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SUBSURFACE TILL STRATIGRAPHY OF THE TODD COUNTY AREA, CENTRAL MINNESOTA

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SUBSURFACE TILL STRATIGRAPHY OF THE TODD COUNTY AREA, CENTRAL MINNESOTA

by

Gary N. Meyer

ABSTRACT

Drilling logs, cuttings samples, and a limited amount of split-tube samples--acquired as a by-product of a crystalline basement drilling project--provide evidence for informally naming nine new till units in central Minnesota. The Elmdale till may represent the first Pleistocene ice advance into central Minnesota. Other tills of northwestern provenance are the Eagle Bend, Meyer Lake, Green, and Browerville. Although shale is generally rare, these tills typically contain appreciable amounts of Cretaceous rock fragments, chiefly from the Greenhorn Limestone. The Second Red, First Red, Sandy, and Red Sandy are pre-Wisconsinan tills of northeastern provenance. They compose only a minor portion of the Pleistocene deposits in the Todd County area, but indicate alternate northeastern and northwestern ice advances.

The surficial Wadena till had a northeastern source, as indicated by lithology, texture, and drumlin orientation. Its relatively high carbonate content, which led earlier workers to ascribe a northwestern provenance, was derived through incorporation of older drift.

The Elmdale, Second Red, and Eagle Bend tills are thought to be pre-Illinoian; the First Red, Meyer Lake, and Green tills, pre-Illinoian or Illinoian; the Sandy and Browerville, Illinoian; and the Red Sandy, Illinoian or early Wisconsinan in age. A new radiocarbon date of 36,970 B.P. from a wood sample above the Wadena till supports an early Wisconsinan age designation for the surficial till over much of Todd County.

INTRODUCTION

The Todd County study area in central Minnesota (Fig. 1) was repeatedly glaciated, and drift commonly exceeds 200 feet (60 m) in thickness, and in places, exceeds 400 feet (120 m). The tills, which make up the bulk of the drift, differ in color, texture, and lithology, due to provenance and depositional history. This thick sequence of tills makes the Todd County area an ideal location to begin deciphering the complex pre-late Wisconsinan glacial history of Minnesota.

Study of the subsurface drift was made possible through a scientific drilling program of the Minnesota Geological Survey, in cooperation with the Minnesota Department of Natural Resources and the Minnesota Department of Transportation (Southwick, 1980). Drilling commenced in the summer of 1980 approximately along the line of a deep, crustal reflection seismic survey (Fig. 2a), conducted in 1979 by the Consortium for Continental Reflection Profiling (COCORP). A Minnesota Department of Transportation crew and equipment drilled through the glacial drift and regolith and obtained cores of sound Precambrian bedrock. Along the way, continuous cuttings samples were described and bagged at 5-foot (1.5 m) intervals. Split-tube core samples were collected at intervals generally exceeding 30 feet (9 m) that were chosen by the site geologist.

The thickness of the regolith and the crew's lack of experience in drilling to depths of 300 feet (90 m) or more resulted in only 7 of the 43 planned holes being drilled (MGS numbers 1640-1646). Remaining funds were used to contract with Donabauer Well and Pump Company, which completed four additional holes (MGS numbers 1648-1651) along the COCORP line in the fall and winter of 1981-82. Split-tube samples were not collected, and cuttings samples, especially at depth, were typically of poor quality.

The drilling program was continued in the summer of 1982 in conjunction with a high-resolution aeromagnetic survey of the state, begun in the fall of 1979 through funding provided by the Legislative Commission on Minnesota Resources. North Star Drilling, Inc. drilled 15 holes in 1982, but only 3 (MGS numbers 1911-1913) were within the Todd County area. Ben Ervin Well Company drilled an additional 14 holes in 1983, of which MGS numbers 1999-2001 and 2005-2008 were in the study area. Although cuttings samples improved over time with the private contractors, the relatively undisturbed split-tube samples were no longer collected, and log and sample interpretation are consequently less certain.

Cuttings samples were available from a few other holes in the area (MGS numbers 422 and 510; USGS numbers T2B, T2D and TH-104), and both cuttings and split-tube samples were on file from a test site in Stearns County, which was investigated in 1982 by the Minnesota Waste Management Board (MGS numbers 1827-1830). It should be noted that none of the test holes in this study were sited expressly for working out the regional glacial stratigraphy. Rather, this report is a by-product of a drilling project oriented primarily to a better understanding of the Precambrian rock beneath the drift.

PREVIOUS WORK

The northern part of the Todd County area is dominated by the Wadena drumlin field, with the prominent St. Croix moraine to the east, the overlapping features of the Des Moines lobe to the south, and Des Moines outwash to the west (Fig. 2b).

Allison (1932) thought that the bulk of the glacial section in Todd County belonged to the "old gray drift." Schneider (1961, p. 100) found no direct evidence of glacial drift older than the drift of the Wadena drumlin field in his study of the Randall area (Fig. 2a) in Morrison and Todd Counties. Wright (1962, 1972) did not speculate on older drift beneath that of the Wadena lobe.

Matsch (1972) has described several glacial tills exposed in deep cuts in and near the Minnesota River Valley (Fig. 1), about 75 miles (120 km) south and southwest of Todd County. He correlated his Granite Falls till, which underlies his surficial New Ulm till (Des Moines lobe), with the till of the Wadena drumlin field. A till of northeastern provenance, termed the Hawk Creek till, was exposed in places beneath the Granite Falls till, and at least two older tills of northwestern provenance were exposed in a few locations. Matsch likened these tills to similar "old gray drift" present at the surface in the southwestern corner of the state. He noted that although interglacial deposits testified to multiple glaciations, the older tills lacked deeply weathered horizons indicative of long interglacial periods. Still, Matsch concluded that the tills below the Hawk Creek were probably pre-Wisconsinan.

Winter and others (1973) used deep exposures in the open-pit mines of the Mesabi iron range 90 miles (145 km) northeast of Todd County (Fig. 3) to recognize three major till units. The top two, the "surficial" and "bouldery" tills, were shown to be laid down by the late Wisconsinan Des Moines and Rainy lobes, respectively. The "basal" till did not occur consistently in outcrop, nor did it appear very similar from exposure to exposure, but they concluded that it was deposited by a single ice advance from the west-northwest, probably in middle or early Wisconsinan time, but possibly earlier. They found very little similarity between the basal till and till of the Wadena drumlin field.

Harris and others (1974) recognized several units believed to be pre-late Wisconsinan in extensive exposures along the Red Lake River (Fig. 1), about 120 miles (195 km) northwest of Todd County. They correlated one unit, the Marcoux Formation, with the Hawk Creek till of southwestern Minnesota. Later workers in west-central Minnesota, Anderson (1976) and Perkins (1977), agreed, and in addition, correlated the Marcoux with their Sebeka Formation, a surficial unit which is equivalent to the Wadena till of Wright (1962). Harris and others (1974) correlated the lower part of the Red Lake Falls Formation with the Granite Falls till of Matsch (1972), and the upper part with Matsch's New Ulm till. Anderson (1976) and Perkins (1977) agreed and correlated their surficial units, the New York Mills and Dunvilla Formations, with the lower and upper Red Lake Falls Formation. Sack-

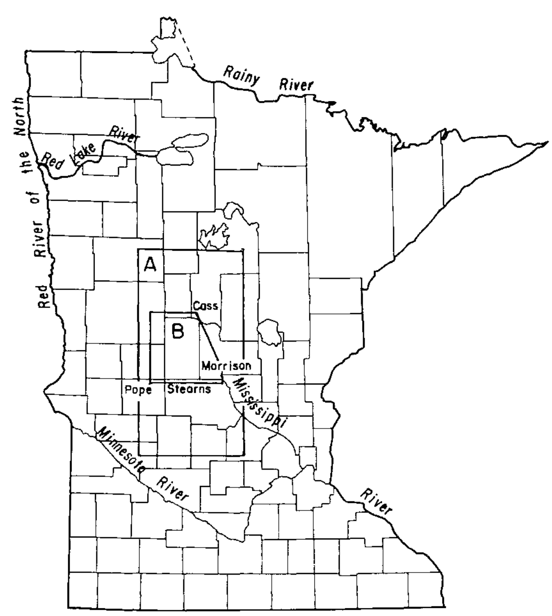

Figure 1. Location map. A, area shown in Figures 2a and 2b. B, Todd County study area shown in Figures 5, 8, 10, 11, 13, 15, 16, 18, and 19.

reiter (1975) encountered two unnamed tills presumed older than the Marcoux in test holes in Clay and Clearwater Counties, north of the Anderson and Perkins study areas, and about 70 miles (113 km) northwest and north of Todd County. Sackreiter correlated the lower part of the Red Lake Falls Formation with the Itasca and St. Croix moraines (Fig. 2b) and the bouldery till of Winter and others (1973).

More recently, Giencke and others (1983/84) recognized an older till below tills of the Des Moines and Wadena lobes in the Alexandria moraine, about 40 miles (64 km) south of the Todd County area in Kandiyohi County. This older till, present at the highest elevations in the county and the surficial unit over a large area around the town of Kandiyohi (Fig. 2a), has been provisionally named the Kandiyohi till. The Kandiyohi till, believed by the authors to have been thrust to the surface by Wisconsinan ice, was thought to be pre-Wisconsinan in age.

METHODS

The recognition and correlation of glacial till units in this study relied primarily on site geologists' description of cuttings, and separation of the very coarse sand (1- to 2-mm) fraction by lithology and geologic age. Textural analysis was completed for all split-tube samples and for some cuttings samples. Electrical and gamma-ray downhole geophysical logs were available for several holes, and were useful primarily to verify the on-site cuttings log.

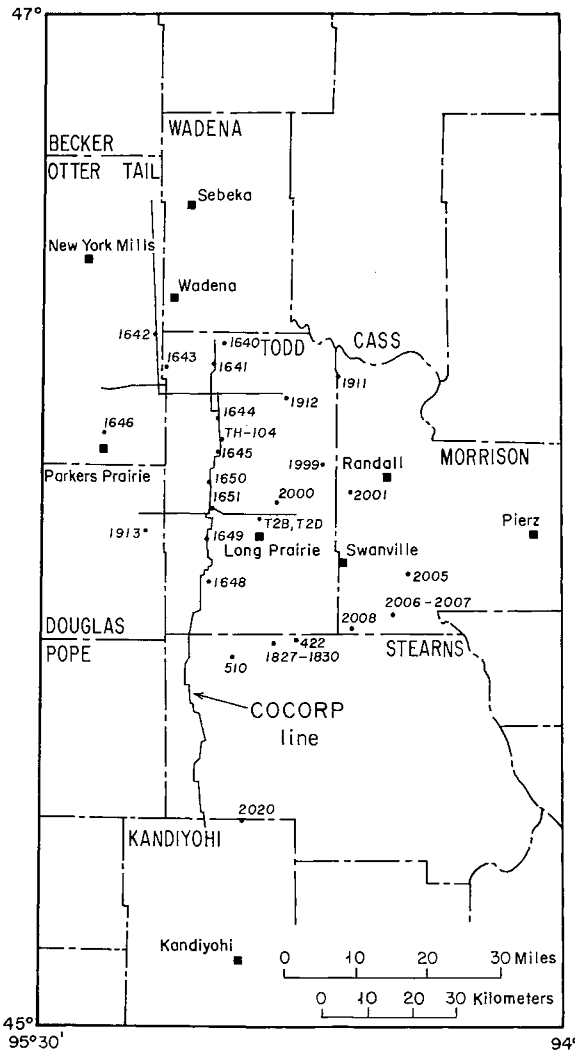

Figure 2a. Locations of COCORP seismic survey and test holes.

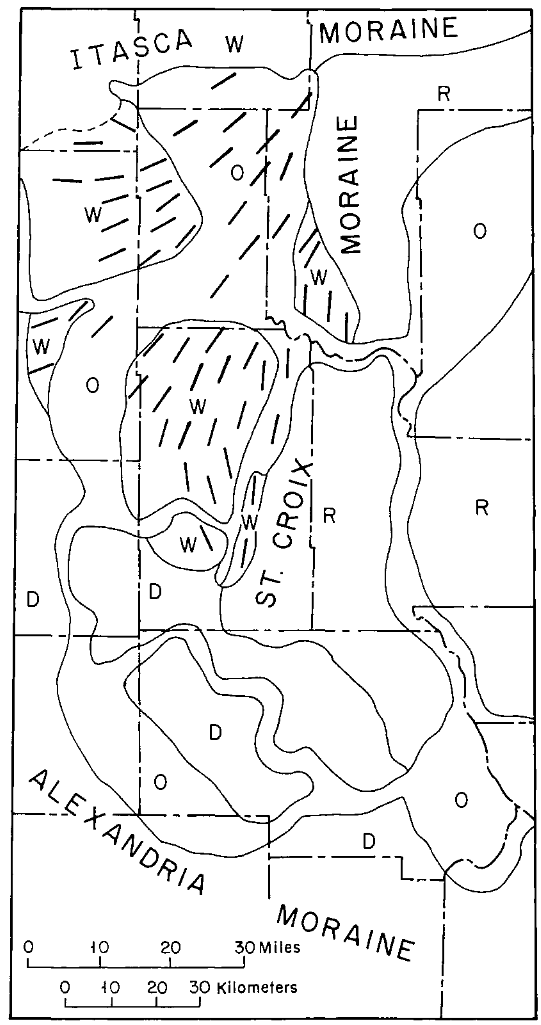

Figure 2b. Surficial geologic map (simplified from Hobbs and Goebel, 1982); D, Des Moines lobe till; R, Rainy lobe till; W, Wadena till; O, outwash. Dashes, Wadena drumlins.

Following Matsch (1971), the 1- to 2-mm size fraction was selected as an index grain size for lithologic study. Fines were washed from samples, and the very coarse sand separated by sieving. About 250 sample counts were completed with the aid of a binocular microscope, each sample containing from 250 to 500 grains. The discovery of a pre-Pierre Shale suite of Cretaceous rock fragments, including limestone, in pre-late Wisconsinan tills, required a change from the standard sand count lithologic division of crystalline, carbonate, and shale. Consequently a division based on geologic age was developed separating grains into Precambrian, Paleozoic, Cretaceous, and "other" categories. Shale was generally rare in the tills of the study area, but total Cretaceous content was commonly significant.

The Precambrian group was subdivided in order to recognize significant index lithologies. These categories were (1) granitic (coarse crystalline, felsic igneous and metamorphic rock fragments, including quartz), (2) mafic (basalt, gabbro, and greenstone), (3) other metamorphic (metagraywacke, slate, phyllite, schist), (4) iron-formation, (5) quartzite, (6) felsite (includes agate), (7) sandstone, and (8) other. Division of dark-colored rock fragments into the "mafic" and "other metamorphic" categories was the most difficult and time-consuming, and helped in most cases in only a very general way to distinguish and correlate till units. The distinction may prove useful east and northeast of Todd County, but these categories are lumped here into a general "darks" category. Iron-formation, quartzite, felsite, sandstone, and "other," are combined in the triangular diagrams and figures, but the felsite and sandstone categories, which indicate a Lake Superior basin provenance, are referred to as "reds" in the following discussion.

The Paleozoic category consists primarily of Ordovician, Silurian, and Devonian limestone and dolomite, with minor chert and sandstone. A few Jurassic carbonate grains were undoubtedly included in this category. The Cretaceous group includes gray shale (Pierre, Carlile, and Belle Fourche formations), speckled shale (Niobrara and Greenhorn formations), limestone (Greenhorn), and pyrite, as well as minor lignite, bone, and sandstone. The white specks in shales of the Niobrara and Greenhorn, which are fecal pellets containing abundant coccolith remains (Hattin, 1975), have also been noted in the Carlile and Belle Fourche (Moore, 1979).

Cretaceous limestone is distinguished from Paleozoic carbonate by its gray color (versus ivory to buff) and its general "grungy" appearance, caused by an abundance of fossil fragments and detrital silt. Cretaceous limestone tends to be tabular in shape, as opposed to the generally equant grains of Paleozoic carbonate. Many grains counted as Greenhorn Limestone are primarily or entirely pelecypod fragments. These fragments should have been placed in a separate category because, although most abundant in the Greenhorn, pelecypod beds occur throughout the Cretaceous section (Moore, 1979). Black to dark-brown fishbone fragments are also common in Cretaceous limestone. Fossils in Paleozoic carbonates, where recognized at all, are much less distinct.

Pyrite grains believed to have a sedimentary origin were generally included in the Cretaceous grouping. Pyrite is most commonly associated with offshore marine facies, and, in this study, was regularly found on grains of fossiliferous Greenhorn limestone. Moore (1979) and other workers in eastern North Dakota have noted that pyrite is especially common in the Belle Fourche Shale. In a study within the Mesabi range, McGill (1955) noted much secondary pyrite associated with Cretaceous sediments, and concluded that the sediments had undergone extensive secondary mineralization from interstitial water prior to deposition of the overlying glacial till. Sulfur is associated with organic carbon, because accumulating organic matter favors direct reduction of sulfate to sulfide, as well as proliferation of sulfate-reducing bacteria (Degens, 1965). As noted below, "dirty" in situ pyrite is common in the Meyer Lake till, which contains incorporated organic debris.

Grains of pyrite-cemented quartz sand also were noted in some till samples and are believed to be Cretaceous in age. A drill hole north of Parkers Prairie (MGS 1646, Fig 2a), just west of the study area, encountered about 50 feet (15 m) of probable Cretaceous quartzose sand beneath glacial drift. Pyrite-cemented sand grains were found associated with an organic layer at the top of this sand.

Split-tube samples were available from only nine of the test holes drilled in the study area. An attempt was therefore made to obtain sand-silt-clay percentages from cuttings. Results from six sampled holes yielded what were considered approximate estimates of actual texture. Very coarse sand was usually a greater percentage of the total sand in cuttings than in split-tube samples, indicating an uncertain combination of contamination from younger units and preferential winnowing by the drilling and sampling process. As is common under poor sampling conditions, till samples from greater depths consisted mostly of very coarse sand. The percentage of 1- to 2-mm sand can therefore serve as an indicator of the accuracy of cuttings samples.

TILL UNITS

At least 12 separate till units (Plate 1) are recognized in the Todd County area, nine of which are new units. Tills of the late Wisconsinan Des Moines and Rainy lobes are at the surface in the southern and eastern parts of the area, and the early Wisconsinan Wadena till is the surficial unit over much of the rest of the area (Fig. 2b). The bulk of the glacial sediments in the subsurface is of northwestern (Keewatin) provenance (Table 1), having been laid down by glaciers advancing from the Winnipeg lowland (Fig. 3). Tills of northeastern (Labradorean) provenance laid down by ice advancing across the Canadian Shield (Rainy lobe) and out of the Lake Superior basin (Superior lobe), were encountered in enough holes, however, to indicate alternate advances from the northeast and the northwest throughout the glacial period.

Table 1. Average thickness and provenance of till units in the Todd County study area

Till	Thickness (feet)	Range (feet)	Holes to base	Provenance
Des Moines	not studied			NW
Pierz	31.2	8-86.5	10	NE
Wadena	37.2	6-103	18	NE
Browerville	79.2	7-150	10	NW
Sandy	21.4	12-45	5	NE
Red Sandy	19.5	-	1	NE
Green	61.0	17-96	3	NW
Meyer Lake	38.5	12-64	12	NW
First Red	14.5	4-29	4	NE
Eagle Bend	38.4	5-93	13	NW
Second Red	40.0	-	1	NE
Elmdale	35.0	14.5-79	6	NW

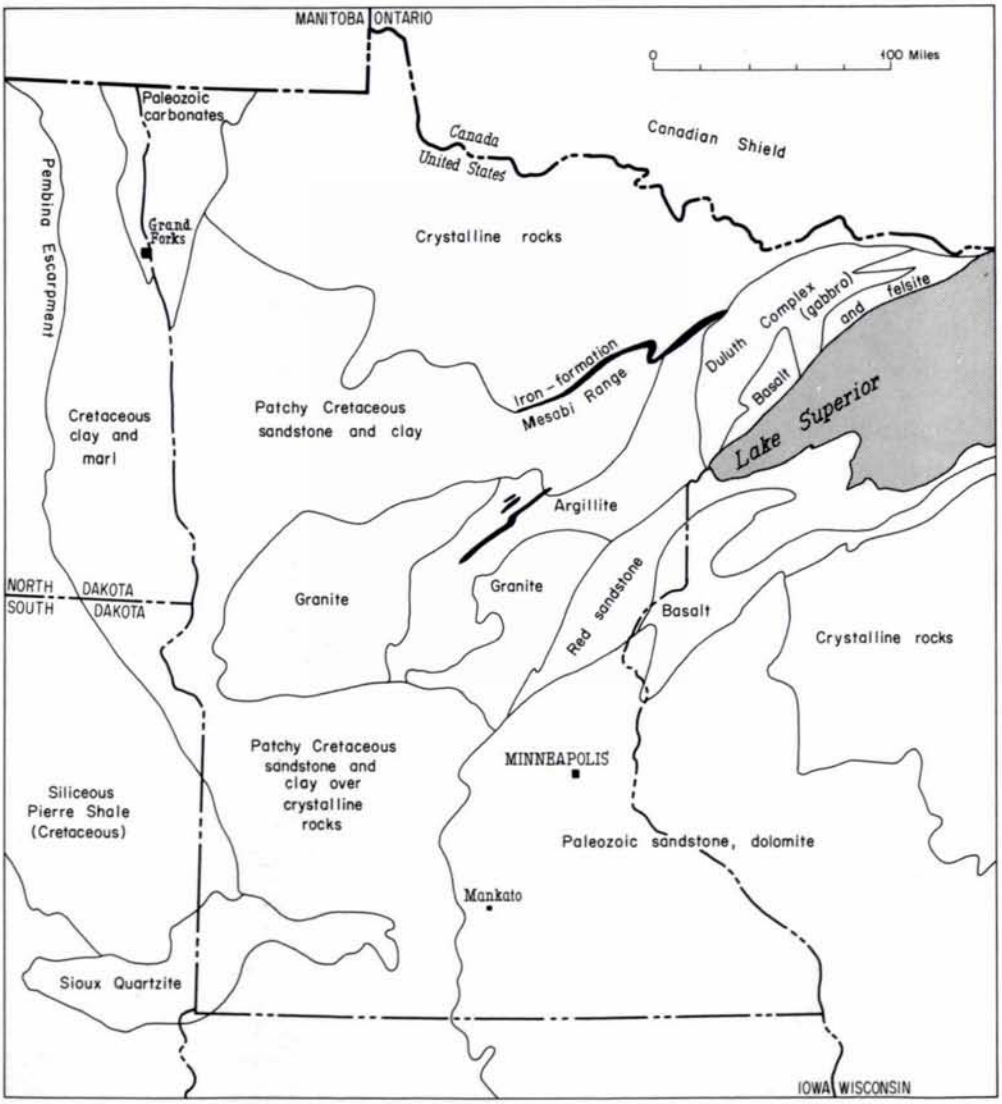

Figure 3. Simplified bedrock geologic map of Minnesota and adjacent areas (modified from Wright, 1972).

Elmdale Till

The oldest till recognized in this study is named informally after the small town of Elmdale in southwestern Morrison County. The thickest section of the till, 79 feet (24 m), was encountered in MGS hole 2007 about a mile (1.6 km) south of town, at a depth of 110 feet (34 m). Here the Elmdale overlies about 7.5 feet (2.5 m) of reworked regolith over clay regolith. The till is a very dark gray (5Y3/1) clay loam, but in places (Fig. 4) ranges to a dark-gray (5Y4/1) sandy clay loam with sand streaks.

The till is exposed 6 miles (10 km) east of Elmdale in a cut bank along Two River near its mouth at the Mississippi River. About 12 feet (3.7 m) of mottled till overlies 10 or more feet (3 m) of nonmarine Cretaceous siltstone and lignitic shale, and some of the shale has been incorporated in the till. At the other five sites (Figs. 5a and 5b), the Elmdale lies directly on regolith. Marine Cretaceous limestone, however, is common in the Elmdale till (Table 2), composing 8 percent of the very coarse sand, and 26 percent of the pebble fraction. One sample from the Two River site exhibited reversed magnetiza-

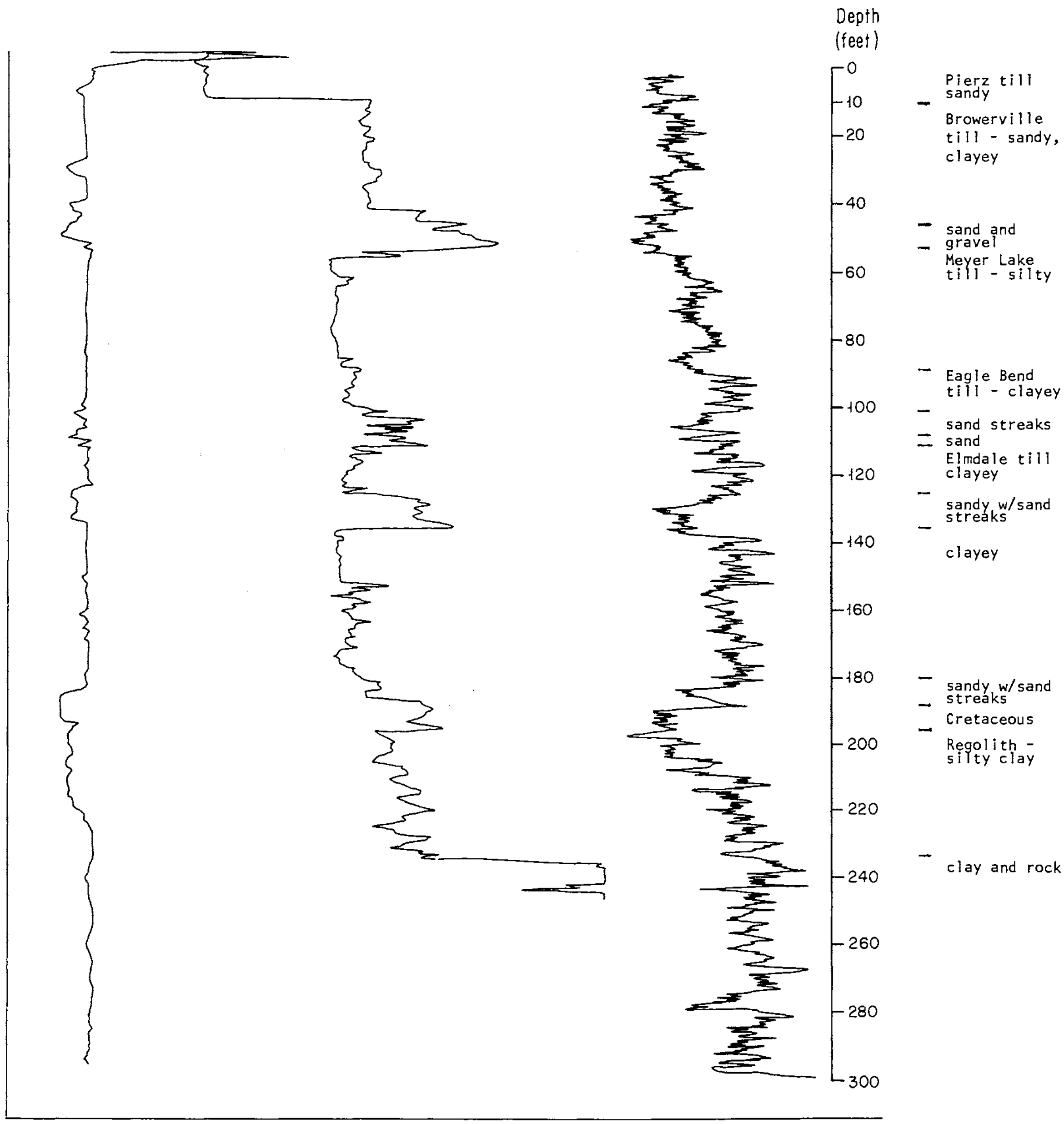

Figure 4. Spontaneous-potential, resistivity, gamma-ray, and on-site logs for MGS hole 2007, Morrison County. Surface elevation 1153 ± 5 feet. See Appendix A for expanded log.

tion, indicating a probable age of more than 700,000 years, but all subsequent sample runs were equivocal (Howard C. Hobbs, oral communication).

The Elmdale till is characterized by a high content of Cretaceous rock fragments, more than any other till studied (Table 2), relatively low Paleozoic content, high granitics (Figs. 6a, 6b), and little or no red sandstone or felsite from the Lake Superior basin. Pisoliths, iron concretions, quartz, and local rock fragments are common, indicating incorporation of underlying regolith. Texture ranges from clay to sandy loam, but in general is more sandy than that of other tills of northwestern provenance. Textural analyses for three undisturbed samples are shown in Figure 7. The sandy loam sample, from MGS hole 1640, contained about 9 percent iron concretions plus at least 40 percent locally derived rock fragments in the 1- to 2-mm size range, indicating possible incorporation of

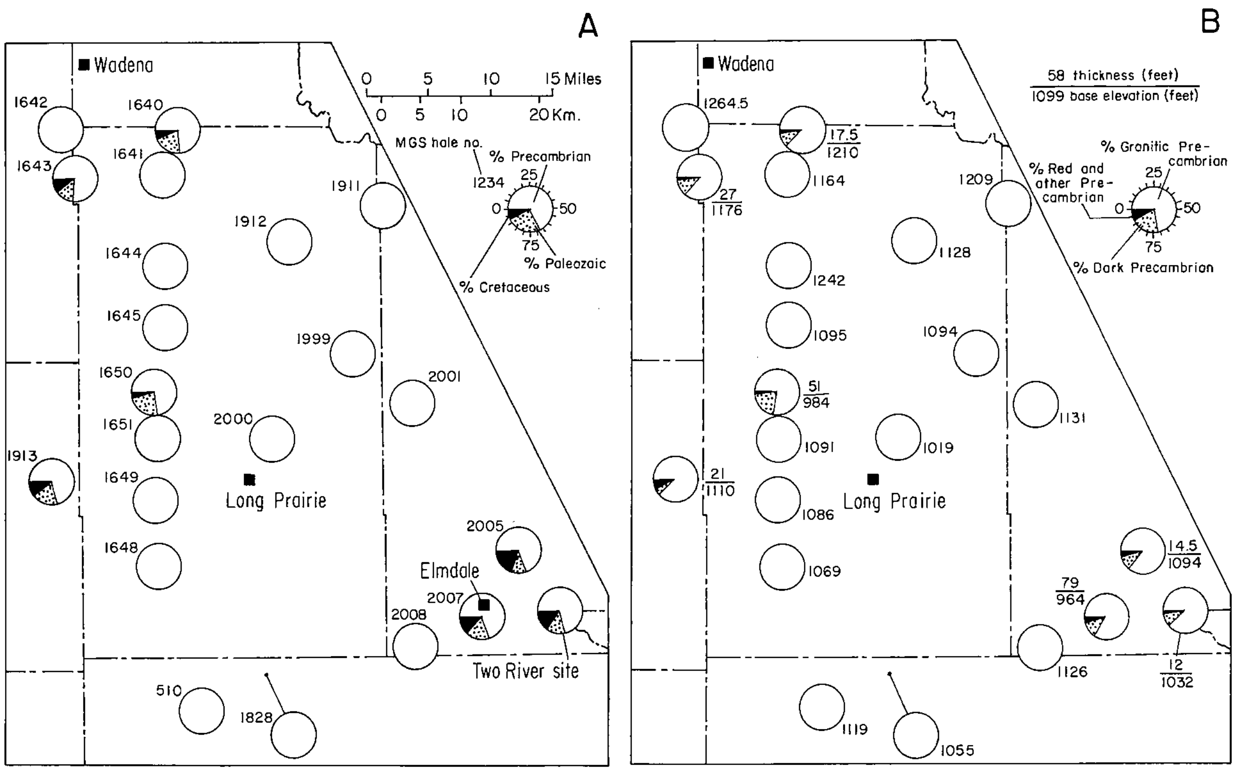

Figure 5. Elmdale till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Elmdale till. Basal 3 feet (1 m) of sand in MGS hole 1912 is probably related to the Elmdale advance.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Elmdale till were present. For numerical lithologic data see Appendix B.

Table 2. Cretaceous content of the 1- to 2-mm sand fraction of tills of northwestern provenance

Till	Percent of total sample: Total Cretaceous	Cretaceous shale	Percent of total Cretaceous sample: Limestone	Speckled shale	Gray shale	Pyrite	Other	Sites
Browerville	7.8	2.4	64.1	9.3	17.2	7.8	1.6	12
Green	0.8	0.3	71.1	5.7	17.0	6.2	0.0	5
Meyer Lake	2.7	0.5	65.7	2.2	19.7	9.2	3.2	13
Eagle Bend	4.2	0.4	82.6	3.0	8.4	5.6	0.4	13
Elmdale	11.4	2.4	74.6	6.6	11.9	4.8	2.1	7
Average	5.4	1.2	71.6	5.4	14.8	6.7	1.5	10

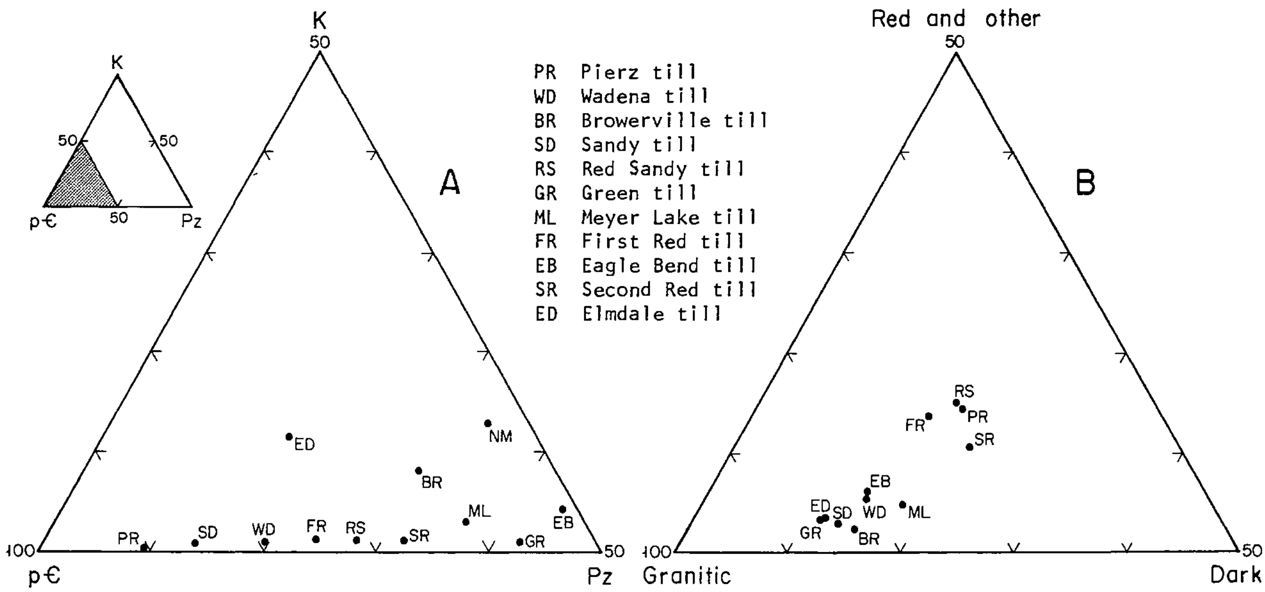

Figure 6. Average lithologies of the 1- to 2-mm sand fraction of tills in the Todd County area. A, by geologic age; the North Mankato (NM) till is plotted for comparison. B, average for Precambrian grains.

sandy, reworked regolith. The more clayey textures of samples from the three sites in Morrison County (Figs. 5a and 5b, Appendix A), especially MGS hole 2005, probably also are related to incorporation of clay-rich regolith and/or local Cretaceous sediments. The relatively high percentage of very coarse sand (Table 3) may result from incorporation of regolith, which commonly consists primarily of sand-clay mixtures. Where more samples are available, the percentage of very coarse sand may prove a useful parameter in till correlation.

As at the Two River site, the Elmdale till is oxidized (2.5Y6/4-4/4) to mottled to its base in MGS holes 1640, 1650, and 1913, and it is oxidized in the top 5 feet (1.5 m) in hole 1643. In holes 2005 and 2007 it is unoxidized and overlain by thin sands; no evidence of leaching was found, nor were any buried soils recognized. Anomalously high values from hole 1650 for Paleozoic and "dark" Precambrian content (Figs. 5a and 5b) can be attributed to poor samples, due in part to the depth of 370 feet (113 m). This section and that at Elmdale are by far the thickest preserved, and both are believed to be part of the fill of the same buried valley, which deepens to the southeast (Plate 1).

Fragments of red sandstone and felsite are absent in the available undisturbed samples, and are absent to rare in cuttings samples. Those grains that are present can be attributed to contamination from units stratigraphically above the Elmdale. The lack of Lake Superior detritus, the till's position, its abundance of regolith and Cretaceous rock fragments, and the apparent influence of underlying pre-glacial sediments on texture all suggest that the Elmdale was the first Pleistocene till laid down in the area.

Second Red Till

The oldest till of northeastern provenance, provisionally named the Second Red, was found only in MGS hole 2000 (Figs. 8a and 8b), about 3 miles (5 km) northeast of Long Prairie. Here the "First Red" till was encountered at a depth of 146 feet (45 m), a till of northwestern provenance (the Eagle Bend) at 175 feet (53 m), the Second Red at 268 feet (82 m), and regolith at 308 feet (94 m). The log of a water well drilled about 17 miles (27 km) to the northwest records 5 feet (1.5 m) of red sand and clay at a depth of 265 feet (81 m), underlain by 45 feet (13.5 m) of blue clay, underlain by white clay (regolith). The sequence there may represent Second Red over Elmdale, but because no younger red till was encountered and the hole was drilled at an elevation more than 100 feet higher than MGS hole 2000, the correlation is uncertain.

In the field, the Second Red was recognized by a color change, from the overlying dark gray (5Y4/1) to a dark grayish brown (10YR4/2-4/1), the top few feet exhibiting a definite reddish tinge, and by a textural change from the clay loam above to a sandy clay loam. The upper and

Table 3. Very coarse (1- to 2-mm) sand as percentage of total sand content

Till	Split-tube, outcrops Avg	Split-tube, outcrops Range	Split-tube, outcrops Sites	Cuttings Avg	Cuttings Range	Cuttings Sites
Pierz	8.6	8.3-9.0	2	-	-	-
Wadena	8.8	7.9-9.6	6	11.9	11.2-12.6	2
Browerville	9.1	8.1-10.4	7	-	-	-
Sandy	7.6	7.2-8.0	2	10.3	-	1
Green	8.1	-	1	9.4	8.1-10.6	2
Meyer Lake	7.8	5.9-9.3	3	8.6	6.9-10.9	3
First Red	-	-	-	5.7	-	1
Eagle Bend	9.8	8.1-11.5	2	11.2	10.6-11.7	2
Elmdale	11.5	9.9-13.2	3	-	-	-

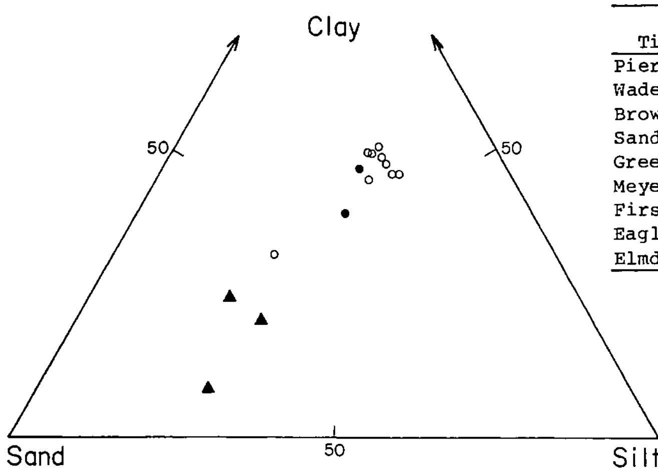

Figure 7. Grain-size distribution of the Elmdale (▲) and Eagle Bend (● o) tills. ▲ ●, split-tube samples; o, cuttings.

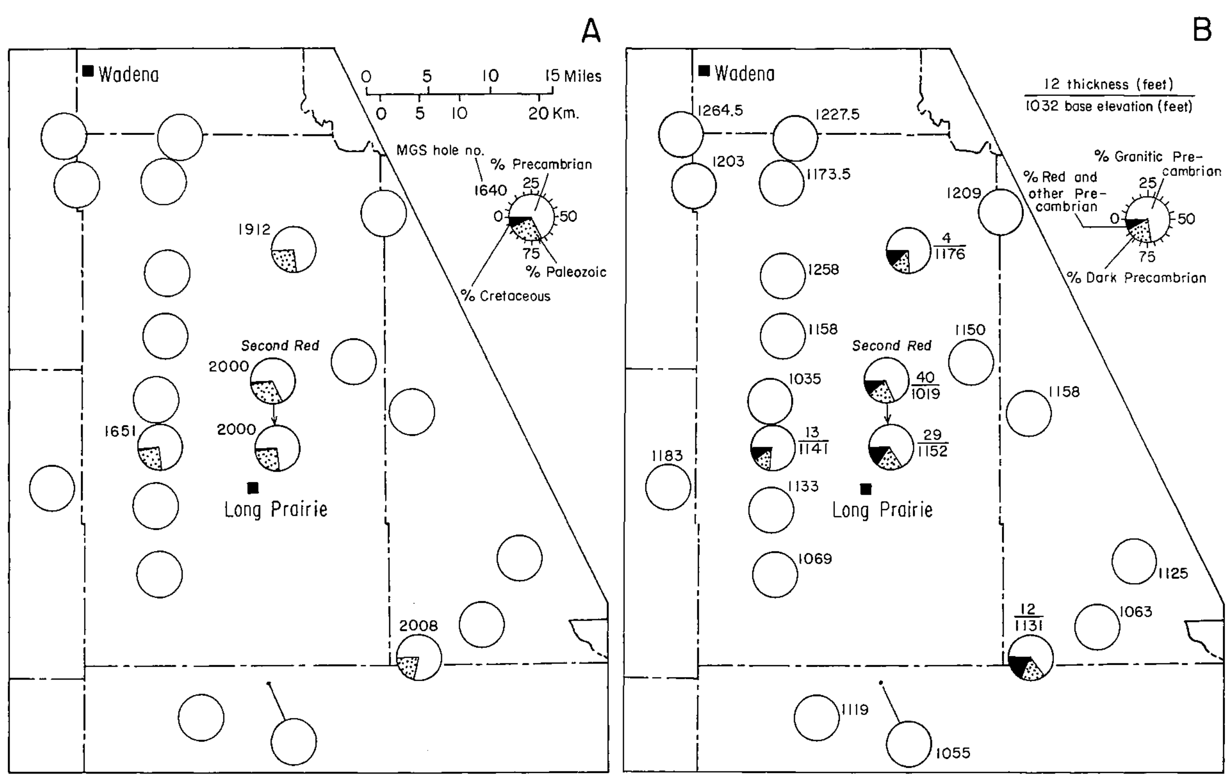

Figure 8. Second Red and First Red tills. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering either till. The Second Red was encountered only in MGS hole 2000.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if First Red till were present. For numerical lithologic data see Appendix B.

lower contacts are readily distinguished on Figure 9. It would appear from the wire line logs that the Second Red is somewhat more sandy than the First Red.

Unfortunately, three sand counts from the Second Red and five from the overlying Eagle Bend till were equivocal. The Second Red contained almost as much Paleozoic and Cretaceous sand as the Eagle Bend, which in this hole contained less Paleozoic and much less Cretaceous than typical. The Second Red had about the same amount of red and somewhat more dark Precambrian grains as the Eagle Bend. It contained more Paleozoics and dark Precambrian and fewer red Precambrian grains than the average for the First Red till (Figs. 6a and 6b). In the field, samples from MGS hole 2000 were thought to be adequate, but possibly the Second Red till samples were especially contaminated by overlying material. The Eagle Bend samples in turn may have been contaminated by material from the

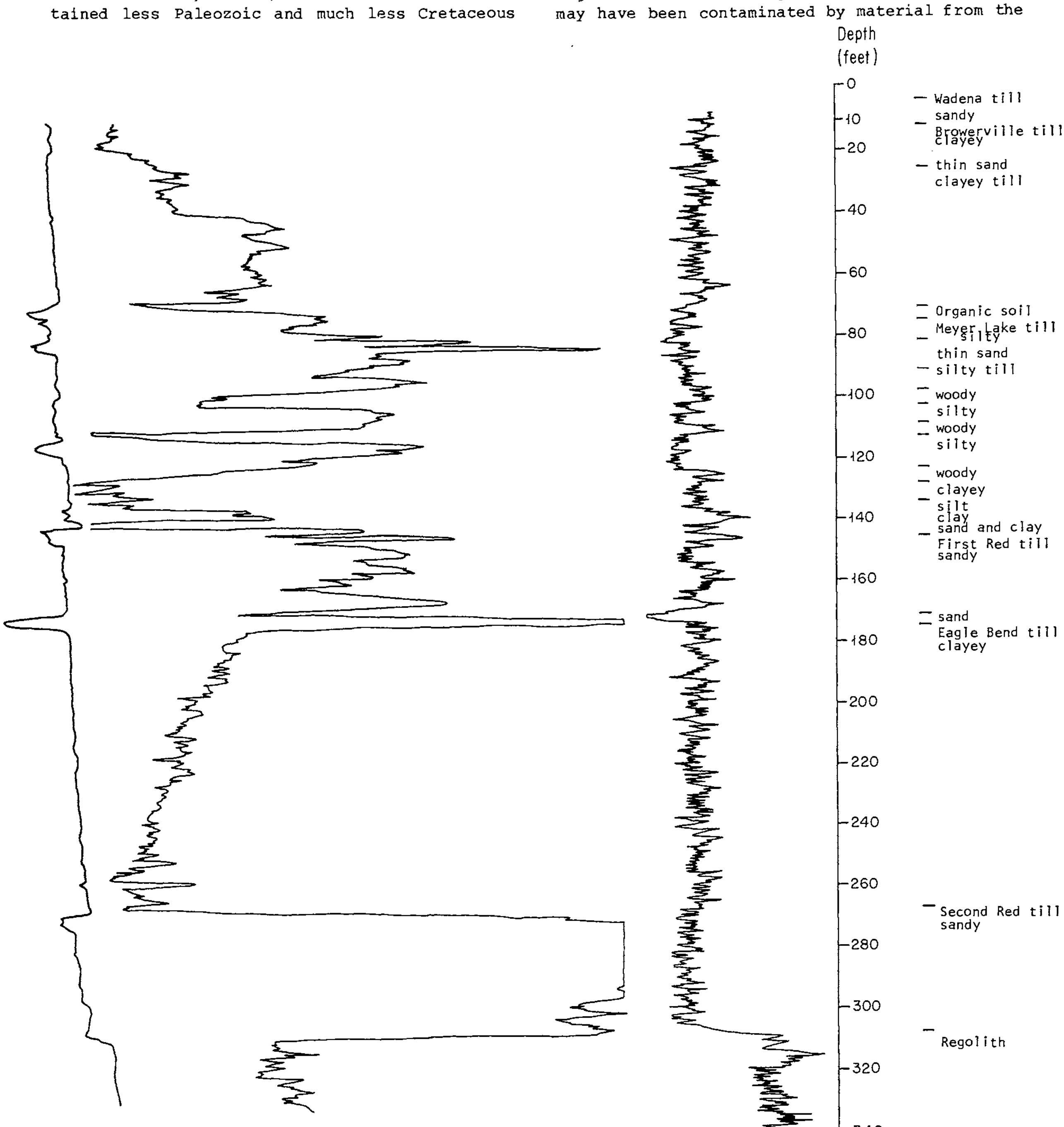

Figure 9. Spontaneous-potential, resistivity, gamma-ray, and on-site logs for MGS hole 2000, Todd County. Surface elevation 1327 ± 5 feet. See Appendix A for expanded log.

First Red till. More than likely, however, the ice which deposited the Eagle Bend till incorporated great amounts of Second Red till in the vicinity of MGS hole 2000, possibly because much Second Red till was preserved in the underlying bedrock valley (Plate 1).

Eagle Bend Till

The most clayey and carbonate-rich till in the area is informally named after the western Todd County town of Eagle Bend. The Eagle Bend till, because of its distinct characteristics and its widespread occurrence, is the most easily correlatable subsurface unit across the study area (Plate 1). MGS hole 1645 about 2 miles (3.2 km) southeast of Eagle Bend (Fig. 10a) penetrated 63 feet (19 m) of this till. It was oxidized (2.5Y5/4-5/6) to its base which directly overlies regolith. A split-tube sample from the top portion of the till yielded a clay texture. The only other split-tube sample of Eagle Bend till available, from MGS hole 1644, 5-1/2 miles (9 km) to the north, was found to be a clay loam. Six cuttings samples of the till from MGS hole 1912 and two from MGS hole 1913 all yielded a clay texture, whereas a sample (almost certainly poor) from MGS hole 1651 had a clay loam texture (Fig. 7).

The Eagle Bend till has the highest average 1- to 2-mm content of Paleozoic carbonates, about 44 percent (Fig. 6a). In addition, more of its total Cretaceous content is limestone and less is shale (Table 2). Three holes encountered Eagle Bend till with fewer Paleozoic and Cretaceous grains than typical (Fig. 10a). As discussed in the above section, the Eagle Bend till in MGS hole 2000 may have been contaminated by erosion and incorporation of the underlying Second Red till by the Eagle Bend ice. The atypical samples from MGS hole 1649 are probably simply poor samples. The Eagle Bend till in MGS hole 2008 was only 5 feet (1.5 m) thick over regolith, and may have been partially leached.

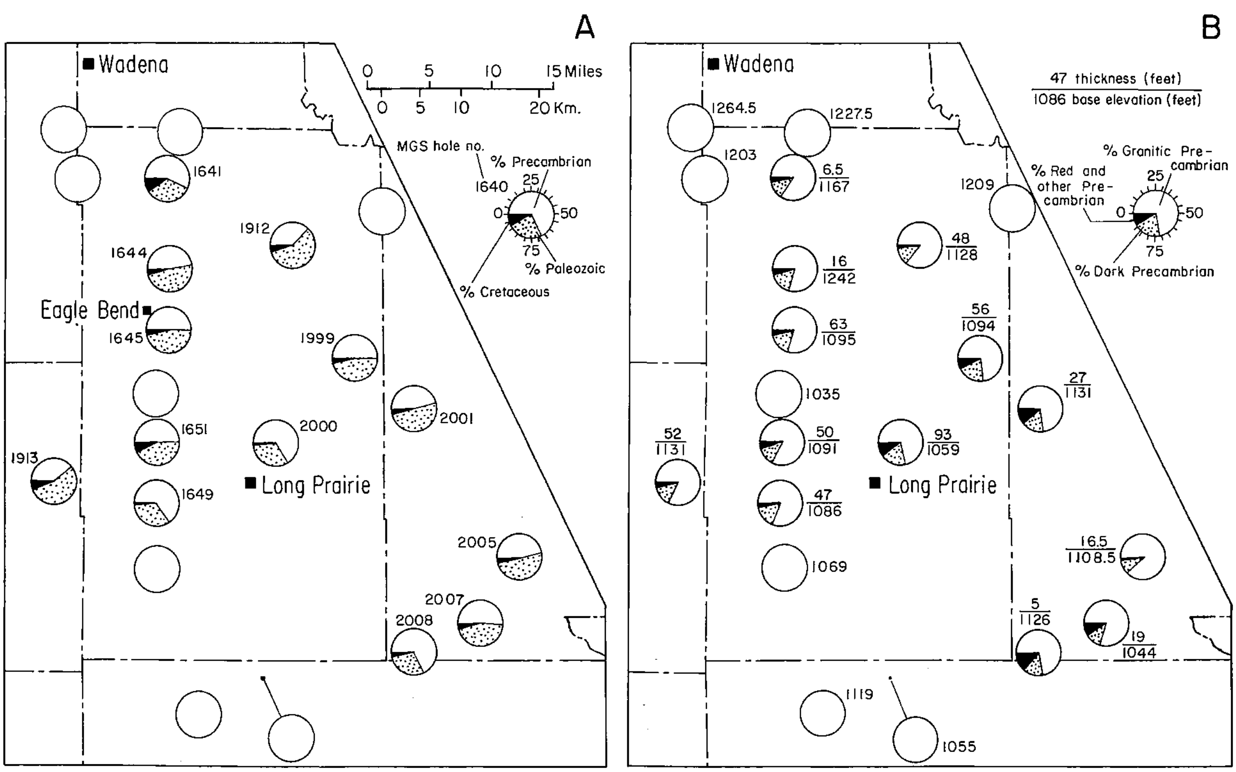

Figure 10. Eagle Bend till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Eagle Bend till.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Eagle Bend till were present. For numerical lithologic data see Appendix B.

The small but significant presence of northeastern grains in the Eagle Bend till throughout the study area, especially east of MGS hole 2000 (Fig. 10b), is evidence that Eagle Bend ice must have overridden an older northeastern-source till or an unknown outwash deposit. Besides the superposition over the Second Red till in MGS hole 2000, the Eagle Bend overlies Precambrian regolith in eight holes, and Elmdale sediments in four holes. The till is thickest in a northeast-southwest strip across central Todd County where its thickness in six holes (Fig. 10b) ranges from 47 to 63 feet (14.5 to 19 m).

In the 13 holes in which the Eagle Bend was penetrated, 2 sections were topped with an organic layer, 3 had a recognizable solum, and 9 were oxidized; 3 or 4 of these were oxidized to the base of the till, most dramatically in MGS hole 1645. Only two or three till sections showed evidence of possible partial leaching. The deep oxidation of the Eagle Bend till indicates a relatively long exposure prior to the deposition of the First Red till. Possibly the period of exposure was relatively dry, inhibiting leaching.

First Red Till

The first "reddish" colored till encountered in MGS hole 2000 (Fig. 9) has been correlated with till in three other holes (Figs. 8a, 8b) and is provisionally named the First Red till. In MGS hole 2000, 29 feet (8.8 m) of the First Red is overlain by 4 feet (1.2 m) of light-brown (7.5YR6/4) lacustrine clay and sand. The till here is a loam to sandy clay loam, and is brownish gray to dark brownish gray (7.5YR4/1-4/2, possibly ranging to 5YR) in color. The only textural analysis completed was on a cuttings sample from MGS hole 1912, which yielded a loam texture. Till in this hole and in MGS hole 2008 had a brown to dark-brown (7.5YR4/2) color, which in 2008 changed to gray in its lower portion. Color in the First Red till of MGS hole 1651 was reddish brown (5YR5/4), with gray mottling toward the bottom. Texture in MGS holes 2008 and 1651 ranged from loam to sandy loam.

Felsite and red sandstone each compose about 5 percent of the total Precambrian in the very coarse sand fraction, and much of the fine quartz sand is stained red, indicating a Lake Superior basin provenance. The till includes Paleozoic carbonates (averaging 24 percent; Fig. 6a), presumably derived through incorporation of carbonate-rich Eagle Bend till.

First Red sediments were encountered at an elevation of about 1,185 feet in MGS hole 2000. A well drilled in Long Prairie, about 3 miles (5 km) to the southwest, encountered 28 feet (8.5 m) of "red clay and sand" at an elevation of 1,193 feet. The log of a well about 4 miles (6.5 km) northeast of MGS hole 2000 records 1 foot (0.3 m) of pink sand overlying 24 feet (7.3 m) of "blue clay with red streaks" at an elevation of 1,218 feet.

In MGS hole 2008 at an elevation of 1,143 feet, 12 feet (3.7 m) of First Red sediments overlie 5 feet (1.5 m) of oxidized Eagle Bend till. A water well drilled about a mile (1.6 km) northwest penetrated, at an elevation of 1,153 feet, 7 feet (2.1 m) of red clay (First Red), overlying 20 feet (6.1 m) of yellow clay (Eagle Bend), overlying white clay (regolith). About 10 miles (16 km) northeast of MGS hole 2008, 5 feet (1.5 m) of red clay was encountered in a water well at an elevation of 1,136 feet.

The occurrences of "red" sediments, however, are rare in the total water-well record (Plate 1). The remnants of the First Red till in the Todd County area may represent the farthest extent of any Superior lobe.

Meyer Lake Till

The type section of the Meyer Lake till also is MGS hole 2000 (Figs. 9, 11a and 11b), 1 mile (1.6 km) north of the small lake for which it is informally named. In MGS hole 2000 it consists of 60 feet (18.5 m) of gray to greenish-gray (5Y5/1-5GY6/1) loamy till, with dark-grayish-brown (10YR4/2) woody zones. The lower 6 feet (1.8 m) is a hard, dark-gray clay loam. It is separated from the First Red till by 7 feet (2.1 m) of light-greenish-gray (5GY7/1) lacustrine silt and clay and 4 feet (1.2 m) of light-brown lacustrine sand and clay. The Meyer Lake here is topped by 3 feet (0.9 m) of black organic clay loam. To the west, MGS hole 1651 also encountered a thick section of Meyer Lake till, consisting of 64 feet (19.5 m) of gray to dark-gray loam to clay loam. A sample from a marl bed on top of the till yielded a U-series date of more than 350,000 years B.P.

The Meyer Lake till has a relatively high Paleozoic carbonate content, exceeded only by the Eagle Bend and Green tills (Fig. 6a), and Cretaceous rock fragments are common. It contains more dark Precambrian grains than the other northwestern tills in the very coarse sand size (Fig. 6b). Texturally the Meyer Lake is a loam to clay loam (Fig. 12), coarser than the Eagle Bend and Browerville tills.

Color also is a distinguishing characteristic of the Meyer Lake. All but four sections of the till contained intervals of greenish-gray to olive-gray color, and all 13 sections were either reduced or unoxidized at the top. "Dirty" pyrite, as opposed to the relatively "clean" detrital Cretaceous pyrite, together with incorporated organic debris, is common in the Meyer Lake till, and is thought to have formed in the till, because the organic debris would have consumed oxygen. Brownish colors in MGS holes 2000 and 1643 (Appendix A) are caused by woody zones. Leverett (1932, p. 17) noted that a similar till, the lowest that he observed in the Minnesota River Valley, in places had a greenish-gray cast "like a swamp subsoil, but without associated peat beds," and in other places a dark-brown color.

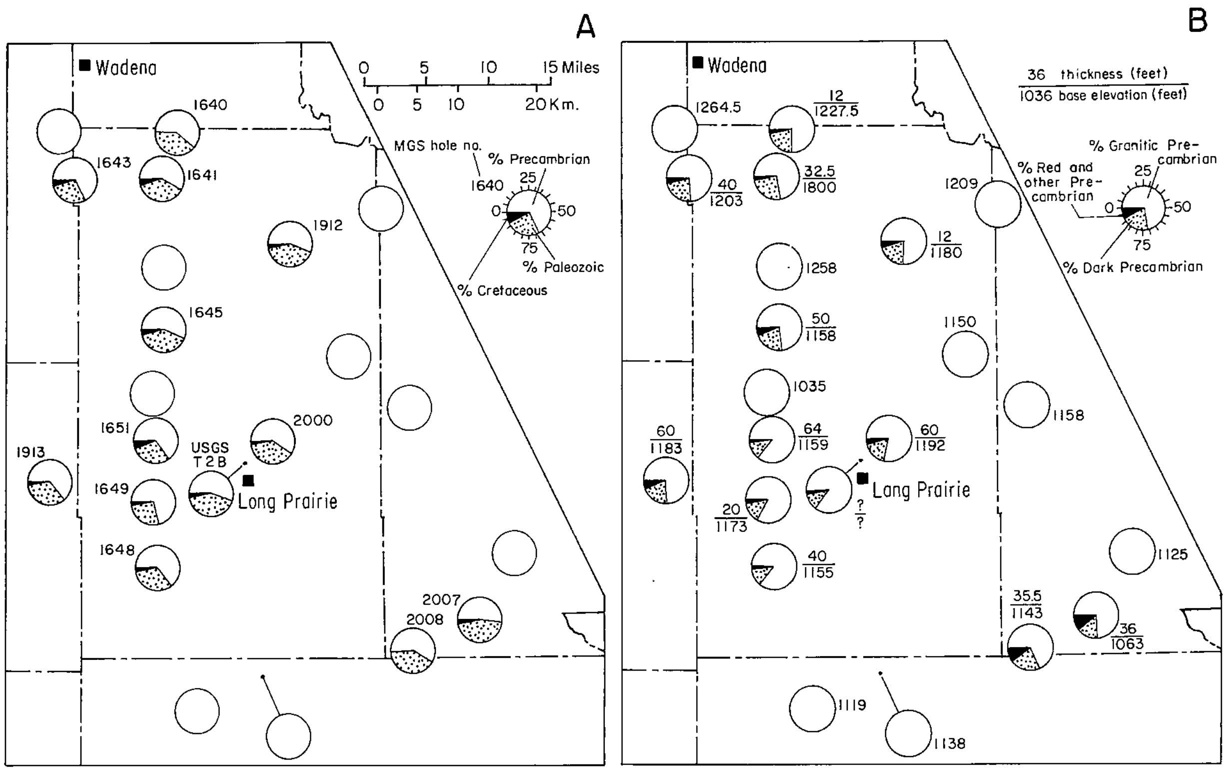

Figure 11. Meyer Lake till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Meyer Lake till.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Meyer Lake till were present. For numerical lithologic data see Appendix B.

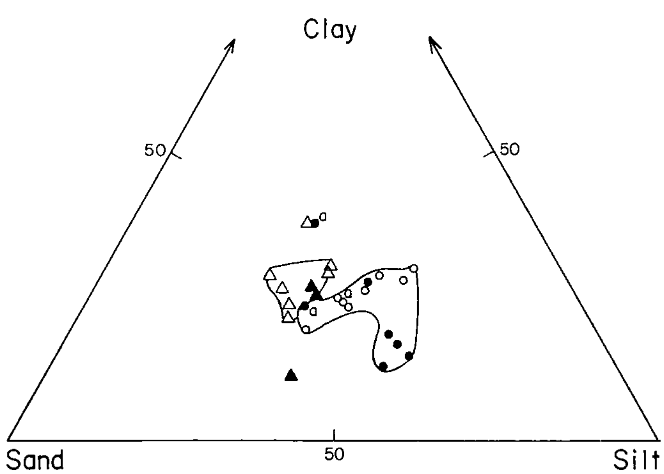

Figure 12. Grain-size distribution of the Meyer Lake (▲ △) and Green (● o) tills. ▲ ●, split-tube samples; △ o, cuttings. [a]till partly leached.

Brownish to reddish colors in the Meyer Lake till in MGS holes 1645, 1913, 2007 and 2008 (Appendix A) can be attributed to incorporation of the underlying First Red till, as can in part the low percentage of very coarse sand (Table 3). The low percentage of 1- to 2-mm sand may also be due to incorporated organic-rich, fine, sandy silt as noted in some till sections. The high percentage of dark Precambrian grains cannot be attributed to incorporation of First Red till, as it averages less than the Meyer Lake (Fig. 6b).

The interval between deposition of the First Red and the Meyer Lake tills may have been fairly short, as indicated by the apparently continuous lacustrine section in MGS hole 2000, between First Red and Meyer Lake sediments. The organic debris in the Meyer Lake may have been derived from a boreal forest beyond the First Red ice, because there is no evidence of an organic layer on top of the First Red till. The First Red till was strongly oxidized only in MGS hole 1651, and there possibly as a result of oxygenated ground water flowing through the overlying sand subsequent to burial. The hiatus between deposition of the Meyer Lake and the overlying Green till may also have been relatively short.

The loamy alluvium below the Green till in MGS hole 1649 possibly is the sediment of a stream cut into the underlying Meyer Lake till, which here is only 20 feet (6.1 m) thick. The stratigraphic succession is more complex in MGS hole 1913 (Appendix A). There the Green till overlies two sequences of recessional outwash over till, both attributed to the Meyer Lake advance. The bottom of the Meyer Lake section is a 14-foot (4.3-m) thick, gray to dark-gray clay loam with 44 percent Paleozoics and 6 percent Cretaceous, a "typical" northwestern-provenance till. Its associated recessional outwash is 18 feet (5.5 m) thick, and is in turn overlain by 28 feet (8.5 m) of till of uncertain origin. This second till was included in the Meyer Lake because it contains a relatively high percentage of dark Precambrian grains. Cretaceous grains are practically absent, however, and Paleozoics decrease upward. The lower 7 feet (2.1 m) of this till is oxidized, with a textural break at the color contact from loam to clay loam (Appendix B). A sample from the lower part of the loam and one from the clay loam both contained evidence of incorporation of a till of northeastern provenance, possibly the First Red. These samples and incorporated First Red or organic debris toward the middle or top of the Meyer Lake till in MGS holes 1643, 1645, 2000, 2007, and 2008 may simply be characteristic of depositional processes of the Meyer Lake ice advance. However, further drilling in the area may show that the upper sequence was deposited by an early phase of the Green advance which incorporated Meyer Lake till.

Green Till

The informally named Green till was first recognized in MGS hole 1649, where 70 feet (21 m) of hard loamy till was encountered beneath unoxidized Wadena till. The Green till is pale olive (5Y6/4) in color on top, changing to olive (5Y5/3-5/6), and finally to dark greenish gray (5GY4/1) in the last 15 feet (4.6 m) below an intervening gravel bed (Appendix A). The Green till has since been drilled to its base in only two other holes in the Todd County area, MGS holes 1913 and 1828 (Figs. 13a and 13b). The latter hole, which penetrated 96 feet (29 m) of Green till, was drilled as part of a hazardous-waste siting program of the Minnesota Waste Management Board, and was accompanied by three shallow holes from which split-tube samples were derived. Two of these holes, MGS 1827, located 0.6 mile (1 km) southwest of 1828, and MGS 1830, located 0.7 mile (1.1 km) to the northeast, drilled 57 and 4 feet (17.5 and 1.2 m), respectively, into the Green till. A test hole about 20 miles (32 km) due south of these holes, MGS 2020 (Fig. 2a), penetrated a silty, greenish-colored till, which contains abundant carbonate pebbles, that may correlate with the Green till.

The Green till tends to be more silty than other tills in the area (Fig. 12); it has fewer dark Precambrian fragments, more Paleozoic carbonate content, and very few Cretaceous fragments (Figs. 6a and 6b). Compared to other tills of northwestern provenance, the Green contained a high percentage of lithic fragments versus quartz in the 1- to 2-mm size fraction of the Precambrian "granitic" subgroup.

The Green till was apparently exposed for a relatively long time after deposition. A split-tube sample from the top of the Green in MGS hole 1827 had been almost entirely leached and contained much more clay and less silt than typical (Fig. 12), and apparently represents a buried illuviated horizon. The till in this hole had been oxidized to at least a 40-foot (12-m) depth. The first sample from MGS hole 1828 and the only sample from MGS hole 1830 are believed to be partially leached. The first 38 feet (11.5 m) of Green till in MGS hole 1828 had been oxidized. The olive-colored oxidized till in these three holes and in MGS 1649 are believed to have derived their "greenish" colors from a change in environment, from oxidizing to reducing, upon burial of the Green till and the subsequent rise in the water table. In contrast to the Meyer Lake till, organic content is relatively rare and does not appear to have been a major factor in removing oxygen. However, the somewhat more permeable silty matrix of the Green till may have allowed more rapid reduction, than the less permeable clayey matrix of the Eagle Bend till, which exhibits typical oxidation colors.

The Green till was found only in the southwestern part of the area (Figs. 13a and 13b), and thus possibly came from that direction. The 200 feet (60 m) of lacustrine sediment filling the buried valley in MGS hole 1650 (Plate 1, Appendix A) may have been laid down in a lake dammed by the Green ice advance to the south. The valley may have been cut by meltwater from retreating Meyer Lake ice, as Meyer Lake and most older tills have been removed. The silty texture of the Green till can be attributed to its having incorporated sediment from a proglacial lake. The absence of a till of northeastern provenance separating the Meyer Lake and Green tills (Table 1), however, may indicate that both tills were laid down as part of the same general event.

The buried bedrock valley encountered in MGS hole 1650 was also penetrated in holes 2000 and 2007, each disclosing differing fill sequences. These three sections indicate a complex glacial history with numerous glacial meltwater episodes moving across and through bedrock valleys and older buried glacial valleys.

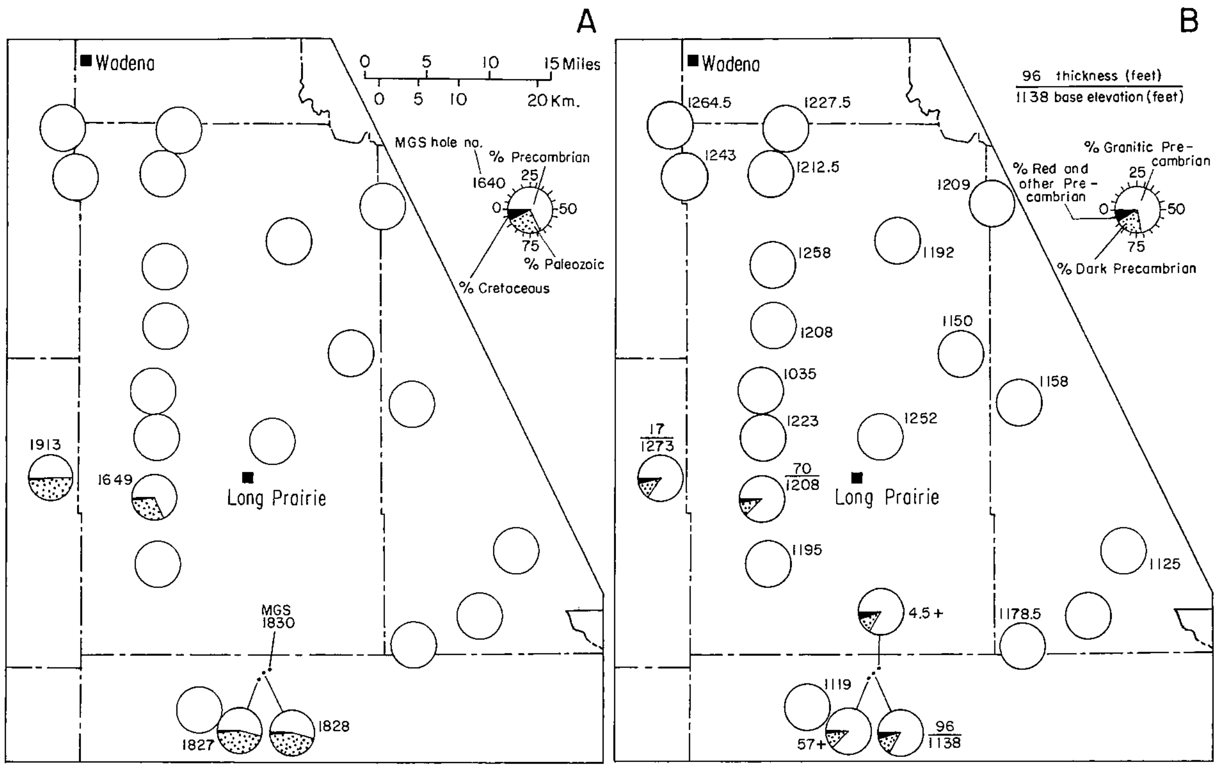

Figure 13. Green till. A, distribution and lithology of 1- to 2-mm sand (carbonate leached from only sample in hole 1830). Blank circles are holes drilled to bedrock without encountering Green till.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Green till were present. For numerical lithologic data see Appendix B.

Sandy Till

A sandy loam till similar in texture to the Wadena till (Fig. 14) was found in the subsurface in west-central Todd and northwestern Stearns Counties (Figs. 15a and 15b). This informally named Sandy till underlies Browerville till in MGS hole 1650, and overlies Green till in holes 1827 and 1828 (Plate 1). It is separated from Wadena till in MGS holes 510, 1827, 1828 and 1829 by proglacial Wadena outwash, instead of Browerville till. The Sandy is distinguished in this area from the Wadena by its higher sand and lower Paleozoic content (Fig. 14). Farther north, the two tills would probably be difficult to distinguish without the intervening Browerville till.

The Sandy and Wadena tills apparently had similar source areas, with the Sandy less "contaminated" by underlying northwestern-source

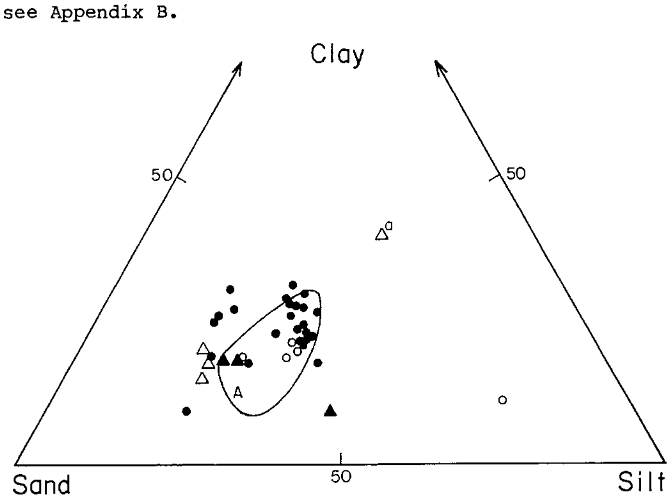

Figure 14. Grain-size distribution of the Sandy (▲ △) and Wadena (● o) tills. ▲ ●, split-tube samples; △ o cuttings. A, average from Kandiyohi County (Giencke and others, 1983/84). Circled area is range in values for the Swanville area (Hobbs, unpublished data). [a]till contaminated with marl.

tills in the southern part of the study area. However, MGS hole 2020, about 20 miles (32 km) south of the area (Fig. 2a), encountered 46 feet (14 m) of sandy but carbonate-rich till between the Wadena and probable Green tills, thus indicating contamination of the Sandy till by carbonate farther south of the study area. The only occurrence of thick Sandy till in the Todd County area is in MGS hole 1651, but the lower portion consists largely of a reworked marl deposit. Lacustrine sediments underlying the Sandy in this hole and in MGS holes 1650 and 510 may be related to the ice that deposited the Green till. In between lacustrine sediments and the Sandy till in MGS hole 1650 are 13 feet (4 m) of outwash sand and gravel with a Superior lobe component, and thus the outwash may be related to the possibly contemporaneous Red Sandy till.

The hiatus between deposition of the Sandy and Browerville tills is unknown. In the one hole where they are superposed (MGS 1650) the Sandy is olive gray to nearly greenish gray. The Sandy till encountered in holes in Stearns County had the same color, except in MGS 510, where it was clearly oxidized and Browerville till may have been stripped off prior to weathering. It would be attractive to suggest the repetition of an initial northeastern advance, followed soon after by a northwestern advance, as postulated for the First Red-Meyer Lake sequence, but this idea can not be substantiated with available data.

Red Sandy Till

A reddish-brown (2.5YR4/4) sandy loam to sandy clay loam till was penetrated in MGS hole 2008 (Figs. 15a and 15b). It is overlain by proglacial Wadena outwash, similar to that above the Sandy till to the west, and its lower portion is contaminated with plant debris, clay, and Paleozoic carbonate grains from the underly-

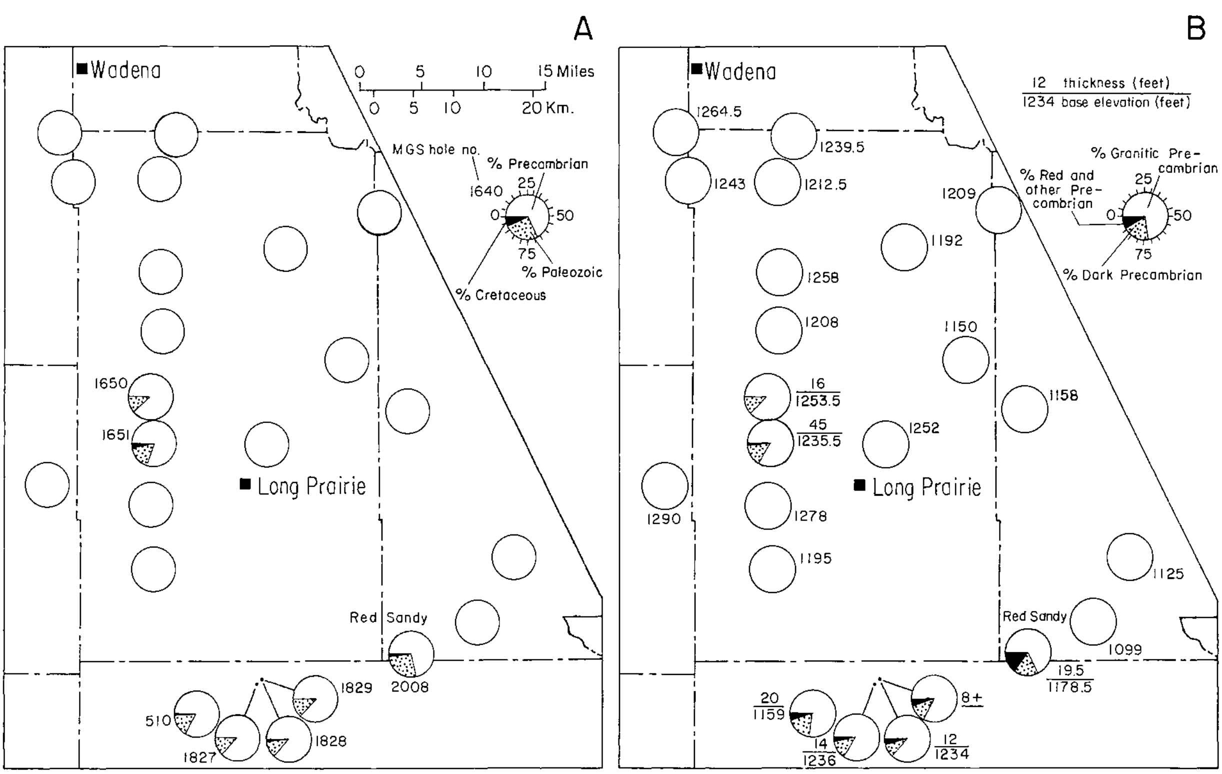

Figure 15. Sandy and Red Sandy tills. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering either till. The Red Sandy till was encountered only in MGS hole 2008.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if either till were present. For numerical lithologic data see Appendix B.

ing organic sediment and Meyer Lake till. Felsite composes about 7 percent and red sandstone about 6 percent of the total Precambrian 1- to 2-mm sand grains of a sample from the upper portion of the till.

The informally named Red Sandy till may be equivalent to the "red sandy Superior till" in Schneider's (1961, p. 44) Irish Creek section, about 15 miles (24 km) north of MGS hole 2008. Schneider's impression was that the overlying Wadena till was deposited only a short time after the red till, and was itself soon buried by the brown, sandy "Pierz-lobe" till. The Red Sandy in hole 2008 is not overlain by Browerville, and Browerville till in the adjacent MGS hole 2007 lies directly over Meyer Lake till, with the only northeastern-source till in the entire section being the surficial Pierz till. Although it cannot now be established, it is conceivable that the Sandy and Red Sandy tills represent pre-Browerville equivalents of the Wisconsinan Rainy and Superior lobe advances into central Minnesota.

Browerville Till

A dense, dark-gray (5Y4/1) clay loam is the dominant till in the subsurface below the Wadena drumlin field in Todd County (Plate 1, Figs. 2b, 16a and 16b). About 10 feet (3 m) of this till is exposed in a gravel pit 1.5 miles (2.4 km) southeast of the town of Browerville, for which it is informally named. Another exposure is in a gravel pit 1 mile (1.6 km) southeast of Long Prairie. The Browerville contains the most gray shale and speckled shale of the tills studied, is second to the Elmdale till in total Cretaceous content (Fig. 6a), and it contains the least Cretaceous limestone (Table 2). The Browerville is high in "granitics" versus "dark" and "red" Precambrian fragments (Fig. 6b), and the granitics in the 1- to 2-mm size fraction are in turn high in quartz versus lithic grains.

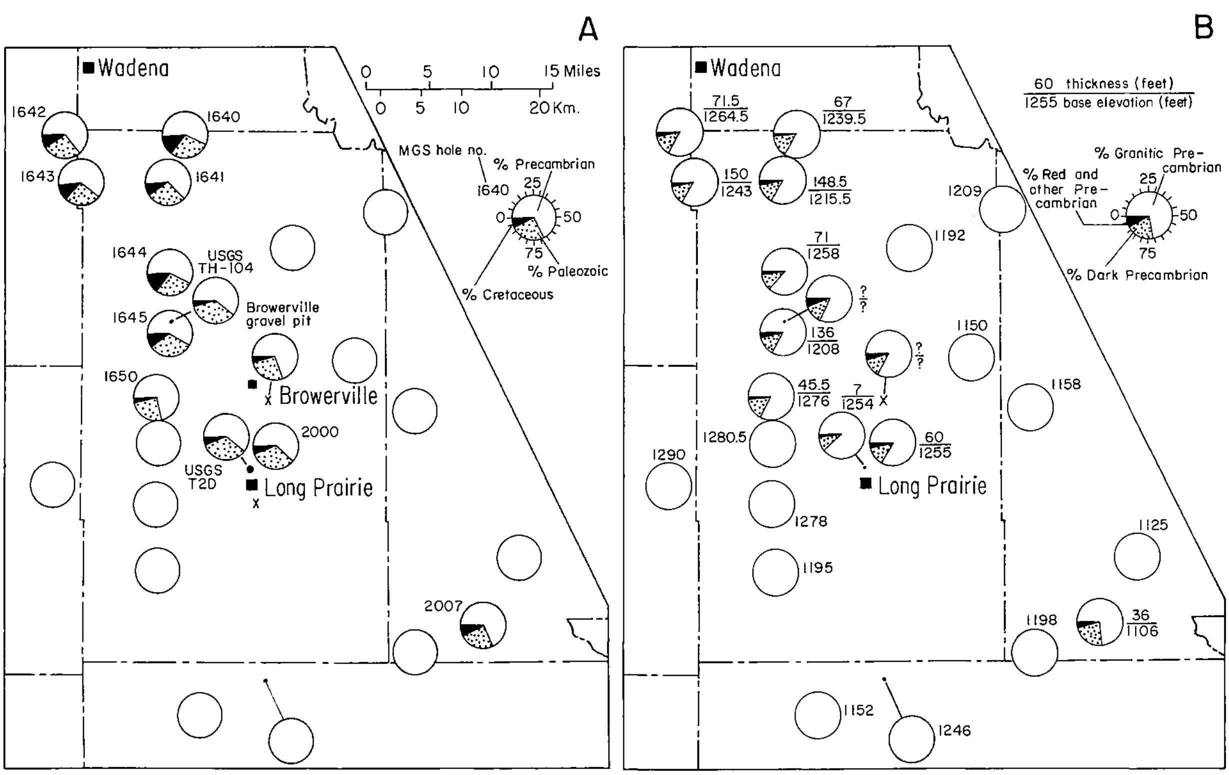

Figure 16. Browerville till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Browerville till. X, exposures of Browerville till.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Browerville till were present. For numerical lithologic data see Appendix B.

The Browerville till is, on average, the thickest, and includes the thickest single section in the Todd County area (Table 1). Only the three sections thicker than 136 feet (41 m) are oxidized at the top, implying some, and perhaps substantial, removal of Browerville till by the subsequent Wadena ice advance.

A split-tube sample taken 5 feet (1.5 m) below the top of the Browerville in MGS hole 1643 was an oxidized, light-olive-brown to olive-brown (2.5Y5/4-4/4) clay till. The till graded to an olive-gray (5Y5/2) color, but was at least partially oxidized for 25 feet (7.6 m). Other Browerville samples from this and other holes (Fig. 17) had less clay, implying that some of the clay near the top of the till was illuviated. The sample contained about half the typical carbonate content, as did cuttings from 10 to 15 feet (3 to 4.6 m) into the till, indicating partial leaching to that depth. These factors, as well as the presence of iron concretions, indicate an extensive period of soil formation. The Browerville in MGS hole 1643 is at its highest known elevation; its presence on a topographic high would have aided the soil-forming process.

Sand and gravel layers are present within the thick Browerville till. A 14-foot (4.3-m) layer in MGS hole 1641 is correlated, with the aid of water-well logs, to a 13.5-foot (4.1-m) layer in MGS hole 1644 (Plate 1). The sand possibly divides two phases of the Browerville. Thick sands are also present in MGS holes 1643 and 1645, but cannot be correlated with confidence. Grain count differences are noticeable within the thicker sections of Browerville till, commonly on opposite sides of sand bodies, but the same differences are not recognized from

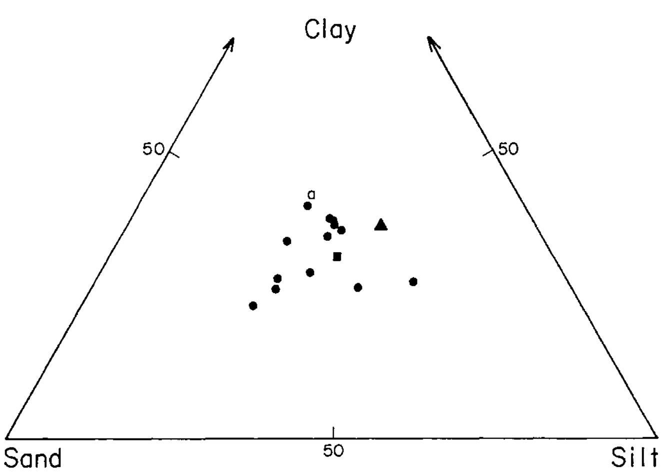

Figure 17. Grain-size distribution of Browerville till. •, split-tube samples; ▲, average for Kandiyohi till (Giencke and others, 1983/84); ■, average for North Mankato till; [a]till partly leached.

hole to hole. Therefore, although the thick sections of Browerville till may represent more than one phase of deposition, the hiatus between phases and the possible differences in source areas between phases was not great.

The southeasternmost hole in which Browerville till was found is MGS 2007 (Fig. 16a). The till here is coarser grained (Fig. 4 and Appendix A), a loam to sandy clay loam with cobbly zones, and is lighter gray (5Y5/1) in color than is typical. The upper portion of the till also contains more dark Precambrian grains than typical (Fig. 16b), probably due to a combination of contamination of drilling mud from the Pierz till above and incorporation into the Browerville of local, shallow bedrock. The Browerville till is probably preserved in this location in a pre-advance topographic low, which in turn may have reflected the underlying bedrock valley (Plate 1).

A till similar to the Browerville is exposed below "Granite Falls" till in a large cut at North Mankato in the Minnesota River Valley, 110 miles (175 km) southeast of MGS hole 2007. It is quite dense, has the same color (5Y4/1), and texturally averages only a slightly higher silt content (Fig. 17), although it contains somewhat more Cretaceous (including 6 percent shale) and Paleozoic grains in the very coarse sand fraction (Fig. 6a).

The Kandiyohi till of Giencke and others (1983/84) is a dense clay loam, more silty and less sandy than the Browerville (Fig. 17). It contains appreciable amounts of rounded Cretaceous shale fragments, as opposed to the platy Pierre Shale in the Des Moines lobe till of the area. Shale percentage in general is much higher in the Kandiyohi till than in the Browerville till (James R. Crum, oral communication). This difference may be explained by Matsch's (1972) model of shale distribution in the Des Moines lobe. In this model, the margins of the ice lobe are progressively diluted with locally derived shale-poor debris, whereas the sediment load in the axial part of the lobe, where little erosion occurs, remains strongly influenced by the source area. The shale-poor Browerville till may be a remnant of a marginal moraine that may trend northwestward beneath the drumlin field in Wadena County and into the Itasca moraine in Becker County (Fig. 2b; Hobbs and Goebel, 1982). The shale-rich Kandiyohi till may core the entire Alexandria moraine, trending northwest through Otter Tail County, and correspond to a recessional moraine of the same general ice advance that laid down both the Browerville till and the lithologically "in between" till exposed at North Mankato.

A relatively long period between deposition of the Browerville and the overlying Wadena till is indicated by the weathering profiles and the 33.5-foot (10-m) sequence of oxidized lacustrine and fluvial deposits, which separate the Browerville in MGS hole 1650 from unoxidized Wadena till.

Wadena Till

Wright (1962, 1972) first recognized and described the Wadena till. He postulated deposition by glacial ice advancing from the northwest, but east of the source of the Des Moines lobe, because the Wadena till is high in carbonate from the Winnipeg lowland, but low in Cretaceous shale (Fig. 3). The Wadena drumlin field, however, is evidence of ice advance from the northeast (Fig. 2b). Wright suggested that the Wadena lobe was diverted southwestward by a contemporaneous advance of the Rainy lobe. Incorporation of debris from the Rainy lobe thus accounted for "anomalous" leaching depths and pebble counts in the northeastern part of the drumlin field. Thus "contaminated" Wadena till was thought to be present in the north in Wadena and Cass Counties, whereas "pure" Wadena till was found mostly to the south in Todd County.

Anderson (1976), whose study area included part of the Wadena drumlin field, disagreed, stating that the drumlins were composed of northeastern-source sediment. Goldstein (1986) and this author confirm the simpler explanation of Anderson, that the Wadena till was laid down by an advance of the Rainy lobe, with the primary source area of glacial sediment lying north of the Mesabi iron range (Fig. 3). The evidence for a source area north of the range lies in the orientation of the drumlin field, together with the paucity of Animikie basin slate and Lake Superior basin felsite in the till.

The presence of carbonate in the Wadena till (Fig. 18a) can be explained as incorporation of older, carbonate-rich tills. Wadena till sampled from holes in the eastern portion of the area is generally higher in carbonates because the subcropping tills--the Meyer Lake and Eagle Bend--are richer in carbonate. Wadena till, especially in eastern Todd and Morrison Counties, also contains Superior lobe index rocks (Fig. 18b), probably derived from the underlying

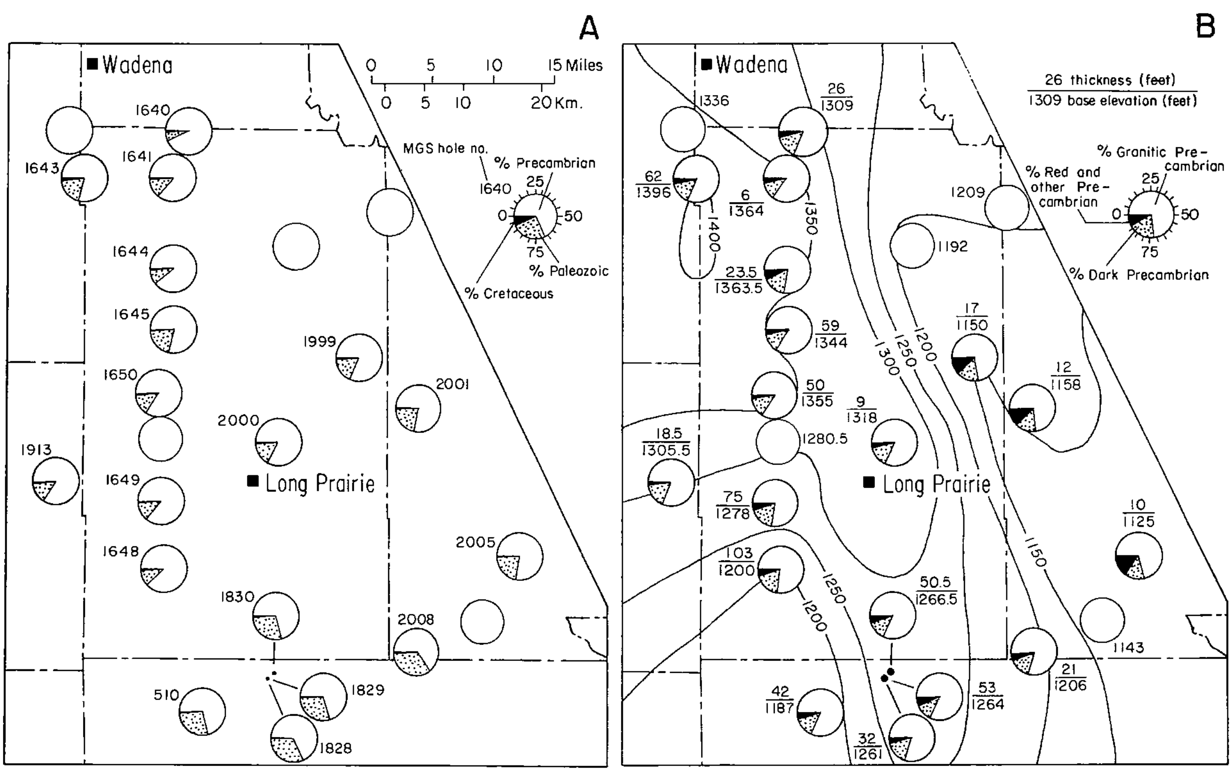

Figure 18. Wadena till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Wadena till.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Wadena till were present. Contour interval, 50 feet. For numerical lithologic data see Appendix B.

First Red and/or Red Sandy tills. In summary, the sediment load of Wadena ice became progressively contaminated with underlying sediments with distance from its source area, rather than undergoing an intermediary contamination through confluence with a contemporary ice advance.

Lithology not only varies across the till body, but also vertically within individual till sections. For example, the top half of the Wadena till section in MGS hole 1640 appears to be a typical Rainy lobe till, with very little carbonate and a sandy loam texture. The bottom half, however, is more a sandy clay loam, with about 10 percent carbonate. Samples from the bottom half of the Wadena till in MGS hole 1643 contain over 20 percent Paleozoic carbonate and 2 to 3 percent Cretaceous grains, indicating local incorporation of Browerville till. Carbonate-rich Wadena till in this hole overlies leached and oxidized Browerville till, indicating that erosion of the Browerville occurred upice. The ridge through which MGS hole 1643 (Plate 1) is drilled probably was formed by the piling up of eroded material by Wadena ice on top of a Browerville high. Progressive contamination with depth also is evident in MGS holes 1645, 1999, and 2001.

Texture of the Wadena till also varies across the study area, ranging from sandy loam to sandy clay loam in the north to loam to clay loam in the south (Fig. 14). MGS holes 1648 and 1649 in southern Todd County contain thick sections of Wadena till, which are lithologically relatively consistent, both internally and in relation to Wadena till farther north. Contamination from local underlying sediment is obvious only in the lower 5 feet (1.5 m) or so. In contrast, test holes in Stearns and Morrison Counties, MGS holes 1828, 1829, 1830, and 2008, exhibit extensive evidence of contamination from the underlying silty and carbonate-rich Green and Meyer Lake tills. The underlying topography probably affected deposition. In the area of MGS holes 1648 and 1649, Wadena till filled in a topographic low, whereas to the southeast, Wadena till was piled on pre-existing topographic highs (Fig. 18b, Plate 1), and more local erosion and incorporation occurred.

Variations in underlying topography also may have influenced the formation of the Wadena drumlin field. The most well-developed portion of the drumlin field in Todd County overlies a topographic high of Browerville till (Figs. 2b, 16b, and 18b). The great difference between the relatively permeable and incoherent Wadena till, and the underlying impermeable and dense Browerville till, may also have played a part in drumlin formation.

In 10 of the 18 holes, the Wadena till is underlain by proglacial outwash. The silty texture of the Wadena sample from MGS hole 1913 (Fig. 14) may indicate incorporation of proglacial lake sediments. Wadena till in MGS hole 1650, however, overlies what seem to be interglacial lacustrine and alluvial deposits. The majority of the Wadena till section in MGS holes 2005 and 2008 consists of reworked organic-rich clay.

The unmixed upper portion of Wadena till in MGS hole 2005 contains relatively large proportions of red Precambrian grains, whereas the comparable zone in MGS hole 2008 does not (Fig. 18b and Appendix A). Two Superior lobe tills, the Red Sandy and First Red, are present in the drift section below the Wadena in MGS hole 2008, but are absent in 2005. Apparently Wadena ice removed and incorporated older Superior lobe tills in the vicinity of MGS hole 2005.

It is important to establish that the 10-foot (3-m) section of till in MGS hole 2005 is indeed Wadena till, because a radiocarbon date of 36,970 $\pm$ 950 B.P. was obtained from a wood sample (sample CD-8525) found in bedded sediment above the till. This date tends to confirm Wright's (1972) designation of an early Wisconsinan age for the Wadena till. The wood sample was taken 8 feet (2.4 m) above the top of the Wadena till, at or near the contact between fine sand and overlying lacustrine silt and clay. The wood was either from a thin clayey soil, which contained tiny shell fragments, or from the sand immediately beneath. Subsequent cuttings samples from the hole were full of wood fragments, making it uncertain whether wood was present throughout the sand, or only near the contact. The overlying 18 feet (5.5 m) of calcareous lacustrine sediment apparently did not contain organic debris, and may be significantly younger than the sand. The relationship of the lake sediment to the late Wisconsinan advance of the Rainy lobe, which deposited 8 feet (2.4 m) of overlying Pierz till, is uncertain.

Pierz Till

The brown, sandy till in and behind the St. Croix moraine in this study is herein referred to as the Pierz till, after Schneider (1961). The Pierz till contained the largest percentage of Precambrian grains in the 1- to 2-mm size fraction (Fig. 6a) and was coarser in texture than any other till in the area. Paleozoic carbonate is anomalously high in MGS holes 1828, 1829, 1830, and 2008 (Fig. 19a), due to extensive incorporation of Wadena and older tills in this westernmost protuberance of the St. Croix moraine. Precambrian lithologic groupings varied widely from hole to hole, reflecting both Rainy and Superior lobe source areas (Fig. 19b). At present the Pierz till is interpreted to have been laid down by a sublobe of the Rainy lobe, having incorporated older Superior lobe (Red Sandy?) till as it advanced over eastern Minnesota. Texture generally ranged from sandy loam to gravelly sandy loam, but in the southwest sandy clay loam and loam-textured samples were found (Fig. 20).

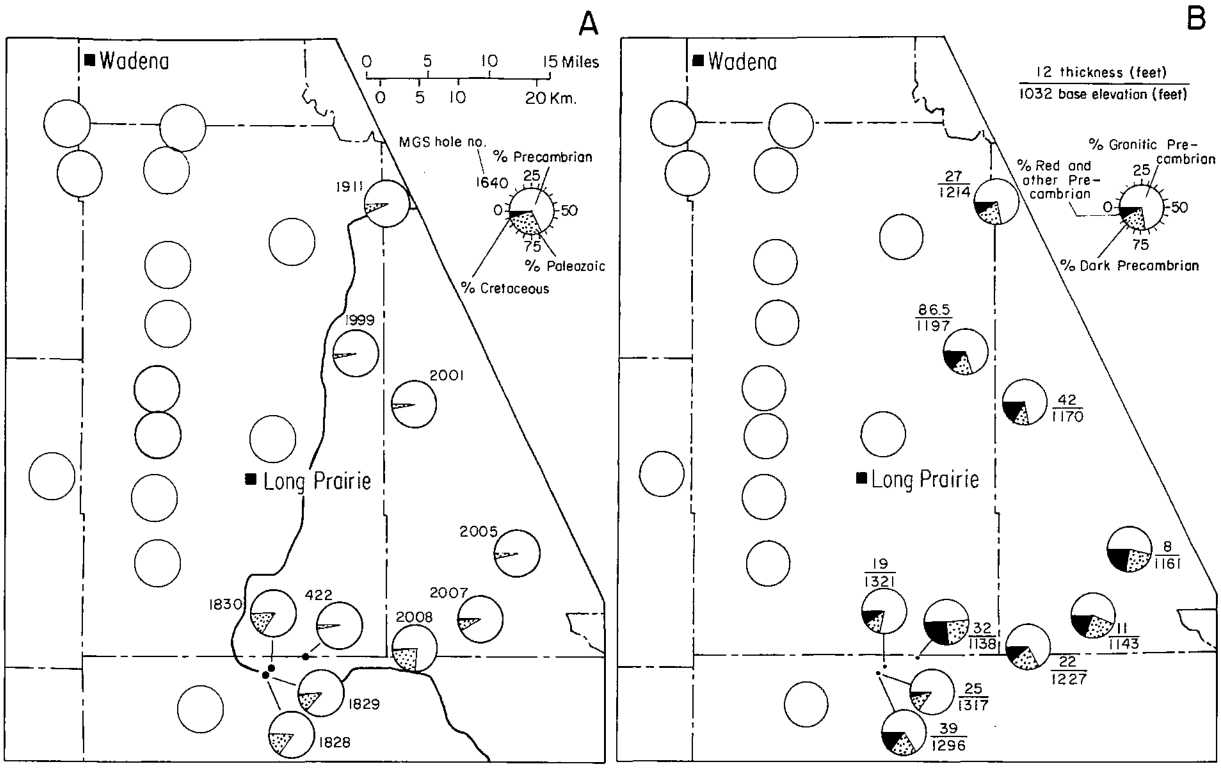

Figure 19. Pierz till. A, distribution and lithology of 1- to 2-mm sand; blank circles are holes drilled to bedrock without encountering Pierz till. Line marks the western boundary of Pierz till, according to Hobbs and Goebel (1982). Des Moines lobe drift overlaps the Pierz in the southern part of the area.
B, lithology of Precambrian 1- to 2-mm sand grains; thickness; and elevation at the base. Numbers adjacent to blank circles are lowest possible elevations if Pierz till were present. For numerical lithologic data see Appendix B.

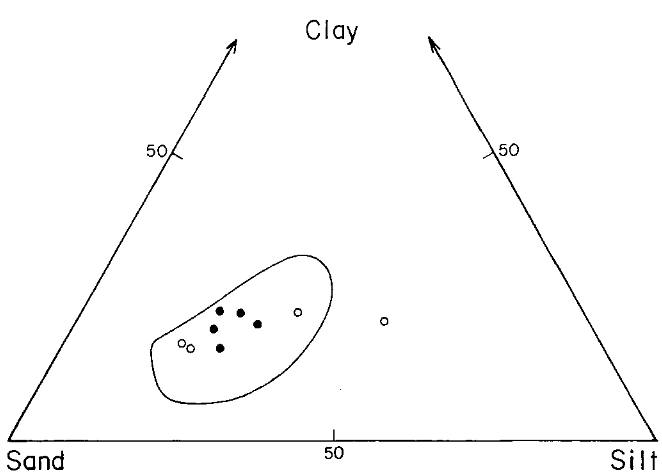

Figure 20. Grain-size distribution of the Pierz till. •, split-tube samples; o, cuttings. Circled area is range in values for the Swanville area (Hobbs, unpublished data).

THE CRETACEOUS RECORD IN TILLS OF NORTHWESTERN PROVENANCE

Limestone is by far the major component of the 1- to 2-mm Cretaceous suite found in northwestern provenance tills of the Todd County area (Table 2). Paradoxically, limestone makes up only a very small portion of the Cretaceous section at the eastern edge of the Williston basin, occurring only in the Greenhorn Limestone. The Greenhorn is as much as 95 feet (29 m) thick near Grand Forks in eastern North Dakota (Fig. 3), but consists primarily of marlstone and calcareous shale, and is overlain by well over 300 feet (90 m) of Carlile and Niobrara shale. Underlying shales are also substantially thicker than the Greenhorn (Hansen and Kume, 1970). In southeastern North Dakota, the Greenhorn consists primarily of fossiliferous, calcareous shale, 30 to 40 feet (9 to 12 m) thick (Moore, 1979). The Greenhorn is only about 2 to 3 miles

(3.2 to 4.8 km) wide in subcrop in Manitoba (McRitchie, 1980), and is likewise narrow in its subcrop in northeastern North Dakota to about as far south as Grand Forks, where it then widens rapidly to 10 miles (16 km) or more (Bluemle, 1983). Cretaceous sediments, apparently pre-Greenhorn, are present only in patches in northwestern Minnesota (Morey and others, 1982).

It is obvious that large amounts of sediment from Manitoba, eastern North Dakota, and northwestern Minnesota have been eroded and transported to central Minnesota by a number of distinct glacial ice advances. Apparently Greenhorn Limestone once lay over much of this area, along with older and younger associated shales. The lack of appreciable amounts of Pierre Shale in older tills of central Minnesota indicates that the Pembina escarpment in eastern North Dakota, formed by the Pierre (Fig. 3), was west of the path of ice which deposited these tills. The marine Coleraine Formation in the Mesabi iron range in northeastern Minnesota apparently was protected by the range from erosion by glaciers advancing from the north. The Cretaceous record is very poorly known between the range and the far western tier of counties in Minnesota.

Early workers (Upham, 1888, p. 459) saw the bulk of the clayey drift in western Minnesota as being derived from Cretaceous shale. Matsch (1972), noting the absence of shale grains, thought that the fine-grained textures of older tills exposed in the Minnesota River Valley might have resulted from erosion of regolith developed on the Precambrian. Although regolith undoubtedly contributed significantly to till composition, the relative abundance of Cretaceous limestone in older tills, such as the Elmdale, Eagle Bend, and Browerville, points to the likely contribution of Cretaceous shale to the till matrix. Older shales, unlike the Pierre, are not siliceous and have a greater tendency to slake. A weathered upper portion especially would tend to be broken up and disseminated within glacial ice. Another characteristic pointing to significant contribution of Cretaceous shale is the typically dark-gray color of both the unoxidized till matrix and Cretaceous shale. Regolith, however, tends to range from a light grayish white to grayish green (Moore, 1979).

Moore (1979, p. 38) thought that the Ordovician escarpment of the Williston basin "formed either a strandline against which sedimentation largely ceased during periods of inundation or formed a base for the erosion which removed post-Red River [post-Ordovician] sediments during periods of emergence." Thus, the Cretaceous section in northern Minnesota may have been much smaller and thinner prior to glaciation than the section in eastern North Dakota and southern Minnesota, and it has since largely been removed by glacial ice.

The flow path of the late Wisconsinan Des Moines lobe must have been different from the flow paths of earlier glaciers from the northwest, because its till is rich in Pierre Shale. The early flowlines presumably were east of the Pembina escarpment (Fig. 3), and down the Red River Valley rather than across it. Possibly, with reference to Table 2, the Elmdale and Eagle Bend advances stripped away much of the Cretaceous section in southeastern Manitoba and north-central Minnesota, leaving only isolated patches for the subsequent Meyer Lake and Green ice advances. The Browerville ice advance may have been confined to the Red River lowland, moving southward in a more lobate form than previous northwestern-provenance advances. This might explain the massive lateral moraines postulated earlier in this report. Confinement of the ice advance to the Red River lowland, where more Cretaceous section could have been preserved just east of the Pembina escarpment, would also explain the relatively high percentage of shale (Table 2), especially speckled shale (Niobrara?), within the Browerville.

AGE AND CORRELATION OF PRE-LATE WISCONSINAN TILLS

Pre-Illinoian tills recognized in Iowa (Hallberg, 1980), Illinois (Willman and Frye, 1970), and Wisconsin (Mickelson and others, 1984) cannot currently be correlated with tills recognized in this study, although the Elmdale, Second Red, and Eagle Bend tills probably are pre-Illinoian in age (Fig. 21).

The U-series date of greater than 350,000 years B.P. from marl on top the Meyer Lake till indicates that it and the First Red till are no younger than early Illinoian.

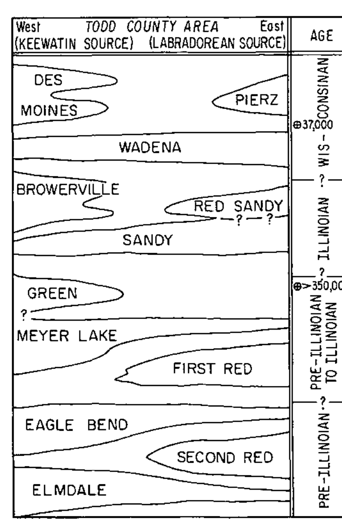

Figure 21. Time-distance diagram showing relative timing and extent of glacial events in the Todd County area.

The Gervais Formation of northwestern Minnesota contains wood radiocarbon dated at >46,900 years B.P. (Ashworth, 1980). It may correlate with the Meyer Lake or the Green till (Table 4) or may simply be a basal member of the Marcoux Formation, corresponding to the organic-rich basal portion of the Wadena till encountered in MGS holes 2005 and 2008 (Appendix A).

The Browerville till is thought to be Illinoian in age, because of its well-developed soil profile and its position beneath the Wadena till. The underlying Sandy till is also probably Illinoian in age.

The Hawk Creek till (Matsch, 1972) may correlate with the First Red till. Baker (1984) correlates the Hawk Creek till and the Hampton moraine of eastern Minnesota (Ruhe and Gould, 1954) with his River Falls Formation in western Wisconsin, which he believes to be Illinoian in age. If the Red Sandy till of this study correlates with the Hawk Creek, it may be Illinoian in age, and the Superior lobe equivalent to the

Table 4. Regional lithostratigraphic correlation chart
[Texture (percentage of sand-silt-clay) and
lithology (percentage of crystalline-carbonate-shale grains of total 1- to 2-mm fraction).
Modified from Perkins (1977)]

Red Lake Falls, NW Minnesota (Harris and others, 1974)	Grand Forks-Bemidji, NW Minnesota (Sackreiter, 1975)	Moorhead-Park Rapids, W-central Minnesota (Perkins, 1977)	Comstock-Sebeka, W-central Minnesota (Anderson, 1976)	Todd County study area	Kandiyohi County, S-Central Minnesota (Giencke and others, 1983/84)	South-western Minnesota (Matsch, 1971)	North Mankato site, southern Minnesota
Upper Red Lake Falls Formation 35-41-24 (loam) 53-34-13	28-45-27 (clay loam) 60-27-13	Dunvilla Formation 36-39-25 (loam) 41-24-35	40-35-25 (loam) 40-25-35		Des Moines lobe till 40-36-24 (loam)	New Ulm till 43-31-26 (loam) 40-25-35	
Lower Red Lake Falls Formation 44-36-20 (loam) 53-45-2	45-39-16 (loam) 82-17-1	New York Mills Formation 50-31-17 (loam) 71-27-2	49-30-21 (loam) 64-32-4			Granite Falls till 41-37-22 (loam) 54-44-2	
St. Hilaire Formation 35-42-23 (loam) 40-32-28	27-42-32 (clay loam) 43-27-29						
Marcoux Formation 53-34-13 (sandy loam) 78-18-4	47-31-22 (loam) 85-13-1	Sebeka Formation 61-26-13 (sandy loam) 80-20-0	66-21-13 (sandy loam) 93-7-0	Wadena till 54-24-22 (sandy clay loam) 80-20-0	Wadena till 59-28-13 (sandy loam)	Hawk Creek till 55-23-22 (sandy clay loam) >80-20-0	
	Unit 2 37-32-29 (clay loam) 69-28-3	Unit A		Browerville till 36-32-32 (clay loam) 63-35-2	Kandiyohi till 24-39-27 (clay loam)		North Mankato till 34-34-32 (clay loam) 54-40-6
Gervais Formation 18-48-34 (silty clay loam)	Unit 1 17-46-36 (silty clay loam) 61-39-<1			Green or Meyer Lake			

Rainy lobe Sandy till. Alternatively, the Red Sandy may be the equivalent to the early Wisconsinan Wadena till, having advanced into eastern Todd County shortly before being buried by the Wadena advance (Schneider, 1961). If so, the Hawk Creek may be early Wisconsinan in age.

Many workers in Canada believe the early Wisconsinan, placed between 64,000 and 75,000 B.P., to have been the period of maximum ice advance in the Wisconsinan stage. Western and southern Canada are thought to have been ice free in the middle Wisconsinan, except for a period of ice advance in the Great Lakes region (Fulton, 1984). The Wadena till in Minnesota may correlate with the Hawk Creek till, which extends as far west as South Dakota (Matsch, 1972), and the Marcoux Formation of eastern North Dakota and northwestern Minnesota. Therefore it apparently represents the greatest westward extent of Labradorean ice in the Wisconsinan. This implies, and radiocarbon dates do not preclude, that the Wadena advance was early Wisconsinan. Possible Keewatin equivalents are the St. Hilaire Formation of the Red River Valley (Harris and others, 1974) and the Snow School Formation of western North Dakota (Clayton and Moran, 1982).

The Wadena till probably is an equivalent of one of the early Wisconsinan tills recognized in northern Illinois (Winnebago Formation) and southeastern Wisconsin (Walworth Formation). The Capron Till probably is younger (middle Wisconsinan?) than the Wadena, as it overlies the Plano Silt, which has been radiocarbon dated from 32,600 to 41,000 B.P. The Plano Silt overlies the Argyle Till in Illinois, which in turn overlies older, unnamed Wisconsinan tills (Johnson, 1976). The Argyle equivalent in Wisconsin (Allens Grove) is underlain by the Foxhollow Member of the Walworth Formation, and is overlain by the pre-Capron Clinton Member. Where at the surface, the Clinton is "characterized by a distinctly drumlinoid topography" (Schneider, 1983). If the Wadena till correlates with the River Falls Formation of western Wisconsin (Mickelson, 1984), it also may correlate with the Lincoln Formation of north-central Wisconsin.

On the basis of similar lithology, Matsch (1972) correlated the Granite Falls till of the Minnesota River Valley with the Wadena till. However, wood collected from sediment below the Granite Falls yielded radiocarbon dates of 34,000 and greater than 39,000 B.P., and correlation of the Granite Falls with the lower Red Lake Falls and New York Mills Formations appears more likely. It is uncertain how far south of the Alexandria moraine the Wadena-Sebeka-Marcoux ice advanced. Its till is in places similar to the Granite Falls, and they may be difficult to differentiate if both are present in the Minnesota River Valley. Granite Falls (New York Mills) till may be present at the surface in the southern portion of the Todd County area, mapped as stagnation moraine of the Wadena lobe and ground moraine of the Des Moines lobe (Fig. 2b).

The "extra-morainic" till of Matsch (1972) in southwestern Minnesota and the "Tazewell" drift of Ruhe (1969) in northwestern Iowa, which has been dated at about 20,000 B.P., may be equivalent to the Granite Falls till. The Granite Falls would then correlate with the formation of the St. Croix and Itasca moraines (Wright, 1972), as inferred by Sackreiter (1975). Winter and others (1973) noted a textural and color boundary within their "bouldery" till, which may represent two advances of the Rainy lobe, the lower corresponding to the early Wisconsinan Wadena till and the upper to the late-Wisconsinan Granite Falls.

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APPENDIX A

LOGS OF SELECTED DRILL HOLES AND DESCRIPTIONS OF EXPOSURES

[Till name abbreviations are DM, Des Moines; PR, Pierre; WD, Wadena; BR, Browerville; SD, Sandy; RS, Red Sandy; GR, Green; ML, Meyer Lake; FR, First Red; EB, Eagle Bend; SR, Second Red; and ED, Elmdale. Detailed logs of all drill holes mentioned in this report are available in the files of the Minnesota Geological Survey.]

MGS 1643, NE1/4NW1/4NW1/4NW1/4 sec. 30,
T. 133 N., R. 35 W.,
Todd County, MN
Surface elevation = 1458 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Brownish-yellow sandy clay loam; more clayey w/depth; sand seam at 8'	WD	10YR6/8
30	Brownish-yellow clay loam	WD	10YR6/8
36	Gray clay loam	WD	10YR5/1
38	Gray sandy clay loam	WD	10YR5/1
62	Sand and gravel	WD	10YR5/1
65	Lt.-olive-brown clay loam; grading to olive gray	BR	2.5Y5/4
75	Olive-gray clay loam	BR	5Y5/2
82	Sand and gravel	-	5Y5/2
84	Olive-gray grading to gray clay loam	BR	5Y5/2-5/1
90	Gray clay loam	BR	5Y4/1
94	Loamy coarse sand and gravel	-	-
123	Dark-gray clay loam (different geologist)	BR	5Y4/1-3/1
160	Gray sandy clay loam, very hard	BR	5Y4/1
195	Gray sandy loam (or mixed w/sand from seams)	BR	5Y4/1
205	Gray sandy clay loam	BR	5Y4/1
215	Lighter gray sandy clay loam	ML	5Y5/1
231.5	Sand and gravel	-	5Y6/1
238.5	Gray and brown sandy clay loam; wood chips	ML	N5/0 and 10YR3/1
240	Greenish-gray sandy loam; wood chips	ML	5G5/1+ 5GY5/1
248	Olive sandy loam	ML	5Y4/3
255	Lt.-olive-brown sandy loam	ED	2.5Y5/4
260	Dark-gray sandy loam; hard (mottled?)	ED	N4/0
270	Sand and gravel, hard (till?)	ED	2.5Y6/2
280.5	Dark-gray sandy clay loam	ED	N3/0
282	Sand	-	10YR6/3
294.5	Regolith		
410	Bottom of hole		

MGS 1645, NE1/4SE1/4SE1/4SE1/4 sec. 19,
T. 131 N., R. 34 W.
Todd County, MN
Surface elevation = 1403 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Yellow-brown clay to silt loam	WD	2.5Y5/6
6.5	Yellow-brown sandy loam	WD	2.5Y6/4
27.5	Gray-brown sandy loam	WD	2.5Y5/2
30	Gray sandy clay loam	WD	N5/0
43	Olive-brown sandy clay loam	WD	2.5Y5/4
50	Olive-yellow fine sand	-	2.5Y6/6
51.5	Olive-brown sandy clay loam	WD	2.5Y5/4
59	Clay loam, gray to dark olive brown; hard	BR	5Y4/3
66	Brown sand and gravel	-	-
68	Olive-gray to gray clay loam; hard	BR	5Y4/2
80	Dark-gray clay loam; sand seam at 81'	BR	5Y3/1-4/1
100	Gray silty clay loam	BR	N5/0
140	Gray silty clay loam	BR	5Y3/1-4/1
175	Gravel	-	5Y5/2
183	Gray silty clay loam	BR	5Y5/1
190	Light-gray silty clay loam	BR	N6/0
195	Bluish-gray silty clay loam	ML	5B6/1
200	Olive-gray silty clay loam; very hard	ML	5Y4/2-5/2 and 10YR5/2
240	Olive-gray clay loam; very hard	ML	5Y4/1
245	Light-olive-brown silty loam	EB	2.5Y5/4
285	Olive-yellow silty loam	EB	2.5Y6/6
295	Light-olive-brown silty loam	EB	2.5Y5/6
300	Light-olive-brown sandy loam	EB	2.5Y5/6
305	Olive-brown sandy loam	EB	2.5Y4/4
308	Regolith		
503	Bottom of hole		

MGS 1649, NE1/4SE1/4NE1/4SE1/4 sec. 25,
T. 129 N., R. 35 W., Todd County, MN
Surface elevation = 1358 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Fill		
5	Light-brown sandy loam	WD	2.5Y6/6
17	Gray sandy loam	WD	5Y4/1
57	Gravel	-	-
59	Gray sandy loam	WD	5Y4/1
75	Gray clay loam to loam; hard	WD	5Y4/1
80	Pale-olive loam, very hard	GR	5Y6/4
85	Olive loam, very hard	GR	5Y5/4
110	Olive clay loam	GR	5Y5/3
115	Olive loam, with gravel layer	GR	5Y5/3
125	Loam, much greener in color	GR	5Y5/6
130	Sand and gravel	-	-
135	Dark-gray sandy loam	GR	5GY4/1
150	Dark-gray loam (not till)	-	5GY4/1
165	Dark-gray loam	ML	5GY4/1
170	Dark-gray clay loam	ML	5GY4/1
185	Greenish-gray clay	-	5G5/1
200	Olive gravelly sandy loam (not till)	-	5Y4/3
205	Dark-gray loam (not till)	-	5G4/1
210	Dark-gray clay loam (not till)	-	5G4/1
215	Dark-gray loam (not till)	-	5G4/1
225	Dark-gray loam	EB	5G4/1
240	Dark-gray sandy loam	EB	5G4/1
250	Very dark gray sandy loam; very slow drill-ing (poor samples)	EB	5Y3/1
265	Olive sandy loam	EB	5Y4/4
272	Regolith		
483	Rock		
522.5	Bottom of hole		

MGS 1650, NE1/4NE1/4NE1/4SE1/4 sec. 13,
T. 130 N., R. 35 W., Todd County, MN
Surface elevation = 1405 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Olive-yellow sandy loam	WD	2.5Y6/6
24	Gray sandy loam, gravel seams from 40 to 45 ft	WD	5Y5/1
50	Very fine to fine clayey sand; lt. yellowish brown; drills harder; wood from 60'	-	2.5Y6/4
64	Sand and gravel		
70.5	Sandy clay loam; not as slow drilling as above clayey unit; poor samples	-	2.5Y7/4
82	Sand and gravel; wood	-	-
83.5	Gray clay loam; mostly poor samples; sand and gravel from 98-100, 114-115; drilling very slow from 118'	BR	5Y4/1
129	Sand and gravel; possible clay layers toward bottom	-	-
135.5	Olive-gray sandy loam; almost greenish gray	SD	5Y5/2
151.5	Sand and gravel; lot of red and black pebbles with white carbonate	-	-
164.5	Clay loam (not till)	-	5Y5/2
168	Coarse pebbly sand; may be clayey or silty in places	-	-
189	Very fine to fine sand; gray; may include clay layers; charcoal and wood chips; sand coarse from about 250-260; clay layers in last 6 or 7 ft as sand is finer	-	-
270	Gray, sticky, silty clay; drills fast; soft and plastic	-	5Y4/2-4/1
310	Dark-gray silty clay; some lt.-gray and greenish-gray colors; rock at 360'; generally poor samples	-	5Y4/1
370	Olive-gray to olive-brown sandy loam; drills very fast	ED	-
421	Regolith		
428.5	Bottom of hole		

MGS 1651, SE1/4SE1/4NE1/4SE1/4 sec. 36,
T. 130 N., R. 35 W.
Todd County, MN
Surface elevation = 1324 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Dark-brown sandy loam	-	-
3	Coarse gravel	-	-
43.5	Gray sandy loam	SD	-
50	Gravel	-	-
55.5	Gray sandy loam; a little clayey with depth	SD	-
70	Dark-gray clay loam; drills faster (mixed with marl deposit)	SD	-
88.5	Olive-gray coarse silt to sandy silt; drills much slower; wood, iron-staining; very well to poorly sorted material, gravel layer from 95.5 to 97.5 ft; organic layers (marl) are dark yellow brown with plant remains	-	-
101	Dark-gray loam to clay loam; drilling very slow; more sandy in last few feet	ML	-
165	Sand and gravel	-	-
170	Red-brown to reddish-brown loam to sandy loam; very slow drilling; sand seam at 175'	FR	-
183	Olive-brown loam to clay loam; more clayey with depth to silty clay	EB	-
205	Light-brown and light-gray loam; poor samples	EB	-
220	Light-gray clay loam	EB	-
233	Regolith		
265	Rock		
395	Bottom of hole		

MGS 1913, NW1/4SW1/4NW1/4NE1/4 sec. 22,
T. 129 N., R 36 W.
Douglas County, MN
Surface Elevation = 1345 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Brown fine to coarse sand, little gravel	-	-
9	Gray fine to coarse sand, little gravel	-	-
12	Gray, silty, coarse sand and gravel	-	-

MGS 1913 (continued)

21	Olive-gray grading to dark-gray silt loam to clay loam; sand seam at 27'	WD	5Y4/2-4/1
35	Gray silt loam and sand and gravel; poor samples	WD	5Y4/1
39.5	Coarse sand and gravel; abundant dolomite pebbles (Green outwash)	-	-
55	Gray silt loam; olive brown in top 6 inches	GR	5Y5/1
68	Olive-gray silt loam; olive brown at base	GR	5Y5/2
72	Medium to coarse sand and gravel; fines upward (recessional)	-	-
98	Greenish-gray loam; poor sample	?	5G5/1
99	Fine to medium quartz sand	-	-
102	Gray sandy loam	ML	5Y5/1
110	Olive-gray sandy loam; sand seams at 110 and 115 feet	ML	5Y5/2
115	Gray sandy loam	ML	5Y5/1
123	Lt.-olive-brown loam; more clayey than above	ML	2.5Y5/4
126	Olive-gray loam	ML	5Y5/2
130	Coarse sand to sand and gravel; fines upward (recessional)	-	-
148	Gray to dark-gray loam	ML	5Y5/1-4/1
162	Very dark gray (purple tint) clay loam; very stiff	EB	5Y4/1-3/1
165	Olive clay loam to silty clay; very stiff; about 10% of samples are gray	EB	5Y5/4-5/6 and 5Y5/1
192	Olive and gray sandy clay loam; very stiff	EB	5Y5/4-5/6 and 5Y5/1
197	Mostly gray but some olive sandy clay loam, very stiff	EB	5Y5/1 and 5Y5/6
214	Olive-brown loamy sand; inclusions of brown, white and reddish regolith blebs; drills moderately fast	ED	2.5Y4/4
231	Olive-gray loamy sand; as above	ED	5Y5/2
235	Regolith		
260	Rock		
273.5	Bottom of hole		

MGS 2000, SE1/4SE1/4SE1/4SW1/4 sec. 34,
T. 130 N., R. 33 W.
Todd County, MN
Surface elevation = 1327 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Sandy loam, olive yellow to lt. yellowish brown; with lt.-brownish-gray mottles	WD	2.5Y6/6-6/4 and 2.5Y6/2
9	Gravelly sand, possibly mixed with sandy loam	-	-
12	Dark-gray clay loam; sand seam at 26'	BR	5Y4/1
72	Black organic clay loam	-	5Y2.5/1
75	Gray silt loam; black sand seam at 82'	ML	5Y5/1
84	Greenish-gray silt loam	ML	5GY6/1
99	Dark-grayish-brown silt loam with wood; drills fast	ML	10YR4/2
104	Gray to greenish-gray silt loam	ML	5Y5/1 to 5GY6/1
110	Dark-grayish-brown silt loam, with wood; drills fast; may extend to 117'	ML	10YR4/2
114	Greenish-gray silt loam; to gray color with depth; drills fast; more wood toward base, fines downward	ML	5GY6/1 to 5Y5/1
129	Dark-gray clay (till); drills much slower than above	ML	5Y4/1
135	Lt.-greenish-gray, coarse silt to silt loam, fining to silty clay by 140, and clay by 142; drills hard as above but is lacustrine		5GY7/1
142	Sand and clay, lt. brown; approaches 5YR colors; lacustrine	-	7.5YR6/4
146	Brown to dark-gray sandy clay loam; general color is "reddish gray"; may range to 5YR color; contains few pebbles or rocks; could be lacustrine silt and clay in last 4 ft	FR	7.5YR4/1-4/2
170	Gravelly sand	-	-
174	Dark-gray clay loam; drills very steady, uniform; more rocky from 244 to 256	EB	5Y4/1
268	Sandy clay loam, reddish tinge in top few feet, gray changing to dk. grayish brown to dk. gray; gray to dk. gray by 300'	SR	10YR5/1 to 10YR4/2-4/1 to 5Y5/1-4/1
308	Regolith		
559	Rock		
578.5	Bottom of hole		

MGS 2005, SE1/4NE1/4SE1/4SE1/4 sec. 15,
T. 128 N., R. 30 W.
Morrison County, MN
Surface elevation = 1169 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Strong brown, gravelly sandy loam; changing to yellowish brown by 4 ft	PR	7.5YR5/6 to 10YR5/6
8	Clayey silt (lacustrine); brownish yellow grading to lt. yellowish brown; olive gray by 12', grading to gray by 14'; hard, smooth drilling; calcareous; very fine sandy silt by 14', silt to clayey silt by 17', silty clay by 21'; laminated	-	10YR6/6 to 10YR6/4 to 5Y5/2 to 10YR5/1
26	Very fine to fine sand, wood layer at top; coarse sand in last 2 feet (clayey soil at top)	-	-
34	Gray sandy loam; reddish tinge to some blebs	WD	5YR5/1
37	Very dark gray clay (till); hard (includes tiny shell fragments)	WD	5Y3/1
44	Greenish-gray clay loam; little more sand than above; dk. gray by 54'	EB	5G6/1 to 5GY6/1 to 5Y4/1
58.5	Sand	-	-
60.5	Dk.-gray to very dk. gray clay (till); may be lacustrine in upper part	ED	5Y4/1-3/1
75	Regolith (drills faster than above)		
154	Rock		
171	Bottom of hole		

MGS 2007, SW1/4SW1/4SW1/4SW1/4 sec. 8,
T. 127 N., R. 30 W.
Morrison County, MN
Surface elevation = 1153 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Yellowish-brown sandy gravelly loam	PR	10YR5/6
9	Dk.-reddish-brown sandy gravelly loam	PR	5YR3/4
11	Gray sandy clay loam	BR	5Y5/1
15	Gray cobbly sandy clay loam	BR	5Y5/1
18	Gray sandy clay loam	BR	5Y5/1
22.5	As above but cobbly	BR	5Y5/1
26	Gray sandy clay loam	BR	5Y5/1
47	Coarse sand and fine gravel	-	-
54	Lt.-brownish-gray loam; some gray blebs with reddish tinge; more clayey than above	ML	2.5Y6/2 and 5YR5/1
60	Greenish-gray sandy clay loam; few reddish blebs below could be unoxidized "reddish" till (mixed) (different geologist)	ML	5GY6/1 to 5GY5/1
74	Olive-gray clay loam; grades to dk. gray by 81'	ML	5Y5/2 to 5Y4/1
90	Very dk. gray clay loam; sand seams from 102 to 107 feet	EB	5Y3/1
109	Sand	-	-
111.5	Very dk. gray clay loam	ED	5Y3/1
126	Very dk. gray sandy loam; possible sand layers, coarser with depth	ED	5Y3/1
133.5	Sand		
136	Very dk. gray clay loam; contains Cretaceous fragments; sand seam at 157', possibly others below	ED	5Y3/1
181	Dark-gray clay loam (probably more sandy than above)	ED	5Y4/1
189	Black lignitic clay loam interbedded with lt.-gray to white, very fine sandy loam; Cretaceous sediments	-	-
196.5	Regolith		
293	Rock		
298.5	Bottom of hole		

MGS 2008, NW1/4NE1/4SE1/4NE1/4 sec. 29,
T. 127 N., R. 31 W.
Morrison County, MN
Surface elevation = 1249 ± 5

Depth (feet)	Description (on site)	Till	Munsell color
0	Black pebbly loam	PR	-
2	Gravelly sandy loam; pale brown to lt. yellowish brown by 4'; yellowish brown by 5'; mixed with reddish brown blebs by 8'; gray by 12.5'; very sandy and gravelly from 17'; more clayey and carbonate-rich than typical	PR	10 YR6/3 to 10YR6/4 to 10YR5/4 with 5YR5/4 to 10YR5/1
22	Gray sandy clay loam; harder, more clayey than above; dolomite common	WD	5Y5/1
28	Very dark gray clay (till); harder than above, woody (dk. brownish gray when dry)	WD	5Y3/1
43	Coarse gravelly sand	-	-
51	Reddish-brown sandy loam; drills much faster than clay above	RS	2.5YR4/4
55	Gray sandy loam to sandy clay loam	RS	5YR5/1
65	Gray sandy clay loam; hard	RS	10YR5/1
70.5	Dk.-gray sandy silt loam; drills faster than above; thin organic soil layer at top	ML	10YR4/1 to 2.5Y4/1
85	Dk.-gray clay loam	ML	5Y4/1
93	Sandy clay loam; reddish brown quickly grading to gray color	ML	5YR5/4 to 5YR5/1 to 10YR5/1
100	Dark-gray sandy silt loam; soft	ML	10YR4/1
106	Brown to dk.-brown sandy loam; gray by 112; sand seam at 114'	FR	7.5YR4/2 to 5YR5/1
118	Olive clay (till); may be mixed with regolith; olive gray by 121'	EB	5Y5/3 to 5Y5/2
123	Regolith		
179.5	Rock		
196	Bottom of hole		

Exposure in Browerville gravel pit
SW1/4SW1/4NW1/4SE1/4 sec. 16,
T. 130 N., R. 33 W.
Todd County, MN
Section top = 1320 ± 5

Thickness (feet)	Description (on site)	Till	Munsell color
3	Sand and gravel	-	-
15	Sandy clay loam	WD	10YR6/4
10+	Clay loam, dark gray	BR	5Y4/1

(Browerville is exposed mostly in the sloping floor of the cut, half overgrown with vegetation. Contact between the Wadena and Browerville is sharp, with oxidation (10YR3/2) occurring only along joints in the Browerville till.)

Two River exposure
SE1/4NE1/4NE1/4SW1/4 sec. 8,
T. 127 N., R. 29 W.
Morrison County, MN
Section top = 1035 ± 5

Thickness (feet)	Description (on site)	Till	Munsell color
5±	Loamy colluvium	-	-
12±	Clay loam, brown; complex variation in color, deoxidized along joints, some 7.5YR colors; disseminated carbonate, inclusions of sand and smeared out Cretaceous clay	ED	10YR4/3 and 10YR7/1
10+	Cretaceous siltstone and lignite; unoxidized except along joints; sharp contact with oxidized till above (Cretaceous sediments extend below water line of river)		

APPENDIX B

TILL TEXTURAL AND SAND COUNT DATA

Sample type includes drill cuttings (C), split tube (S), and outcrop (O). Under texture, gravel (G) is given as percentage of total sample weight, whereas the sand (S), silt (Si), and clay (C) values are given as percentage of the 2-mm and smaller fraction. Very coarse sand (1- to 2-mm) lithology is divided between Precambrian (p€), Paleozoic (Pz), and Cretaceous (K), and presented as a percentage of grains counted after the "others" category was excluded. The "others" (Oth) value is a percentage of the total sample.

The Precambrian category is divided into "granitics" (Gr), "darks" (D), "reds" (R), and "others" (Oth) subgroups; values given are a percentage of total Precambrian grains counted. The Cretaceous category is divided into limestone (L), gray shale (Gs), speckled shale (Ss), pyrite (P), and "others" (Oth); values given are a percentage of total Cretaceous grains counted. T (trace) represents a value of 0.5 percent or less. Blank lines indicate no data.

Till unit	Depth (feet)	Sample type	Texture G - S - Si - C	Lithology 1- to 2-mm sand p€ - Pz - K - Oth	Lithology in % p€ 1- to 2-mm sand Gr - D - R - Oth	Lithology in % K 1- to 2-mm sand L - Gs - Ss - P - Oth	Total shale %	Number grains counted
Hole 422								
Pierz	40-50	C	-	97 - 3 - T - 2	48 - 26 - 18 - 9	100	0.0	399
Hole 510								
Wadena	33-37	C	-	73 - 26 - 1 - T	80 - 14 - 3 - 2	100	0.0	287
Wadena	50-65	C	-	39 - 30 - T - 2	83 - 12 - 3 - 2	50 - 50	0.2	420
Sandy	73-93	C	-	84 - 15 - 1 - 2	79 - 16 - 1 - 4	100	0.0	449
Hole 1640								
Wadena	5-6	S	7 - 69 - 22 - 9	97 - 3 - 0 - 3	82 - 14 - 4 - 1	0	0.0	496
Wadena	15-20	C	-	89 - 10 - 1 - 2	82 - 15 - 2 - 1	100	0.0	269
Browerville	30-31	S	4 - 33 - 41 - 26	60 - 21 - 19 - 1	84 - 16 - 0 - 0	43 - 47 - 10	10.9	258
Browerville	60-61	S	2 - 24 - 49 - 27	50 - 27 - 23 - 2	82 - 17 - 1 - 1	34 - 1 - 60 - 5 - 0	14.2	323
Browerville	70-75	C	-	63 - 29 - 8 - 2	85 - 13 - 1 - T	77 - 0 - 8 - 15 - 0	0.6	353
Browerville	90-95	C	-	55 - 34 - 11 - 2	84 - 14 - 1 - 1	82 - 11 - 4 - 4 - 0	1.5	269
Meyer Lake	100-101	S	5 - 51 - 38 - 11	61 - 39 - T - T	77 - 20 - 1 - 2	100	0.0	448
Elmdale	108-110	C	-	74 - 20 - 7 - 2	87 - 10 - 1 - 2	90 - 10 - 0 - 0 - 0	0.6	324
Elmdale	112-115	C	-	93 - 6 - 1 - 10	88 - 11 - 0 - 1	100	0.0	305
Elmdale	115-120	C	-	89 - 9 - 2 - 7	84 - 14 - 0 - 2	100	0.0	288
Elmdale	120-121	S	14 - 65 - 27 - 9	92 - 6 - 2 - 10	44 - 55 - 0 - 1	100	0.0	514

Hole 1641

Wadena	0-5	C	-	85 - 15 - 1 - 1	85 - 11 - 2 - 2	100	0.0	401
Browerville	6-10	C	-	72 - 24 - 4 - 3	83 - 16 - 1 - T	100	0.0	440
Browerville	10-11	S	3 - 40 - 26 - 34	67 - 28 - 5 - 2	84 - 16 - 0 - 0	100	0.0	247
Browerville	15-20	C	-	70 - 21 - 10 - 2	80 - 17 - 1 - 1	91 - 0 - 0 - 4 - 4	0.0	246
Browerville	40-41	S	6 - 46 - 28 - 26	56 - 35 - 9 - 1	84 - 13 - 1 - 1	77 - 8 - 5 - 3 - 8	1.2	425
Browerville	110-111	S	4 - 30 - 34 - 36	52 - 34 - 14 - 2	90 - 9 - 0 - 2	76 - 0 - 23 - 0 - 2	3.2	381
Browerville	130-135	C	-	55 - 37 - 7 - 2	81 - 19 - 0 - 1	67 - 10 - 0 - 24 - 0	0.7	295
Browerville	145-150	C	-	58 - 31 - 11 - 2	84 - 15 - T - 1	74 - 7 - 12 - 7 - 0	2.0	405
Meyer Lake	160-165	C	-	62 - 34 - 4 - T	68 - 28 - 1 - 3	75 - 12 - 0 - 12 - 0	0.5	376
Meyer Lake	165-170	C	-	56 - 40 - 4 - 2	78 - 18 - 1 - 3	60 - 30 - 0 - 10 - 0	1.1	271
Meyer Lake	170-175	C	-	58 - 38 - 4 - 2	68 - 28 - 1 - 3	76 - 12 - 0 - 12 - 0	0.5	435
Meyer Lake	175-180	C	-	60 - 36 - 4 - 1	71 - 26 - 0 - 3	50 - 40 - 10 - 0 - 0	2.1	235
Meyer Lake	185-190	C	-	56 - 34 - 9 - 2	76 - 21 - 2 - 1	68 - 27 - 4 - 0 - 0	2.9	245
Eagle Bend	195-200	C	-	57 - 34 - 8 - 1	84 - 12 - 1 - 2	70 - 17 - 0 - 13 - 0	1.4	285

Hole 1642

Browerville	45-50	C	-	63 - 25 - 12 - 2	84 - 14 - T - 2	77 - 0 - 8 - 15 - 0	1.0	420
Browerville	50-55	C	-	72 - 21 - 6 - 1	82 - 16 - 1 - 1	67 - 0 - 29 - 4 - 0	1.9	378
Browerville	65-70	C	-	57 - 31 - 12 - 2	76 - 19 - 2 - 3	47 - 0 - 47 - 3 - 3	5.8	302
Browerville	75-80	C	-	71 - 24 - 4 - 2	86 - 12 - 2 - 1	77 - 8 - 8 - 8 - 0	0.7	298
Browerville	90-95	C	-	65 - 29 - 6 - 2	84 - 14 - T - 1	63 - 5 - 16 - 16 - 0	1.4	296
Browerville	100-101	S	4 - 33 - 32 - 35	56 - 30 - 13 - 1	88 - 11 - 0 - 1	57 - 0 - 33 - 5 - 5	4.5	317
Browerville	105-110	C	-	66 - 25 - 9 - 1	88 - 12 - 0 - 1	75 - 5 - 16 - 5 - 0	1.9	213

Hole 1643

Wadena	5-6	S	4 - 57 - 18 - 25	82 - 17 - 1 - 2	84 - 14 - T - 1	100	0.0	380
Wadena	20-25	C	-	83 - 16 - 1 - 3	82 - 15 - 2 - 2	100	0.0	256
Wadena	30-35	C	-	76 - 22 - 2 - 3	85 - 11 - T - 3	100	0.0	292
Wadena	40-41	S	6 - 53 - 20 - 27	71 - 26 - 4 - 0	85 - 13 - T - 1	60 - 10 - 20 - 10 - 0	1.1	274
Wadena	45-50	C	-	78 - 20 - 2 - 2	79 - 18 - T - 3	88 - 0 - 12 - 0 - 0	0.3	391
Browerville	70-71	S	2 - 33 - 26 - 41	83 - 16 - 1 - 1	79 - 19 - 0 - 2	100	0.0	313
Browerville	75-80	C	-	82 - 17 - 1 - 3	82 - 15 - 1 - 2	100	0.0	309
Browerville	90-95	C	-	61 - 32 - 7 - 3	78 - 19 - T - 2	96 - 0 - 0 - 0 - 4	0.0	346
Browerville	125-130	C	-	62 - 30 - 8 - 2	86 - 13 - 0 - 1	52 - 26 - 4 - 18 - 0	2.4	332
Browerville	140-141	S	3 - 31 - 31 - 38	50 - 25 - 25 - 1	86 - 12 - 1 - 1	28 - 60 - 6 - 5 - 1	16.7	332
Browerville	170-175	C	-	62 - 32 - 6 - 2	82 - 16 - 1 - 1	69 - 23 - 0 - 8 - 0	1.3	240
Browerville	190-191	S	4 - 31 - 32 - 37	62 - 24 - 15 - 2	88 - 12 - 0 - 0	56 - 5 - 30 - 5 - 5	5.1	299
Browerville	205-210	C	-	61 - 31 - 9 - 1	83 - 14 - T - 2	81 - 8 - 0 - 11 - 0	0.7	426
Meyer Lake	220-225	C	-	69 - 28 - 3 - 1	76 - 22 - 0 - 2	88 - 0 - 0 - 12 - 0	0.0	279
Meyer Lake	230-235	C	-	67 - 26 - 7 - 1	81 - 16 - 0 - 2	53 - 13 - 0 - 33 - 0	1.0	408
Meyer Lake	240	S	4 - 40 - 35 - 25	70 - 29 - 1 - 4	55 - 36 - 2 - 7	33 - 67 - 0 - 0 - 0	0.9	287
Meyer Lake	250-255	C	-	62 - 33 - 5 - 0	85 - 12 - 1 - 2	84 - 10 - 0 - 5 - 0	0.5	413
Elmdale	260	S	1 - 54 - 22 - 24	77 - 14 - 9 - 6	88 - 10 - 0 - 2	91 - 0 - 2 - 7 - 0	0.1	754
Elmdale	265-270	C	-	69 - 22 - 9 - 3	83 - 15 - 0 - 2	90 - 0 - 0 - 10 - 0	0.0	491
Elmdale	281-282	S	8 - 52 - 28 - 20	80 - 7 - 12 - 7	87 - 11 - 0 - 3	9 - 0 - 86 - 3 - 2	0.7	501

Till unit	Depth (feet)	Sample type	Texture G - S - Si - C	Lithology 1- to 2-mm sand pЄ - Pz - K - Oth	Lithology in % pЄ 1- to 2-mm sand Gr - D - R - Oth	Lithology in % K 1- to 2-mm sand L - Gs - Ss - P - Oth	Total shale %	Number grains counted
				Hole 1644				
Wadena	5-6	S	9 - 60 - 21 - 19	88 - 11 - 1 - T	78 - 15 - 5 - 2	100	0.0	338
Browerville	60-61	S	5 - 39 - 32 - 29	58 - 30 - 12 - 2	82 - 17 - 0 - 1	65 - 0 - 26 - 9 - 0	3.2	288
Browerville	110-111	S	5 - 31 - 31 - 28	57 - 28 - 15 - 2	89 - 8 - 1 - 2	58 - 2 - 36 - 4 - 1	5.7	916
Eagle Bend	132-133	S	6 - 29 - 32 - 39	47 - 48 - 5 - 1	80 - 16 - 2 - 2	100	0.0	366
				Hole 1645				
Wadena	5-6	S	5 - 56 - 17 - 27	82 - 17 - 2 - 1	83 - 12 - 1 - 4	67 - 0 - 33 - 0 - 0	0.5	377
Wadena	30-31	S	11 - 51 - 17 - 32	76 - 23 - 1 - 2	83 - 13 - 2 - 2	100	0.0	395
Wadena	45-50	C	-	76 - 23 - 1 - 4	86 - 13 - 1 - 1	75 - 0 - 0 - 25 - 0	0.0	435
Browerville	80-81	S	7 - 44 - 28 - 28	66 - 30 - 4 - 1	87 - 11 - 1 - 2	80 - 0 - 0 - 20 - 0	0.0	256
Browerville	110-115	C	-	59 - 39 - 3 - 1	76 - 22 - 1 - 1	86 - 14 - 0 - 0 - 0	0.4	263
Browerville	140-141	S	4 - 50 - 26 - 23	65 - 30 - 5 - 1	86 - 11 - T - 2	56 - 22 - 0 - 22 - 0	1.0	487
Browerville	170-175	C	-	49 - 34 - 17 - T	87 - 9 - 2 - 2	79 - 0 - 19 - 2 - 0	3.2	252
Browerville	185-190	C	-	53 - 27 - 20 - 2	76 - 19 - 4 - 2	55 - 2 - 44 - 0 - 0	8.8	335
Meyer Lake	200-201	S	4 - 40 - 33 - 26	52 - 46 - 2 - 0	80 - 19 - 1 - 1	100	0.0	434
Meyer Lake	215-220	C	-	53 - 40 - 7 - 1	71 - 25 - 1 - 3	67 - 20 - 7 - 7 - 0	1.8	225
Meyer Lake	230-235	C	-	69 - 28 - 3 - 2	74 - 16 - 8 - 2	73 - 0 - 9 - 18 - 0	0.3	370
Meyer Lake	240-245	C	-	54 - 42 - 5 - 3	69 - 23 - 4 - 4	50 - 0 - 0 - 42 - 8	0.0	263
Eagle Bend	250-251	S	4 - 23 - 30 - 47	39 - 55 - 6 - 1	83 - 15 - T - 2	100	0.0	492
Eagle Bend	275-280	C	-	60 - 36 - 4 - 2	85 - 11 - 2 - 1	82 - 9 - 0 - 9 - 0	0.4	279
Eagle Bend	285-290	C	-	49 - 47 - 4 - 1	74 - 18 - 5 - 3	100	0.0	250
Eagle bend	295-300	C	-	53 - 43 - 4 - 1	76 - 18 - 3 - 3	67 - 8 - 0 - 25 - 0	0.3	289
				Hole 1648				
Des Moines(?)	0-8	C	-	81 - 18 - 2 - 2	84 - 12 - 1 - 3	40 - 60 - 0 - 0 - 0	0.9	336
Wadena	15-20	C	-	84 - 15 - 1 - 2	76 - 17 - 2 - 4	100	0.0	508
Wadena	35-40	C	-	87 - 12 - 1 - 1	75 - 18 - 4 - 3	50 - 50 - 0 - 0 - 0	0.4	506
Wadena	55-60	C	-	86 - 13 - T - 1	74 - 19 - 4 - 2	100	0.0	339
Wadena	65-70	C	-	86 - 14 - T - 1	77 - 17 - 3 - 4	100	0.0	253
Wadena	85-90	C	-	86 - 14 - 0 - 1	81 - 15 - 1 - 3	0	0.0	332
Wadena	105-110	C	-	83 - 16 - 2 - 1	74 - 20 - 4 - 2	25 - 50 - 0 - 25 - 0	0.7	274
Meyer Lake	125-130	C	-	60 - 38 - 2 - 2	86 - 12 - 1 - 1	33 - 67 - 0 - 0 - 0	1.5	273
Meyer Lake	145-150	C	-	69 - 28 - 2 - 1	83 - 12 - 1 - 4	62 - 25 - 0 - 12 - 0	0.6	364
				Hole 1649				
Wadena	10-15	C	-	89 - 11 - T - 1	80 - 15 - 2 - 3	100	0.0	414
Wadena	30-35	C	-	83 - 15 - 2 - 1	79 - 18 - 1 - 2	88 - 0 - 0 - 0 - 12	0.0	536
Wadena	45-50	C	-	85 - 14 - 1 - 1	79 - 18 - 1 - 2	67 - 33 - 0 - 0 - 0	0.3	301

Wadena	65-70	C	-	83 - 16 - 1 - 1	76 - 16 - 5 - 3	67 - 33 - 0 - 0 - 0	0.2	514
Green	85-90	C	-	57 - 42 - 1 - 1	87 - 11 - 2 - 1	100	0.0	430
Green	125-130	C	-	75 - 24 - 1 - 1	87 - 10 - 2 - 1	100	0.0	431
Green	145-150	C	-	74 - 26 - 0 - 1	88 - 10 - 1 - 1	0	0.0	407
Meyer Lake	180-185	C	-	71 - 27 - 2 - 1	84 - 14 - T - 2	30 - 20 - 0 - 40 - 10	0.4	517
Eagle Bend	230-235	C	-	67 - 32 - 1 - 2	82 - 16 - 1 - 2	20 - 80 - 0 - 0 - 0	0.9	471
Eagle Bend	245-250	C	-	61 - 37 - 2 - 2	79 - 17 - 1 - 2	62 - 0 - 38 - 0 - 0	0.7	468
Eagle Bend	255-260	C	-	67 - 32 - 1 - 2	84 - 13 - 1 - 2	57 - 0 - 14 - 29 - 0	0.2	526
Hole 1650								
Wadena	15-20	C	-	86 - 13 - 1 - 2	85 - 13 - T - 2	100	0.0	338
Wadena	45-50	C	-	82 - 18 - 1 - 5	85 - 14 - T - T	100	0.0	336
Browerville	90-95	C	-	67 - 32 - 1 - 2	80 - 18 - 1 - T	100	0.0	482
Browerville	120-125	C	-	76 - 24 - T - 3	83 - 16 - 1 - 0	0 -100	0.3	324
Browerville	125-130	C	-	70 - 28 - 3 - 3	85 - 14 - 1 - 1	89 - 11 - 0 - 0 - 0	0.3	342
Sandy	145-150	C	-	88 - 11 - T - 2	87 - 12 - T - 0	100	0.0	583
Elmdale	385-390	C	-	71 - 24 - 5 - 2	75 - 24 - 1 - 0	67 - 33 - 0 - 0 - 0	1.7	239
Elmdale	405-410	C	-	75 - 21 - 4 - 10	80 - 19 - T - T	83 - 0 - 6 - 11 - 0	0.2	536
Hole 1651								
Sandy	45-50	C	-	82 - 17 - 1 - 2	85 - 14 - T - 0	38 - 62 - 0 - 11 - 0	0.9	587
Sandy	60-65	C	-	78 - 20 - 2 - 2	80 - 19 - T - 1	62 - 38 - 0 - 0 - 0	0.7	415
Sandy	70-85	C	6 - 23 - 37 - 40	-	-	-	-	-
Sandy	80-85	C	-	87 - 12 - 1 - 10	88 - 10 - T - 1	62 - 38 - 0 - 0 - 0	0.5	634
Meyer Lake	115-120	C	-	68 - 27 - 5 - 0	84 - 15 - 0 - 1	50 - 39 - 0 - 11 - 0	1.9	362
Meyer Lake	115-130	C	5 - 46 - 26 - 28	-	-	-	-	-
Meyer Lake	130-145	C	4 - 45 - 29 - 26	-	-	-	-	-
Meyer Lake	155-160	C	-	61 - 32 - 6 - 2	85 - 12 - 1 - 2	75 - 11 - 0 - 14 - 0	0.7	445
Meyer Lake	155-165	C	5 - 45 - 32 - 23	-	-	-	-	-
First Red	175-180	C	-	74 - 24 - 2 - 1	77 - 14 - 8 - 2	80 - 13 - 0 - 7 - 0	0.3	619
Eagle Bend	195-200	C	-	54 - 41 - 5 - 2	86 - 12 - 3 - 0	77 - 8 - 8 - 8 - 0	0.8	539
Eagle Bend	195-210	C	8 - 43 - 25 - 32	-	-	-	-	-
Eagle Bend	210-215	C	-	53 - 42 - 6 - 3	82 - 12 - 4 - 3	90 - 3 - 3 - 3 - 0	0.4	507
Eagle Bend	220-225	C	-	43 - 48 - 9 - 2	83 - 10 - 3 - 4	81 - 0 - 6 - 8 - 4	0.6	544
Hole 1827								
Sandy	30-31	S	11 - 47 - 44 - 9	85 - 15 - 0 - 1	83 - 14 - 1 - 2	0	0.0	307
Sandy	34-39	C	2 - 61 - 21 - 18	84 - 16 - T - 1	86 - 10 - 3 - 2	0 -100	0.3	310
Sandy	39-44	C	6 - 61 - 19 - 20	89 - 10 - 1 - T	83 - 14 - 2 - 2	100	0.0	230
Green	45-46	S	1 - 35 - 28 - 37	93 - 6 - 1 - 1	93 - 6 - T - T	100	0.0	364
Green	55-56	S	5 - 36 - 51 - 12	58 - 41 - 1 - 1	87 - 13 - 1 - 0	100	0.0	235
Green	65-66	S	4 - 32 - 49 - 18	54 - 45 - 1 - T	85 - 14 - 0 - 1	33 - 67	0.8	254
Green	75-76	S	8 - 32 - 52 - 16	48 - 51 - 1 - 1	90 - 9 - 0 - 1	100	0.0	459
Green	85-86	S	5 - 31 - 54 - 15	57 - 42 - T - T	88 - 11 - 0 - 2	100	0.0	429
Green	100-101	S	4 - 31 - 42 - 27	53 - 47 - T - 1	88 - 9 - 0 - 2	100	0.0	293

Till unit	Depth (feet)	Sample type	Texture G - S - Si - C	Lithology 1- to 2-mm sand p€ - Pz - K - Oth	Lithology in % p€ 1- to 2-mm sand Gr - D - R - Oth	Lithology in % K 1- to 2-mm sand L - Gs - Ss - P - Oth	Total shale %	Number grains counted
				Hole 1828				
Pierz	10-20	C	6 - 45 - 33 - 22	81 - 19 - 0 - 1	64 - 23 - 8 - 4	0	0.0	432
Pierz	25-35	C	5 - 32 - 48 - 21	88 - 11 - 1 - 2	69 - 15 - 11 - 6	33 - 33 - 0 - 0 - 33	0.3	397
Wadena	45-50	C	10 - 48 - 33 - 19	71 - 28 - 1 - 1	84 - 13 - 2 - 1	100	0.0	267
Wadena	50-55	C	6 - 47 - 34 - 19	-	-	-	-	-
Wadena	65-70	C	8 - 47 - 32 - 21	68 - 31 - 1 - 1	78 - 18 - 3 - 2	33 - 33 - 0 - 0 - 33	0.2	445
Wadena	70-75	C	15 - 56 - 26 - 18	-	-	-	-	-
Sandy	95-100	C	7 - 64 - 22 - 15	86 - 13 - 1 - 1	86 - 10 - 2 - 2	100	0.0	307
Green	100-105	C	7 - 37 - 39 - 24	72 - 28 - T - 2	86 - 10 - 2 - 2	100	0.0	390
Green	110-115	C	10 - 45 - 36 - 19	53 - 47 - T - 1	84 - 11 - 2 - 2	100	0.0	228
Green	135-140	C	4 - 37 - 38 - 25	50 - 50 - T - T	85 - 11 - 1 - 3	100	0.0	365
Green	155-160	C	3 - 32 - 42 - 26	57 - 42 - 1 - 1	82 - 13 - 3 - 2	100	0.0	343
Green	165-170	C	4 - 29 - 42 - 29	58 - 41 - 1 - 1	82 - 12 - 2 - 4	50 - 25 - 0 - 25 - 0	0.3	326
Green	185-190	C	2 - 26 - 47 - 28	48 - 50 - 1 - 1	86 - 12 - 0 - 2	83 - 0 - 0 - 17 - 0	0.0	438
Green	190-195	C	4 - 23 - 47 - 30	60 - 38 - 2 - 2	80 - 12 - 4 - 4	50 - 25 - 25 - 0 - 0	0.8	258
				Hole 1829				
Pierz	13-14	S	5 - 56 - 21 - 22	89 - 10 - 1 - 2	87 - 10 - 1 - 2	100	0.0	264
Pierz	18-19	S	4 - 59 - 22 - 20	86 - 13 - T - T	83 - 12 - 2 - 3	100	0.0	480
Pierz	23-24	S	6 - 54 - 24 - 22	-	-		-	-
Wadena	28-29	S	3 - 42 - 31 - 27	68 - 30 - 2 - 2	91 - 6 - 2 - 1	50 - 33 - 17 - 0 - 0	1.0	305
Wadena	34-35	S	6 - 44 - 32 - 24	72 - 27 - 1 - 3	82 - 12 - 4 - 2	33 - 67 - 0 - 0 - 0	0.6	336
Wadena	39-40	S	7 - 44 - 34 - 23	-	-	-	-	-
Wadena	44-45	S	5 - 43 - 35 - 22	65 - 32 - 4 - 1	86 - 9 - 2 - 3	80 - 10 - 0 - 10 - 0	0.3	290
Wadena	49-50	S	6 - 45 - 35 - 21	-	-		-	-
Wadena	54-55	S	4 - 40 - 34 - 26	-	-		-	-
Wadena	59-60	S	6 - 43 - 32 - 24	67 - 32 - 1 - 1	82 - 11 - 5 - 3	67 - 33 - 0 - 0 - 0	0.3	337
Wadena	64-65	S	5 - 44 - 27 - 29	-	-	-	-	-
Wadena	69-70	S	8 - 41 - 27 - 31	-	-	-	-	-
Wadena	74-75	S	4 - 48 - 29 - 23	81 - 18 - 1 - 3	79 - 12 - 7 - 2	33 - 33 - 0 - 33 - 0	0.3	352
Sandy	94-95	S	7 - 59 - 23 - 18	87 - 13 - 0 - 1	85 - 10 - 4 - 2	0	0.0	431
Sandy	99-100	S	7 - 57 - 25 - 18	89 - 10 - T - 2	82 - 14 - 3 - 2	100	0.0	467
				Hole 1830				
Pierz	12-13	S	7 - 60 - 24 - 16	86 - 14 - 1 - 2	83 - 12 - 3 - 2	100	0.0	322
Pierz	17-18	S	7 - 52 - 28 - 20	81 - 18 - T - 3	75 - 13 - 7 - 4	100	0.0	451
Wadena	23-24	S	20 - 44 - 34 - 22	-	-	-	-	-
Wadena	29-30	S	5 - 45 - 33 - 22	69 - 31 - T - 2	78 - 15 - 4 - 2	50 - 50 - 0 - 0 - 0	0.2	431
Wadena	34-35	S	4 - 40 - 30 - 30	-	-	-	-	-

Wadena	39-40	S	7 - 44 - 29 - 28	66 - 33 - 1 - 2	84 - 12 - 3 - 1	100	0.0	264
Wadena	44-45	S	6 - 44 - 38 - 17	-	-	-	-	-
Wadena	48-50	S	5 - 45 - 29 - 26	61 - 38 - 1 - 1	86 - 10 - 2 - 1	25 - 75 - 0 - 0 - 0	1.1	285
Wadena	59-60	S	7 - 43 - 29 - 28	70 - 29 - 1 - 2	84 - 9 - 4 - 3	50 - 25 - 0 - 25 - 0	0.3	365
Wadena	69-70	S	4 - 55 - 27 - 18	88 - 12 - 0 - 2	87 - 8 - 3 - 3	0	0.0	411
Green	98-99	S	6 - 43 - 33 - 23	70 - 28 - 2 - 2	83 - 11 - 2 - 4	33 - 67 - 0 - 0 - 0	1.1	384
				Hole 1911				
Pierz	45-50	C	13 - 64 - 20 - 16	94 - 6 - 0 - 2	73 - 16 - 10 - 1	0	0.0	465
Pierz	55-60	C	13 - 65 - 18 - 17	94 - 6 - 0 - 2	72 - 20 - 6 - 2	0	0.0	479
				Hole 1912				
Meyer Lake	65-70	C	9 - 37 - 35 - 29	57 - 40 - 3 - 1	76 - 19 - 2 - 3	86 - 0 - 0 - 14 - 0	0.0	255
First Red	70-74	C	4 - 38 - 43 - 19	73 - 26 - T - 1	75 - 14 - 8 - 4	0 - 50 - 0 - 50 - 0	0.3	368
Eagle Bend	75-78	C	7 - 17 - 37 - 46	41 - 55 - 4 - T	85 - 14 - 1 - 1	100	0.0	430
Eagle Bend	78-80	C	4 - 18 - 31 - 51	35 - 60 - 5 - T	91 - 8 - 1 - 0	100	0.0	298
Eagle Bend	80-85	C	5 - 20 - 30 - 50	36 - 59 - 5 - 3	85 - 12 - 2 - 2	100	0.0	375
Eagle Bend	85-90	C	2 - 20 - 31 - 50	39 - 57 - 4 - 2	82 - 14 - 2 - 1	100	0.0	407
Eagle Bend	95-100	C	3 - 18 - 36 - 46	39 - 56 - 5 - 2	81 - 15 - 2 - 1	88 - 6 - 6 - 0 - 0	0.5	380
Eagle Bend	110-115	C	6 - 22 - 32 - 45	35 - 62 - 3 - 1	90 - 9 - 1 - 1	64 - 0 - 0 - 36 - 0	0.0	355
				Hole 1913				
Wadena	30-35	C	17 - 20 - 69 - 11	84 - 15 - 1 - 2	82 - 18 - T - 1	0 - 60 - 20 - 20 - 0	1.0	424
Green	60-65	C	8 - 36 - 41 - 23	48 - 51 - 1 - 1	82 - 13 - 2 - 3	0 - 0 50 - 50 - 0	0.3	298
Green	70-75	C	-	52 - 47 - T - 1	86 - 12 - 1 - 2	100	0.0	335
Meyer Lake	105-110	C	9 - 46 - 33 - 21	79 - 21 - T - 1	82 - 17 - 1 - 1	100	0.0	494
Meyer Lake	115-120	C	-	67 - 33 - 0 - 1	60 - 28 - 6 - 6	0	0.0	276
Meyer Lake	125-130	C	3 - 36 - 34 - 30	64 - 35 - 1 - T	75 - 16 - 6 - 3	67 - 0 - 33 - 0 - 0	0.3	397
Meyer Lake	155-160	C	5 - 35 - 27 - 37	50 - 44 - 6 - 1	79 - 17 - 1 - 3	73 - 0 - 10 - 7 - 10	0.6	484
Eagle Bend	165-170	C	-	39 - 58 - 3 - 8	80 - 15 - 2 - 3	100	0.0	266
Eagle Bend	180-185	C	2 - 18 - 33 - 49	39 - 54 - 7 - 2	84 - 13 - 2 - 2	96 - 4 - 0 - 0 - 0	0.2	412
Ealge Bend	190-195	C	-	41 - 55 - 5 - 2	76 - 19 - 0 - 6	100	0.0	319
Eagle Bend	205-210	C	2 - 18 - 34 - 47	45 - 47 - 8 - 2	90 - 8 - 0 - 2	75 - 0 - 12 - 12 - 0	1.0	296
Elmdale	220-225	C	-	72 - 18 - 10 - 12	89 - 3 - 0 - 8	100	0.0	237
				Hole 1999				
Pierz	55-60	C	-	98 - 2 - 0 - 1	66 - 18 - 9 - 6	0	0.0	283
Pierz	75-80	C	-	98 - 2 - T - T	70 - 13 - 9 - 7	0 - 0 - 0 - 0 - 100	0.0	406
Pierz	105-110	C	-	97 - 3 - 0 - 2	70 - 14 - 10 - 5	0	0.0	290
Pierz	120-125	C	-	97 - 3 - T - 1	73 - 16 - 7 - 4	0 - 0 - 0 -100	0.0	484
Wadena	160-165	C	-	84 - 15 - T - 1	72 - 17 - 6 - 5	0 - 0 - 0 - 0 - 100	0.0	285
Wadena	170-175	C	-	77 - 22 - T - 2	72 - 17 - 6 - 5	100	0.0	301
Eagle Bend	180-185	C	-	63 - 35 - 2 - 2	70 - 20 - 6 - 4	100	0.0	266
Eagle Bend	190-195	C	-	48 - 48 - 4 - 3	72 - 21 - 4 - 2	100	0.0	346
Eagle Bend	205-210	C	-	50 - 46 - 5 - 3	76 - 18 - 3 - 3	71 - 0 - 12 - 0 - 18	0.5	374
Eagle Bend	220-225	C	-	40 - 56 - 4 - 2	76 - 18 - 4 - 2	73 - 0 - 9 - 18 - 0	0.4	250

Till unit	Depth (feet)	Sample type	Texture G - S - Si - C	Lithology 1- to 2-mm sand pЄ - Pz - K - Oth	Lithology in % pЄ 1- to 2-mm sand Gr - D - R - Oth	Lithology in % K 1- to 2-mm sand L - Gs - Ss - P - Oth	Total shale %	Number grains counted
				Hole 2000				
Wadena	5-9	C	-	83 - 16 - 1 - T	82 - 15 - T - 2	100	0.0	255
Browerville	15-20	C	-	59 - 36 - 5 - 2	80 - 15 - 0 - 5	83 - 8 - 8 - 0 - 0	0.9	240
Browerville	35-40	C	-	66 - 30 - 3 - 2	84 - 14 - 0 - 1	71 - 0 - 14 - 14 - 0	0.4	238
Browerville	55-60	C	-	61 - 30 - 9 - 1	84 - 12 - 1 - 2	57 - 26 - 3 - 14 - 0	2.6	388
Meyer Lake	75-80	C	-	64 - 33 - 3 - 4	76 - 18 - 3 - 4	54 - 46 - 0 - 0 - 0	1.4	430
Meyer Lake	90-95	C	-	67 - 31 - 2 - 3	79 - 18 - 1 - 1	25 - 50 - 0 - 0 - 25	0.9	236
Meyer Lake	100-105	C	-	58 - 41 - 1 - 11	77 - 21 - T 2	0 - 50 - 0 - 0 - 50	0.3	393
Meyer Lake	105-110	C	-	56 - 41 - 3 - 4	76 - 18 - T - 6	78 - 0 - 11 - 11 - 0	0.3	365
Meyer Lake	110-115	C	-	58 - 39 - 2 - 28	79 - 18 - 0 - 3	25 - 62 - 12 - 0 - 0	1.8	458
Meyer Lake	120-125	C	-	53 - 46 - 1 - 7	82 - 12 - 2 - 4	100	0.0	374
Meyer Lake	129-135	C	-	56 - 40 - 4 - 12	80 - 17 - T - 2	43 - 7 - 7 - 29 - 14	0.5	423
First Red	150-155	C	-	72 - 25 - 3 - 5	69 - 19 - 6 - 6	62 - 12 - 0 - 25 - 0	0.4	290
First Red	160-165	C	-	74 - 26 - T - 5	64 - 17 - 12 - 7	0 -100	0.3	317
Eagle Bend	180-185	C	-	75 - 24 - 1 - 4	75 - 16 - 4 - 5	33 - 33 - 0 - 33 - 0	0.4	246
Eagle Bend	200-205	C	-	67 - 32 - 1 - 2	70 - 17 - 6 - 6	0 - 67 - 33 - 0 - 0	0.9	353
Eagle Bend	220-225	C	-	64 - 36 - T - 3	74 - 15 - 6 - 5	100	0.0	447
Eagle Bend	240-245	C	-	61 - 37 - 2 - 3	72 - 21 - 3 - 3	100	0.0	351
Eagle Bend	260-265	C	-	61 - 38 - 1 - 1	68 - 23 - 5 - 4	50 - 50 - 0 - 0 - 0	0.4	235
Second Red	275-280	C	-	67 - 32 - 1 - 3	74 - 17 - 4 - 4	75 - 25 - 0 - 0 - 0	0.4	288
Second Red	290-295	C	-	69 - 30 - T - 2	64 - 25 - 6 - 5	100	0.0	304
Second Red	300-305	C	-	65 - 33 - 2 - 1	68 - 20 - 5 - 8	62 - 12 - 0 - 0 - 25	0.2	474
				Hole 2001				
Pierz	5-10	C	-	99 - 1 - 0 - 5	76 - 8 - 7 - 8	0	0.0	260
Pierz	15-20	C	-	96 - 4 - 0 - 1	77 - 10 - 6 - 7	0	0.0	279
Pierz	25-30	C	-	94 - 6 - 0 - 2	69 - 12 - 11 - 8	0	0.0	224
Pierz	35-40	C	-	96 - 4 - T - 3	68 - 16 - 9 - 7	100	0.0	402
Wadena	40-45	C	-	85 - 15 - 0 - 2	72 - 14 - 5 - 8	0	0.0	258
Wadena	50-55	C	-	72 - 27 - 1 - 8	76 - 16 - 6 - 2	60 - 20 - 0 - 0 - 20	0.3	416
Eagle Bend	60-65	C	-	48 - 48 - 5 - 3	67 - 21 - 8 - 4	100	0.0	309
Eagle Bend	70-75	C	-	44 - 53 - 3 - 2	78 - 12 - 5 - 4	92 - 8 - 0 - 0 - 0	0.2	473
				Hole 2005				
Pierz	0-5	C	-	97 - 3 - 0 - 7	54 - 24 - 11 -10	0	0.0	335
Wadena	30-37	C	-	78 - 22 - 1 - 2	71 - 14 - 7 - 8	50 - 0 - 0 - 50 - 0	0.0	360
Wadena	41-45	C	-	80 - 18 - 2 - 5	87 - 8 - 2 - 4	83 - 0 - 17 - 0 - 0	0.3	350
Eagle Bend	50-55	C	-	46 - 50 - 4 - 3	89 - 9 - 1 - 1	89 - 11 - 0 - 0 - 0	0.4	265
Elmdale	65-70	C	-	69 - 11 - 20 - 9	86 - 10 - 1 - 3	77 - 1 - 10 - 7 - 4	2.3	387

				Hole 2007				
Pierz	5-10	C	-	91 - 8 - 1 - 2	56 - 26 - 11 - 7	100	0.0	370
Browerville	10-15	C	-	75 - 21 - 3 - 2	72 - 24 - 2 - 1	85 - 8 - 0 - 8 - 0	0.3	399
Browerville	20-25	C	-	66 - 28 - 6 - 3	68 - 23 - 3 - 5	47 - 53 - 0 - 0 - 0	3.0	341
Browerville	30-35	C	-	63 - 30 - 8 - 4	82 - 16 - T - 2	42 - 36 - 3 - 9 - 9	3.1	439
Meyer Lake	55-60	C	-	67 - 29 - 4 - 8	73 - 16 - 6 - 4	7 - 57 - 7 - 7 - 21	2.3	426
Meyer Lake	65-70	C	-	51 - 47 - 2 - 5	71 - 16 - 9 - 4	57 - 43 - 0 - 0 - 0	0.8	398
Meyer Lake	80-85	C	-	39 - 59 - 2 - 4	80 - 12 - 4 4	80 - 0 - 0 - 0 - 20	0.0	280
Eagle Bend	95-100	C	-	51 - 46 - 4 - 2	80 - 11 - 5 - 4	90 - 10 - 0 - 0 - 0	0.4	282
Elmdale	115-120	C	-	69 - 18 - 13 - 9	82 - 13 - 1 - 4	78 - 0 - 4 - 6 - 13	0.5	464
Elmdale	125-130	C	-	72 - 14 - 14 - 6	86 - 10 - 0 - 4	67 - 22 - 6 - 4 - 0	4.1	365
Elmdale	150-155	C	-	69 - 17 - 14 - 3	84 - 9 - 1 - 6	59 - 3 - 8 - 23 - 8	1.4	298
Elmdale	165-170	C	-	68 - 17 - 14 - 3	85 - 11 - T - 4	67 - 23 - 4 - 4 - 2	3.9	344
Elmdale	180-185	C	-	70 - 17 - 13 - 5	80 - 15 - T - 4	51 - 16 - 0 - 32 - 0	2.1	296
				Hole 2008				
Pierz	10-15	C	-	75 - 23 - 1 - 2	67 - 21 - 6 - 6	75 - 25 - 0 - 0 - 0	0.3	315
Wadena	25-28	C	-	65 - 34 - 1 - 1	81 - 13 - 2 - 3	75 - 0 - 0 - 25 - 0	0.0	386
Wadena	30-35	C	-	83 - 16 - 1 - 6	82 - 13 - 4 - 1	100	0.0	301
Wadena	35-40	C	-	89 - 11 - T - 8	82 - 12 - 2 - 4	100	0.0	565
Red Sandy	55-60	C	-	78 - 22 - 1 - 7	64 - 17 - 13 - 5	50 - 50 - 0 - 0 - 0	0.3	325
Red Sandy	65-70	C	-	65 - 34 - 2 - 10	71 - 17 - 8 - 4	100	0.0	301
Meyer Lake	75-80	C	-	60 - 40 - 0 - 4	65 - 24 - 4 - 8	0	0.0	324
Meyer Lake	85-90	C	-	58 - 42 - 1 - 3	67 - 20 - 6 - 6	100	0.0	533
Meyer Lake	95-100	C	-	57 - 43 - 0 - 5	72 - 18 - 6 - 4	0	0.0	365
First Red	106-110	C	-	79 - 21 - T - 2	65 - 17 - 14 - 4	100	0.0	478
Eagle Bend	120-123	C	-	67 - 31 - 2 - 4	74 - 13 - 10 - 3	86 - 0 - 0 - 14 - 0	0.0	376
				USGS Hole T2D				
Browerville	30-37	C	-	66 - 30 - 4 - 1	89 - 10 - 0 - T	43 - 36 - 0 - 7 - 14	1.6	322
Browerville	59-62	C	-	55 - 37 - 8 - 4	87 - 12 - 0 - 1	90 - 10 - 0 - 0 - 0	0.7	282
				USGS Hole T2B				
Meyer Lake	59-62	C	-	56 - 41 - 3 - 2	85 - 13 - 1 - 1	100	0.0	415
				USGS Hole TH-104				
Browerville	55-60	C	-	60 - 37 - 3 - 2	81 - 14 - 1 - 3	50 - 25 - 0 - 25 - 0	0.8	261

Till unit	Sample type	Texture G - S - Si - C	Lithology 1- to 2-mm sand p€ - Pz - K - Oth	Lithology in % p€ 1- to 2-mm sand Gr - D - R - Oth	Lithology in % K 1- to 2-mm sand L - Gs - Ss - P - Oth	Total shale %	Number grains counted
			Browerville Gravel Pit				
Browerville	O	-	70 - 25 - 5 - 2	83 - 14 - 0 - 4	43 - 43 - 7 - 0 - 7	2.4	296
Browerville	O	-	69 - 28 - 3 - 2	82 - 15 - 0 - 3	71 - 14 - 0 - 14 - 0	0.4	463
Browerville (pebbles)	O	-	50 - 44 - 6 - 0	-	50 - 33 - 17 - 0 - 0	2.8	108
			Two River Site				
Elmdale	O	-	71 - 14 - 16 - 13	88 - 10 - 0 - 2	52 - 44 - 0 - 0 - 4	6.9	385
Elmdale (pebbles)	O	-	46 - 20 - 34 - 7	-	68 - 32 - 0 - 0 - 0	11.0	88
			North Mankato Site				
North Mankato 45*	O	5 - 32 - 36 - 32	52 - 35 - 13	85 - 14 - 1		5.9	516
North Mankato 36	O	2 - 32 - 35 - 33	54 - 35 - 12	88 - 12 - 0		3.7	546
North Mankato 24	O	5 - 34 - 34 - 32	55 - 34 - 11	86 - 13 - T		5.6	740
North Mankato 20	O	3 - 31 - 36 - 33	46 - 37 - 16	87 - 12 - T		7.1	529
North Mankato 15	O	3 - 33 - 35 - 32	51 - 40 - 10	84 - 16 - 0		3.9	515
North Mankato 11	O	3 - 31 - 38 - 30	56 - 31 - 14	88 - 12 - 0		7.9	596
North Mankato 6	O	3 - 33 - 37 - 30	54 - 30 - 16	88 - 11 - 1		9.5	336
North Mankato 1	O	4 - 32 - 36 - 32	54 - 33 - 13	85 - 15 - T		5.7	617
North Mankato 0	O	4 - 53 - 26 - 21	58 - 36 - 6	88 - 12 - 0		3.4	617

*Height in feet above base of till which overlies sand.