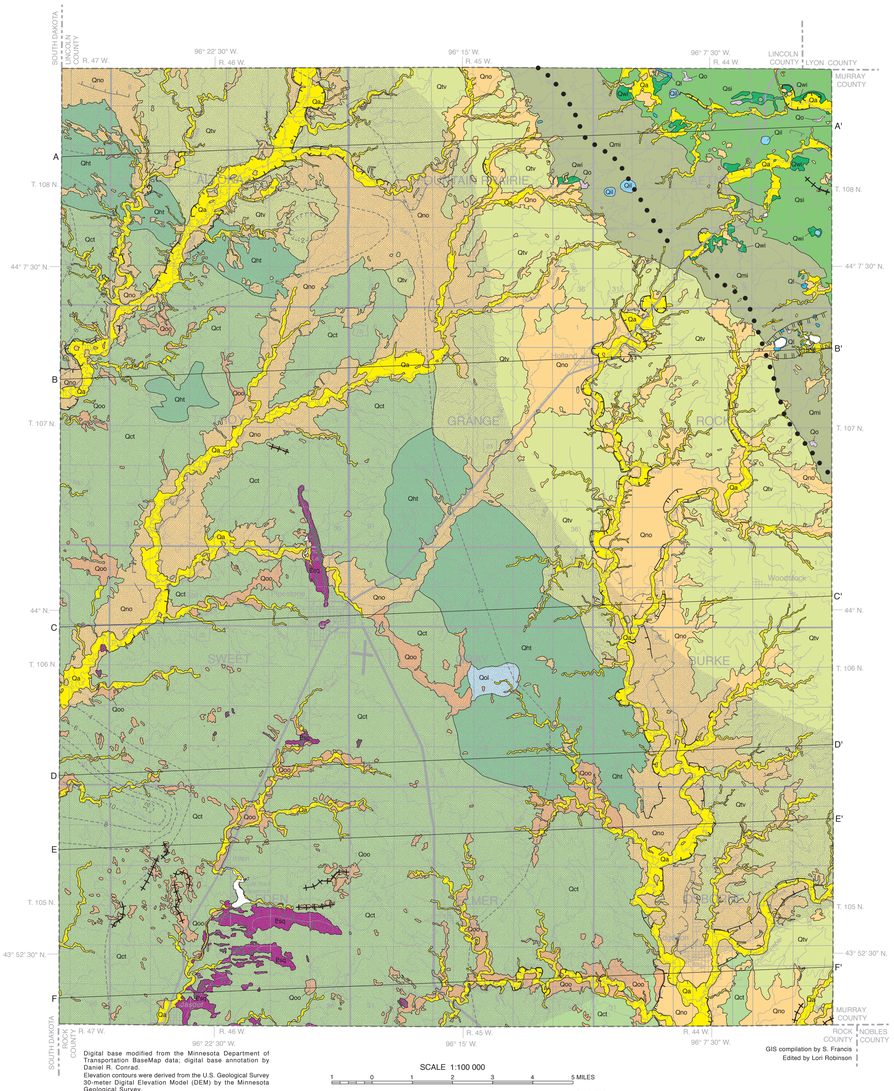
UNIVERSITY OF MINNESOTA
MINNESOTA GEOLOGICAL SURVEY
Anthony C. Runkel, Interim Director

Prepared and Published with the Support of
THE PIPESTONE 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-59, PART A
Pipestone County
Plate 3—Surficial Geology



Digital base modified from the Minnesota Department of Transportation BaseMap data; digital base annotation by Daniel R. Conrad.
Elevation contours were derived from the U.S. Geological Survey 30-meter Digital Elevation Model (DEM) by the Minnesota Geological Survey.
Universal Transverse Mercator Projection, grid zone 15
1983 North American Datum

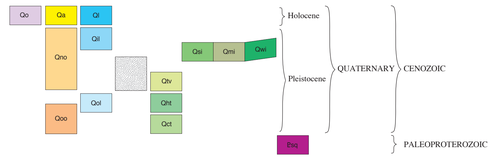
SCALE 1:100 000

CONTOUR INTERVAL 20 METERS

GIS compilation by S. Francis
Edited by Lori Robinson

LOCATION DIAGRAM

CORRELATION OF MAP UNITS



MAP SYMBOLS

Geologic contact—Approximately located.

Loess thickness—Approximately located, shown at variable foot contour intervals. Hachures point to areas of thinner loess.

Bemis moraine—Dots mark the moraine crest.

Ridge—Elongate or curvilinear ridge; up to 1.7 miles (2.7 kilometers) long with up to 30 feet (9 meters) of relief. May be composed of till or sorted sediments. The ridges may be related to subglacial drainage processes, formed while ice advanced, or they may be related to erosion by meltwater while ice receded.

Stream-cut scarp—Marks the bank of a former fluvial channel. Hachures point down scarp.

Relict scarp—Less distinctly visible, marks the bank of a former fluvial channel. May be loess-draped. Hachures point down scarp.

Broad, irregular trough—Trough is likely a former tunnel valley, a subglacial drainage channel of the Des Moines lobe. Only one was identified in the northeastern part of the county, occupying the Engbarth Slough. Hachures point down scarp.

Bedrock outcrop—See plate 2, *Bedrock Geology*, for details.

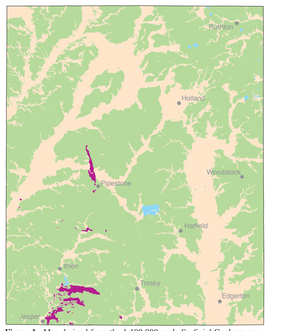


Figure 1. Map derived from the 1:100,000-scale Surficial Geology map showing map units combined into four simplified units: bedrock (purple), very low-permeability silt and clay (lake sediment; blue); low permeability diamicton (glacial till; green); and very permeable bedded sand to gravel (outwash and alluvium; tan). Scale is 1:300,000.

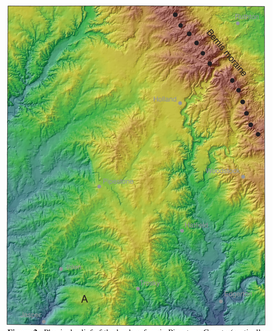
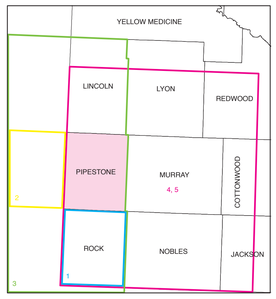


Figure 2. Physical relief of the land surface in Pipestone County (vertically exaggerated 7.5x). Elevation is shown by color: red-orange (higher elevation) grading to blue (lower elevation). Elevation ranges from 1,994 to 1,531 feet (607 to 466 meters) above sea level. A false-sun illumination at an elevation of 30° from the northwest (315°) provides contrast to accent landform details. This map was created using the U.S. Geological Survey's digital elevation model with a 10-meter grid; scale 1:300,000. The northeast corner of the county is highlighted by the prominent northwest–southeast-trending Bemis moraine. The youngest glacial sediments at the surface are northeast of the moraine, where the topography is very hummocky. To the west, the county is covered by glacial materials that are older and are dissected by a well-developed network of streams. Another notable feature in the county is near Jasper and Ihlen (marked with the letter A), where there is a smooth, rounded area of Sioux Quartzite outcrop and shallow subcrop.



INDEX TO PREVIOUS MAPPING

Numbers for previous mapping projects correspond with those listed in the references.

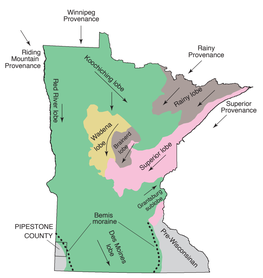


Figure 3. Location of major provenances and the distribution of ice-lobe materials at the land surface in Minnesota. Glacial sediments acquired their distinct material content from bedrock and sediment found in these provenances. The extent of Des Moines-, Red River- and Koochiching-lobe (all of Riding Mountain provenance) deposits is shown in green. The surface extent of the Wadena-lobe (Rainy provenance) deposits is shown in tan, Rainy- and Brainerd-lobe (Rainy provenance) deposits in brown, and Superior-lobe deposits in pink. The Bemis moraine is indicated by the labeled, dotted line. Pre-Wisconsinan aged materials are gray.

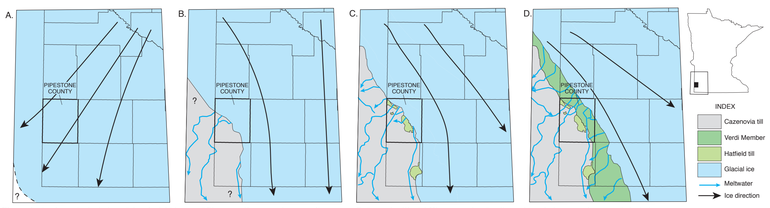


Figure 4. A schematic depiction of the glacial history of Pipestone County and surrounding areas. Refer to the Glacial History section for discussion relating to each stage of glaciation.

A. Rainy-provenance ice advanced from the northeast and deposited the oldest pre-Wisconsinan glacial sediment, the Cazenovia till, at the surface in Pipestone County (unit Qct). The ice margin outside of Minnesota is unknown. Deposition ended prior to 458,000 ± 66,000 YBP, based on an IRSL age acquired below the Cazenovia till (Plate 4).

B. After an indeterminate amount of time, Winnipeg-provenance glacial ice advanced from the north–northwest to the center of the county, depositing the Hatfield till (unit Qht). The ice margin outside of Minnesota is unknown.

C. Des Moines-lobe ice advanced from the north–northwest. The Verdi Member of the New Ulm Formation was deposited (unit Qtv). Estimated to be 34,000 to 25,000 cal YBP (Clayton and Moran, 1982; Kerr and others, 2021).

D. Des Moines-lobe ice readvanced from the north and northwest, where it deposited the Ivanhoe Member of the New Ulm Formation and created the Bemis moraine (units Qsi, Qmi, Qwi). Estimated age is approximately 17,250 cal YBP (Kemmis and others, 1981).

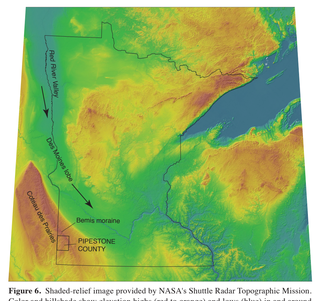


Figure 6. Shaded-relief image provided by NASA's Shuttle Radar Topographic Mission. Color and hillshade show elevation highs (red to orange) and lows (blue) in and around Minnesota. The Coteau des Prairies stands out prominently in the southwest, with the dark orange ridge of the Bemis moraine prominent in Pipestone County. The Des Moines lobe followed the low-lying path southward along the Red River Valley and then was diverted to the southeast by the Coteau des Prairies.

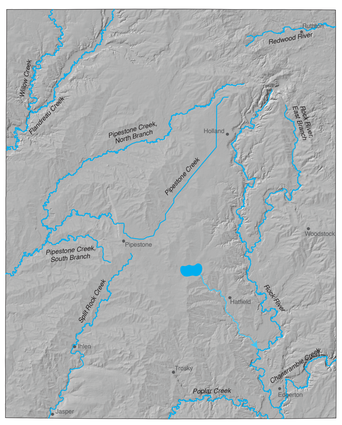


Figure 5. Modern drainage pathways and major streams in Pipestone County (see text for descriptions). The outlined lake basin is pre-Wisconsinan in age (unit Qol).

Table 1. Provenance and physical characteristics of glacial deposits in Pipestone County. Deposits are present at the surface except for those in gray, which were not encountered but are thought to be present in the subsurface (see Plate 4, *Quaternary Stratigraphy*).

SOURCE AREA PROVENANCE	NORTHWEST RIDING MOUNTAIN	NORTH–NORTHWEST WINNIPEG	NORTH–NORTHEAST RAINY	NORTHEAST SUPERIOR
LOBE (Formation)	Des Moines (New Ulm)	Pre-Wisconsinan (unnamed)	Pre-Wisconsinan (unnamed)	Pre-Wisconsinan (unnamed)
TILL TEXTURE	Loam to silt loam to clay loam	Loam to silt loam to clay loam	Clay loam to loamy sand	Loam to sandy loam
TILL COLOR				
Oxidized	Light olive-brown	Olive-brown	Olive-brown	Brown to red-brown
Unoxidized	Dark grayish-brown	Very dark grayish-brown	Very dark grayish-brown	Gray to red-gray
PEBBLE TYPE				
Carbonate	Common	Common to abundant	Rare to common	Rare to common
Gray-green rock	Uncommon to common	Uncommon to common	Uncommon to common	Common
Red felsite	Absent to rare	Absent to uncommon	Rare to common	Common
Gray shale	Uncommon to abundant	Absent to uncommon	Absent	Absent
Clear quartz	Common	Common to abundant	Common	Common

Table 2. Average values for the matrix texture and composition of sediments recognized in Pipestone County at or near the surface. Matrix texture (the less than 2-millimeter grain-size fraction of the sample) is expressed as relative proportions of sand, silt, and clay in percent. The lithologic composition of the very coarse-grained sand fraction (1-2 millimeters) is expressed in percent as relative proportions of crystalline rocks, carbonate rocks, and shale fragments using the classification system of Hobbs (1998). The Precambrian 1-2 millimeter fraction is further differentiated by rock type—light (granite and gneiss, monomineralic quartz), dark (mafic-rich igneous and metamorphic rocks), and red (rhyolite, sandstone, and iron formation). The lithologic composition can also be divided into relative proportions of grains based on age—Precambrian, Paleozoic, and Cretaceous (see Hobbs, 1998 for rock types included in these categories).

		MATRIX TEXTURE				CLAST TYPE									
		Percentage of the less than 2 millimeter fraction				Percentage of total grains counted of the 1-2 millimeter fraction						Percentage of total crystalline grains counted			Percentage of lights
Deposit description and geologic units	Total number of samples	Gravel (percentage of total sample weight)	Sand	Silt	Clay	Average USDA Texture	Total number of samples	Precambrian	Paleozoic	Cretaceous	Crystalline	Carbonate	Shale	Lights	Darks	Reds	Clear quartz
Holocene deposits															
Floodplain alluvium (unit Qa)	*4*	0	45	37	18	Loam									
Late Wisconsinan deposits															
Peoria Formation, loess	*31*	0	10	63	27	Silty clay loam									
New Ulm Formation															
Outwash, undifferentiated (unit Qno)	*27*	20	71	21	8	Sandy loam	*24*	67	27	6	67	30	3	89	11	0	10
Ivanhoe Member till (units Qmi, Qsi, Qwi)	*5*	4	27	44	29	Clay loam	*5*	60	32	8	60	34	6	89	11	0	11
Verdi Member till (unit Qtv)	*75*	4	28	45	27	Loam/clay loam	*73*	43	38	19	43	41	16	89	11	0	12
Pre-Wisconsinan deposits															
Outwash, undifferentiated (unit Qoo)	*11*	13	79	16	5	Loamy sand	*11*	82	16	2	72	17	1	86	13	1	10
Hatfield till (unit Qht)	*70*	3	22	53	25	Silt loam	*38*	47	44	9	47	47	6	87	12	1	9
Cazenovia till (unit Qct)	*114*	3	30	39	31	Clay loam	*49*	72	22	6	72	25	3	87	12	1	10

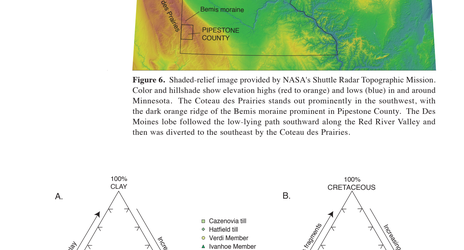


Figure 7. Ternary diagrams showing the texture and composition of till samples mapped at the surface in Pipestone County.

A. Matrix texture (less than 2-millimeter grain-size fraction). Includes Peoria Formation samples.

B. Composition of the very coarse-grained (1-2 millimeters) sand fraction (after Hobbs, 1998).

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

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ENVIRONMENT and NATURAL RESOURCES TRUST FUND

SURFICIAL GEOLOGY

By

Daniel R. Conrad and Angela S. Gowan

2024

INTRODUCTION

This map shows the spatial distribution of geologic materials expected to be at or near the land surface, but below the topsoil, in Pipestone County, Minnesota. The distribution of these sediments is simplified in Figure 1. These materials are predominantly glacial sediments known to reach thicknesses of 701 feet (213.6 meters) based on water-well records and passive seismic data (see Plate 6, *Bedrock Topography* and *Depth to Bedrock*). Bedrock is commonly exposed in central and southwestern Pipestone County (particularly in Pipestone National Monument, Split Rock Creek State Park, and near the city of Jasper), where glacial sediments are thin to absent; elsewhere outcrops are rare. Map-unit delineation and landform distribution were based on 1-meter resolution lidar elevation imagery collected in 2010 (available from the Minnesota Department of Natural Resources <http://www.mngeo.state.mn.us/chouse/elevation/lidar.html>), a 10-meter digital elevation model (Fig. 2), the Pipestone County soil survey map (Natural Resources Conservation Service, 2019), and previous studies (see Index to Previous Mapping). The geologic interpretations were drawn using geographic information system (GIS) software over the lidar imagery. To aid the delineation of map units, various datasets were consulted including well logs on file in the Minnesota County Well Index (CWI) and the Quaternary Data Index (QDI, an internal working database at the Minnesota Geological Survey that includes geologic descriptions and textural, lithologic, and stratigraphic data), and Minnesota Department of Transportation bridge boring records (contained within QDI). Fieldwork for this study was conducted during 2018, 2019, and 2020. Twenty-eight new exposures were sampled and described; these consisted of excavations that included gravel pits and road cuts. These were supplemented with 74 two-inch auger borings drilled to an average depth of about 15 feet (4.6 meters), and two, four-inch-diameter rotary-sonic drill cores drilled to depths of 159 to 300 feet (48.5 to 91.4 meters; PSR-1, PSR-2 on Plate 4, *Quaternary Stratigraphy*). Additional data from previous mapping (Patterson, 1995, 1997) were included in the analyses and interpretation of map units. A total of 311 new and 91 previously collected near-surface samples were analyzed for texture and composition.

GLACIAL HISTORY

The start of the Quaternary Period and Pleistocene Epoch was marked by glaciations in the northern hemisphere, which began about 2.6 million years ago. Like most of Minnesota, Pipestone County was repeatedly covered by ice and debris of advancing and retreating glaciers throughout this time. Episodic warming events that interrupted cold periods are called interglacials. During interglacials, conditions were favorable for plants and animals to repopulate the region and soils could form. In some locations, these ancient soils have been preserved through burial by glacial debris (locally seen in shallow borings in southwestern Minnesota, where they developed at the top of map unit Qct [Patterson, 1997]). These ancient buried soils are referred to as paleosols. Their preservation in outcrops or drill core in Pipestone County is indicative of an interglacial, and represents an area where the glacier could have advanced over the paleosol but did not deeply erode the substrate, or where a glacier had never advanced before.

Glaciers advanced into Minnesota from different directions, typically following routes of preexisting low topography, and left behind sediment of different colors and rock-type (lithologic) compositions. Most of these sediments are diamicton (poorly sorted sediment, ranging from clay to boulders) that has been interpreted to be glacial till (sediment transported and deposited by glacial ice). Differences in lithologic composition indicate the provenance from which they originated due to distinct up-ice bedrock lithology (Fig. 3; Table 1). The most recent glacial period, known as the Wisconsinan Episode, lasted from about 75,000 years ago to the start of the Holocene Epoch, 11,700 years ago. The Holocene Epoch marks the end of glaciation in Minnesota and the transition to warmer, present-day conditions.

Pre-Wisconsinan glaciation

Pre-Wisconsinan ice advances came from the northwest, north, and northeast (Fig. 4), leaving behind a thick sequence of glacial sediments. The glacial deposits at the surface in Pipestone County decrease in age from southwest to northeast, some being deposited before the Wisconsinan Episode, which began 75,000 calendar years before present (cal YBP; Johnson and others, 1997). Key indications for this time frame include a more mature landscape marked by the absence of lakes and the presence of a well-developed dendritic stream system with sharp ridges dividing stream valleys; and the significant thicknesses of wind-blown silt or loess. In Pipestone County, there are two advances that left glacial sediment at the surface during the pre-Wisconsinan glaciation. Older advances and their deposits in the subsurface are discussed on Plate 4, *Quaternary Stratigraphy*.

The oldest unit preserved at the surface in Pipestone County is the Cazenovia till (unit Qct; Gowan, 2020). The Cazenovia till was deposited after the underlying Magnolia till by a glacier that advanced from the northeast, covering the entire county and extending south across Rock County and into Iowa and South Dakota (Fig. 4A). It was at this time that the modern stream network began to develop, as glacial ice melted and water flowed south and westward, depositing outwash (unit Qoo).

The age of the Cazenovia till was originally based on the work of Bierman and others (1999). They used cosmogenic exposure dating on samples of glacially abraded surfaces of Sioux Quartzite outcrops, located in Rock County to the south (north of Hardwick), to determine how long ago the outcrops were exposed to sunlight after glacial ice melted. The Cazenovia till surrounds these outcrops. Bierman and others (1999) determined that glacial ice last covered the outcrop at least 500,000 years ago, providing a minimum age for the Cazenovia till. This age conflicts with a recently acquired date of 458,000 ± 66,000 YBP for the older Magnolia till obtained using infrared stimulated luminescence (IRSL) dating of a glacio-lacustrine deposit within the till (see Plate 4). This date indicates the overlying Cazenovia till must be younger than that age. The older age obtained by Bierman and others (1999) is most likely the result of the extreme hardness of the Sioux Quartzite. When exposed to sunlight, rocks acquire cosmic-ray produced nuclides in their surfaces. As glaciers advance over the rocks, the nuclides are removed from softer rocks as the surfaces are eroded. Very hard, erosion-resistant rocks will retain those original nuclides and acquire more of them after the glacial ice melts. The original nuclides, termed "inheritance," may result in an overestimation of the age for exposure of the rock (Colgan and others, 2002). See Plate 4 for more details regarding the IRSL age.

After an indeterminate amount of time, a glacier of Winnipeg provenance advanced into the center of the county from the north and deposited the newly designated Hatfield till (map unit Qht [map unit Qt1 in Gowan, 2020]), which has limited surface exposure (Fig. 4B). Map unit Qht is not adjacent to any bedrock exposures in Rock (Gowan, 2020) or Pipestone County, and therefore cannot be dated using the method discussed above. Meltwater drainage from this glacial advance was through the channels currently occupied by Flandreau Creek, Pipestone Creek, and Rock River (Fig. 5).

There is only one recognizable post-glacial lake basin from pre-Wisconsinan time in Pipestone County. It is between Pipestone and Hatfield, near the headwaters of an unnamed tributary to the Rock River (Fig. 5). Its natural drainage is through this intermittent stream and drains southeast into the Rock River. The passage of time and processes of erosion, such as drainage development, have likely eliminated any other pre-Wisconsinan post-glacial lakes in Pipestone County.

Wisconsinan glaciation

After development of paleosols during an interglacial warm period called the Sangamonian stage (125,000 to 80,000 years ago; Markewich and others, 2011), middle to late Wisconsinan Des Moines-lobe ice advanced southeastward along a broad trough centered over the modern-day Minnesota River valley. Ice flow was mostly constrained to the southwest by thick deposits left by earlier glaciers and a topographic high of resistant Sioux Quartzite. Scouring by glacial ice and subsequent erosion have shaped these thick, older deposits into a north-pointing highland, called the Coteau des Prairies (Fig. 6). Des Moines-lobe ice left behind the youngest glacial deposits in Pipestone County, the Verdi Member (unit Qtv) and the Ivanhoe Member (units Qsi, Qmi, Qwi), which are the oldest members of the New Ulm Formation in southwest Minnesota. The eastern crest line of the Coteau des Prairies is referred to as the Bemis moraine (or locally, Buffalo Ridge; see Map Symbols). It was named for the town of Bemis in Deuel County, South Dakota, through which it passes. On the southwest side of the Bemis moraine, the landscape is older and more mature, which is evidenced by more stream erosion and sharp inclisions by a well-developed network of dendritic stream channels (Fig. 2). In contrast, the landscape to the northeast of the Bemis moraine is younger and more hummocky.

The first advance of the Des Moines lobe in Pipestone County deposited Verdi Member sediments (unit Qtv; Fig. 4C; Johnson and others, 2016). The Verdi Member is texturally similar to the Ivanhoe Member in Pipestone County but has a relatively high amount of Cretaceous rock fragments in the 1-2 millimeter very coarse-grained sand fraction (Fig. 7; Table 2). It is suggested that the Verdi Member was deposited ~24,000 to 34,000 cal YBP (Johnson and others, 2016). Clayton and Moran (1982) reported a date of approximately 24,756 ± 3,432 cal YBP[1] from southwestern Minnesota. The Verdi Member has been correlated to the informal "Toronto till" of South Dakota, which has reported dates of 34,231 ± 2,136 cal YBP[2] (Gilbertson, 1990), 30,431 ± 6,181 cal YBP[3], and 27,134 ± 2,061 cal YBP[4] (Beissel and Gilbertson, 1987). In Iowa, the Sheldon Creek Formation may correlate to the Verdi Member (Kerr, 2018). Research by Kerr and others (2021) indicated the Sheldon Creek Formation was deposited in two advances, the Fort Dodge and Lehigh phases. The Fort Dodge phase deposited between 44,600 and 40,500 cal YBP[5], while the Lehigh phase deposited between 34,500 and 29,500 cal YBP[6]. These ages suggest that the Verdi Member may be time correlative with the Lehigh phase. In Minnesota, the Verdi Member may be correlative with the Moland Member in southeastern Minnesota because these two tills were deposited prior to formation of the Bemis moraine (Marshall and McDonald, 2019; Nguyen and Marshall, 2022).

The middle to late Wisconsinan Peoria Formation consists of variable thicknesses of windblown silt, called loess, and overlies glacial deposits of variable ages across roughly half of Pipestone County (pattern). The thickest deposits (up to 12 feet [3.7 meters]) occur in the southwest part of the county overlying the Cazenovia till, and thinner deposits occur to the northeast. Deposition of Peoria Formation sediment may have occurred intermittently over a long period of time, between about 33,500 and 17,000 years ago (Zanner, 1998; Muhs and others, 2013; Johnson and others, 2016).

In northeastern Pipestone County near Ruthton, most of the Verdi Member was covered by sediment and/or eroded by the next advance of the Des Moines lobe, which is composed of sediment of the Ivanhoe Member (units Qsi, Qmi, Qwi). The Bemis moraine, which can be traced on maps and digital imagery in an arc between Des Moines, Iowa, and southeastern Minnesota, was created during this advance of the Des Moines lobe at about 17,250 ± 644 cal YBP[1] (Fig. 4D; Kemmis and others, 1981). Compositionally, the Ivanhoe Member has more Precambrian rock fragments and lower amounts of Cretaceous rock fragments compared to the Verdi Member (Fig. 7; Table 2). The Ivanhoe Member is in part overlain by the Des Moines Formation in Iowa (Hallberg and Kemmis, 1986).

At the Des Moines lobe's maximum extent, the Bemis moraine, drainage of glacial meltwater initially flowed southwest, as seen by the broad, deep stream channels that cut through the moraine, one of which is currently occupied by Flandreau Creek. Drainage during this advance flowed through rivers and washed till channels, along today's Chanarambie Creek, Flandreau Creek, Pipestone Creek, Rock River, and Willow Creek (Fig. 5). Retreat from this advance is characterized by distinct ice-stagnation features including hummocky terrain, washed till channels, kames, and numerous ice-walled lake plains (unit Qti). These features formed during periods of stagnation and down-wasting, resulting in supraglacial sediment accumulating and insulating ice in places.

POST-GLACIAL HISTORY

During the Holocene Epoch, beginning around 11,700 years ago, the landscape left by glaciers was modified by wind and water, similar to conditions today. Glacial meltwater from the retreating Des Moines lobe behind the Bemis moraine cut channels through the moraine in discrete locations that discharged large quantities of water to the southwest. The Rock River, North Branch Pipestone Creek, and Flandreau Creek carried large amounts of New Ulm Formation outwash deposits (unit Qno) away from the moraine and redeposited them downstream. When flow decreased, finer-grained alluvium was deposited (unit Qa) and organic-rich deposits (units Qo, Ql) accumulated in low-lying areas, including ice-block melt-out depressions and abandoned drainageways. Many thousands of years of erosion by water and wind has resulted in a landscape that is sharply incised and well-drained.

ACKNOWLEDGEMENTS

Clare Johnson, Alex Lutze, and Kevin Murphy of the Minnesota Geological Survey assisted in drilling auger holes in Pipestone County. Thanks to Pipestone County and landowners that allowed permission to look at exposures and gravel pits on their land.

DESCRIPTION OF MAP UNITS

QUATERNARY

Holocene

Qo **Clay, silt, and disseminated organic debris**—Wetland areas containing more than 50 percent silt and clay and partially to fully decomposed organic matter (peat), infilling shallow water bodies such as seasonal or ephemeral ponds, lakes, slackwater areas along low-gradient modern and glacial streams, and other depressions in the landscape. Typically occurs east of the Bemis moraine in Pipestone County. Over time, the organic content will increase and peat will infill the basin. Distribution of this unit has been modified from the Natural Resources Conservation Service (2014). *Wetland deposits*.

Qa **Sand, gravel, and sandy loam to silt loam**—Generally coarse-grained sediment (sand and gravel) in channels, and finer-grained sediment (fine-grained sand and silt) on floodplains; coarsens with depth. Locally capped by and/or interbedded with organic-rich layers. Low areas are typically filled with thick silty sediment. Sediment along smaller streams is generally finer-grained. Deposited by modern streams in channels and on floodplains. *Floodplain alluvium*.

Qf **Silt, clay, and loamy sand**—Massive to laminated fine-grained sand, silt, and clay that is gray to greenish-gray in color. Locally includes organic-rich layers and typically overlies, or is overlain by, fine-grained organic matter in some areas. Mollusk shells are present in places. Typically coarser-grained at the shoreline where waves erode the sediment and concentrate the sand; includes human-made beaches. The extent of exposure depends on the water level in the lake; includes lakes that have been drained or are now reservoirs. Deposited in post-glacial lakes. *Lake sediment*.

Pleistocene

Late Wisconsinan glaciation

New Ulm Formation (Johnson and others, 2016)—Sediment deposited by ice of the Riding Mountain provenance Des Moines lobe. Members of the New Ulm Formation in Pipestone County include the Ivanhoe and Verdi. They are differentiated by depositional features, texture, and 1-2 millimeter very coarse-grained sand fraction lithology (Table 2).

Qti ***Clay, silt, and sand***—A thin cap of massive to laminated fine-grained sand, silt, and clay overlying glacial till. Sediments are typically coarser-grained at the former shoreline, where sand was concentrated by wave action. Rims, composed of glacial till and mass-movement deposits, are typically present around the outer margin. This unit is located within areas of hummocky stagnation topography. When ice melted, some ice-walled lake plains collapsed, but many remained positive relief features (Clayton and others, 2008). Not all ice-walled lake plains were mapped; those too small to map at this scale and those that collapsed are included in stagnation map unit Qsi. *Ice-walled lake plain sediment*.

Qno ***Silty sand, sand, sandy silt, gravelly sand, and sandy gravel***—Stratified, medium- to very coarse-grained sand and gravel. Undivided as to member, includes locally sourced Verdi Member and more distally sourced Ivanhoe Member sediments. Moderately to poorly sorted, cross-bedded to flat-bedded. Deposited by meltwater streams in pro-glacial, ice-marginal, or ice-proximal settings, where isolated cobbles and boulders were present locally. Locally present beneath Holocene stream sediment (unit Qa). *Glacial stream sediment, outwash*.

Ivanhoe Member—Member of the New Ulm Formation associated with the formation of the Bemis moraine in Pipestone County. It is found at the surface northeast of the Bemis moraine near Ruthton.

Qsi ***Clay-loam diamicton***—Slightly pebbly, unsorted; locally contains lenses of silt, sand, and/or gravel that may be from collapsed ice-walled lake plains. Generally light olive-brown (2.5Y 5/6) where oxidized and dark grayish-brown (2.5Y 4/2) where unoxidized. Average composition of the very coarse-grained sand fraction is shown in Table 2 and Figure 7B. Precambrian rock fragments are a key indicator rock type for this unit, averaging 60 percent. Defined by areas with highly irregular topography marked by numerous closed depressions where glacial meltwater accumulated to form lakes. Interpreted to have originated in an unstable, supraglacial sediment layer near a former ice margin that differentially insulated stagnant ice, resulting in uneven downwasting and redeposition of material. *Stagnation glacial till*.

Qwi ***Washed diamicton***—Diamicton as above, but defined with a subdued surface expression that may be streamlined in places. Interpreted to have been washed by water (predominantly rivers, ephemeral streams, slopewash, and wave action). May be capped by a coarse-grained lag resulting from the erosion of finer-grained particles by water and/or have a cover of fine-grained sediment deposited by waning flows. *Washed glacial till*.

Qmi ***Transverse ridge***—Predominantly diamicton, as above; forms a linear topographic high, the Bemis moraine. Composed of poorly sorted glacial sediment that was deposited through a combination of transverse ice-marginal processes that typically include meltout of a basal debris layer, thrusting, and debris flows, and therefore subject to sorting and redeposition locally. *Moraine*.

Middle to late Wisconsinan glaciation

Peoria Formation (Johnson and others, 2016)—Typically silt, with minor clay and very fine-grained sand, deposited by wind during the last glaciation. The advancing glaciers created barren, seasonally dry landscapes in which the very fine-grained sediments were easily transported by wind. Deposition initiated between about 24,000 and 33,500 years ago and ended, in most places, about 16,000 years ago (Johnson and others, 2016). Locally, ages as young as 11,000 years ago have been documented (Zanner, 1998), indicating continued lack of vegetative cover to anchor sediments in the post-glacial environments.

Silt with minor clay and/or very fine-grained sand—Generally grayish-brown to light olive-brown (2.5Y 5/2 to 2.5Y 5/6), oxidized in some places. Shown on the map with contoured lines of thickness, contour interval 2 feet (0.6 meter). May not be present everywhere mapped and may occur locally beyond mapped boundaries. *Loess*.

Verdi Member—Oldest member of the New Ulm Formation in Pipestone County. At the surface southwest of the Bemis moraine.

Qtv ***Clay loam to loam diamicton***—Slightly pebbly, unsorted; contains lenses of silt, sand, and gravel in places; near-surface samples are generally olive-yellow (2.5Y 6/6) where oxidized and dark grayish-brown (2.5Y 4/2) where unoxidized. Average composition of the very coarse-grained sand fraction is shown on Table 2 and Figure 7B. Cretaceous rock fragments are key indicators for this unit, averaging 19 percent, the highest among all units in Pipestone County. Lithologically, the Verdi Member is similar to the Sheldon Creek Formation in Iowa (Kilgore, 2008). The unit locally is covered by up to 4 feet (1.2 meters) of loess (pattern), with the greatest thicknesses in the northwest. *Glacial till*.

Pre-Wisconsinan glaciation

Qol **Silt, clay, and loamy sand with some gravel**—Locally includes organic-rich layers and typically overlies, or is overlain by, fine-grained organic matter. Typically coarser-grained at the shoreline where waves winnow the sediment and concentrate the sand. Includes lakes that have been drained. Deposited in post-glacial lakes. The unit is covered by a variable thickness of loess (pattern). *Lake sediment*.

Qoo **Silt to sand with some gravel**—Stratified sand that ranges from very coarse- to very fine-grained and is poorly to well-sorted. Unit was deposited in meltwater streams that issued from the pre-Wisconsinan ice front(s). The unit is typically covered by a variable thickness of loess (pattern). *Glacial stream sediment, outwash*.

Qht **Clay-loam to silt-loam diamicton of Winnipeg provenance—Hatfield till**—Unsorted, slightly pebbly; contains lenses of silt, sand, and gravel in places. Generally oxidized light olive-brown (2.5Y 5/3). This unit has a silt loam texture, averaging approximately 53 percent silt, with roughly equal amounts of sand and clay. It contains roughly equal amounts of Precambrian and Paleozoic grains (47 and 44 percent, respectively) and less Cretaceous grains (9 percent; Fig.7B; Table 2). It is possible that this unit could correlate with the older advance of the Sheldon Creek Formation in Iowa, as discussed above in the Verdi Member description, but additional research is required to evaluate this possibility. The unit is typically covered by 2 to 4 feet (0.6 to 1.2 meters) of loess (pattern). *Glacial till*.

Qct **Clay-loam to loam diamicton of modified Rainy provenance—Cazenovia till**—Unsorted, with pebbles; contains pockets of silt, sand, and gravel in places. Generally oxidized olive-brown (2.5Y 5/4), and in places unoxidized very dark grayish-brown (2.5Y 3/2). This unit is less silty than overlying unit Qht and has significantly more Precambrian and less Paleozoic grains (72 and 22 percent, respectively; Fig. 7B; Table 2). Rainy-provenance tills described elsewhere in the state have sandier textures and little to no Cretaceous clasts compared to this unit. Incorporation of underlying finer-grained and Cretaceous-rich sediments may have modified the original Rainy-provenance signature. It is probable that this unit correlates with one or more of the till units within the Wolf Creek Formation in Iowa (Hallberg, 1980). The unit is typically covered by 2 to 4 feet (0.6 to 1.2 meters) and up to 12 feet (3.7 meters) of loess (pattern) on the western half of the county. Loess is absent across a small extent of this unit in the southeast corner of the county. *Glacial till*.

PALEOPROTEROZOIC

Pzvq **Areas of bedrock at or near the land surface**—Bedrock that is at or within 3 feet (1 meter) of the land surface. Outcrops consist of Sioux Quartzite; see Plate 2, *Bedrock Geology*, for details. The bedrock is covered by as much as 2 feet (0.6 meter) of loess. *Bedrock exposure shown with a map symbol*.

REFERENCES

Numbers in parentheses correspond with those shown on the Index to Previous Mapping.

Beissel, D.R., and Gilbertson, J.P., 1987, Geologic map of Deuel and Hamlin Counties, S.D., pl. 1 *of* Beissel, D.R., and Gilbertson, J.P., 1987, Geology and water resources of