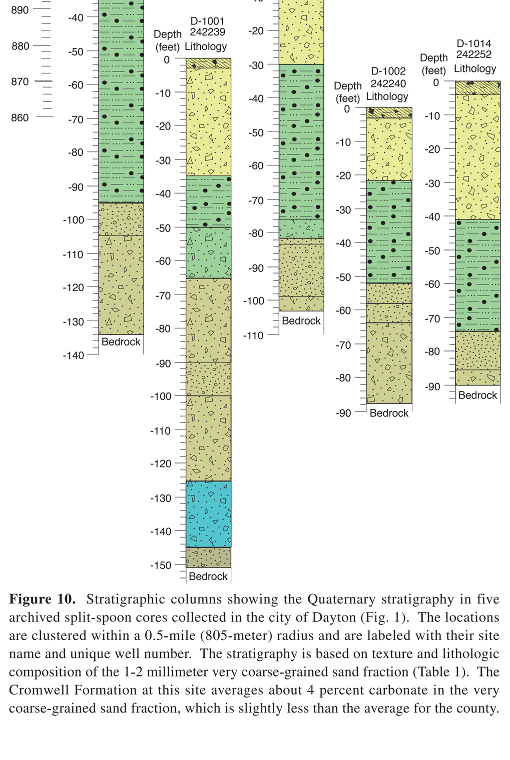


Figure 10. Stratigraphic columns showing the Quaternary stratigraphy in five archived split-spoon cores collected in the city of Dayton (Fig. 1). The locations are clustered within a 0.5-mile (805-meter) radius and are labeled with their site name and unique well number. The stratigraphy is based on texture and lithologic composition of the 1-2 millimeter very coarse-grained sand fraction (Table 1). The Cromwell Formation at this site averages about 4 percent carbonate in the very coarse-grained sand fraction, which is slightly less than the average for the county.

REFERENCES

Baker, R.W., Diehl, J.F., Simpson, T.W., Zelazny, L.W., and Beske-Diehl, S., 1983, Pre-Wisconsinan glacial stratigraphy, chronology, and paleomagnetics of west-central Wisconsin: Geological Society of America Bulletin, v. 94, p. 1442-1449.

Hobbs, H.C., 1998, Use of 1-2 millimeter sand-grain composition in Minnesota Quaternary studies, *in* Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations RI-49, p. 193-208.

Johnson, M.D., Adams, R.S., Gowan, A.S., Harris, K.L., Hobbs, H.C., Jennings, C.E., Knaeble, A.R., Lusardi, B.A., and Meyer, G.N., 2016, Quaternary lithostratigraphic units of Minnesota: Minnesota Geological Survey Report of Investigations RI-68, 262 p.

Knaeble, A.R., 2013, Quaternary stratigraphy, pl. 4 *of* Tipping, R.G., project manager, Geologic atlas of Wright County, Minnesota: Minnesota Geological Survey County Atlas C-30, 6 pls., scale 1:100,000.

Knaeble, A.R., and Meyer, G.N., 2007, Quaternary stratigraphy, pl. 4 *of* Setterholm, D.R., project manager, Geologic atlas of Todd County, Minnesota: Minnesota Geological Survey County Atlas C-18, 6 pls., scale 1:100,000.

Lisiecki, L.E., and Raymo, M.E., 2005, A Pliocene–Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records: Paleoceanography, v. 20, no. 1, p. 1-17.

Lusardi, B.A., 2013, Quaternary stratigraphy, pl. 4 *of* Lusardi, B.A., project manager, Geologic atlas of Sherburne County, Minnesota: Minnesota Geological Survey County Atlas C-32, 5 pls., scale 1:100,000.

Lusardi, B.A., and Tipping, R.G., 2006, Quaternary stratigraphy, pl. 4 *of* Setterholm, D.R., project manager, Geologic atlas of Scott County, Minnesota: Minnesota Geological Survey County Atlas C-17, 6 pls., scale 1:100,000.

Meyer, G.N., 1986, Subsurface till stratigraphy of the Todd County area, central Minnesota: Minnesota Geological Survey Report of Investigations RI-34, 40 p.

———1996, Geology of the Bassett valley area: Minnesota Geological Survey Open-File Report 96-3, 6 p.

———1997, Pre-late Wisconsinan till stratigraphy of north-central Minnesota: Minnesota Geological Survey Report of Investigations RI-48, 67 p.

———1998, Glacial lakes of the Stacy basin, east-central Minnesota and northwest Wisconsin, *in* Patterson, C.J., and Wright, H.E., Jr., eds., Contributions to Quaternary studies in Minnesota: Minnesota Geological Survey Report of Investigations RI-49, 208 p.

———2013, Quaternary stratigraphy, pl. 4 *of* Setterholm, D.R., project manager, Geologic atlas of Anoka County, Minnesota: Minnesota Geological Survey County Atlas C-27, 6 pls., scale 1:100,000.

———2016, Quaternary stratigraphy, pl. 4 *of* Bauer, E.J., project manager, Geologic atlas of Washington County, Minnesota: Minnesota Geological Survey County Atlas C-39, 6 pls., scale 1:100,000.

Meyer, G.N., and Hobbs, H.C., 1989, Surficial geology, pl. 3 *of* Balaban, N.H., project manager, Geologic atlas of Hennepin County, Minnesota: Minnesota Geological Survey County Atlas C-4, pt. A, 9 pls., scale 1:100,000.

Reimer, P.J., 2012, Refining the radiocarbon time scale: Science, v. 338, p. 337-338.

Stuiver, M., Reimer, P.J., and Reimer, R.W., 2017, CALIB radiocarbon calibration program: Calib7.1, accessed December, 2017, <http://www.calib.org>.

Syverson, K.M., Clayton, L., Attig, J.W., and Mickelson, D.M., 2011, Lexicon of Pleistocene stratigraphic units of Wisconsin: Wisconsin Geological and Natural History Survey Technical Report 1, 180 p.

Walker, M., 2005, Quaternary dating methods: West Sussex, England, John Wiley and Sons, Ltd., 286 p.

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