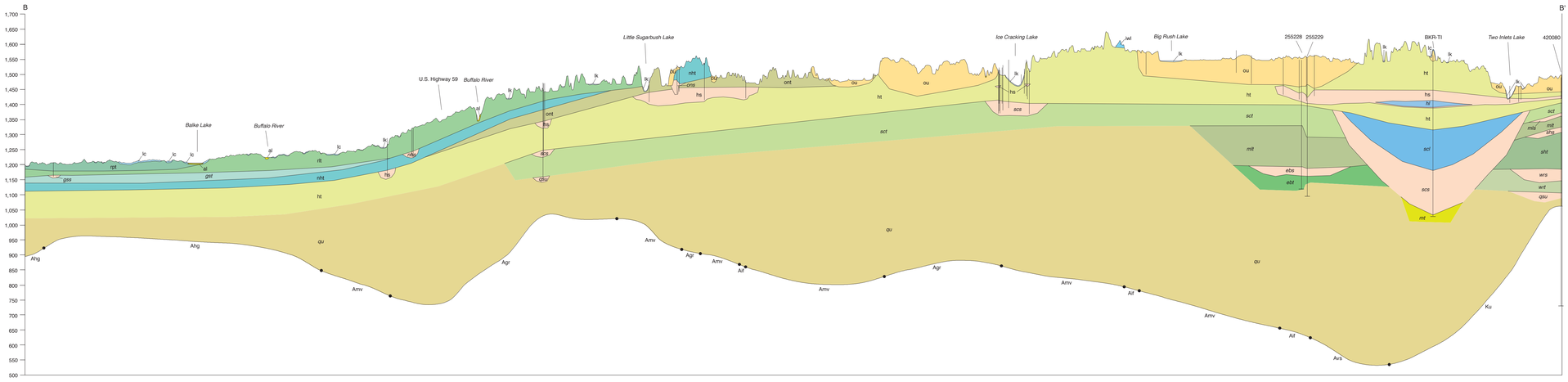
UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Harvey Thorleifson, Director

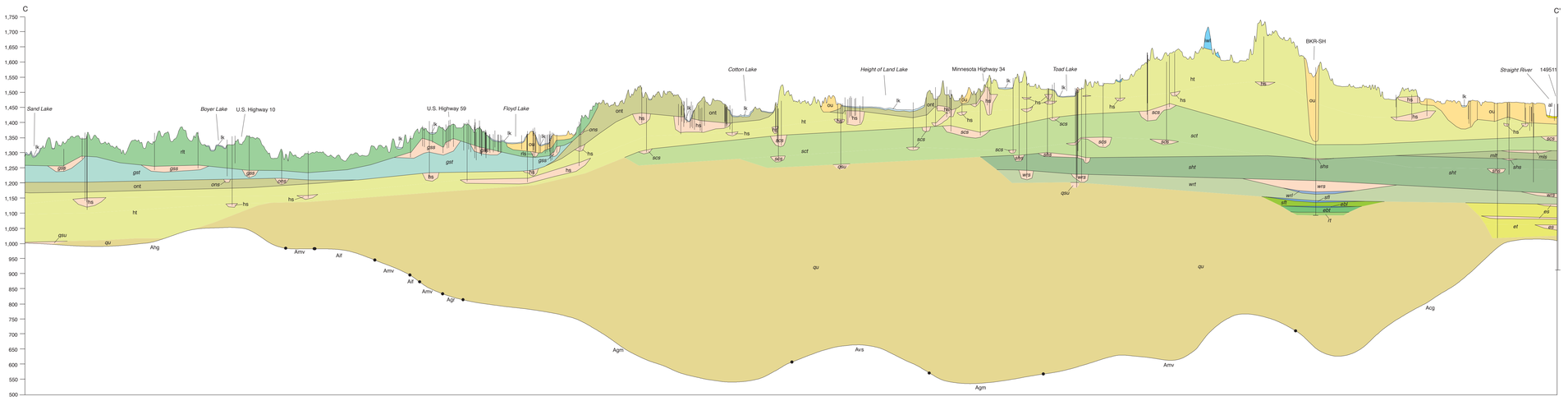
Prepared and Published with the Support of
THE BECKER COUNTY BOARD OF COMMISSIONERS
AND THE MINNESOTA ENVIRONMENT AND NATURAL RESOURCES TRUST FUND
AS RECOMMENDED BY THE LEGISLATIVE-CITIZEN COMMISSION ON MINNESOTA RESOURCES

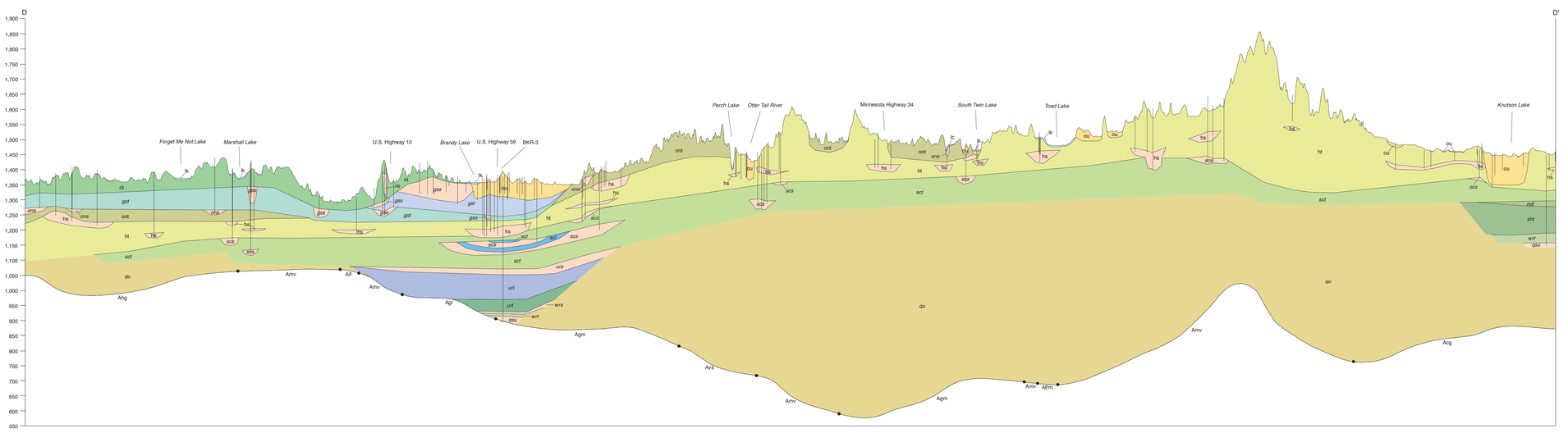
COUNTY ATLAS SERIES
ATLAS C-42, PART A
Becker County
Plate 4—Quaternary Stratigraphy

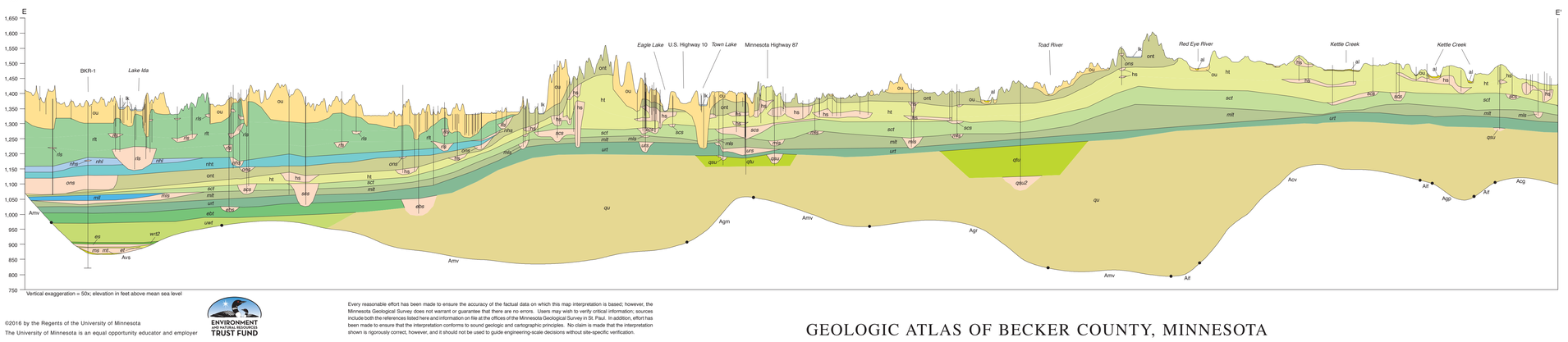







Vertical exaggeration = 50x; elevation in feet above mean sea level

# QUATERNARY STRATIGRAPHY

By

Angela S. Gowan and Katherine J. Marshall

2016

## INTRODUCTION

This Quaternary Stratigraphy plate shows the unconsolidated materials expected to be encountered between the land surface and bedrock surface in Becker County (Fig. 1; Plate 5, Fig. 1). Cross sections A–A' through E–E' are representative of the 50 west–east oriented cross sections at 0.6 mile (1 kilometer) spacing (Plate 5, Fig. 2) that were constructed to create a three-dimensional model of the Quaternary deposits of Becker County. Accompanying figures for the cross sections are shown on Plate 5, *Supplemental Quaternary Stratigraphy*, and in the digital data accompanying this atlas. The major sand and gravel bodies from this model are depicted on Plate 5, *Sand-Distribution Model*; the full model and all the cross sections used to develop it can be accessed through the digital files of the Minnesota Geological Survey. The Quaternary geologic units shown on the cross sections were defined from interpretation of new data collected for this study and from existing data from previous investigations. These include rotary-sonic drill core from three drill holes completed by the Minnesota Geological Survey for this project (BKR-1, BKR-2, BKR-3), one rotary-sonic drill hole completed as part of the Otter Tail Regional Hydrologic Assessment by the Minnesota Geological Survey (OTT-1; Harris and others, 1999), two rotary-sonic drill holes completed for another agency in eastern Becker County (BKR-TI, BKR-SH; Plate 5, Figs. 2, 6, 7), well cuttings descriptions, water-well drillers' logs, and bridge boring logs (Minnesota Department of Transportation, 2015; Plate 1, *Data-Base Map*).

The cross sections (A–A' through E–E') that appear on this plate show the rotary-sonic drill holes, which are the key stratigraphic control points in the county (Plate 5, Fig. 2). The core associated with each of these drill holes was logged and interpreted by Minnesota Geological Survey staff. Core logs for these borings are shown on Plate 5, Figures 3 through 7. In the cross sections, rotary-sonic holes, well cuttings sets, and water wells are shown as black vertical lines; the rotary-sonic holes and borings with cuttings sets are labeled. Where surface elevations differ from those at the cross-section line, these vertical lines may start above or below the land surface because the data are projected onto the cross section from a distance of up to 0.3 mile (0.5 kilometer), where the land surface may be higher or lower. Vertical exaggeration is 50x for all cross sections.

Some of the surficial units are modified from those on Plate 3, *Surficial Geology*. However, most of the units that appear on the cross sections are present in the subsurface only, and therefore are unique to this plate. Peat, wetland deposits, and beach sediments (units Qp, Qo, and Qb, respectively, on Plate 3) are too thin to show in cross section and are combined with the underlying surficial units as noted in the unit descriptions.

By convention, the name designations of buried sand and gravel bodies are associated with the underlying till. However, sand and gravel units are likely an admixture of material from immediately above or below the named unit. For example, sand unit aca is composed chiefly of outwash sediment laid down as the glacier that deposited unit *act* retreated. However, it may also include proglacial meltwater deposits from the advance of ice that deposited the overlying unit ht. Where a particular stratigraphic unit is absent from the section, the units immediately above and below that missing unit likely include eroded remnants that are not shown. Figure 1 on Plate 5, *Sand-Distribution Model*, shows the correlation of units mapped in Becker County with those mapped in adjacent Wadena (Lusardi and Marshall, 2016) and Clay (Gowan, 2014) Counties, where they can reasonably be made.

Previously unidentified lacustrine sediments were encountered in all five rotary-sonic cores collected for this study (see cross sections; Plate 5, Figs. 3 through 7). The tills encountered in rotary-sonic core BKR-2, located in the low relief, topographically lower, northwestern corner of the county (Plate 3, Fig. 1), were consistently finer-grained than they were in the other borings. This could indicate the presence of a series of glacial lakes in this region, the sediment from which was incorporated into the matrix of the tills. Although glacial Lake Agassiz did not extend into Becker County, smaller glacial lakes covered portions of the county at times. The extents of these lakes are most likely underrepresented on this plate due to the difficulty of identifying lake sediment using water-well records. Further study of these lacustrine sediments could provide additional information about the glacial history in the region, especially if climate information or age dates could be obtained from them.

Variations in the apparent complexity of subsurface units shown on the cross sections are partly a function of the amount of data available. Where the data are scarce, the cross section units are generally portrayed as continuous, with relatively uniform thicknesses and minimal elevation change. Where there are more data, units tend to be discontinuous and variable in thickness and elevation over relatively short distances—which reflects more accurately the complexity of glacial deposits, especially those that are older, more deeply buried, and extensively eroded and dissected. Where data are absent, below the depth of available water-well records and above the bedrock surface, the sediment is labeled "undifferentiated sediment" (unit *qu*). These factors should be kept in mind when viewing the cross sections. Diamicton units, interpreted to be glacial till, are extended across areas where there are little to no data but where it seems reasonable that the tills are continuous. Although sand bodies are not drawn in all of these areas, sand and gravel commonly occur at till boundaries and may, therefore, be encountered in future drill holes at the approximate depth of till contacts shown.

## DESCRIPTION OF CROSS SECTION UNITS

The units presented below were correlated to the regional glacial stratigraphy using information from Johnson and others (2016), the County Geologic Atlases for Clay (Gowan, 2014) and Wadena (Lusardi and Marshall, 2016) Counties, and other references as noted. Color, clast type percentages, matrix texture, and stratigraphic position were the primary characteristics used to distinguish and correlate units. Texture and composition can vary significantly within individual units, and units may overlap. Sediment colors presented below were described using the Munsell color system. Textures are based on the U.S. Department of Agriculture soil texture classification definitions. Unit labels shown in parentheses below indicate units from Plate 3, *Surficial Geology*.

lk — **Silt, clay, and loamy sand**—*Sediment beneath existing lakes.*

lc — **Silt, clay, and loamy sand** (predominantly map unit Ql with minor associated Qo and Qp)—*Post-glacial lake sediment.*

al — **Sand and gravel, sandy loam to silt loam** (predominantly mapped units Qa and Qb with minor associated Qo and Qp)—*Alluvium.*

ou — **Sand to gravelly sand** (predominantly mapped unit Qs with minor associated Qo and Qp)—*Undifferentiated outwash.*

iwl — **Silt, clay, and loamy sand** (predominantly map unit Qll with minor associated Qo and Qp)—*Ice-walled lake sediment.*

**Red Lake Falls Formation** (Harris and others, 1974)—Sediment deposited by ice of the Red River lobe (Fig. 1). The source area of the Red River lobe shifted during deposition of the Red Lake Falls Formation and is divided into two members, the Upper and Lower. The Upper member has a greater percentage of shale grains than does the Lower member, and contains more silt (Plate 5, Table 1). The Upper member has a mixed Riding Mountain/Winnipeg provenance and the Lower member has an unmixed Winnipeg provenance (Plate 5, Fig. 1).

**Upper member**

rpt — ***Clay loam diamicton*** (predominantly mapped units Qug and Qus with minor associated Qo and Qp)—Pebbly, unsorted; calcareous; generally light olive-brown (2.5Y 5/6) where oxidized and dark grayish-brown (2.5Y 4/2) where unoxidized. Approximately 30 feet (9 meters) of this unit occur in rotary-sonic core BKR-2, where its texture fines with depth (Plate 5, Fig. 4)—*Glacial till.*

**Lower member**

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

rlt — ***Clay loam diamicton*** (predominantly mapped units Qlg, Qls, and Qlw with minor associated Qo and Qp)—Unsorted; calcareous; generally very dark gray (2.5Y 3/1). Approximately 110 feet (34 meters) of this unit occur in rotary-sonic core BKR-1 (Plate 5, Fig. 3), which had thin, silty clay to silty clay loam inclusions between the depths of 110 and 130 feet (34 and 40 meters). Stratigraphic data from rotary-sonic cores and water-well records in Becker County indicate that there are commonly sand bodies within this till—*Glacial till.*

**Goose River formation—St. Hilaire member** (Johnson and others, 2016, Table 5)—Sediment deposited by ice of the Riding Mountain sourced Red River lobe. Unit was intersected in the subsurface in rotary-sonic cores BKR-2 and BKR-3 (Plate 5, Figs. 4, 5), but was not encountered at the surface in Becker County. This unit is identified on the basis of its stratigraphic position and moderate shale content (Plate 5, Table 1).

gsl — ***Silt and clay***—Rhythmically bedded, fines downwards, clay layers are typically dark gray and silt layers are dark grayish-brown—*Glacial lake sediment.*

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

gst — ***Clay loam diamicton***—Pebbly, unsorted; calcareous; very dark grayish-brown (2.5Y 3/2) to dark olive-gray (5Y 3/2). Unit is typically finer-grained in the northwest corner of Becker County, where it occurs as a silty clay loam in core BKR-2, and coarsens to the south and east in core BKR-3, where it has a loam texture—*Glacial till.*

**New Ulm Formation—Heiberg Member** (Johnson and others, 2016)—Sediment deposited by ice of the Riding Mountain sourced Des Moines lobe. Unit occurs in the subsurface in rotary-sonic cores BKR-1 and BKR-2 (Plate 5, Figs. 3, 4), and also in two small areas at the surface in Becker County (Plate 3). This unit is identified on the basis of its stratigraphic position and high shale content (Plate 5, Table 1).

nhl — ***Sand, silt, and clay***—Rhythmically bedded silt and clay with inclusions of sand and gravel, unit is dark olive-gray to dark grayish-brown. Approximately 20 feet (6 meters) were intersected in rotary-sonic core BKR-2 (Plate 5, Fig. 4); the unit is finer-grained with depth—*Glacial lake sediment.*

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

nht — ***Loam diamicton*** (predominantly mapped unit Qns with minor associated Qo and Qp)—Unsorted, pebbly; calcareous; grayish-brown (2.5Y 5/2) to dark grayish-brown (2.5Y 4/2). Approximately 40 feet (12 meters) of this unit are present in core BKR-1 (Plate 5, Fig. 3) and 45 feet (13 meters) in core BKR-2 (Plate 5, Fig. 4)—*Glacial till.*

**Otter Tail River formation—New York Mills member** (Johnson and others, 2016, Table 5)—Sediment deposited by ice of the Riding Mountain/Winnipeg sourced Red River lobe. A very thin layer of this unit was intersected in the subsurface in rotary-sonic core BKR-1 (Plate 5, Fig. 3), but it occurs in a broad band at the surface in Becker County. This unit is identified on the basis of its stratigraphic position, high amount of crystalline grains, and low shale content (Plate 5, Table 1).

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

ont — ***Sandy loam diamicton*** (predominantly mapped units Qoc and Qos with minor associated Qo and Qp)—Unsorted, pebbly; calcareous; grayish-brown (2.5Y 5/2)—*Glacial till.*

**Hewitt Formation** (Johnson and others, 2016)—Sediment deposited by the Rainy sourced Wadena ice lobe. Unit was intersected in the subsurface in all five rotary-sonic cores with thickness ranging from 2 feet (0.6 meter) in core BKR-1 to 220 feet (67 meters) in core BKR-TI (Plate 5, Figs. 3 through 7), and commonly occurs at the surface in eastern Becker County. This unit is identified on the basis of its sandy loam texture and lack of shale (Plate 5, Table 1).

hl — ***Silt and clay***—Gray; identified in water-well drillers' logs and from a previously described rotary-sonic core (unique number 251484; Harris and others, 1999)—*Glacial lake sediment.*

hs — ***Sandy to gravelly sand***—*Outwash.*

ht — ***Sandy loam diamicton*** (predominantly mapped units Qhc, Qhg, and Qhs with minor associated Qo and Qp)—Pebbly, unsorted; calcareous; the matrix color is light yellowish-brown (2.5Y 6/4) where oxidized and dark olive-gray (5Y 3/2) to very dark grayish-brown (2.5Y 3/2) where unoxidized—*Glacial till.*

**Lake Henry Formation** (Johnson and others, 2016)—Sediment deposited by Winnipeg sourced ice. The formation is divided into two Members: the Sauk Centre and Meyer Lake. The members of the Lake Henry Formation are similar in texture; however, the Meyer Lake Member is generally finer-grained than the Sauk Centre Member (Plate 5, Table 1). Additionally, the Sauk Centre Member contains more carbonate clasts, averaging almost 50 percent, compared to 36 percent for the Meyer Lake Member. The two members of the Lake Henry Formation are typically separated by the uppermost red till of the St. Francis Formation (Plate 5, Fig. 1). The upper St. Francis Formation till was not identified in cores or in water-well records in Becker County.

**Sauk Centre Member**—Unit was intersected in the subsurface in all rotary-sonic cores except BKR-2, with thickness ranging from 20 feet (6 meters) in core BKR-1 to 285 feet (87 meters) of outwash and lacustrine sediments in core BKR-TI (Plate 5, Figs. 3, 5, 6, 7).

scl — ***Fine-grained sand and silt***—Laminated, dark olive-gray (5Y 3/2); becomes finer-grained with depth; calcareous. Core BKR-TI (Plate 5, Fig. 7) contains approximately 48 feet (15 meters) of shells and wood fragments from this unit in three zones: 244 to 264 feet (74.4 to 80.5 meters), 312 to 327 feet (95.1 to 99.7 meters), and 365 to 378 feet (111.3 to 115.2 meters)—*Glacial lake sediment.*

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

sct — ***Loam diamicton***—Pebbly, unsorted; calcareous; matrix color is light brownish-gray (10YR 6/2) to grayish-brown (10YR 5/2) where oxidized and dark grayish-brown (10YR 4/2) where unoxidized. In rotary-sonic core BKR-3, this unit is interbedded in places with sand and gravel outwash and silt and clay lacustrine sediments (Plate 5, Fig. 5)—*Glacial till.*

**Meyer Lake Member**—Unit only is present in rotary-sonic core BKR-1 (Plate 5, Fig. 3), but was also detected in several well cuttings sets.

mll — ***Silt with clay***—Gray; laminated; calcareous—*Glacial lake sediment.*

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

mlt — ***Silt loam diamicton***—Pebbly, unsorted; calcareous; the matrix color is light brownish-gray (2.5Y 6/2). Contains wood fragments in places—*Glacial till.*

**Smoky Hills formation**—Sediment deposited by Riding Mountain sourced ice. This unit is distinctive in its stratigraphic position and higher shale content, which had been thought to be restricted to younger units, especially of the New Ulm and Goose River formations (Plate 5, Table 1). Based on discrete increases of shale and total Cretaceous content with depth (Plate 5, Table 1), this publication divides the Smoky Hills formation into three members: the Upper, Middle, and Lower. These members are undivided on the cross sections. The average ratio of total Cretaceous to shale grains is almost 2:1, also distinguishing it from younger units where the shale percentage is typically 80 to 90 percent of the total Cretaceous grains. Texturally, the Upper member till is sandier, with a loam texture, and the lower two member tills are finer-grained clay loam. This unit was first identified in rotary-sonic core BKR-SH (Plate 5, Fig. 6), where 70 feet (21 meters) were recovered, and also in a Becker County water-well cuttings set (unique number 241269), where 55 feet (17 meters) were described. It has also been tentatively identified in rotary-sonic borings in Renville, Redwood, and Stearns Counties. This new interpretation is not reflected in previously published maps for these counties.

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

sht — ***Loam to clay loam diamicton***—Pebbly, unsorted; calcareous; the matrix color varies from dark grayish-brown (2.5Y 4/2) to very dark grayish-brown (2.5Y 3/2)—*Glacial till.*

**Unnamed formation of Rainy provenance**—Sediment deposited by Rainy sourced ice. Unit was intersected in rotary-sonic borings BKR-1 and BKR-3 (Plate 5, Figs. 3, 5).

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

url — ***Silt and clay loam***—Laminated; calcareous; olive-gray, fines with depth. This unit was intersected only in rotary-sonic core BKR-3, from 334 to 407 feet (102 to 124 meters) deep (Plate 5, Fig. 5). It contains wood and shell fragments throughout—*Glacial lake sediment.*

urt — ***Sandy loam diamicton***—Pebbly, unsorted; calcareous; grayish-brown (2.5Y 5/2) to light grayish-brown (2.5Y 6/2). Approximately 10 feet (3 meters) were intersected in rotary-sonic core BKR-1, and 40 feet (12 meters) in BKR-3 (Plate 5, Figs. 3, 5)—*Glacial till.*

**Unnamed formation of Winnipeg/Rainy provenance**—Sediment deposited by Winnipeg/Rainy sourced ice. Unit was intersected in rotary-sonic borings BKR-3 and BKR-SH (Plate 5, Figs. 5, 6).

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

wrl — ***Silt and clay***—Dark gray; laminated; calcareous—*Glacial lake sediment.*

wrt — ***Loam diamicton***—Pebbly, unsorted; calcareous; the matrix color is grayish-brown (2.5Y 5/2) to light grayish-brown (2.5Y 6/2)—*Glacial till.*

**St. Francis Formation** (Johnson and others, 2016)—Sediment deposited by Superior sourced ice. Regionally, the St. Francis Formation consists of two distinct till layers; the upper layer separates members of the Lake Henry Formation and the lower layer occurs under the Meyer Lake Member of the Lake Henry Formation. Only the lower till (unit *sft*) was identified and sampled in Becker County.

sft — ***Silty clay loam***—Light gray, calcareous. This unit was intersected in rotary-sonic core BKR-SH (Plate 5, Fig. 6) and was identified further east in Wadena County in rotary-sonic core WAD-3 (Lusardi and Marshall, 2016)—*Glacial lake sediment.*

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

sft — ***Silty clay loam diamicton***—Pebbly, unsorted, calcareous; averages 11 percent red clasts. The color of the matrix is dark grayish-brown (10YR 4/2) to dark brown (10YR 3/3) where unoxidized. In Becker County, this unit was only intersected in core BKR-SH (Plate 5, Fig. 6), but was also described in Wadena County in rotary-sonic cores WAD-1 and WAD-3 (Lusardi and Marshall, 2016)—*Glacial till.*

**Eagle Bend Formation** (Johnson and others, 2016)—Sediment deposited by Winnipeg-provenance ice. Unit occurs in rotary-sonic borings BKR-1 and BKR-SH (Plate 5, Figs. 3, 6).

ebl — ***Silt and clay***—Laminated to massive; black (5Y 2.5/1 to 2.5/2); silty sand layers above and below. Unit occurs in rotary-sonic core BKR-SH (Plate 5, Fig. 6). *Glacial lake sediment.*

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

ebt — ***Loam diamicton***—Pebbly, unsorted; calcareous; matrix color is grayish-brown (2.5Y 5/2) where oxidized to dark grayish-brown (2.5Y 4/2) where unoxidized. Approximately 60 feet (18 meters) of this unit occur in core BKR-1, and 5 feet (1.5 meters) in core BKR-SH—*Glacial till.*

**Second red till** (Meyer, 1986)—Sediment deposited by Superior sourced ice. Unit was intersected in rotary-sonic boring BKR-SH (Plate 5, Fig. 6) and also in a Hubbard County water-well cuttings set (unique number 420078) just east of Becker County, where 95 feet (29 meters) were described.

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

rt — ***Clay loam diamicton***—Pebbly, unsorted; calcareous; generally light olive-brown (2.5Y 5/6) where oxidized and dark grayish-brown (2.5Y 4/2) where unoxidized; averages 14 percent red clasts—*Glacial till.*

**Unnamed formation of Winnipeg provenance**—Sediment deposited by Winnipeg sourced ice. Unit occurs in rotary-sonic boring BKR-1 (Plate 5, Fig. 3).

uwt — ***Loam diamicton***—Pebbly, unsorted; highly calcareous, averages greater than 60 percent carbonate clasts (Plate 5, Table 1); matrix color is light yellowish-brown (2.5Y 6/4) where oxidized to grayish-brown (2.5Y 5/2) where unoxidized—*Glacial till.*

**Unnamed formation of Winnipeg/Rainy provenance 2**—Sediment deposited by mixed Winnipeg/Rainy sourced ice. Unit is present in rotary-sonic boring BKR-1 (Plate 5, Fig. 3).

wrt2 — ***Clay loam diamicton***—Pebbly, unsorted; calcareous; finer-grained and contains slightly fewer dark grains than unit *wrt* (Plate 5, Table 1); matrix color is dark grayish-brown (2.5Y 4/2)—*Glacial till.*

**Elmdale Formation** (Johnson and others, 2016)—Sediment deposited by Winnipeg sourced ice. Unit occurs in rotary-sonic boring BKR-1 (Plate 5, Fig. 3).

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

et — ***Loam diamicton***—Pebbly, unsorted; calcareous; matrix color is olive-yellow (2.5Y 6/6) where oxidized to grayish-brown (2.5Y 5/2) where unoxidized—*Glacial till.*

**Mulligan Formation** (Johnson and others, 2016)—Sediment deposited by Rainy sourced ice. Unit occurs in rotary-sonic borings BKR-1 and BKR-TI (Plate 5, Figs. 3, 7).

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

mt — ***Sandy loam diamicton***—Pebbly, unsorted; calcareous; matrix color is light yellowish-brown where oxidized and gray to dark gray where unoxidized. Identified near the bottom of rotary-sonic cores BKR-1 and BKR-TI (Plate 5, Figs. 3, 7)—*Glacial till.*

**Undifferentiated Quaternary deposits**

qsu — ***Undifferentiated sand and gravel***—Identified in County Well Index well logs, but unit lacks stratigraphic framework for reliable naming. May include till in places—*Outwash.*

qtu — ***Undifferentiated diamicton***—Identified in County Well Index well logs, but unit lacks stratigraphic framework for reliable naming. May include outwash in places—*Glacial till.*

qu — ***Undifferentiated sediment***—Locally includes till, sand, gravel, and/or fine-grained lake sediments. Shown in areas where control data are scarce or absent.

## CROSS SECTION SYMBOLS

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

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

**Drill hole**—The top of the drill hole may not coincide with the cross section surface elevation line because the drill hole may be located near (commonly within 0.3 mile [0.5 kilometer]) but not on the cross section line and therefore may have a slightly different surface elevation. Minnesota Geological Survey unique well numbers and names are given for rotary-sonic drill holes, for which logs are provided on Plate 5, Figures 3 through 7, and for cuttings sets that were described. Those scientific drill holes are shown with a foot.




**Figure 1.** Location of major provenances and the distribution of ice-lobe materials at the land surface. Glacial sediments derive their distinct material from bedrock and sediment in the region of these source areas. Generalized ice flow directions are shown by arrows. The extent of Riding Mountain provenance Des Moines and Koochiching lobe and associated sublobe deposits is shown in shades of green. The surface extent of the Rainy provenance Wadena, Brainerd, and Rainy lobe deposits is shown in shades of brown. The extent of Superior lobe deposit is shown in pink. Moraines are indicated by the labeled dotted or dashed lines.

## ACKNOWLEDGEMENTS

Rotary-sonic drilling was conducted by Traut Companies. Minnesota Geological Survey staff members Emily Bauer, Meagan Harold, Matthew Porter, and Brittany Wagner provided essential support during rotary-sonic drilling. Thanks are extended to all landowners who allowed drilling on their property. Angela Berthold and Kaleb Wagner assisted with logging the rotary-sonic drill core. Amie Staley assisted with figure preparation.

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# GEOLOGIC ATLAS OF BECKER COUNTY, MINNESOTA