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QUATERNARY STRATIGRAPHY

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INTRODUCTION

This plate provides an interpretation of the depositional setting, distribution and relative age of stratigraphic units documented from subsurface data and surficial mapping (Plate 1) in the upper Minnesota River basin area. The stratigraphic framework (Table 1) allows one to predict where certain units will be encountered, based on their known distribution and on the nature of the geologic processes that formed them. The stratigraphic framework facilitates exploration for targets such as subsurface aquifers. This plate includes a digital elevation model (Fig. 1), a map showing the thickness of glacial sediments (Fig. 2), and a model of the bedrock elevation (Fig. 3). Figure 4 shows the location of subsurface stream sediment associated with till units 5 and 6, and Figure 5 shows the location of subsurface stream sediment associated with Till units 7, 8, 9, and 10. The index map shows the location of the three cross sections (A–A', B–B', and C–C') and the three continuous cores (Figs. 6, 7, and 8). The essential characteristics of the 11 till units are given in Table 1, and the relative age of lake and stream sediments, and soil horizons or organic deposits is indicated.

Data used to develop the stratigraphic interpretation shown here include the three continuous cores that were drilled for this project (UMRB-1, 2 and 3, Figs. 6, 7, and 8), water-well records, cuttings from rotary drill holes, gamma logs of wells and holes drilled for scientific purposes, as well as shallow auger holes, and the multi-till outcrops present along tributaries to the Minnesota River (see figure on Plate 1 for data location). These data are of varying quality. Outcrops are the best source of information because the continuity and context of the units can be directly observed. A few outcrops such as those along the Yellow Medicine River and Hawk Creek near their confluence with the Minnesota River include many or most of the tills recognized. The continuous cores (Figs. 6, 7, and 8) provide deep (as much as 225 ft below the land surface) stratigraphic information away from the Minnesota River, although the nature of the contacts and the continuity of the units is not as easily discerned. Gamma logs are useful for identifying sandy units, some till-till contacts and the contact between glacial sediments and bedrock. Water-well records also assist in distinguishing sandy from non-sandy units, as well as in identifying coloration associated with oxidized zones (which may represent units formerly at the land surface), and allowing an interpretation of the depth to bedrock. Cuttings from rotary drilling provide information about the general lithology and approximate contacts of subsurface units, but mixing during the drilling process results in the cuttings becoming increasingly unreliable with depth.

Past glaciations had global effects, and one can use information from a variety of sources to interpret glacial events. Ocean sediments and ice cores provide evidence for numerous glacial periods during the Pleistocene Epoch. The Upper Midwest was directly affected by ice during at least three of the ten most recent glacial periods during the last 800,000 years (Table 1). During any glacial period, many ice lobes can flow into an area, and each lobe may have multiple advances. For example, surficial sediments together with the Quaternary stratigraphy show that during the last glaciation the upper Minnesota River basin was affected by the Red River lobe and the Des Moines lobe. These ice lobes did not simply advance and retreat. Quaternary sediments indicate that they show complex patterns including multiple advances, stagnations, and retreats. The oscillations of the Des Moines lobe alone indicate four distinct ice margins in the area—the Altamont, Gary, Marshall, and Antelope ice margins (Plate 1). There are probably three to five more ice margins between the Antelope ice margin and the Big Stone moraine in the north of the area mapped. The Des Moines lobe therefore had the potential to stack as many as seven to nine similar tills in the region of the Big Stone moraine, with the number decreasing to the south. A total of five Des Moines-lobe till units has been distinguished in this study. The Red River lobe as well as earlier ice lobes probably behaved in a similar manner.

Multiple advances of one ice lobe may create very similar tills. If the source area for the ice does not change from one glacial period to the next, the tills of these glacial periods will be similar, which adds to the difficulty of distinguishing between stratigraphic units. In the upper Minnesota River basin region most of the ice advanced from the north-northwest or north, incorporating many of the same rock types. Thus, out of the total of 11 till units identified in the region, only till unit 9 is from a distinctly different source area. Therefore an exposure of till examined out of stratigraphic context cannot be classified on the basis of field criteria alone. There is also significant overlap in the laboratory-determined criteria (textural and grain-count data, Figs. 6, 7, and 8). Many of the units documented from outcrops and even some from continuous cores have not been positively classified (they are identified as 'unnamed tills' in Table 1 and Figs. 6, 7, and 8). Geochemistry of the fine fraction of the till (Gowan, 1998) may help classification, but was not undertaken.

Quaternary glacial sediment in the study area is thickest in the southwest and northeast (Fig. 2). Geomorphic and subsurface data (see cross sections A–A' and B–B') provide some evidence for an unconformity (a gap in the geologic record) beneath till units 4, 5, and 6. This unconformity is associated with the broad lowland that extends from the northwest to the southeast through the region (Figs. 1 and 2). The unconformity may be the result of erosion related to advances of the Des Moines lobe. Erosion surfaces are difficult to identify from well-logs, and very few holes penetrate the deepest glacial sediment, but if this hypothesis is correct, till units directly beneath the Des Moines lobe tills in the lowland should correlate with more deeply buried till units in the highlands to the southwest and northeast. There may be some tills that are preserved in highland areas that are missing from the lowland areas.

We have not determined dates for any of the many advances of the Des Moines lobe in the upper Minnesota River basin region, but based on the continuity of the surficial deposits it is possible to correlate ice margins with dated margins in nearby areas (Table 1). Organic remains (red cedar branches) present beneath the Des Moines-lobe tills are older than 48,500 yrs B.P., and beyond the limits of radiocarbon dating. Evidence for previous nonglacial periods has been found above till unit 9 (a soil development horizon) and below till unit 10 (wood, peat and other organic material). These nonglacial deposits may contain distinct pollen and plant assemblages that would allow correlation with nonglacial deposits elsewhere in the region.

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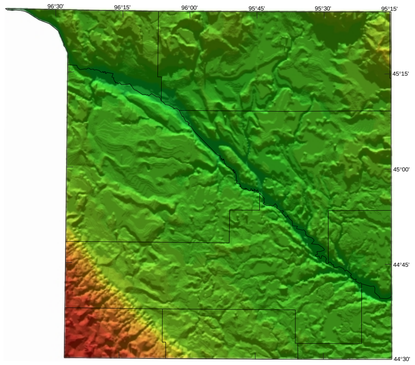

Figure 1. Digital elevation model of land surface. Shaded relief is portrayed using U.S. Geological Survey 90-meter grid cell digital elevation data. The model has 940 ft of overall relief, with a maximum grid elevation of 1790 ft in the southwest corner of the study area.

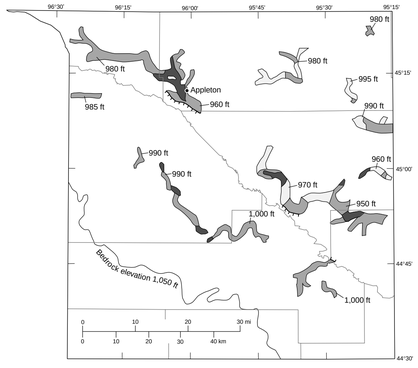

Figure 4. Subsurface stream sediment associated with till units 5 and 6. This map shows the distribution of known sand and gravel bodies that are at least 20 ft thick, and have surface elevations between 950 ft and 1000 ft. Elevations given on the map are the approximate upper surfaces of the sediment, although this will vary along the stream course. The medium gray areas indicate sand and gravel bodies that are well defined by existing data. The light gray areas indicate sand and gravel bodies defined by fewer data points. Areas where sand and gravel deposits may be connected to the underlying sand and gravel units (Fig. 5) are shown in dark gray; in these areas water in otherwise-separate aquifers may be hydraulically connected. Areas along the Minnesota River Valley where buried aquifers may be hydraulically connected with surface waters are shown with a hachured line. The 1,050 ft bedrock elevation contour is shown. The subsurface sand and gravel deposits were identified using well-construction records. The stratigraphic context of these deposits was used to construct probable channel networks. In the region near Appleton, sandy subsurface stream sediment is abundant, and these aquifers are probably hydraulically connected to the bedrock surface.

INDEX MAP
Shows location of cross sections and drill core.

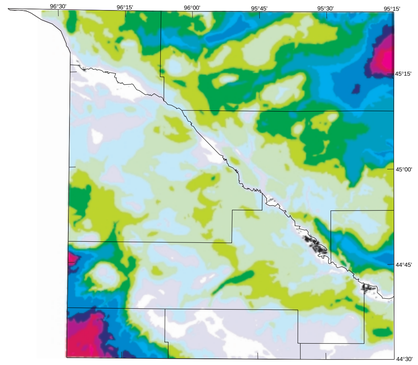

Figure 2. Thickness of Quaternary sediment. The sediment between the land surface and bedrock surface is mostly of glacial origin. Thickness was determined by subtracting the gridded bedrock-elevation data (Fig. 3) from the gridded land-surface digital elevation data (Fig. 1). The sediment thickness data were then contoured with a 50-ft interval. Bedrock outcrop is shown in black. Quaternary sediment is thinnest (<50 ft, white) in the upper Minnesota River Valley, which marks the axis of the most recent advances of the Des Moines lobe. Quaternary sediment is thick (600–650 ft) in the southwest where Des Moines-lobe deposits overlie a thick sequence of older, pre-Wisconsinan glacial sediment that forms the Coteau des Prairies. Quaternary sediment is also thick in the northeast where the Des Moines lobe deposits overlie sediments of the Alexandria Moraine.

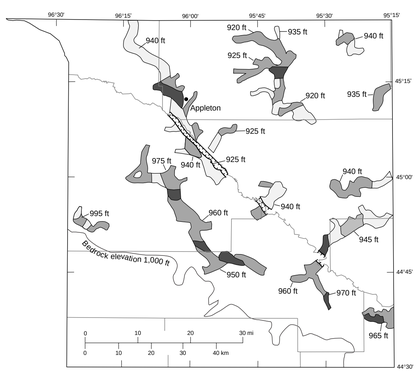

Figure 5. Subsurface stream sediment associated with till units 7, 8, 9, and 10. This map shows the distribution of sand and gravel bodies that are at least 20 ft thick, that have upper surface elevations mostly between 975 ft and 925 ft (stream sediments at higher elevations are shown in Figure 4). The medium gray areas indicate sand and gravel bodies that are well defined by the existing data. The light gray areas indicate sand and gravel bodies defined by fewer data points. Areas where stream sediments may be hydraulically connected to otherwise separate underlying sands (Fig. 3) are shown in dark gray. Areas where the buried aquifers associated with till units 7, 8, 9, and 10 may be hydraulically connected with surface waters along the Minnesota River valley are indicated with a hachured line. The sand and gravel body with a surface elevation of 995 ft is stratigraphically linked to subsurface stream sediments associated with till units 7, 8, 9, and 10. The elevations given on the map are the approximate upper surfaces of the sand and gravel bodies, although this may vary along the stream course. The subsurface sand and gravel deposits were identified using well-construction records. The stratigraphic context of these deposits was used to construct probable channel networks.

CROSS SECTIONS

The location of cross sections A–A', B–B', C–C', and of the continuous drill core are shown on the index map. The well-log data has mostly been projected in to the lines of cross section. The well-logs used are from wells drilled within one mile of each cross-section line. Where the vertical lines representing well-log data terminate above or below the ground surface elevation on the cross sections, data is derived from a nearby location where the ground surface elevation varies from that on the line of cross section. For most logs it is only possible to tell sandy units from non-sandy units. The cross sections are drawn at map scale (1:200,000) with 50 times vertical exaggeration. It is not possible to show units less than 20 ft thick. Some units are shown as being thicker than they actually are, some are grouped with others, and others are simply not shown. Many units that appear on the surficial map (Plate 1) were too thin to show on the cross sections. Units Qsh, Qsd, Qsld, Qsw, Qtld, Qtbr and Qssd are shown on the cross sections as undifferentiated Quaternary surficial sediments, with their identity indicated. Sediments of glacial Lake Benson are identified as separate units (sandy delta sediment; silts and clays), as are other lake sediments. Till units 1, 2, and 3 (numbers refer to unit designation in Table 1) are grouped on the cross sections, as are till units 5 and 6, till units 7 and 8, and till units 10 and 11. There are also an uncertain number of undifferentiated units below till unit 11 that are grouped with till units 10 and 11.

In some cases the till units were grouped, not because they were too thin to show, but because it was impossible to tell them apart with the data available. A dashed line through these grouped units indicates the possible location of a contact based on the presence of sand layers at that horizon. Unit 9 is thin and apparently discontinuous but is not grouped with any other unit because it is the only till of northeastern source. Its reddish brown color is occasionally noted in well logs and it is easily distinguished in outcrop. However, it can be gray when unoxidized, and may include both local and northwest-provenance clasts. It can be missed if special attention is not paid to pebble types. Subsurface sand and gravel bodies have not been assigned to till units, they are shown as separate units on the cross sections. Clayey or silty lake sediment in the subsurface is mostly too thin or too difficult to portray on the cross sections. Lake sediment from a once-extensive lake lies stratigraphically below till units 7/8, and is exposed in valleys of the Yellow Medicine River and Hawk Creek. In some places till unit 7 is stratified, indicating that the ice depositing it advanced into a lake.

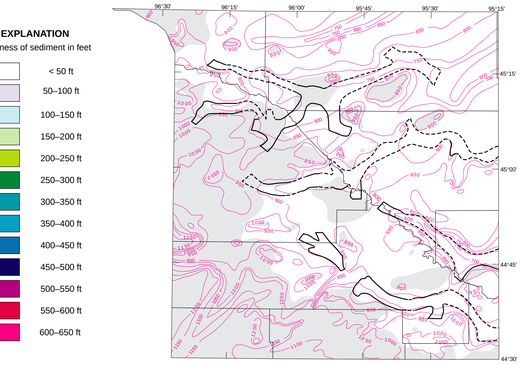

Figure 3. Bedrock elevation, extent of Cretaceous bedrock, and distribution of subsurface stream sediment greater than 20 ft thick at the base of the Quaternary units. Bedrock elevation is contoured in 50-ft intervals. The gray stipple shows the extent of Cretaceous bedrock. Stream deposits that are well constrained by existing data are indicated by solid lines. Stream deposits that are poorly constrained by existing data are indicated by dashed lines. The bedrock surface elevation model was created using data obtained from water-well construction, scientific test drilling and bedrock outcrops. Bedrock mainly crops out along the Minnesota River Valley. The bedrock elevation data were interpreted and a geomorphologically probable surface was contoured. The model exhibits 665 ft of overall relief, with a maximum elevation of 1285 ft and a minimum elevation of 620 ft. In areas to the southwest the uppermost bedrock is Cretaceous in age. Elsewhere, Cretaceous-age rock was either not deposited or was eroded prior to or during the Quaternary, and the first bedrock encountered is Precambrian in age. These areas of Precambrian rock may be deeply weathered (weathering took place prior to the late Cretaceous) so that saprolite (deeply weathered rock) is encountered at the elevations indicated here, and unweathered rock is only found at greater depths below the bedrock surface. The bedrock surface contoured here was not necessarily ever completely exposed at the land surface. The dendritic network of stream sediments documented in areas of lower elevation (shown with heavy solid and dashed lines) indicate that at least the central corridor (about two-thirds of the mapped area) was exposed at the surface.

Table 1. General description of major stratigraphic units

	Sedimentary Unit	Texture	Composition, Grain-Count Data	Location, Correlation, Ice-lobe affiliation	Possible Age
Till units grouped on cross sections	Till unit 1	Clay 21–25%; sand = silt	Trace or no Cretaceous shale; Precambrian > Paleozoic	Present in Big Stone moraine	
	Till unit 2	Clay 22–29%; sand ≤ silt	Cretaceous shale 15–30%; Precambrian = Paleozoic	Present in Big Stone moraine; may correlate to St. Hilaire Fm. (Harris and others, 1995); a till of the Red River lobe	
	Lake sediment	Laminated, varved or massive silts and clays		Glacial Lake Benson II	
	Till unit 3	Clay 25–40%; sand < silt	Cretaceous shale 30–60%; Precambrian = Paleozoic	Present in the Big Stone moraine may correlate with Dahlen Formation (Harris and others, 1995); a Des Moines-lobe till	10,000–30,000 yrs B.P. Late Wisconsinan (marine oxygen isotope stage 4)
	Lake sediment	Laminated, varved or massive silts and clays		Glacial Lake Benson I	
Till units grouped on cross sections	Till unit 4	Clay 20–35%; sand < silt	Cretaceous shale 30–60%; Precambrian ≥ Paleozoic	Present in the Cottonwood Till Plain; main surface unit in study area; a Des Moines-lobe till	
	Till unit 5	Clay 20–30%; sand = silt	Cretaceous shale 20–30%; Precambrian ≥ Paleozoic	Present in the Marshall Till Plain; may be missing due to erosion; a Des Moines-lobe till	
	Till unit 6	Clay 19–27%; sand < silt	Cretaceous shale 16–22%; Precambrian ≥ Paleozoic	May be missing due to erosion; probably includes older phases of the Des Moines lobe; may correlate with units D-1 through D-3 (Patterson and others, 1995)	
	soil development				
Till units grouped on cross sections	Till unit 7	Clay 15–24%; sand = silt	Cretaceous shale 0–10%; Precambrian > Paleozoic	Well exposed, locally stratified may correlate with Granite Falls Till of Matsch (1972)	120,000–200,000 OR 420,000–460,000 yrs B.P. (marine oxygen isotope stages 6 or 12)
	Till unit 8	Clay 18–25%; sand < silt	Cretaceous shale 0–15%; Precambrian ≤ Paleozoic	Not stratified; otherwise similar to Till unit 7; may correlate with SWRA-1 or SWRA-2 (Patterson and others, 1995)	
	Lake sediment	includes soil development and organic deposits > 48,500 yrs B.P.			
	Till unit 9	Clay 10–21%; sand > silt	Trace Cretaceous shale; Precambrian > 80% (5–25% red)	Superior provenance; correlates with Hawk Creek Till of Matsch (1973)	
Till units grouped on cross sections	Till unit 10	Clay 20–30%; sand = silt	Cretaceous shale 0–10%; Precambrian > Paleozoic	Contains wood (red cedar)	420,000–460,000 OR 620,000–660,000 yrs B.P. (marine oxygen isotope stages 12 or 16)
	organic deposits				
	Till unit 11	Clay 20–30%; sand ≤ silt	Cretaceous shale 0–15%; Precambrian ≤ Paleozoic	Not many samples	

A pavement of faceted and striated boulders is present at various stratigraphic horizons between till units 4 and 5, 4 and 6, 6 and 8, 6 and 9 as well as between till units 5 and 7.

There are an uncertain number of unnamed till units present beneath till unit 11 at some locations

EXPLANATION FOR CROSS SECTIONS

- Surficial stream sediments
- Sandy delta sediment of Glacial Lake Benson
- Silts and clays of Glacial Lake Benson
- 7/8 — Till unit. Numbers indicate stratigraphic unit(s). Some till units are grouped.
- Subsurface sand and gravel units
- Lake sediment, clayey silt and very fine sand
- Bedrock, undifferentiated
- Drill hole
- Possible contact between till units

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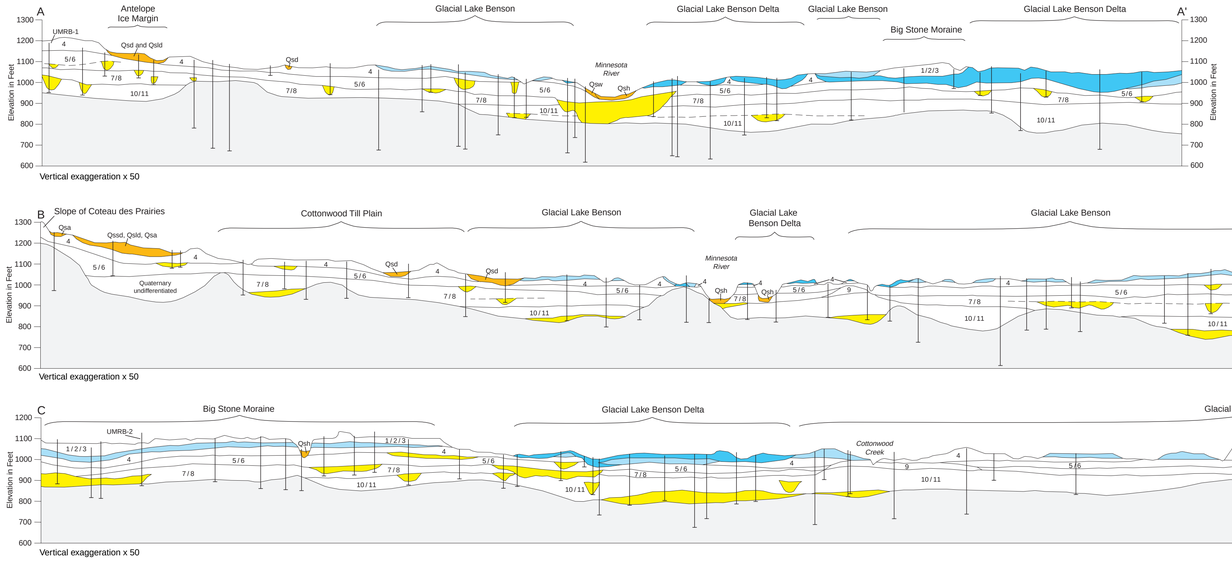
0 5 10 mi
0 5 10 15 km

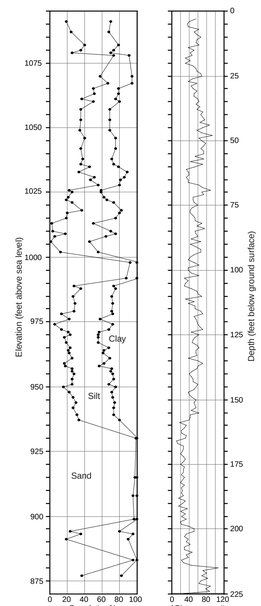


CONTINUOUS DRILL CORE

Three holes drilled for this study (Figures 6, 7, and 8) provide continuous, essentially undisturbed four-inch-diameter core to depths of 225 ft (UMRB-1 and UMRB-2) and 205 ft (UMRB-3). The core provides the most detailed and reliable source of information available on subsurface stratigraphy. Figures 6, 7, and 8 show the elevation above sea level and the depth below ground surface for each core. Matrix texture of the glacial sediment and other non-glacial sediments is presented here as cumulative percentages of sand, silt and clay for each interval sampled. Gravel percentages are not given. Natural gamma logs are useful for distinguishing sandy units (which plot to the left) from more clayey units (which plot to the right). The core descriptions are summaries of the stratigraphic units identified. A geologist monitored the drilling and logged the core on site. The core was then sampled and described in greater detail in the laboratory. The interpretation of the stratigraphic units is shown in italics, and a summary of the inferred stratigraphic sequence is shown in Table 1. The coarse sand grain (1–2 mm) composition was determined. Coarse sand grains were divided on the basis of the inferred age of the rock type (Precambrian, Paleozoic and Cretaceous) and counted. The resulting counts were then averaged for samples within each stratigraphic unit. The relative proportions of different rock types can indicate the source and path of the depositing ice, and assist in correlation of units over a wider area.

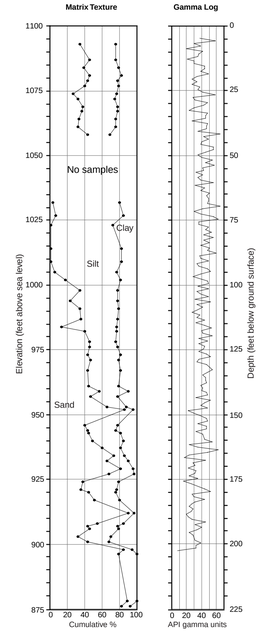
Every reasonable effort has been made to ensure the accuracy of the factual data on which this map interpretation is based; however, the Minnesota Geological Survey does not warrant or guarantee that there are no errors. Users may wish to verify critical information; sources include both the references listed here and information on file at the offices of the Minnesota Geological Survey in St. Paul. In addition, effort has been made to ensure that the interpretation conforms to sound geologic and cartographic principles. No claim is made that the interpretation shown is rigorously correct, however, and it should not be used to guide engineering-scale decisions without site-specific verification.

Figure 6. UMRB-1 (SW1/4 NW1/4 sec. 34, T. 117 N., R. 46 W., Lac qui Parle County)



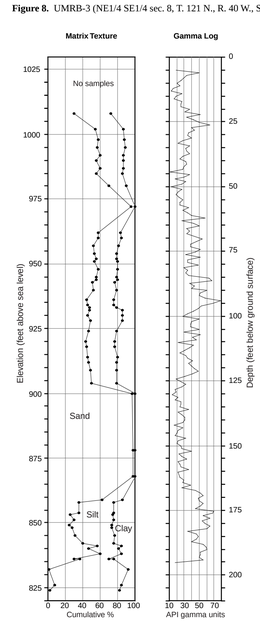
Lithologic Description and Interpretation	Coarse Sand Grain Counts Precambrian:Paleozoic:Cretaceous
0–9 ft Diamicton, light olive brown; upper 5 ft is clast-poor and has a silt matrix; secondary gypsum at 4–5 ft; below 5 ft the matrix is a clay loam. *Unnamed till*	55 : 29 : 16
9–18 ft Diamicton, loam matrix, variable to olive brown in color; sharp upper contact, although similar to overlying till; abundant shale clasts; sandy and gravelly towards base. *Till unit 4*	42 : 25 : 33
18–29 ft Sandy loam; gray; laminated in places. *Lake sediment*	
29–36 ft Diamicton, loam to sandy clay loam matrix, black; below 33 ft becomes denser, more uniform and fissile, with a clay loam to loam matrix; includes Cretaceous non-Pierre Shale clasts (probably Fairport Mbr. of Carlile Fm.). *Unnamed supraglacial or glaciolacustrine till*	42 : 27 : 31
36–61 ft Diamicton, clay loam matrix; dense and uniform; very dark gray to black; fissile in places; clasts include Cretaceous concretions and shells. *Unnamed till (not till unit 4)*	52 : 17 : 31
61–62.5 ft Medium sand grading up to fine sand; dark gray to dark gray brown. *Stream sediment*	
62.5–63.5 ft Fine sand and silt with scattered clasts; mottled. *Lake or stream sediment*	85 : 12 : 03
63.5–68 ft Diamicton, loam to sandy clay loam matrix; light olive gray. *Till unit 7*	
68–72 ft Diamicton, clay to clay loam matrix, dark gray to black, contains waxy dark shale clasts; sharp contact with overlying unit; silt stringers present throughout; thin fine sand and silt layer near base; basal 1 inch is sheared. *Unnamed subglacial till*	62 : 23 : 15
72–75 ft Diamicton, silty clay loam to clay loam matrix; light gray to dark gray; calcareous. *Unnamed till*	98 : 02 : 00
75–93.5 ft Silt with clay and fine sand, coarsens upward; includes shells, and some pebbles; at 84.5 ft it is slightly coarser, more oxidized, and contains clay intraclasts in silt; at 92 ft the sediment grades down to a very clayey and dense unit. *Lake sediment*	
93.5–95 ft Diamicton, silty clay matrix; dark grayish brown; chalk clasts, large shale clasts, numerous Precambrian grains. *Unnamed till*	99 : 01 : 00
95–100 ft Coarse sand with pebbles; dark grayish brown to light olive brown; grus-like composition; contains no mafic, metasedimentary, sedimentary or carbonate grains. *Leached stream sediment*	98 : 02 : 00
100–105.5 ft Gravel; calcareous; basal contact is a sharp erosion surface. *Unleached stream sediment*	76 : 24 : 00
105.5–117.5 ft Diamicton, clay loam to loam matrix; gray brown to dark gray; calcareous; contains blocky shale clasts and yellow orange-stained carbonate clasts. *Till unit 8*	54 : 46 : 00
117.5–120.5 ft Diamicton, silty clay loam to clay matrix; olive brown; upper and lower contacts marked by thin black silty zone (possibly a soil or reworked fines); numerous lenticular white zones (marl); silty clay near lower contact. *Flow till or glaciolacustrine facies of till unit 8*	45 : 55 : 00
120.5–123.5 ft Silty clay loam; very dark gray; locally carbonate-rich. *Lake sediment*	
123.5–129 ft Diamicton, clay matrix with polished pebbles; olive brown; contains secondary carbonate on fractures; strongly oxidized. *Unnamed till*	60 : 32 : 08
129–158 ft Diamicton, clay loam matrix, with silty clay loam and silt loam; black to very dark grayish black; variably oxidized; calcareous throughout; snail shell and wood at 137.5 ft; lighter gray below 141.5 ft; shark tooth at 148.5 ft; sharp basal contact. *Unnamed till*	53 : 45 : 02
158–199 ft Fine to coarse sand; grayish brown; calcareous throughout; 80 percent quartz grains; scattered pebbles at 181 ft; at 186 ft it is a medium to coarse sand with local concentrations of black granules (lignite?); below 186 ft it is a coarse sand with polished and rounded pebbles. *Stream or delta sediment*	90 : 10 : 00
199–201 ft Diamicton, silt loam matrix; very dark gray. *Unnamed till*	61 : 38 : 01
201–204 ft Gravel, silt matrix, some matrix support; below 202 ft it is almost clast-supported. *Gravelly till or silty gravel sieve deposit*	44 : 51 : 05
204–218 ft Sand, fines upward from medium to coarse sand to fine sand with silt; gray; calcareous throughout. *Stream or delta sediment*	81 : 19 : 00
218–219 ft Diamicton, loam matrix; gray. *Unnamed till*	59 : 40 : 01
219–225 ft Shale; dark; waxy. *Cretaceous bedrock*	

Figure 7. UMRB-2 (NE1/4 NE1/4 sec. 18, T. 122 N., R. 46 W., Big Stone County)



Lithologic Description and Interpretation	Coarse Sand Grain Counts Precambrian:Paleozoic:Cretaceous
0–5 ft Pebbly silt; dark grayish brown; organic-rich; calcareous; weakly laminated. *Holocene lake sediment*	46 : 54 : 00
5–25 ft Diamicton, loam to clay loam matrix; soil structure in upper part; light yellowish brown to pale brown; non-calcareous to weakly calcareous; includes carbonate clasts, but no shale clasts. *Till unit 1*	
25–45 ft Diamicton, loam matrix; similar to overlying till unit 1, but firmer; dark gray to light brownish gray. *Till unit 2*	39 : 41 : 20
45–96 ft No core recovered from 45–66 ft. Below 66 ft: silt loam with sand and occasional granule- and pebble-size clasts; finely laminated; increase in amount of pebbles and granules in lower 1.5 ft. *Glacial Lake Benson sediment*	
96–117 ft Diamicton, silt loam matrix, possible soil structure in upper part; dark gray; blocky; calcareous; below 100 ft the sediment is a dense, fairly uniform diamicton with a loam to silt loam matrix, and contains abundant shale granules and pebbles between 100 ft and basal contact. *Till unit 4*	22 : 18 : 60
117–130 ft Diamicton, loam matrix, contact with overlying unit may be gradational between 114 to 117 ft; thin sand layers; very dark gray; extremely dense; fewer shale clasts than in overlying unit. *Till unit 5*	39 : 35 : 26
130–132 ft Fine sand, fines upward; dark gray; sharp upper and basal contacts. *Lake sediment*	40 : 38 : 22
132–135 ft Diamicton, loam matrix; very dark gray; clasts include dolomite, granite and shale. *Till unit 5*	
135–137 ft Cobbly gravel with coarse sand. *Stream sediment*	35 : 37 : 28
137–141 ft Diamicton, loamy matrix; very dark gray; clasts include dolomite, granite and shale. *Till unit 5*	
141–142 ft Fine sand; light grayish brown; sharp upper and basal contacts. *Lake sediment*	
142–149 ft Diamicton, loam matrix; dark gray; calcareous; includes limestone, shale, metamorphic and igneous clasts, some are distinctly striated; becomes sandier towards base, where it is a sandy loam to loamy sand with visible sand layers. *Till unit 5*	41 : 38 : 21
149–153 ft Coarse sand with fine pebbles; gray; includes small lignite grains; thin diamicton at 152 ft; fine sand layer at 153 ft. *Delta or stream sediment*	38 : 39 : 23
153–165 ft Diamicton, loam matrix; very dark gray; uniform and unoxidized; gravelly and sandy at base. *Till unit 6*	
165–175 ft Coarse sand and gravel, poorly sorted; sharp upper contact with overlying till unit 6; above 167 ft it is clast-supported gravel with a sandy matrix that grades up to a sand and pebbly sand; below 167 ft it contains less fines in the matrix, but is still not well sorted. *Stream sediment*	39 : 39 : 22
175–184 ft Diamicton, loam matrix; very dark grayish brown; dense and firm; includes sand layers up to 1 inch thick; pebbly towards the base; Sharp basal and upper contacts. *Unnamed till*	41 : 34 : 25
184–193 ft Coarse sand with pebbles; variable color; better sorted near base. *Stream sediment*	58 : 38 : 11
193–196 ft Very pebbly diamicton, loam to clay loam matrix; dark gray; layers of coarse sand at 198 ft. *Till unit 8*	48 : 46 : 06
196–200 ft Coarse, poorly sorted sandy clay loam; pebbly diamicton layer with loam matrix at 198–199 ft; dark grayish brown. *Resedimented till?*	43 : 50 : 07
200–203 ft Sand; gray with black laminae; finely laminated; laminae include lignite (?) or other organic material. *Alluvium*	
203–207 ft Coarse pebbly sand; sharp upper contact; contains well-rounded pebbles. *Stream sediment*	63 : 32 : 05
207–223 ft Sand; fines upwards from well-sorted coarse sand to medium-fine sand. *Stream sediment*	
223–225 ft Loamy sand; dark grayish brown. *Stream or lake sediment*	

Figure 8. UMRB-3 (NE1/4 SE1/4 sec. 8, T. 121 N., R. 40 W., Swift County)



Lithologic Description and Interpretation	Coarse Sand Grain Counts Precambrian:Paleozoic:Cretaceous
0–4 ft Artificial fill	
4–5 ft Fine sand; gray and yellow brown. *Eolian sand or lake sediment*	
5–10 ft Organic-rich black sand grading down to dark gray sand then very fine sand (olive gray) with silt; slightly calcareous; sulfur smell. *Buried soil on delta sediment*	
10–22 ft Fine sand; black to dark gray; grades down to dark gray fine to medium sand; color change parallels grain-size change; calcareous; contains scattered pebbles. *Delta sediment*	
22–33 ft Diamicton, clay loam to sandy loam matrix; dark gray; very soft; contains abundant carbonate clasts and very few shale clasts. *Till unit 7*	62 : 29 : 09
33–35 ft Coarse sand with pebbles, fining up to fine sand; sharp upper contact; fine silty sand near base. *Delta or stream sediment*	
35–43 ft Diamicton, sandy loam matrix; dark gray to very dark gray brown; includes sand at 40 ft and a gravel layer at 40.5 ft; firm below 40.5 ft. *Till unit 7*	
43–47 ft Fine silty sand; pale gray; mostly quartz sand; contains lignite granules. *Delta and/or lake sediment*	
47–48 ft Sandy diamicton, sandy loam matrix; gray; sharp upper and lower contacts. *Resedimented till*	79 : 19 : 02
48–65 ft Medium to coarse pebbly sand; variable color; contains lignite granules and other black grains as well as red grains; grades down from a fine-to-coarse pebbly sand with minor silt as well as granules and pebbles, to a medium-to-coarse sand with granules to a coarse pebbly sand at base. *Stream sediment*	77 : 22 : 01
65–90 ft Diamicton, sandy loam matrix; dark gray; calcareous throughout; includes many sand layers between upper contact and 72 ft; includes Cretaceous pyrite and limestone clasts; high gamma signal below 83 ft probably due to blocky Cretaceous shale clasts. *Resedimented till*	70 : 20 : 10
90–95 ft Diamicton, clay loam matrix with cobbles near base; dark gray; similar to overlying unit (65–90 ft); includes speckled shale clasts; records the highest gamma signal. *Unnamed till*	56 : 21 : 23
95–125 ft Diamicton, loam matrix texture, blocky structure at top (probably a truncated soil profile); very dark gray-brown; contains dominantly Precambrian grains, some carbonate grains, and only rare Cretaceous grains; unoxidized (very dark gray-brown to very dark gray) below 99 ft; sandy at 111.5 ft and 112–113.5 ft; very firm till below 113.5 ft; sharp basal and upper contacts. *Unnamed till(s)*	76 : 23 : 01
125–145 ft Fine sand; variable color; contains lignite and wood grains and clay intraclasts; contact with overlying unit is sharp; below 129 ft it is a well sorted, fine to medium sand; at 137.5 ft it includes a zone with lignite, wood and organic material; at 143.5 ft there is a sharp change to very fine sand. *Stream sediment*	82 : 11 : 07
145–168 ft Medium to coarse pebbly sand, fining upwards; contains lignite, shell fragments, red sandstone, red shale, and red siltstone in pebble and coarse-sand fraction; at 155 ft it changes sharply to a quartz-rich upwards-fining very fine sand unit that contains red (northeast-source) grains near the base. *Stream sediment*	85 : 14 : 01
168–193 ft Diamicton, with matrix composed of alternating layers of dark reddish gray sandy loam and dark gray clay loam; includes a possible truncated soil profile; core missing from 171.5 to 173 ft; below 173 ft it is a dark gray to grayish brown diamicton with scattered red pebbles and seams of diamicton with a dark reddish gray sandy loam matrix. *Glaciotectonically layered till*	85 : 13 : 02
193–195 ft Clay; black; grades down to bedded silt, very fine sand then clay, with wood at the base. *Lake sediment*	
195–205 ft Very fine sand to silt; gray; rare pebbles; homogeneous, with occasional hints of bedding; includes shells and flakes of black organic material. *Lake sediment*	

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