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COUNTY ATLAS SERIES
ATLAS C-31, PART A
Morrison County
Plate 4—Quaternary Stratigraphy

QUATERNARY STRATIGRAPHY

By

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INTRODUCTION

This Quaternary Stratigraphy plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Morrison County (Figs. 1, 2). Cross sections A–A' through F–F' are representative of 67 cross sections (Fig. 3) that were constructed to create a three-dimensional model of the Quaternary deposits of Morrison 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 shown on the cross sections were defined from interpretation of new data collected for this study and from existing data from previous investigations. These include rotary-sonic drill core from six drill holes completed by the Minnesota Geological Survey for this project, rotary-sonic drill core from three drill holes completed by the Minnesota Geological Survey for projects in Todd and Benton Counties (Knaeble and Meyer, 2007; Meyer and Gowan, 2010), rotary-sonic drill core from seven additional drill holes described and sampled by the Minnesota Geological Survey but completed for other agencies (University of Minnesota Duluth, 2002; Pekarek, unpub. data; Fig. 3), water-well drillers' logs, bridge boring logs (Minnesota Department of Transportation, 2013), exposures, and auger samples (Plate 1, *Data-Base Map*).

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. Till units 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.

In places, multiple sand bodies are stacked on top of each other, as shown east of the Mississippi River on cross section C–C'. This thick sequence of sand has been interpreted to be part of an erosional channel that parallels the modern Mississippi River and contains as much as 100 feet (30 meters) of sand and gravel (Helgesen, 1973). Helgesen believed that the channel was cut and that the sand was deposited during a single flood event when the Brainerd ice lobe retreated far enough to the northeast to open a pathway for meltwater to drain southward along the retreating Superior ice lobe (see Plate 3, *Surficial Geology*, Fig. 3E). An alternate explanation is that the Mississippi River corridor has been a path for multiple outflows of meltwater throughout the Pleistocene Epoch. Interpretations based on water well logs located for this study indicate that sediment in the channel north of Little Falls (a portion of which is shown on cross section C–C') may be much older. It is possible that meltwater re-occupied this trough several times as ice advanced and retreated across the area (Fig. 4). Regardless of whether the sand was deposited during one or multiple glacial events, for the purpose of ground-water modeling, connected sand bodies likely behave as a single aquifer unit.

The surficial units that appear in the cross sections are similar, but not identical to those mapped and described on the surficial geologic map on Plate 3, *Surficial Geology*. Peat (unit Qp on Plate 3) is too thin to show in cross section and is combined with the surrounding surficial units as noted in the unit descriptions. Sandy units including alluvium (Qa), fan and terrace deposits (units Qf, Qtt, and Qtu), and windblown sand (unit Qe) are combined into one unit (pgs) for the purpose of modeling. Fine-grained sediments including lake deposits, slackwater sediment, and loess (units Ql, Quf, Qnl, and Qz) are combined with the surface till for the purpose of the sand-distribution models and are shown as unit sc on the printed cross sections. Ice contact and ice contact/till complex units (for example Qii and Qig) are combined into one unit (ist) because they are mostly sand and gravel. The till that is included is coarse-textured and difficult to distinguish from the surrounding sand and gravel. Deeper units appear only on the cross sections.

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. 5). Bear in mind, however, that sand and till units are likely an admixture of material from immediately above or below the actual named unit. For example, sand unit *mls* is composed chiefly of outwash sediment laid down as the glacier depositing unit *mit* retreated. However, it may also include proglacial meltwater deposits from the advance of ice that deposited the overlying St. Francis Formation (unit *ft1*). 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 Morrison County with those mapped in adjacent Todd and Benton Counties, where correlations can be made.

Rotary-sonic drill holes are differentiated on the cross sections with their associated unique number. Interpreted logs of the six Minnesota Geological Survey rotary-sonic cores are shown in Figures 6 through 11. Their locations are shown on Figure 3. Some water-well drillers' logs and cuttings samples collected from sites outside the county were used for interpretation because they were near the county border and provided significant detailed stratigraphic control. Drill holes, represented by vertical lines on the cross-sections, 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 differ from those at the cross-section line. Vertical exaggeration is 50x for all cross sections.

DESCRIPTION OF CROSS SECTION UNITS

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

sc — **Fine-grained surface sediments** (includes mapped units Ql, Quf, Qnl, Qz, and Qp)—Silt and clay of modern and Pleistocene lake sediment, slackwater fluvial sediment, and windblown loess.

pgs — **Sandy surface sediments** (post-glacial sands not part of a named lithostratigraphic unit listed below; includes mapped units Qe, Qa, Qf, Qtt, Qtu, and Qp)—Sand and gravel of modern and Pleistocene stream and windblown sediment.

New Ulm Formation (Johnson and others, in press)—Yellow-brown to dark gray, sandy loam to loam tills and bedded sediments of northwestern (Riding Mountain) provenance associated with the Des Moines lobe (Fig. 2; Table 2).

ns — ***Sand and gravel above unit nt*** (includes mapped units Qno and Qp).

nt — ***Till*** (unnamed member; includes mapped units Qnt and Qp)—Not shown on printed cross sections, but included in the digital files accompanying this atlas.

Sediment of mixed provenance—Sediment associated with the Brainerd and Superior lobes.

ou — ***Sand and gravel above unit ms and older till*s** (includes mapped units Qo and Qp).

Cromwell Formation (Johnson and others, in press)—Red-brown to dark gray, sandy loam till and bedded sediments of northeastern (Superior) provenance.

Mille Lacs Member (Johnson and others, in press)—Sediment associated with the Automba phase of the Superior lobe (Wright, 1972; Meyer, 1998).

ms — **Sand and gravel above units mst and mt** (includes mapped units Qmo and Qp).

mst — **Sand and gravel and till above unit mt** (includes mapped units Qmi and Qp)—Not shown on printed cross sections, but included in the digital files accompanying this atlas.

mt — **Till of the Mille Lacs Member** (includes mapped units Qmt and Qp).

Sediment of mixed provenance—Sediment associated with the Brainerd, Superior, and Wadena lobes.

ii — ***Sand above units ist, it, cst, ct, and hst*** (includes mapped units Qil and Qp)—Not shown on printed cross sections, but included in the digital files accompanying this atlas.

Independence Formation (Johnson and others, in press)—Brown to brown-gray, sandy loam tills and bedded sediments of north–northeastern (Rainy) provenance. Stratigraphic data from rotary-sonic core Mo-01 (Fig. 6) indicated that there are six till layers that may be attributed to the Brainerd ice lobe that deposited what is known as the Independence Formation. 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. These changes likely signal the shifting of the ice margin and this series of stacked tills represents the building of the end moraine at the maximum extent of the ice. Further to the east, data from rotary-sonic core Mo-05 (Fig. 10) indicated at least three till layers that are attributed to the Rainy provenance Brainerd ice lobe. These layers are separated by tills of similar texture but are interpreted to be deposited by ice of Superior provenance. Changes in the percentage of red rock fragments and clear quartz grains in the 1-2 millimeter very coarse-grained sand are key in distinguishing between these tills (Table 2; see Plate 3, Fig. 5).

is — ***Sand and gravel above units ist and*** it (includes mapped units Qio and Qp).

ist — ***Sand and gravel and till above unit*** it (includes mapped units Qil and Qig).

it — ***Till*** (South Long Lake Member; includes mapped units Qit and Qp)—Separate till layers are numbered 1 through 6 as encountered from the surface (top to bottom). The youngest (uppermost) occurrence is labeled without a number, as is any location where the stratigraphic order is uncertain. In some cases, the till unit at the surface is not the youngest, and is labeled accordingly based on stratigraphic correlation with surrounding units.

Cromwell Formation (Johnson and others, in press)—Red-brown to dark gray, sandy loam till and bedded sediments of northeastern (Superior) provenance. Stratigraphic data from rotary-sonic cores Mo-03 (Fig. 8), Mo-04 (Fig. 9), and Mo-05 (Fig. 10) indicate that there are multiple till layers that may be attributed to the Superior ice lobe that deposited what is known as the Cromwell Formation. 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 and that the ice advanced and retreated.

Unnamed members associated with the St. Croix (ct and ct1; Wright, 1972), Emerald (ct2; Johnson, 2000), and older (ct3) phases of the Superior lobe.

cs — **Sand and gravel above unit ct** (includes mapped units Qco and Qp).

cst — **Sand and gravel and till above unit ct** (includes mapped units Qci and Qcg).

ct — **Till** (unnamed member; includes mapped units Qct, Qcd, Qcfi, Qcb, Qcp, and Qp)—Separate till layers are numbered 1 through 3 as encountered from the surface (top to bottom). Where the stratigraphic order is uncertain, the uppermost occurrence is labeled without a number, as in the western part of the county. It is possible that the lowermost occurrence (ct3) may be pre-Wisconsinan in age and therefore would not be included in the Cromwell Formation as defined in Johnson and others (in press).

Sediment of mixed provenance—Sediment associated with the Brainerd, Superior, and Wadena lobes.

ou2 — ***Sand and gravel below unit ct that cuts through several older tills***—This unit may represent sediment deposited in an ice marginal stream that flowed along the edge of the Brainerd lobe as it was forming a portion of the St. Croix moraine in northern Morrison County. The sand cuts through several older till units and likely includes sediments from those units. Not shown on printed cross sections, but included in the digital files accompanying this atlas.

Hewitt Formation (Johnson and others, in press)—Yellow-brown to dark gray sandy loam till and bedded sediments of Rainy provenance.

hss — ***Sand and gravel above unit hst*** (includes mapped units Qho and Qp).

hst — ***Sand and gravel and till above units hs and ht*** (includes mapped unit Qhi).

hs — ***Sand and gravel above unit ht***

ht — ***Till***

Browerville Formation (Johnson and others, in press)—Light olive-brown to dark gray loamy till and bedded sediments of northern (Winnipeg) provenance. Dark gray Cretaceous limestone is a key indicator clast of this unit.

brs — ***Sand and gravel above unit bt***

bt — ***Till***

Lake Henry Formation—(Johnson and others, in press)—Yellow-brown to gray, dense, generally silt-rich to loamy tills and bedded sediments of Winnipeg provenance. The two till members are nearly indistinguishable in texture; however, the Sauk Centre Member contains more carbonate and fewer crystalline rock fragments than does the Meyer Lake Member (Fig. 12, Table 2). In addition, these two members are typically separated by the uppermost red till of the St. Francis Formation.

Sauk Centre Member

scs — **Sand and gravel above unit *set***

sct — **Sauk Centre Member till**

Meyer Lake Member

mls — **Sand and gravel above unit *mit***

mit — **Meyer Lake Member till**

St. Francis Formation (Johnson and others, in press)—Red-brown to gray, dense, loam to sandy loam tills and bedded sediments of Superior provenance.

fs1 — ***Sand and gravel above unit ft1***

ft1 — ***St. Francis Member till (upper unit)***

fs2 — ***Sand and gravel above unit ft2***

ft2 — ***St. Francis Member till (lower unit)***

Eagle Bend Formation (Johnson and others, in press)—Light olive-brown to dark gray clayey till and bedded sediments of northern (Winnipeg) provenance. This unit has more carbonate rock fragments and clear quartz grains in the 1-2 millimeter very coarse-grained sand fraction than does till of the overlying Elmdale Formation (Table 2).

ebs — ***Sand and gravel above unit ebt***

ebt — ***Till***

Elmdale Formation (Johnson and others, in press)—Very dark gray silt loam to clay loam till and bedded sediments of northern (Winnipeg) provenance.

es — ***Sand and gravel above unit et***

et — ***Till***

Unnamed till—Very dark gray loam to clay loam till and bedded sediments of northern (Winnipeg) provenance. This unit has more carbonate rock fragments and clear quartz grains in the 1-2 millimeter very coarse-grained sand fraction than does till of the overlying Elmdale Formation (Table 2). Approximately 20 feet (6 meters) of this unit was sampled near the bottom of rotary-sonic core Mo-02 (Figs. 3, 7). This may be related to the "YW till" of Meyer and Knaeble (1996) that has been found in deep drill holes in southwestern Stearns County. Units *vt* and *vs* are only identified within the general vicinity of the drill hole where *vt* was encountered. These units likely occur elsewhere but without additional samples to support identification as such, they have been labelled as the unknown units below.

vs — ***Sand and gravel above unit vt***

vt — ***Till***

Unknown units

suu — ***Sand and gravel***—Encountered in isolated water wells within otherwise undifferentiated sediment.

ups — ***Undifferentiated Pleistocene sediment***—This unit includes all sediment below the lowermost identified till unit. Although some water wells extend below this boundary, the data are too few and far between to make meaningful correlations.

CROSS SECTION SYMBOLS

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

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 for which logs are provided in Figures 6 through 11.

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Table 1. Correlation of stratigraphic units in Morrison County with units identified in adjacent Todd (Knaeble and Meyer, 2007) and Benton (Meyer and Gowan, 2010) Counties.

Formation	Todd County	Morrison County	Benton County
New Ulm	ntu, nou	ns, nt	Qnd
Cromwell, Mille Lacs Member		ms, mst, mt	
Independence		ii, is, ist, it (1-6)	
Cromwell	ci, ci, ctt, cou, ctu	ci, cs, cst, ct (1-3)	Qcr, Qce
Hewitt	hou, hhi, htu	hss, hst, *hs, ht*	
Browerville	bt	*bt*	Qbs
Lake Henry, Sauk Centre Member	xls	*sct*	
St. Francis (upper)	xsu	*ft1*	
Lake Henry, Meyer Lake Member	xlm	*mlt*	Qbs
St. Francis (lower)	xsl	*ft2*	Qbs
Eagle Bend	xet	*ebt*	Qxe
Elmdale	et	*et*	Qwt
unnamed		*vt*	
older deposits	ups	*ups*	

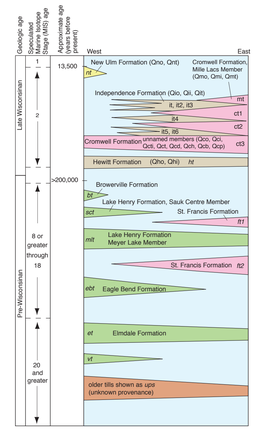

Figure 1. Diagram showing relative age, location (from west to east), provenance (Fig. 2), and related unit labels from the cross sections for Wisconsinan and pre-Wisconsinan glacial deposits. The age column and deposit drawings are representative and not to scale. Multiple advances of an individual formation are not shown (see Fig. 5 for detail). Marine Isotope Stage correlations were estimated using figures in Jennings and others (2006). Marl deposits stratigraphically above the Lake Henry Formation in central Minnesota had a uranium series minimum age of 200,000 years before present (Knaeble and Meyer, 2007). Modified from Knaeble and Meyer (2007).

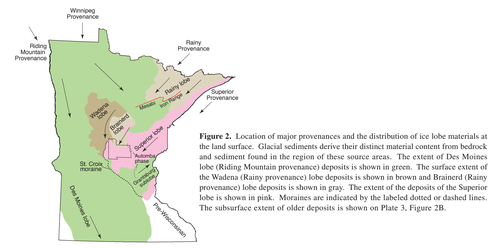

Figure 2. Location of major provenances and the distribution of ice lobe materials at the land surface. Glacial sediments derive their distinct material content from bedrock and sediment found in the region of these source areas. The extent of Des Moines lobe (Riding Mountain provenance) deposits is shown in green. The surface extent of the Wadena (Rainy provenance) lobe deposits is shown in brown and Brainerd (Rainy provenance) lobe deposits is shown in gray. The extent of the deposits of the Superior lobe is shown in pink. Moraines are indicated by the labeled dotted or dashed lines. The subsurface extent of older deposits is shown on Plate 3, Figure 2B.

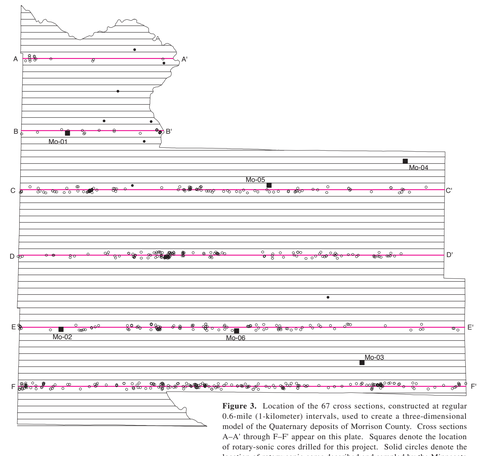

Figure 3. Location of the 67 cross sections, constructed at regular 0.6-mile (1-kilometer) intervals, used to create a three-dimensional model of the Quaternary deposits of Morrison County. Cross sections A–A' through F–F' appear on this plate. Squares denote the location of rotary-sonic cores drilled for this project. Solid circles denote the location of rotary-sonic cores described and sampled by the Minnesota Geological Survey but completed for other agencies. Open circles denote the location of water wells within 0.3 mile (0.5 kilometer) of published cross sections.

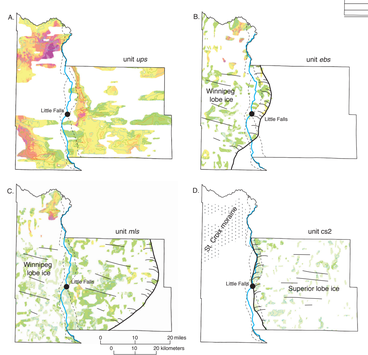

Figure 4. Schematic depiction of Wisconsinan glacial events interpreted from the distribution of sand bodies modeled from cross section interpretations (see Plate 5, *Sand Distribution Model*). The modern Mississippi River is shown in blue. The extent of Mississippi River terrace sediment is shown in dashed lines on either side of the river. The St. Croix moraine is shown by a stippled pattern. Sand distribution models are simplified from those shown on Plate 5. Black lines indicate the generalized ice front and ice flow direction.

A. Model-generated map of the extent of unknown Pleistocene sediment (unit *ups*) for which no descriptive data are available. This glacial sediment lies atop the bedrock surface and is older than the units above it (see Fig. 1). Note the linear channel just east of the modern Mississippi River in the northern part of the county. This channel is cut into the bedrock and is filled with glacial sediment of unknown age or provenance.

B. Model-generated map of the extent of sand bodies associated with the Eagle Bend Formation (unit *ebs*). An ice margin of Winnipeg-provenance ice that deposited the Eagle Bend Formation is shown based on the limit of mapped sand bodies. Note the ice margin roughly corresponds to the modern Mississippi River corridor.

C. Model-generated map of the extent of sand bodies associated with the Meyer Lake Member of the Lake Henry Formation (unit *mls*). An ice margin of Winnipeg-provenance ice that deposited the Meyer Lake Member of the Lake Henry Formation is shown based on the limit of mapped sand bodies. Although the ice advanced beyond the Mississippi River corridor, the associated sand bodies are composed chiefly of outwash sediment laid down as the glacier depositing unit *mit* retreated.

D. Model-generated map of the extent of sand bodies associated with the Cromwell Formation (unit *cs2*). An ice margin marking a recessional position of the Superior-provenance ice that deposited the Cromwell Formation is shown based on the limit of mapped sand bodies. Note the ice margin roughly corresponds to the modern Mississippi River corridor.

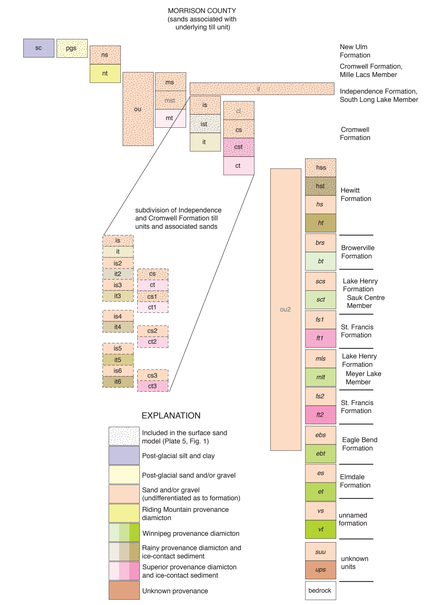

Figure 5. Stratigraphic position of sand and gravel bodies depicted in cross sections and figures. Not all units appear on the printed cross sections (gray labels indicate units that are not on the plate but appear in the digital files). By convention, the name designations of sand and gravel bodies depicted are associated with their underlying till. Tills and associated sands of the Independence and Cromwell Formations are subdivided into multiple, interfingering layers (inset). These layers are identified by number 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.

Figure 6. Morrison rotary-sonic core Mo-01 (location shown on Fig. 3). Dark brown till from 209-215 feet may be part of the Eagle Bend Formation. Inclusions of sand and mixed material alter the texture and lithology and make a definitive correlation difficult. For the most part, however, the till is very fine-grained with a high percentage of carbonate rock fragments and clear quartz grains (Table 2). This thin unit underlies a thick sequence of Independence Formation that is interpreted to have been deposited at an ice margin. All of the intervening units (Hewitt, Lake Henry, and St. Francis Formations), however, are missing. It is possible that these intervening tills were eroded by the ice depositing the Independence Formation, or that the thin section of Eagle Bend Formation till encountered in the core is simply an inclusion pushed up into the moraine by advancing ice. An interval of Superior-provenance till underlies the Eagle Bend Formation in this core. The texture and lithology suggest that this till is part of the Cromwell Formation, which underlies the Independence Formation in many locations. However, the depth of this unit (216 feet) in relation to the interpreted stratigraphy (see cross section B–B') suggests that it may be an older Superior-source till, perhaps the St. Francis Formation.

Figure 7. Morrison rotary-sonic core Mo-02 (location shown on Fig. 3).

Figure 8. Morrison rotary-sonic core Mo-03 (location shown on Fig. 3).

Figure 9. Morrison rotary-sonic core Mo-04 (location shown on Fig. 3).

Figure 10. Morrison rotary-sonic core Mo-05 (location shown on Fig. 3).

Figure 11. Morrison rotary-sonic core Mo-06 (location shown on Fig. 3).

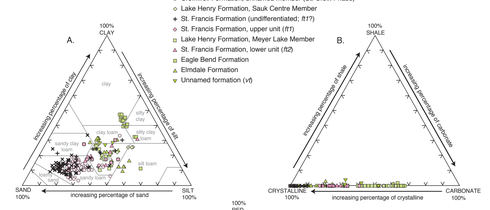

Figure 12. A. Ternary diagram showing matrix texture (less than 2-millimeter size fraction).

B. Ternary diagram showing composition of the very coarse-grained (1-2 millimeters) sand fraction in samples from the rotary-sonic cores in Morrison 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 12B.

Table 2. Average values for the texture and composition of till units (listed in stratigraphic order) recognized in Morrison County. 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), clear quartz, dark (mafic-rich igneous and metamorphic rocks), and red (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
Description	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay	Precambrian Paleozoic Carbonate Rocks Shale	Light	Dark	Red	Clear quartz
New Ulm Formation	1	4	40	39	21	69	20	11	81	9	10	0
Independence Formation, South Long Lake Member	76	11	67	20	13	97	3	0	74	17	9	24
Cromwell Formation, Mille Lacs Member	202	11	63	25	12	99	1	0	58	23	19	14
	2	15	55	32	13	100	0	0	66	13	21	17
Hewitt Formation	7	9	60	28	12	87	13	0	79	15	6	25
Browerville Formation	3	3	44	36	20	65	35	0	86	12	2	43
Lake Henry Formation, Sauk Centre Member	2	16	37	48	15	70	30	0	72	21	7	20
	7	4	31	48	21	47	53	0	67	29	4	36
Meyer Lake Member	19	5	42	39	19	64	36	0	68	27	5	31
St. Francis Formation (und)	28	6	46	34	20	79	21	0	72	19	9	38
St. Francis Formation (1)	8	6	44	37	19	69	31	0	67	25	8	34
St. Francis Formation (2)	8	5	45	36	19	76	24	0	74	15	11	43
Eagle Bend Formation	19	4	20	42	38	46	54	0	83	13	4	47
Elmdale Formation	23	5	39	39	22	84	16	0	77	19	4	38
Unnamed formation (Winnipeg)	4	2	33	37	31	60	38	2	89	11	0	44

GEOLOGIC ATLAS OF MORRISON COUNTY, MINNESOTA